Monographie BIPM-5

Table of Radionuclides
(Comments on evaluation)

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Volumes 1-7, 2013

BUREAU INTERNATIONAL DES POIDS ET MESURES

Pavillon de Breteuil, F-92310 SÈVRES

Édité par le BIPM,
Pavillon de Breteuil
F-92312 Sèvres Cedex
France

Imprimé par Reproduction Service

ISBN-13 978-92-822-2248-5 (Vol. 7)
ISBN-13 978-92-822-2249-2 (CD-Rom)

TABLE DE RADIONUCLÉIDES
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COMMENTS ON EVALUATIONS

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- 2013 -

Monographie BIPM-5 - Table of Radionuclides, Comments on evaluations, Volume 7

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Sommaire

Depuis quelques années, un groupe composé d’évaluateurs spécialistes des données de décroissance radioactive s’est formé, avec l’objectif de réaliser une évaluation soigneuse et documentée de ces données pour des radionucléides intervenant dans de nombreuses applications. Ces évaluateurs se sont mis d’accord sur une méthodologie commune. Ce rapport inclut les commentaires sur les évaluations des radionucléides figurant dans le rapport Monographie BIPM-5, volume 7 :

^{14}C, ^{35}S, ^{36}Cl, ^{37}Ar, ^{45}Ca, ^{67}Ga, ^{68}Ga, ^{68}Ge,^{127}Sb, ^{127}Te, ^{127m}Te, ^{134}Cs, ^{141}Ce, ^{147}Nd, ^{147}Pm, ^{195}Au, ^{206}Hg, ^{207}Tl, ^{208}Tl, ^{209}Tl, ^{211}Pb, ^{211}At, ^{213}Bi, ^{215}Bi, ^{228}Th, ^{242}Cm, ^{243}Cm, ^{244}Cm, ^{245}Cm.

Summary

Over the past years, an informal collaboration of decay-data evaluators has been assembled with the goal of creating high-quality, well-documented evaluations of the decay data for a selected set of radionuclides that are of interest in various applications. This report includes, for each radionuclide, the evaluator’s comments on how the evaluation was carried out for the radionuclides that are in the Monographie BIPM-5, volume 7:

^{14}C, ^{35}S, ^{36}Cl, ^{37}Ar, ^{45}Ca, ^{67}Ga, ^{68}Ga, ^{68}Ge,^{127}Sb, ^{127}Te, ^{127m}Te, ^{134}Cs, ^{141}Ce, ^{147}Nd, ^{147}Pm, ^{195}Au, ^{206}Hg, ^{207}Tl, ^{208}Tl, ^{209}Tl, ^{211}Pb, ^{211}At, ^{213}Bi, ^{215}Bi, ^{228}Th, ^{242}Cm, ^{243}Cm, ^{244}Cm, ^{245}Cm.

Monographie BIPM-5 - Table of Radionuclides, Comments on evaluations, volumes 1 to 6

^{3}H, ^{7}Be, ^{11}C, ^{13}N, ^{15}O, ^{18}F, ^{22}Na, ^{24}Na, ^{32}P, ^{33}P, ^{40}K, ^{41}Ar, ^{44}Sc, ^{44}Ti, ^{46}Sc, ^{51}Cr, ^{54}Mn, ^{55}Fe, ^{56}Mn, ^{56}Co, ^{57}Co, ^{57}Ni, ^{59}Fe, ^{59}Ni, ^{60}Co, ^{63}Ni, ^{64}Cu, ^{65}Zn, ^{66}Ga, ^{67}Ga, ^{75}Se, ^{79}Se, ^{85}Kr, ^{85}Sr, ^{88}Y, ^{89}Sr, ^{90}Sr, ^{90}Y, ^{90m}Y, ^{93m}Nb, ^{99}Mo, ^{99}Tc, ^{99m}Tc, ^{108}Ag, ^{108m}Ag, ^{109}Pd, ^{109}Cd, ^{110}Ag, ^{110m}Ag, ^{111}In, ^{123m}Te, ^{123}I, ^{124}Sb, ^{125}Sb, ^{125}I, ^{129}I, ^{131}I, ^{131m}Xe, ^{132}Te, ^{133}I, ^{133}Xe, ^{133m}Xe, ^{133}Ba, ^{135m}Xe, ^{137}Cs, ^{139}Ce, ^{140}Ba, ^{140}La, ^{152}Eu, ^{153}Sm, ^{153}Gd, ^{154}Eu, ^{155}Eu, ^{159}Gd, ^{166}Ho, ^{166m}Ho, ^{169}Yb, ^{170}Tm, ^{177}Lu, ^{182}Ta, ^{186}Re, ^{198}Au, ^{201}Tl, ^{203}Hg, ^{203}Pb, ^{204}Tl, ^{206}Tl, ^{207}Bi, ^{208}Tl, ^{209}Pb, ^{209}Po, ^{210}Tl, ^{210}Pb, ^{210}Bi, ^{210}Po, ^{211}Bi, ^{211}Po, ^{212}Pb, ^{212}Bi, ^{212}Po, ^{213}Po, ^{214}Pb, ^{214}Bi, ^{214}Po, ^{215}Po, ^{215}At, ^{216}Po, ^{217}At, ^{217}Rn, ^{218}Po, ^{218}At, ^{218}Rn, ^{219}At, ^{219}Rn, ^{220}Rn, ^{221}Fr, ^{222}Rn, ^{223}Fr, ^{223}Ra, ^{224}Ra, ^{225}Ra, ^{225}Ac, ^{226}Ra, ^{227}Ac, ^{227}Th, ^{228}Ra, ^{228}Ac, ^{228}Th, ^{231}Th, ^{231}Pa, ^{232}Th, ^{232}U, ^{233}Th, ^{233}Pa, ^{234}Th, ^{234}Pa, ^{234m}Pa, ^{234}U, ^{235}U, ^{236}U, ^{236}Np, ^{236m}Np, ^{237}U, ^{237}Np, ^{238}U, ^{238}Np, ^{238}Pu, ^{239}U, ^{239}Np, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{241}Am, ^{242}Pu, ^{242}Am, ^{242m}Am, ^{242}Cm, ^{243}Am, ^{244}Am, ^{244m}Am, ^{244}Cm, ^{246}Cm, ^{252}Cf.

TABLE DE RADIONUCLÉIDES – COMMENTAIRES SUR LES ÉVALUATIONS

De nombreuses applications nécessitent la connaissance des données liées à la désintégration des radionucléides, telles que la période radioactive, les énergies et les intensités des divers rayonnements. Pour répondre aux demandes des utilisateurs, le Laboratoire National Henri Becquerel (LNE - LNHB, France) a, de 1982 à 1987, publié une table en quatre volumes [87Ta, 99Be]. Puis, en 1993 une coopération a été établie avec le Physikalisch-Technische Bundesanstalt (PTB, Allemagne) afin de reprendre cette étude et de la développer. En 1995, un nouveau groupe de travail international nommé Decay Data Evaluation Project (DDEP) s'est formé qui, en plus des deux laboratoires nationaux précédents, inclut : Idaho National Engineering and Environmental Laboratory (INEEL, USA), Lawrence Berkeley National Laboratory (LBNL, USA), Brookhaven National Laboratory (BNL, USA) et Khlopin Radium Institute (KRI, Russie).

Le propos de ce groupe est de fournir aux utilisateurs des données soigneusement évaluées qui puissent servir de référence. A cette fin, tous les membres du groupe suivent une méthodologie commune qui comprend :

- la lecture attentive de toutes les publications relatives à une grandeur ;
- une analyse statistique des données retenues ;
- le choix et l'utilisation des mêmes jeux de données, pour celles ayant fait l'objet d'études spécifiques par des spécialistes, tels les coefficients de conversion interne.

Tous ces points sont développés en détail dans le chapitre « Rules for evaluation and compilations ».

Par ailleurs, toutes les évaluations sont documentées et l'établissement des valeurs retenues explicité. Ce document est ensuite relu par deux membres du groupe.

Ce 7^{e} volume regroupe les commentaires liés à l'évaluation des radionucléides suivants :

^{14}C, ^{35}S, ^{36}Cl, ^{37}Ar, ^{45}Ca, ^{67}Ga, ^{68}Ga, ^{68}Ge,^{127}Sb, ^{127}Te, ^{127m}Te, ^{134}Cs, ^{141}Ce, ^{147}Nd, ^{147}Pm, ^{195}Au, ^{206}Hg, ^{207}Tl, ^{208}Tl, ^{209}Tl, ^{211}Pb, ^{211}At, ^{213}Bi, ^{215}Bi, ^{228}Th, ^{242}Cm, ^{243}Cm, ^{244}Cm, ^{245}Cm.

Ainsi que ceux précédemment publiés dans les volumes 1 à 6 :

^{3}H, ^{7}Be, ^{11}C, ^{13}N, ^{15}O, ^{18}F, ^{22}Na, ^{24}Na, ^{32}P, ^{33}P, ^{40}K, ^{41}Ar, ^{44}Sc, ^{44}Ti, ^{46}Sc, ^{51}Cr, ^{54}Mn, ^{55}Fe, ^{56}Mn, ^{56}Co, ^{57}Co, ^{57}Ni, ^{59}Fe, ^{59}Ni, ^{60}Co, ^{63}Ni, ^{64}Cu, ^{65}Zn, ^{66}Ga, ^{67}Ga, ^{75}Se, ^{79}Se, ^{85}Kr, ^{85}Sr, ^{88}Y, ^{89}Sr, ^{90}Sr, ^{90}Y, ^{90m}Y, ^{93m}Nb, ^{99}Mo, ^{99}Tc, ^{99m}Tc, ^{108}Ag, ^{108m}Ag, ^{109}Pd, ^{109}Cd, ^{110}Ag, ^{110m}Ag, ^{111}In, ^{123m}Te, ^{123}I, ^{124}Sb, ^{125}Sb, ^{125}I, ^{129}I, ^{131}I, ^{131m}Xe, ^{132}Te, ^{133}I, ^{133}Xe, ^{133m}Xe, ^{133}Ba, ^{135m}Xe, ^{137}Cs, ^{139}Ce, ^{140}Ba, ^{140}La, ^{152}Eu, ^{153}Sm, ^{153}Gd, ^{154}Eu, ^{155}Eu, ^{159}Gd, ^{166}Ho, ^{166m}Ho, ^{169}Yb, ^{170}Tm, ^{177}Lu, ^{182}Ta, ^{186}Re, ^{198}Au, ^{201}Tl, ^{203}Hg, ^{203}Pb, ^{204}Tl, ^{206}Tl, ^{207}Bi, ^{208}Tl, ^{209}Pb, ^{209}Po, ^{210}Tl, ^{210}Pb, ^{210}Bi, ^{210}Po, ^{211}Bi, ^{211}Po, ^{212}Pb, ^{212}Bi, ^{212}Po, ^{213}Po, ^{214}Pb, ^{214}Bi, ^{214}Po, ^{215}Po, ^{215}At, ^{216}Po, ^{217}At, ^{217}Rn, ^{218}Po, ^{218}At, ^{218}Rn, ^{219}At, ^{219}Rn, ^{220}Rn, ^{221}Fr, ^{222}Rn, ^{223}Fr, ^{223}Ra, ^{224}Ra, ^{225}Ra, ^{225}Ac, ^{226}Ra, ^{227}Ac, ^{227}Th, ^{228}Ra, ^{228}Ac, ^{228}Th, ^{231}Th, ^{231}Pa, ^{232}Th, ^{232}U, ^{233}Th, ^{233}Pa, ^{234}Th, ^{234}Pa, ^{234m}Pa, ^{234}U, ^{235}U, ^{236}U, ^{236}Np, ^{236m}Np, ^{237}U, ^{237}Np, ^{238}U, ^{238}Np, ^{238}Pu, ^{239}U, ^{239}Np, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{241}Am, ^{242}Pu, ^{242}Am, ^{242m}Am, ^{242}Cm, ^{243}Am, ^{244}Am, ^{244m}Am, ^{244}Cm, ^{246}Cm, ^{252}Cf.

Les données de décroissance radioactive de ces radionucléides peuvent être trouvées dans la Monographie BIPM-5 de la « Table de radionucléides », dans le CD-Rom NUCLÉIDE édité par le LNHB ou sur les pages web : http://www.nucleide.org/NucData.htm

TABLE OF RADIONUCLIDES – COMMENTS ON EVALUATIONS

Basic properties of radionuclides, such as half-life, decay mode and branchings, radiation energies and emission probabilities are commonly used in various research fields. To meet the demand for these data the LNHB produced a table that was published in four volumes [87Ta, 99Be] from 1982 to 1987. In 1993, a cooperative agreement was established between the Laboratoire National Henri Becquerel (LNE - LNHB, France) and the Physikalisch-Technische Bundesanstalt (PTB, Germany) to continue and expand this work. In 1995, a new international collaboration was formed, the Decay Data Evaluation Project (DDEP), which has the same objectives. Along with the evaluators from LNHB and PTB, this collaboration includes others from the Idaho National Engineering and Environmental Laboratory (INEEL, USA), the Lawrence Berkeley National Laboratory (LBNL, USA), the Brookhaven National Laboratory (BNL, USA) and the Khlopin Radium Institute (KRI, Russia). Its objective has been to provide carefully produced recommended values, which may eventually become standard data. With this goal in mind, the collaboration has adopted a uniform evaluation methodology that contains the following:

- a critical review of relevant publications;
- an accounting of all measured data;
- a uniform statistical analysis of the data;
- a presentation of values for quantities such as internal conversion coefficients, etc.;
- a review of evaluation by two other members of the collaboration.

These topics are described in detail in the chapter "Rules for evaluation and compilations".

The evaluation of each individual radionuclide has a section (presented here) that describes the procedures used for deducing the recommended values. This documentation is included in order to establish the quality and completeness of each evaluation. It can also provide the basis for any future reevaluation by the DDEP or other groups.

This seventh volume contains the procedures and comments relevant to the evaluation for the following radionuclides:

^{14}C, ^{35}S, ^{36}Cl, ^{37}Ar, ^{45}Ca, ^{67}Ga, ^{68}Ga, ^{68}Ge,^{127}Sb, ^{127}Te, ^{127m}Te, ^{134}Cs, ^{141}Ce, ^{147}Nd, ^{147}Pm, ^{195}Au, ^{206}Hg, ^{207}Tl, ^{208}Tl, ^{209}Tl, ^{211}Pb, ^{211}At, ^{213}Bi, ^{215}Bi, ^{228}Th, ^{242}Cm, ^{243}Cm, ^{244}Cm, ^{245}Cm.

As well as those previously published in volumes 1 to 6:

^{3}H, ^{7}Be, ^{11}C, ^{13}N, ^{15}O, ^{18}F, ^{22}Na, ^{24}Na, ^{32}P, ^{33}P, ^{40}K, ^{41}Ar, ^{44}Sc, ^{44}Ti, ^{46}Sc, ^{51}Cr, ^{54}Mn, ^{55}Fe, ^{56}Mn, ^{56}Co, ^{57}Co, ^{57}Ni, ^{59}Fe, ^{59}Ni, ^{60}Co, ^{63}Ni, ^{64}Cu, ^{65}Zn, ^{66}Ga, ^{67}Ga, ^{75}Se, ^{79}Se, ^{85}Kr, ^{85}Sr, ^{88}Y, ^{89}Sr, ^{90}Sr, ^{90}Y, ^{90m}Y, ^{93m}Nb, ^{99}Mo, ^{99}Tc, ^{99m}Tc, ^{108}Ag, ^{108m}Ag, ^{109}Pd, ^{109}Cd, ^{110}Ag, ^{110m}Ag, ^{111}In, ^{123m}Te, ^{123}I, ^{124}Sb, ^{125}Sb, ^{125}I, ^{129}I, ^{131}I, ^{131m}Xe, ^{132}Te, ^{133}I, ^{133}Xe, ^{133m}Xe, ^{133}Ba, ^{135m}Xe, ^{137}Cs, ^{139}Ce, ^{140}Ba, ^{140}La, ^{152}Eu, ^{153}Sm, ^{153}Gd, ^{154}Eu, ^{155}Eu, ^{159}Gd, ^{166}Ho, ^{166m}Ho, ^{169}Yb, ^{170}Tm, ^{177}Lu, ^{182}Ta, ^{186}Re, ^{198}Au, ^{201}Tl, ^{203}Hg, ^{203}Pb, ^{204}Tl, ^{206}Tl, ^{207}Bi, ^{208}Tl, ^{209}Pb, ^{209}Po, ^{210}Tl, ^{210}Pb, ^{210}Bi, ^{210}Po, ^{211}Bi, ^{211}Po, ^{212}Pb, ^{212}Bi, ^{212}Po, ^{213}Po, ^{214}Pb, ^{214}Bi, ^{214}Po, ^{215}Po, ^{215}At, ^{216}Po, ^{217}At, ^{217}Rn, ^{218}Po, ^{218}At, ^{218}Rn, ^{219}At, ^{219}Rn, ^{220}Rn, ^{221}Fr, ^{222}Rn, ^{223}Fr, ^{223}Ra, ^{224}Ra, ^{225}Ra, ^{225}Ac, ^{226}Ra, ^{227}Ac, ^{227}Th, ^{228}Ra, ^{228}Ac, ^{228}Th, ^{231}Th, ^{231}Pa, ^{232}Th, ^{232}U, ^{233}Th, ^{233}Pa, ^{234}Th, ^{234}Pa, ^{234m}Pa, ^{234}U, ^{235}U, ^{236}U, ^{236}Np, ^{236m}Np, ^{237}U, ^{237}Np, ^{238}U, ^{238}Np, ^{238}Pu, ^{239}U, ^{239}Np, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{241}Am, ^{242}Pu, ^{242}Am, ^{242m}Am, ^{242}Cm, ^{243}Am, ^{244}Am, ^{244m}Am, ^{244}Cm, ^{246}Cm, ^{252}Cf.

These evaluations may be found in the BIPM-5 Monographie, on the CD-Rom NUCLÉIDE published by the LNHB or in the web pages: http://www.nucleide.org/NucData.htm

A goal of the DDEP is to avoid future duplication of effort by disseminating these critically evaluated data with the hope that they will be included in many other collections of decay data.

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and
M.-M. Bé, E. Browne, V. Chechev, V. Chisté, R. Dersch, C. Dulieu, R.G. Helmer, N. Kuzmenco, A.L. Nichols, E. Schönfeld. NUCLÉIDE, Table de Radionucléides sur CD-Rom, Version 2-2004, CEA/BNM-LNHB, 91191 Gif-sur-Yvette, France.

[06Be] **Marie-Martine BÉ, Vanessa CHISTÉ, Christophe DULIEU; Edgardo BROWNE, Coral BAGLIN; Valery CHECHEV, Nikolay KUZMENKO; Richard G. HELMER; Filip G. KONDEV; T. Desmond MACMAHON; Kyung Beom LEE.** *Table of Radionuclides, Monographie BIPM-5, vol. 3,* ISSN 92-822-2204-7 (set), ISBN 92-822-2218-7 (Vol. 3) and ISBN 92-822-2219-5 (CD), CEA/LNE-LNHB, 91191 Gif-sur-Yvette, France and BIPM, Pavillon de Breteuil, 92312 Sèvres, France.

[08Be] **Marie-Martine BÉ, Vanessa CHISTÉ, Christophe DULIEU; Edgardo BROWNE; Valery CHECHEV, Nikolay KUZMENKO; Filip G. KONDEV; Aurelian LUCA; Mónica GALÁN; Andrew PEARCE; Xiaolong HUANG.** *Table of Radionuclides, Monographie BIPM-5, vol.4*, ISBN 92-822-2230-6 (Vol. 4) and ISBN 92-822-2231-4 (CD), CEA/LNE-LNHB, 91191 Gif-sur-Yvette, France and BIPM, Pavillon de Breteuil, 92312 Sèvres, France.

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Table of Radionuclides, Monographie BIPM-5, Commentaires, vol.5, ISBN 13 978-92-822-2235-5 (CD-Rom), CEA/LNE-LNHB, 91191 Gif-sur-Yvette, France and BIPM, Pavillon de Breteuil, 92312 Sèvres, France.

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Table of Radionuclides, Monographie BIPM-5, Commentaires, vol.6, ISBN 13 978-92-822-2243-0 (CD-Rom), CEA/LNE-LNHB, 91191 Gif-sur-Yvette, France and BIPM, Pavillon de Breteuil, 92312 Sèvres, France.

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Toutes demandes de renseignements concernant les données recommandées et la façon dont elles ont été établies doivent être adressées directement aux auteurs des évaluations.

Information on the data and the evaluation procedures is available from the authors listed below.

Informationen über die Daten und Evaluationsprozeduren können bei den im folgenden zusammengestellten Autoren angefordert werden.

Todos los pedidos de información sobre datos recomendados y los métodos de evaluacion utilizados, deben dirigirse directamente a los autores de las evaluaciones.

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RULES FOR EVALUATION AND COMPILATIONS

1. DATA SOURCES

Two main sources of data are used to obtain the recommended values:

- specific data evaluated from all available original publications (e.g., half-life),
- data already evaluated and compiled by specialists (e.g., Q-values); if a subsequent experimental study exists, the resulting measured value may be used, and its reference be included in a list of references for such a radionuclide.

2. EVALUATION RULES

All intermediate stages in the compilation and evaluation of a decay parameter are not presented in detail in order to avoid unnecessary complexity. The main stages comprise the following:

- critical analysis of published results and, if necessary, correction of these results to account for more recent values hitherto unavailable to the original experimentalists; as a rule, results without associated uncertainties are discarded, and the rejection of values is documented;
- data obtained through private communications are used only when all of the necessary information has been provided directly by the scientist who performed the measurements;
- adjustments may be made to the reported uncertainties;
- recommended values are deduced from an analysis of all measurements (or theoretical considerations), along with their standard deviations with a 1σ confidence level.

2.1. Evaluation of uncertainties

Definitions from “Guide to the expression of uncertainty in measurement” [1]:

Uncertainty (of measurement): parameter associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measurand.

Standard uncertainty: uncertainty of the result of a measurement expressed as a standard deviation.

Type A evaluation (of uncertainty): method of evaluation of uncertainty by the statistical analysis of a series of observations.

Type B evaluation (of uncertainty): method of evaluation of uncertainty by means other than the statistical analysis of a series of observations.

The uncertainties given by authors are re-evaluated by combining the standard uncertainties σ_A and σ_B through the general law of variance propagation:

$$u_c = \sqrt{\sigma_A^2 + \sigma_B^2} \tag{1}$$

where u_c is the combined standard uncertainty,
σ_A is the type A standard deviation, and
σ_B is the type B standard uncertainty.

When the authors give insufficient information concerning their uncertainty calculations, the combined uncertainty u_c may be estimated by the evaluator, based on a knowledge of the measurement method(s).

2.2. Determination of the best value and associated uncertainty

(a) Results obtained by one author using one method

Sometimes only the final mean value and the combined standard uncertainty are given in the original publication. The following procedure is adopted if sufficient details are known.

For n individual values a_i ($i = 1\ldots n$), the best value is the arithmetical mean:

$$\bar{a} = \sum_{i=1}^{n} \frac{a_i}{n} \tag{2}$$

with type A standard deviation:

$$\sigma_A(\bar{a}) = \left[\frac{\sum_i (a_i - \bar{a})^2}{n(n-1)} \right]^{1/2} \tag{3}$$

If there are m contributions σ_{Bj} (j = 1…m) to the type B standard uncertainty that are independent of each other:

$$\sigma_B(\bar{a}) = \left[\sum_{j=1}^{m} \sigma_{Bj}^2 \right]^{1/2} \tag{4}$$

Combined standard uncertainty:

$$u_c(\bar{a}) = \sqrt{\sigma_A^2(\bar{a}) + \sigma_B^2(\bar{a})} \tag{5}$$

Recommended value:

$$a = \bar{a} \pm u_c(\bar{a}) \tag{6}$$

(b) Results obtained by several authors employing the same method

For n individual values $\bar{a}_i (i = 1 \ldots n)$ having a standard deviation σ_{Ai} and a type B uncertainty σ_{Bi}, the best value is obtained by taking the mean weighted by the inverse of the variances.

$$\overline{\overline{a}} = \frac{\sum_i \left(\overline{a}_i / \sigma_{Ai}^2\right)}{\sum_i \left(1/\sigma_{Ai}^2\right)} \tag{7}$$

The associated values σ_A, σ_B are:

$$\sigma_A\left(\overline{\overline{a}}\right) = \left[\sum_i \left(1/\sigma_{Ai}^2\right)\right]^{-1/2} \tag{8}$$

$$\sigma_B\left(\overline{\overline{a}}\right) = \sum_i \left(\sigma_{Bi}\right)_{min} \quad \text{or} \quad \sigma_B\left(\overline{\overline{a}}\right) = \sqrt{\sum_i \left(\sigma_{Bi}\right)_{min}^2} \quad \text{or} \quad \sigma_B\left(\overline{\overline{a}}\right) = \left(\sigma_B\right)_{min}$$

depending on the individual case, although $\sigma_B\left(\overline{\overline{a}}\right)$ cannot be less than the smallest σ_{Bi}.

σ_A and σ_B are combined quadratically to determine u_c:

$$u_c\left(\overline{\overline{a}}\right) = \sqrt{\sigma_A^2\left(\overline{\overline{a}}\right) + \sigma_B^2\left(\overline{\overline{a}}\right)} \tag{9}$$

and the recommended value is given by the expression:

$$a = \overline{\overline{a}} \pm u_c\left(\overline{\overline{a}}\right) \tag{10}$$

(c) Results obtained by different methods

When different measurement techniques have been applied, a weighted average is calculated using the combined uncertainties of the individual values as weights.

For n independent values a_i, each with a combined standard uncertainty u_{ci}, a weight p_i proportional to the inverse of the square of the individual u_{ci} can be assigned to each value.

$$a_w = \frac{\sum_{i=1}^{n} p_i a_i}{\sum_{i=1}^{n} p_i} \tag{11}$$

where the weights are $p_i = 1/u_{c_i}^2$.

An internal and an external uncertainty can be assigned to the mean value [2, 3]:

$$\sigma_{int}\left(a_w\right) = \left[\sum_i \left(1/u_{c_i}^2\right)\right]^{-1/2} \tag{12}$$

The internal variance $\sigma_{int}^2\left(a_w\right)$ is the expected uncertainty of the mean, based on the individual *a priori* variances $u_{c_i}^2$ (by uncertainty propagation).

The external uncertainty is given by the equation:

$$\sigma_{ext}\left(a_w\right) = \left[\frac{\sum_i \left(a_i - a_w\right)^2 / u_{c_i}^2}{(n-1)\sum 1/u_{c_i}^2}\right]^{1/2} \tag{13}$$

The external variance $\sigma_{ext}^2(a_w)$ includes the scatter of the data, and is based on the amount by which each a_i deviates from the mean when measured as a fraction of each given uncertainty u_{c_i}.

A measure of the consistency of the data is given by the ratio [2, 3]:

$$\sigma_{ext} / \sigma_{int} = \sqrt{\chi^2 / (n-1)} \tag{14}$$

If this ratio is significantly greater than unity, at least one of the input data most probably has an underestimated u_{c_i} which should be increased.

A critical value of $\chi^2/(n-1)$ at 1 % confidence level is used as a practical test for discrepant data. The following table lists critical values of $\chi^2/(n-1)$ for an increasing degree of freedom $\nu = n-1$ [4].

ν	**critical $\chi^2/(n-1)$**	**ν**	**critical $\chi^2/(n-1)$**
1	6.6	12	2.2
2	4.6	13	2.1
3	3.8	14	2.1
4	3.3	15	2.0
5	3.0	16	2.0
6	2.8	17	2.0
7	2.6	18-21	1.9
8	2.5	22-26	1.8
9	2.4	27-30	1.7
10	2.3		
11	2.2	>30	$1 + 2.33\sqrt{2/\nu}$

If $\chi^2/(n-1) \leq \text{critical}\,\chi^2/(n-1)$, the recommended value is given by:

$$a = a_w \pm \sigma_{int}(a_w) \tag{15}$$

If $\chi^2/(n-1) > \text{critical}\,\chi^2/(n-1)$, the method of limitation of the relative statistical weight [3, 5] is recommended when there are three or more values; uncertainty of a value contributing more than 50 % to the total weight is increased to reduce its contribution to 50 % . The weighted and unweighted average and critical $\chi^2/(n-1)$ are then recalculated:

if $\chi^2/(n-1) \leq \text{critical}\,\chi^2/(n-1)$, the recommended value is given by:

$$a = a_w \pm \left(\text{the larger of } \sigma_{int}(a_w) \text{ and } \sigma_{ext}(a_w)\right) \tag{16}$$

if $\chi^2/(n-1) > \text{critical}\,\chi^2/(n-1)$, the weighted or unweighted mean is chosen, depending on whether or not the uncertainties of the average values make them overlap with each other. If overlap occurs, the weighted average is recommended; otherwise the unweighted average is chosen. In either case, the uncertainty can be increased to cover the most accurate value.

Parameters evaluated according to these procedures and rules include half-lives, number of emitted particles, and some internal-conversion coefficients. All remaining data given in the tables of recommended data are generally taken from compilations.

2.3. Balanced decay schemes

All the probabilities for transitions and emitted radiations correspond to balanced decay schemes and permit the formulation of a fully consistent set of values. This balance implies the fulfillment of physical conservation principles as follows:

- The sum of the transition probabilities for all the transitions (α, β, ε) is equal to 1 (or 100 %); consequently, the sum of all the γ-ray transition probabilities (photons + internal conversion electrons) and all the (α, β, or ε) transitions feeding directly to the ground state is equal to 1 (or 100 %).

- For an excited nuclear level, the sum of the transition probabilities (α, β, γ, ε) feeding the level is equal to the sum of the transition probabilities depopulating this level;

- If the relative γ-ray emission probabilities $P(rel)_{\gamma_i}$ are known, the absolute emission probability $P(abs)_{\gamma i}$ can be obtained from the equation:

$$P(abs)_{\gamma i} = P(rel)_{\gamma i} \times N \tag{17}$$

where N is the normalization factor, which may be determined from the equation:

$$N \sum_i P(rel)_{\gamma i} \left(1 + \alpha_{t_i}\right) = 1 - B, \tag{18}$$

where α_{ti} is the total conversion coefficient, and B, the (α, β, or ε) absolute branching to the ground state. The sum in equation (18) includes all the γ-ray transitions feeding the ground state.

3. COMPILATIONS

3.1. β and electron capture transitions

Depending on the individual radionuclide, the β-particle transition energies are either evaluated from experimental data (maximum β energies), or deduced from the atomic mass differences obtained from the tabulations of Audi and Wapstra [6] and the γ transition energies. The average β-particle energies are generally computed [7], and their log *ft* values as well as their ε/β^+ ratios are calculated using the tables of Gove and Martin [8].

Electron-capture transition energies are deduced from atomic mass differences and γ-ray transition energies. Capture probabilities P_K, P_L,… for allowed and non-unique first forbidden transitions can be calculated from equations where the ratios of the radial wave function components of the electron [9-11] and the corrective terms for exchange $X^{L/K}$ [12-16] are evaluated from tables.

3.2. γ-ray transitions

Internal conversion coefficients of pure multipolarity transitions are evaluated and compared with theoretical values that are interpolated from the tables of either Rösel *et al.* using a cubic spline method for $30 \leq Z \leq 104$ [17], or Band *et al.* [18]. The agreement of these theoretical values with experimental results is about 3 %.
Internal-conversion coefficients are calculated as described in Ref. [19] in order to include the effects of nuclear penetration in some M1 and E2 transitions.

Internal conversion coefficients for transitions with mixed multipolarities (e.g., M1 + E2) are calculated using tables of theoretical values using mixing ratios as shown below:

$$\alpha_i(M1+E2) = \alpha_i(M1)\ 1/1+\delta^2 + \alpha_i(E2)\ \delta^2/1+\delta^2 \qquad (19)$$

where i = K, L1, L2, … T, refers to the individual atomic shell.

α_π coefficients for pair production are interpolated from theoretical values [20], with a precision between 5 % and 10 %.

3.3. Level spins and parities

Level spins and parities are usually from Nuclear Data Sheets [21].

3.4. Atomic shell constants

K-shell fluorescence yields ω_K and their uncertainties are taken from the evaluation of Bambynek *et al.* [22-24] with uncertainties ranging from 1 % (Z > 35) to 10 % (Z = 5), and from subsequent experimental results.

Mean L-shell fluorescence yields $\overline{\omega}_L$ are taken from the evaluation of Schönfeld and Janßen [25]. This evaluation includes both experimental [26-28] and theoretical values [29], and their uncertainties are equal to 4 % (for Z > 29).

Mean M-shell fluorescence yields $\overline{\omega}_M$ are obtained from the fitting of experimental data by Hubbell [28, 30].

Relative X-ray emission rates (Kβ/Kα) are taken from Schönfeld and Janßen [25], and $K\alpha_1/K\alpha_2$ from the theoretical values of Scofield [31]; uncertainties are assumed to be of the order of 1 %.

X-ray radiation energies are taken from the tables of Bearden [32].

Relative emission probabilities of K-Auger electron groups are deduced from the X-ray ratio, with uncertainties of the order of 3 % [25].

Energies of the K and L-Auger electrons are taken from Larkins [33].

The mean number of vacancies created in the L shell (from one K hole) n_{KL} and in the M shell (from one L hole) $\overline{n}_{LM}$ are estimated from the preceding values.

3.5. m_0c^2 energy

m_0c^2 energy is defined as 510.998 902 (21) keV, as given by the CODATA Group [34].

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^{3}H – Comments on Evaluation
by V.P. Chechev

The initial ^{3}H decay data evaluation was done by Chechev in 1998 (1999Be). This current (revised) evaluation was carried out in April 2006. The literature available by April 2006 was included.

1. DECAY SCHEME

^{3}H decays 100 % by β^--emission directly to the ground state of ^{3}He.

2. NUCLEAR DATA

Q^- value is from 2003Au03.

The evaluated ^{3}H half-life is based on the experimental data given in Table 1. This table has been taken from the paper of Lucas and Unterweger (2000Lu17) which contains a comprehensive review and critical evaluation of the half-life of tritium.

Table 1. Experimental values of the ^{3}H half-life (in years)

Reference	Author(s)	Measurement method	Half-life (years)	Stated uncertainty (years)	Meaning of the stated uncertainty	Comments
1936 McMillan	McMillan	Ionization current	>10	None	No uncertainty	Followed decay of radiation from irradiated beryllium for 4 months. OMITTED: limit only
1939 Alvarez	Alvarez and Cornog	Beta counting	0.41	0.11	Not given	One sample followed for 80 d. Chamber had diffusion losses. OMITTED: updated in 1940Alvarez
1940 Alvarez	Alvarez and Cornog	Beta counting	>10	None	No uncertainty	One sample followed for 5 months in new chamber. OMITTED: limit only
1940On01	O'Neal and Goldhaber	Beta counting	31	8	Not given	Counted tritium from irradiated lithium metal. OMITTED: outlier
1947Go08	Goldblatt *et al.*	Ionization current	10.7	2.0	Not given	Hydrogen + tritium in ionization chamber over 18 d. OMITTED: outlier
1947No01	Novick	Helium-3 collection	12.1	0.5	Not given	Two samples; accumulation times of 51 d and 197 d
1949Jenks	Jenks *et al.*	Helium-3 collection	12.46	0.20	Not given	Repeated measurements every two weeks until stable. OMITTED: updated in 1950Je60
1950Je60	Jenks *et al.*	Helium-3 collection	12.46	0.10	Probable error [a]	Four measurements over 206 d.
1951Jo15	Jones	Beta counting	12.41	0.05	Probable error [a]	Measurement of specific activity of tritium gas
1955Jo20	Jones	Helium-3 collection	12.262	0.004	Not given	Two samples; accumulation times of 578 d and 893 d
1958Po64	Popov *et al.*	Calorimetry	12.58	0.18	Not given	One sample; 21 measurements over 13 months
1963 Eichelberger	Eichelberger *et al.*	Calorimetry	12.355	0.010	Probable error [a]	Two samples measured over four years. OMITTED: updated in 1967Jo09

1966Merritt	Merritt and Taylor	Beta counting	12.31	0.13	Not given	Five gas counting measurements over 13 years
1967Jo09	Jordan *et al.*	Calorimetry	12.346	0.002	Probable error [a]	Five samples; 266 measurements over 6 years. OMITTED: updated in 1977RuZZ
1967Jo10	Jones	Helium-3 collection	12.25 12.31	0.08 0.42	99.7 % confidence limits	Two samples; accumulation times of 450 d to 800 d. Only the first value is usually quoted
1977RuZZ	Rudy and Jordan	Calorimetry	12.3232	0.0043	95 % confidence limits	Eight samples; 1353 measurements over 16 years
1980Un01	Unterweger *et al.*	Beta counting	12.43	0.05	1 standard uncertainty	Two sets of gas counting measurements 18 years apart. OMITTED: updated in 2000Unterweger
1987Bu28	Budick *et al.*	Bremsstrahlung counting	12.29	0.10	Not given	Two samples of tritium + xenon gas measured over 320 d. OMITTED: updated in 1991Bu13
1987Ol04	Oliver *et al.*	Helium-3 collection	12.38	0.03	1 standard uncertainty	Fifteen samples, each with accumulation times of 1 year to 2 years
1987Si01	Simpson	Beta counting	12.32	0.03	1 standard uncertainty	Tritium implanted in Si(Li) detector measured over 5.5 years
1988 Akulov	Akulov *et al.*	Helium-3 collection	12.279	0.033	1 standard uncertainty	Five series of measurements over 846 d
1991Bu13	Budick et al.	Bremsstrahlung counting	12.31	0.03	1 standard uncertainty	Two samples of tritium + xenon gas measured over 5.5 years
2000 Unterweger	Unterweger and Lucas	Beta counting	12.33	0.03	1 standard uncertainty	Three sets of gas counting measurements over 38 years

[a] The probable error, PE , is the deviation from the population mean, μ , such that 50 % of the observations may be expected to lie between μ – PE and μ + PE . For a normal distribution, the probable error can be converted to the standard deviation by multiplying by 1.4826.

As seen from Table 1 there are a number of measurements of the tritium half-life. Three of them stand out by their high precision (1955Jo20, 1967Jo09, 1977RuZZ). However, the uncertainties stated for the half-life in these works do not include an estimation of possible systematic errors. There are available newer measurements and discussions of the tritium half-life, so it is possible to estimate an "external" minimum uncertainty due to systematic effects (σ_{min}) that should be added to the uncertainties stated in 1955Jo20, 1967Jo09 and 1977RuZZ. At that we can take into account the following circumstances:

a) The ^{3}He collection result of 1955Jo20 has been obtained using only two points on each decay curve (for two samples). In the later work by the same method (1967Jo09) many experimental points were obtained on the decay curves (also for two samples) and the estimated systematic uncertainty made up 0.8 % for a 99.7 % confidence level.

b) The result of 1977RuZZ is a continuation of the measurements of 1967Jo09 for two tritide solids by calorimetric method for an additional 12 years. The difference of results of 1967Jo09 and 1977RuZZ proved to be 0.2 %, more than $5\sigma_{exp}$ from 1977RuZZ and more than $10\sigma_{exp}$ from 1967Jo09.

c) The comparative analysis of measurements of the radioactivity concentrations in several NBS tritiated-water standards over an 18-year period 1961 - 1978 (1980Un01) showed that for agreement of measurements (at given tritium half-life) their estimated standard errors (including a calorimetric method) should not be less 0.2 %.

Thus we have sufficient grounds for adding the "external" systematic error $\sigma_{min} = 0.002 \cdot T_{1/2}$ (^{3}H) into the uncertainties quoted in 1955Jo20, 1967Jo09 and 1977RuZZ. Lucas and Unterweger (2000Lu17) estimated the standard uncertainty of 1955Jo20 as 0.030 yr and that of 1977RuZZ as 0.025 yr.

Table 2 shows the modified set of half-life values, which has been formed from the original set by omitting the ten measurement results (see Comments in Table 1) and adjusting the uncertainties of 1955Jo20, 1977RuZZ and 1966Merritt. Latter was re-estimated in 2000Lu17.

Table 2. Selected measurement results for tritium half-life (in years)

Reference	Half-life	Measurement method	Comments on uncertainty
1947No01	12.1(5)	^{3}He collection	Author's stated uncertainty (ASU)
1950Je60	12.46(15)	^{3}He collection	ASU multiplied by 1.4826
1951Jo15	12.41(7)	Beta counting	Author's stated uncertainty
1955Jo20	12.262(30)	^{3}He collection	Uncertainty re-estimated in 2000Lu17
1958Po64	12.58(18)	Calorimetry	Author's stated uncertainty
1966Merritt	12.31(4)	Beta counting	Uncertainty re-estimated in 2000Lu17
1967Jo10	12.25(3)	^{3}He collection	Author's stated uncertainty
1977RuZZ	12.323(25)	Calorimetry	See text
1987Ol04	12.38(3)	^{3}He collection	Author's stated uncertainty
1987Si01	12.32(3)	^{3}H implanted into Si(Li)	Author's stated uncertainty
1988Akulov	12.279(33)	^{3}He collection	Author's stated uncertainty
1991Bu13	12.31(3)	Bremsstrahlung	Author's stated uncertainty
2000Unterweger	12.33(3)	Three sets of gas counting measurements over 38 years	Author's stated uncertainty

A weighted average for the final data set is 12.312 with an internal uncertainty of 0.010 and an external uncertainty of 0.013 and a reduced $\chi^2/\nu = 1.6$. An unweighted average is 12.33(3). Different statistical procedures from 1994Ka08 give the similar results: UINF, LWM, NORM – 12.312(10), PINF, BAYS and MBAYS – 12.312(13), IEXW – 12.314(14), RAJ – 12.311(10), CHV – 12.317(16). Lucas and Unterweger (2000Lu17) used three other statistical procedures including the method of determining the median and the estimated standard deviation of the median and adopted the value of 12.318(25).

The LWEIGHT computer program using the LWM procedure has led to the recommended value of 12.312(10).

The EV1NEW computer program (2000Ch01) has chosen the weighted average of 12.312 and recommended the smallest experimental uncertainty of 0.025 as a final uncertainty.

The adopted value of the ^{3}H half-life is 12.312(25) years, or 4497(9) days.

It should be noted this half-life value has been evaluated for molecular tritium. The half-life of atomic tritium is less by ~0.26% (2004Ak16). See also 2005Ak04 for a bare triton half-life.

2.1. Tritium Beta End-Point Energy (E_b^0)

The tritium beta end-point energy depends upon the chemical state of the tritium in an experiment. The expression for E_β^0 of molecular tritium differs from that of a "bare" nucleus by the "chemical shift" $\Delta E = B(RHe+) - B(RT)$ (1985Ka21, 1989Re04) which is calculated taking into account the spectrum of final states (SFS). (Here the B values indicate electron binding energies for He+ ion and tritium atom, R indicates a chemical state).

For known ^{3}He-^{3}H atom mass difference (ΔMc^2) the tritium beta "end -point" energy measured in some experiment is :

$E_\beta^0 = \Delta Mc^2 - E_{rec} - [B(He) - B(T)] + [B(RHe+) - B(RT)]$

where E_{rec} is the helium recoil energy.

For tritium atom (nuclide) $E_\beta^0 = \Delta Mc^2 - 3.4$ eV $- 64.3$ eV $+ \Delta E$ where $\Delta E = 40.82$ eV.

With the recommended value of ΔMc^2, the beta end-point energy for tritium nuclide is obtained by this way as 18563.6 eV. It is difficult to estimate the uncertainty of the ΔE calculation in1985Ka21. Supposing it about the evaluated uncertainty of ΔMc^2 (Q value), we have E_β^0 (^{3}H nuclide) = 18.564(2) keV.

For real forms of tritium sources in beta -spectrometry experiments the ^{3}H end-point energies differ from the atomic value. For a molecular forms HT, CH_3T, valine the calculated E_β^0 makes 18572(2) eV. Below the measured end-point energies in some experiments are shown.

1987Bo07	Valine	18.579.4 ± 4 eV
1993Ba08	Molecular tritium	18.574.8 ± 0.6 eV
1993Su32	$C_{14}H_{15}T_6O_2N_3$	18.578.3 ± 5.1 eV
1995St26	Gaseous tritium	18.568.5 ± 2.0 eV
2003Kr17	Gaseous tritium	18.570.5 eV

It should be noted that many works devoted to study of tritium beta -spectrum as it provided the most precise data of neutrino mass upper limit (see, for example, 2005Kr03, 2003Lo10, 2002Bo31 and references therein).

2.2. Average energy of beta particles of tritium per disintegration (<E$_b$>)

In Table 3 the available data of the <E $_\beta$> have been presented. The recommended value <E $_\beta$> has been obtained as the weighted average after corrections into the original results of the experiments and calculations. The calculation of the <E $_\beta$> with the LOGFT computer program using the adopted value Q^- = 18.591(1) keV gives 5.68 (±0.0011) keV.

Table 3. The available data of the tritium average beta energy (per disintegration, keV)

Reference	Method	Original	Re-estimated	Adopted
1950Je60	Calorimetry	5.69(4)	5.68(4) [a]	5.68(4)
1958Gr93	Calorimetry	5.57(1)	5.68(2) [a]	5.68(2)
1961Pi01	Calorimetry	5.73(3)	5.68(3) [b]	5.68(3)
1972Ma72	Calculation	5.7		5.7(1) [d]
1985Martin	Calculation	5.684(5)	5.680(5) [c]	5.68(1) [d]
1985Garcia	TDCR	5.70		5.70(2) [d]
1987Lagoutine, 1994Si21	Calculation	5.71(3)	5.70(3) [c]	5.70(3)
Recommended value 5.68(1) keV				

[a] Corrected for the adopted tritium half-life of 12.312 y and heat output of 0.324(1) W/g

[b] Corrected for the adopted tritium half-life of 12.312 y

[c] Corrected for the adopted decay energy (Q^- = 18.591 keV)

[d] Uncertainty attributed by the evaluator

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^{7}Be - Comments on Evaluation of Decay Data
by R. G. Helmer

This evaluation was originally done in 1996 by R. G. Helmer and E. Schönfeld and minor editing was added in December 2000.

1. Decay Scheme

This decay scheme is complete since the only levels in ^{7}Li below the decay energy are populated.

2. Nuclear Data

The Q value is from the mass evaluation in 1995Au04.

The adopted half-life is 53.22 (6) days.

The ^{7}Be half-life has been observed to vary depending on the chemical form of the ^{7}Be. Some of these measured variations are:

Reference	Chemical forms compared	$(\Delta T_{½} \times 10^4)/T_{½}$
1949Se20	Be - BeO	1.5 (9)
1953Kr16	Be - BeO	1.3 (5)
	BeO- BeF_2	6.1 (6)
	Be - BeF_2	7.4 (5)
1956Bo36	Be - BeF_2	12 (1)
1970Jo21	BeO- BeF_2	11.3 (6)
	BeO - $BeBr_2$	14.7 (6)
	BeO- $Be_4O(CH_3COO)_6$	-7.2 (6)
	BeO- $Be(C_5H_5)_2$	8.0 (7)
	BeO- $Be(OH_2)_4$	-3.7 (8)
	BeF_2- $Be_4O(CH_3COO)_6$	-18.5 (8)
	$Be(C_5H_5)_2$- $Be(OH_2)_4$	-11.7 (11)
1999Hu20	BeO - $Be(OH)_2$	-149.
	BeO - $Be^{2+}(OH_2)_4$	-98.
1999Ra12	Be in Au - Be in Al_2O_3	72 (7)

Excluding the much larger changes reported by 1999Hu20 and 1999Ra12, these measured changes range from 0.01% to 0.2%, or from 0.005 to 0.10 days, or 0.08 days, if the organic compounds are also omitted.

The adopted value of 53.22 (6) is from Limitation of Relative Statistical Weight (LRSW) (1985ZiZY, 1992Ra09) analysis of 53 (2) (1940Hi01), 52.93 (22) (1949Se20), 53.61 (17) (1953Kr16), 53.0 (4) (1956Bo36), 53.5 (2) (1957Wr37), 53.1 (3) (1965En01), 53.52 (10) (1970Jo21), 53.0 (3) (1974Cr05), 53.17 (2) (1975La16), 53.16 (1) (1982ChZF), 53.284 (4) (1982RuZV), and 53.12 (7) (1996Ja10). In this analysis the uncertainty of 1982RuZV value was increased from 0.004 to 0.0088 so that its relative weight was reduced from 83 % to 50 %. The weighted average of these values is 53.225 with an internal uncertainty of 0.006, a reduced-χ^2 of 10.5, and an external uncertainty of 0.020. This uncertainty is increased by the LRSW method to 0.06 so that the most precise value of 53.284 is included; this uncertainty also includes the next most precise value of 53.16.

The chemical forms of the samples for which these half-lives were determined are: 1949Se20 Be metal or BeO and difference is not significant, 1953Kr16 Be metal, 1956Bo36 Be metal or BeF_2 and difference is not significant, 1970Jo21 average of data for BeF_2, BeO, and $Be(C_5H_5)_2$, and 1975La16 isolated Be atoms in aluminum matrix.

The adopted half-life is dominated by the values of 1975La16, 1982ChZF, and 1982RuZV which contribute 10 %, 39 %, and 50 % of the relative weight, respectively. The values of 1982ChZF and 1982RuZV differ by ~ 10σ and contribute 3.8 and 4.1 to the reduced-χ^2 value of 10.5. Since these three values differ by 0.12 days and the chemical forms in the latter two cases are not known, the chemical variation data in the above table suggest that some of this difference may be due to chemical effects. This suggests that the adopted uncertainty of 0.06 days is reasonable for general use. In any case, the data on the chemical effects indicate that the adopted value can certainly be used for Be and BeO sources.

Values not used are 54.5 (J. F. Bonner as quoted in 1953Kr16, no uncertainty); and 54.3 (5) (1947BoAA as quoted in 1953Kr16, superseded by value of 1956Bo36); and 53.694 (6), 53.416 (6), and 54.226 (6) (1999Hu20). The values of 1999Hu20 have very small uncertainties and have very large variations, up to 1.5%, with chemical form which need to be confirmed. If this large shift and that of 1999Ra12 are correct, they would invalidate the uncertainty of our adopted value.

Also, the results of 2000Hu20 and 2000Li21 were obtained after this evaluation was completed, but these results would not change the adopted value.

Recent experiments have shown that the half-life of 7Be increases as much as 0.7% by imbedding this radionuclide in different matrices. The recommended value presented in this evaluation should be adequate for Be and BeO samples.

2.1 Electron-capture transitions

The adopted value for the electron capture to the 477-keV level is $P_\varepsilon(477)$ = 10.44 % (4). This value is a weighted average of 10 (+20-7) (1938RuAA), 10.7 (20) (1949Wi13), 11.8 (12) (1949Tu06), 12.3 (6) (1951Di12), 10.35 (8) (1969TaZX), 10.47 (20) (1970MuZU), 10.42 (18) (1973Po10), 10.35 (8) (1974Go26), 10.10 (45) (1983Ba15), 10.61 (23) (1983Da14), 10.6 (5) (1983Do07), 10.9 (11) (1983Kn10), 10.7 (2) (1983Ma34), 9.8 (5) (1983No03), 11.4 (7) (1984Ev01), 10.61 (17) (1984Fi10), and 10.49 (7) (1984Sk01). This weighted average has an internal uncertainty of 0.039, a reduced-χ^2 of 1.35, and an external uncertainty of 0.045. The adopted value is dominated by the values of 1969TaZX, 1974Go24, and 1984Sk01 which contribute 23 %, 23 %, and 30 % of the relative weight, respectively. The largest contribution to the reduced-χ^2 is 0.6 from 1951Di12.

Values not used are 10.32 (16) (1962Ta11, superseded by 1969TaZX) and 10.5 (2) (W. Poenitz, 1966, superseded by 1973Po10).

The P_K and P_L values of 0.908 (12) and 0.092 (12) were calculated from the tables in 1998Sc28. The values from the LOGFT code are 0.97 and 0.03, which are different.

2.2 Gamma-ray transition

The γ-ray transition energy is computed from the γ-ray energy.

The internal-conversion coefficient is the measured value of 1964Kr04 and the mixing ratio was also determined by 1964Kr04. The theoretical values interpolated from the tables of 1976Ba63 are 7.73×10^{-7} for M1 and 2.96×10^{-6} for E2.

The gamma transition probability is :
Within its uncertainty, $P_\gamma(477) = I_\gamma(477) \times (1.0+\alpha) = P_\varepsilon(477)$
With $I_\gamma(477) = 10.44\ (4)\ \%$ (c.f. § 2.1)

3. Atomic Data

The fluorescence yield is from the compilation of 1994Hu23.

4. Radiations

The conversion electron emission intensity is computed from $P_\gamma(477)$ and α_K.

The γ-ray energy is from the evaluation of 2000He14.

5. Main Production Modes

^{6}Li(d,n), ^{10}B(p,α), and ^{12}C(^{3}He,2α)

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^{11}C – Comments on evaluation of decay data
by V. Chisté and M. M. Bé

1) Decay Scheme

^{11}C disintegrates by β^+ emission (99.750(13)%) and electron capture (0.250(13)%) to the ground state of the stable nuclide ^{11}B.

2) Nuclear Data

The Q value (1982.5(9) keV) is from Audi and Wapstra evaluation (1995Au04), and has been calculated with the formula:

Q = $M(A,Z) - M(A,Z-1)$,
where M(A,Z) and M(A,Z-1) are the measured atomic masses of ^{11}C and ^{11}B, respectively.

$E_{\beta+}$, calculated from this Q value ($E_{\beta+}$ = 960.5(9) keV), is in agreement with a weighted average value of 959.8(5) keV, which was calculated from measured values (see b$^+$ **Transition and Electron Capture Transition**).

The measured ^{11}C half-life values (in minutes) are given below:

$T_{1/2}$

Reference	Value (min)
Smith (1941Sm11)	20.35 (8)
Solomon (1941So01)	20.5 (6)
Siegbahn (1944Si30)	20.0(4)
Dickson (1951Di12)	20.0 (1)
Kundu (1953Ku08)	20.74 (10)
Barber (1955Ba63)	20.26 (10)
Prokoshkin (1957Pr53)	20.8 (2)
Arnell (1958Ar15)	20.11 (13)
Kavanagh (1964Ka31)	20.34 (4)
Patterson (1965Pa10)	20.8 (4)
Awschalom (1969Aw02)	20.40 (4)
Hogstrom (1973Ho43)	19.8 (8)
Singh (1973SiYS)	20.0 (3)
Azuelos (1975Az01)	20.382 (20)
Behrens (1975Be28)	20.32 (12)

Evaluators calculated the weighted average of these 15 values using the Lweight program (version 3) as 20.369 min with an external uncertainty of 0.028 and a reduced χ^2 of 3.07. The value of Azuelos (1975Az01) has a relative statistical weight of 54%. Evaluators rejected Siegbahn's (1944Si30) value (quoted by Janecke (1960Ja12) and Raman (1978Ra21)), because they could not be find the article, and therefore no details were available on how Siegbahn obtained such a value. For the remaining 14 values,

the largest contribution to the weighted average comes from the value of Azuelos (1975Az01), with a relative statistical weight of 57%. The program Lweight 3 has increased the uncertainty of the 1975Az01 value from 0,02 to 0,0231 in order to reduced its relative statistical weight to 50%.
The adopted value is the weighted average : *20.370 min*, with an external uncertainty of *0.029* min. The reduced χ^2 is 3.24.

b$^+$ **Transition and Electron capture transition**

For the K/β^+ ratio, the following values have been found in the literature:

Reference	Value (10^{-3})
Scobie (1957Sc02)	1.9(3)
Campbell (1967Ca21)	2.30 (+0.14;-0.11)

β^+ and electron capture probabilities have been calculated using the most recent value of K/ β^+ ratio measured by Campbell (19 67Ca21), P_K/P_{EC} = 0.9174(91) (See Section 2.2), and normalizing to a total probability ($P_{\beta+}$ + P_{EC}) of 100%. This leads to $P_{\beta+}$ = 99.750(13) % and P_{EC} = 0.250(13), respectively. The uncertainties were calculated through their propagation on the above formulas.

The experimental K/β^+ ratio of Campbell is close to the theoretical values:
a) 2.222 10^{-3} calculated with LOGFT program;
b) 2.00 10^{-3} calculated by Scobie (1957Sc02);
c) 2.18 10^{-3} calculated by Campbell (1967Ca21);
d) 2.46 10^{-3} calculated by Vatai (1968Va23);
e) 2.316 10^{-3} given by Fitzpatrick (1973Fi13);
f) 2.11 10^{-3} given by Bambynek (1977Ba49);

Evaluators calculated a lg ft of 3.592 for this allowed transition. The value agrees with 3.599 suggested by Ajzenberg-Selove (1980Aj01, 1985Aj01 and 1990Aj01).

The partial sub shell capture probabilities given in Section 2.2 were calculated using the program EC - Capture for an allowed transition.

The weighted mean of the β^+ end-point energy has been calculated (with the Lweight program, version 3) using the following measured values (in keV):

Reference	Values (keV)
Townsend (1940To03)	981(5)
Moore (1940Mo40)	1030(30)
Siegbahn(1944Si30)	993(1)
Richards (1950Ri07)	958(3)
Wong (1954Wo19)	968(8)
Campbell (1967Ca21)	958.2(14)
Fitzpatrick (1973Fi13)	960.2(10)
Azuelos (1975Az01)	960.0(10)
Behrens (1978Be28)	960.8(26)
Raman (1978Ra21)	960.1(11)

The weighted average of these 10 values is 967 keV with an uncertainty of 2.6 keV and a reduced χ^2 of 97. The values of 1944Si30, 1973Fi13 and 1975Az01 have a relative weight of 21%. The Townsend (1940To03), Moore (1940Mo40), Siegbahn (1944Si30) and Wong (1954Wo19) values have been rejected by the Lweight program, based on the Chauvenet's criterion. For the remaining 6 values, the largest contribution to the weighted average comes from the values of Fitzpatrick (1973Fi13) and Azuelos

(1975Az01), amounting to a statistical weight of 28%. The weighted average is 959.8 keV, with an internal uncertainty of 0,5 keV and a reduced χ^2 of 0,41. This value is in agreement with $E_{\beta+}$ (960.5(9) keV) deduced from the adopted Q value (1995Au04) in this evaluation.

3) Gamma-ray Emissions

The annihilation radiation emission probability ($I_{\gamma 511}$) is $P_{\beta+}$ (=99.750(13)%), multiplied by 2, without the correction factor for the annihilation-in-flight process in the medium. That is, $I_{\gamma 511}$ = 199.500(26)%.

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^{13}N – Comments on evaluation of decay data
by V. Chisté and M. M. Bé

1) Decay Scheme

^{13}N disintegrates by β^+ emission (99,818 (13) %) and electron capture (0,182 (13) %) to the ground state of the stable nuclide ^{13}C.

2) Nuclear Data

The Q value (2220,44 (27) keV) is from the evaluation of Audi and Wapstra (1995Au04), and has been calculated using the formula:

Q = $M(A,Z) - M(A,Z-1)$,
where M(A,Z) and M(A,Z-1) are the measured atomic masses of ^{13}N and ^{13}C, respectively.

The $E_{\beta+}$ deduced from this Q value ($E_{\beta+}$ = 1198,45 (27) keV) agrees with the weighted average value of 1199,00 (36) keV, deduced from measured values (see § b$^+$ **Transition and Electron Capture Transition**).

The measured ^{13}N half-life values (in minutes) are given below:

$T_{1/2}$

Reference	Value (min)
Ward (1939Wa35)	9,93 (3)
Siegbahn (1945Si02)	10,13 (10)
Cook (1948Co05)	10,2 (1)
Churchill(1953Ch34)	10,048 (32)
Wilkinson (1955Wi43)	10,08 (4)
Daniel (1957Da07)	9,960 (30)
Deineko (1957De22)	10,02 (10)
Norbeck (1957No17)	10,07 (6)
Arnell (1958Ar15)	9,960 (30)
King (1960Ki02)	9,93 (5)
Janecke (1960Ja12)	9,965 (5)
Ebrey (1965Eb03)	9,96 (2)
Bormann (1965Bo42)	10,05 (5)
Ritchie (1968Ri15)	9,963 (9)
Singh (1973SiYS)	10,0 (5)
Azuelos (1977Az01)	9,965(10)
Katoh (1989Ka08)	9,962 (20)

The weighted average has been calculated using the Lweight computer program (version 3).

The Siegbahn (1945Si02) and Cook (1948Co05) values have been shown to be outliers by the Lweight program, based on the Chauvenet's criterion. For the remaining 15 statistically consistent values, the largest contribution to the weighted average comes from the value of Janecke (1960Ja12), with statistical weight of 54 %. The reduced-χ^2 is 1,65.

The adopted value is the weighted average : *9,9670 min*, with an uncertainty of *0,0037min.*

2.1) b$^+$ Transition and Electron capture transition.

The β^+ and electron capture probabilities shown in Tables 2.1 and 2.2, respectively, have been deduced by using a K/ β^+ ratio of (1,68 ± 0,12).10^{-3} measured by Ledingham (1963Le06) and, normalizing to a total probability ($P_{\beta+}$ + P_{EC}) of 100%. This experimental K/ β^+ ratio is close to the following theoretical values:
a) 1,864 10^{-3} calculated with LOGFT program;
b) 1,939 10^{-3} calculated by Fitzpatrick (1973Fi13);
c) 1,800 10^{-3} given by Bambynek (1977Ba49);
d) 1,78 10^{-3} given by Ledingham (1963Le06).
The uncertainties were estimated by standard error-propagation techniques.

The *lg ft* value for β^+ transition (3,654) has been calculated with the program LOGFT for an allowed transition. This value agrees with 3,637 suggested by Ajzenberg -Selove (1981Aj01, 1986Aj01 and 1991Aj01).

The partial sub shell capture probabilities P_K and P_L were calculated for an allowed transition using the computer program EC-Capture.

A weighted average (1199,0(4) keV) of the β^+ end-point energy has been decuded (using the Lweight computer program, version 3) from the following measured values (in keV):

Reference	Values (keV)
Hornyak (1950Ho01)	1202 (5)
Grabowsky (1954Gr03)	1185 (25)
Daniel (1957Da07)	1190 (3)
Fitzpatrick (1973Fi13)	1198,5(9)
Raman (1978Ra21)	1198,7 (4)

The largest contribution (with an statistical weight of 81%) to the weighted average of these 5 values comes from the value of Raman (1978Ra21). The weighted average is 1199,00 keV, with an internal uncertainty of 0,36 and a reduced -χ^2 of 2,2. This value agrees with $E_{\beta+}$ (1198,45(27) keV), which was deduced from the adopted Q value (1995Au04) in this evaluation.

3) Gamma-ray Emissions

The annihilation radiation emission intensity ($I_{\gamma 511}$) is $P_{\beta+}$ (= 99,818 (13)), multiplied by 2, wi thout the correction factor for the annihilation-in-flight processus in the medium. That is, $I_{\gamma 511}$ = 199,636 (26) %.

4) Atomic Data

Atomic K-fluorescence yield (ω_K) is from Bambynek (1984Ba01).

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^{14}C - Comments on evaluation of decay data
by M.M. Bé and V.P. Chechev

This evaluation was completed in 1998, it was updated in January 2012 to include the most recent Q(β^-) update. The literature available by this date was included.

Nuclear Data

Half-life

In literature there are many measurements of the ^{14}C half-life dating from 1946 to 1954 (Table 1). Mann *et al.* (1961) discussed the problem of spread of these measurement results from 4 700 to 7 200 years. They connect the divergence with very low enrichment of ^{14}C (a few percentages) and a large systematic uncertainty arose from retention of a small quantity of carbon dioxide with a high specific activity during a gas dilution phase. Therefore, following Holden (1990Ho28) who evaluated the ^{14}C half-life in 1990, we have omitted the measurement results before 1961 and considered only later measurements (Table 2). In all the latter works the number of ^{14}C atoms has been determined by the mass-spectrometric method and the counting rate was measured by different methods as shown in Table 1.

Table 1: Results of ^{14}C half-life measurements

NSR keynumber	Half-life of ^{14}C, years	Method
1946Re10	4 700 (400)	SA: GM; MS
1948No02	5 100 (200)	- " -
1948Ya02	7 200 (500)	- " -
1949Ha52	6 360 (200)	- " -
1949Jo07	5 589 (75)	- " -
1950En59	5 580 (90)	- " -
1950Mi10	6 360 (190)	- " -
1950Mi10	5 513 (165)	SA: PC ; MS
1951Ma30	5 370 (200)	SA: IC ; MS
1952Je11	6 030	SA: GM ; gas density
1954Ca41	5 900 (250)	SA: Cal ; gas density
1961Ma32	5 760 (50)	SA: PC ; MS
1961Wa16	5 780 (65)	SA: PC ; MS
1962Ol14	5 680 (40)	SA: PC ; MS
1964Hu09	5 745 (50)	SA: PC ; MS. 1961Ma32 value revised
1968Be47	5 660 (30)	SA: PC(GM) ; MS
1968Re13 + 1972Em01	5 736 (56)	SA: LS ; MS

Usual designations:
SA - method of radionuclide specific activity determination, by mean of Geiger-Müller counter (GM), proportional counter (PC), calorimeter (Cal), ionization chamber (IC) or liquid scintillation counter (LS);
MS - determination of the number of atoms by the mass-spectrometric method.

Table 2: Selected measurement results and recommended value of ^{14}C half-life

Year	Half-life of ^{14}C, *a*	Reference NSR keynumber
1961	5 780 (65)	1961Wa16
1962	5 680 (40)	1962Ol14
1964	5 745 (50)	1964Hu09
1968	5 660 (30)	1968Be47
1968	5 736 (56)	1968Re13/1972Em01

χ^2 /n-1 = 1,2 ; critical χ^2 = 3,3

Weighted average	5 697 (21) *a*
Unweighted average	5 720 (22) *a*
Recommended value	5 700 (30) *a*

The adopted value of the ^{14}C half-life is the weighted average of the five results listed in Table 2. Since they were all obtained by the same method of the specific activity measurement, the final uncertainty is taken as the lowest experimental uncertainty of the data set.

It should be noticed that Holden gave a similar evaluation of ^{14}C, $T_{1/2}$ (5 715 ± 30 years), but he adopted the unweighted average of the same measurement results with addition to them of the average of three values obtained in 1949-1950.

From an analysis of fossil corals whose ages were determined *via* ^{234}Th/^{234}U/^{238}U dating, a ^{14}C half-life of "6 030" *a* should be expected (2007Ch**). A re-determination of the ^{14}C half-life is required to improve radiocarbon-based researches.

Decay Energy and Characteristics of Electron Emission (β^-)

The ^{14}C beta decay to the ground state level of ^{14}Ni is expected to be allowed ($0^+ \rightarrow 1^+$). However it has been shown deviations in the shape of the ^{14}C beta spectrum (2000Ku25, 1995Wi20). A summary of measured and predicted spectra is given in 2000Ku25.

The maximum energy of the β spectrum was deduced from the results of measurements, as listed below.

Table 3: Measured β end-point energy, E_0.

Reference	**E_0 (keV)**	**u_c**	**Remarks**
Cook (1948Co10)	156,3	10	
Forster (1954Fo*)	155	1	
Smith (1975Sm02)	156,476	0,005	rf mass spectrometer
Sur (1991Su09)	155,74	0,08	^{14}C-doped Ge detector, taking into account anomalies in the β spectrum
Wietfeldt (1995Wi20)	155,95	0,22	^{14}C-doped Ge detector, taking into account anomalies in the β spectrum
Kuzminov (2000Ku25)	156,27	0,14	Wall-less proportional counter, taking into account anomalies in the β spectrum

It is noteworthy that the value reported by Smith (1975Sm02) is much more precise but also discrepant with the other results obtained by different methods.

The set of the four most precise values is discrepant with a χ^2 /n-1 = 17. Then the uncertainty of the Smith's value has been increased to 0,066 in order to reduce its weight to 50 %. The resulting weighted average with an expanded uncertainty to cover the most precise result is: 156,18 (30) keV.

This value is considerably less precise than the recommended value of 156,476 (4) keV given in Audi *et al.* (2003Au03).
On one hand, the weighted mean is only limited to values following ^{14}C β^- decay and one value that comes from a direct mass-difference measurements using the rf technique; when the value recommended by Audi *et al.* (2003Au03/2011AuZZ) is deduced from the mass differences between ^{14}C and ^{14}N, determined using a robust least-squares procedure.
On the other hand, in that case the whole "robust least-squares procedure" in 2003Au03/2011AuZZ is dominated by the single ultra-precise mass-spectrometric value. And this exact ^{14}C - ^{14}N mass difference affects other masses, and not *vice versa*.

In this evaluation we will accept the Audi *et al.* recommendation, while following the Wietfeld’s conclusion (1995Wi20): “We feel there is a significant problem in the ^{14}C Q value and we hope that this will be resolved by future experiments”.

The average energy per disintegration has been calculated, expecting an allowed form of β^--spectrum, by using the program BetaShape (2012Mo**) which includes the calculations of “exchange effects”.

E_{max} (keV)	E_{mean} (keV)
156,18 (30)	49,1 (3)
156,476 (4)	49,16 (1)

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1995Wi20	F.E. Wietfeldt, *et al.* Phys. Rev. C52, 2 (1995) 1028	[Q]
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2007Ch**	Tzu-Chien Chiu, *et al.* Quaternary Science Reviews 26 (2007) 18	[$T_{1/2}$]
2011AuZZ	G. Audi, W. Meng, http://amdc.in2p3.fr/masstables/Ame2011int/mass.mas114	[Q_{β^-}, Q_{ε}]
2012Mo**	X. Mougeot, M.-M. Bé, C. Bisch, M. Loidl. Evidence for the exchange effect in the beta decay of ^{241}Pu. Physical Review A86 (2012) 042506	[$<E\beta>$]

^{15}O – Comments on evaluation of decay data
by V. Chisté and M. M. Bé

1) Decay Scheme

^{15}O disintegrates by β^+ emission (99,885 (6) %) and electron capture (0,115 (6) %) to the ground state of the stable nuclide ^{15}N.

2) Nuclear Data

The Q value has been calculated using the formula:

$$Q = E_{b+} + 2m_0c^2 = 2757{,}0\ (13)\ \text{keV}$$

where $E_{\beta+}$ = 1735,0 (13) keV is the weighted mean of the β^+ end-point energy (see b^+ **Transition and Electron Capture**) and, $2m_0c^2$ = 1021,9978 (42) keV (2000Co21). The Q value calculated here is in agreement with the value of 2754,0 (5) from the Audi and Wapstra evaluation (1995Au04), which takes into account only Raman's value (1978Ra21, 1731,9 (7) keV) to determine the recommended Q value.

The measured ^{15}O half-life values are, in seconds:

$T_{1/2}$

Reference	Value (sec)
McMillan (1935Mc02)	126 (5)
Brown (1950Br29)	118,0 (6)
Kline (1954Kl36)	123,4 (13)
Bashkin(1955Ba83)	121 (3)
Kistner (1957Ki22)	122 (5)
Penning (1957Pe12)	123,95 (50)
Kistner (1959Ki99)	124,1 (5)
Janecke (1960Ja12)	122,1 (1)
Nelson (1963Ne05)	122,6 (10)
Csikai (1963Cs02)	125 (2)
Vasil'ev (1963Va23)	114 (12)
Azuelos (1977Az01)	122,23(23)

The half-life weighted average has been calculated by the Lweight program (version 3).

The weighted average of all 12 values is 122,16 s with an internal uncertainty of 0,09 and a reduced -χ^2 of 7,3. The value of 1960Ja12 has a relative weight of 76% and that of 1950Br29 contributes 4,4 to the reduced-χ^2.
The evaluator has chosen to reject the McMillan (1935Mc02) and Csikai (1963Cs02), because they are far from the other values and with large uncertainties.
The Brown (1950Br29) and Vasil'ev (1963Va23) values have been rejected by the Lweight program, based on the Chauvenet's criterion. For the remaining 8 values, the largest contribution to the weighted average comes from the value of Janecke (1960Ja12), amounting to a statistical weight of 78% (reduced -

χ^2 = 4,01). The program Lweight 3 has increased the uncertainty of the 1960Ja12 value from 0,1 to 0,186 in order to reduce its relative weight from 78% to 50%.
The adopted value is the weighted mean : *122,40 s*, with an uncertainty of *0,33;* or *2,041 (6) min*. The reduced-χ^2 is 3,2.

2.1) b$^+$ Transition and Electron capture

The β^+ and electron capture probabilities have been calculated taking into account a K/ β^+ ratio of (1,07 ± 0,06).10^{-3} measured by Leiper (1972Le06) and, normalizing to a total probability ($P_{\beta+}$ + P_{EC}) of 100%. The experimental K/β^+ ratio is close of its theoretical value (= 0,99(1) 10 $^{-3}$) calculated with the LOGFT program. The uncertainties were calculated through their propagation on the above formulas.

The value of log ft of the β^+ transition (3,6) has been calculated with the program LOGFT for an allowed transition, in agreement with the value suggested by Ajzenberg-Selove, which is 3,637 (1981Aj01, 1986Aj01 and 1991Aj01).

The partial sub shell capture probabilities were calculated with the program EC-Capture for an allowed transition.

The weighted mean of the β^+ end-point energy has been calculated (with the Lweight program, version 3) using the following measured values (in MeV):

Reference	Values (MeV)
Fowler (1936Fo16)	1,7 (2)
Stephens (1937St03)	1,56 (20)
Perez-Mendez (1949Pe23), Brown (1950Br29)	1,683 (5)
Kington (1955Ki39)	1,735 (8)
Kistner (1957Ki22) (solid target)	1,723 (5)
Kistner (1957Ki22) (gaseous target)	1,736 (10)
Kistner (1959Ki99)	1,739 (2)
Raman (1978Ra21)	1,7319 (7)

The values given by Fowler (1936Fo16), Stephens (1937St03), Perez-Mendez (1949Pe23) and Kistner (1957Ki22 – solid target) were shown (by the Lweight program) to be statistically inconsistent with the other values (based on the Chauvenet's criterion), thus the evaluators rejected those 4 values. The largest contribution to the weighted average of the 4 remaining values comes from the value of Raman (1978Ra21), amounting to a statistical weight of 88% (reduced-χ^2 = 3,8). The program Lweight 3 has increased the uncertainty of the 1978Ra21 value from 0,0007 to 0,0019 in order to reduce its relative weight from 88% to 50%.
The adopted value is the weighted mean : *1735,0 keV*, with an external uncertainty of *1,3* and a reduced-χ^2 of 2,2.

3) Gamma Emissions

The annihilation radiation emission probability (I_γ(511)), is $P_{\beta+}$, or 99,885(6), multiplied by 2, without the correction factor for the annihilation-in-flight in the medium, that is I_γ(511) = 199,770(12)%

4) Atomic Data

Atomic value (ω_K) is from Bambynek (1984Ba01).

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^{18}F – Comments on evaluation of decay data
by V. Chisté and M.M. Bé

1) Decay Scheme

^{18}F disintegrates by β^+ emission (96.86(16)%) and electron capture (3.14(16)%) to the ground state of the stable nuclide ^{18}O.

2) Nuclear Data

The Q value (1655.5 (6) keV) is from Audi and Wasptra (1995Au04), and has been calculated with the formula:

Q = $M(A,Z) - M(A,Z-1)$,
where M(A,Z) and M(A,Z-1) are the measured atomic masses of ^{18}F and ^{18}O, respectively.

$E_{\beta+}$, calculated from this Q value ($E_{\beta+}$ = 633.5(6) keV), is in agreement with a weighted average value of 633.2(3) keV, which was deduced from measured values (see b$^+$ **Transition and Electron Capture Transition**).

The measured ^{18}F half-life values (in minutes) are given below:

Reference	Value (min)
Snell (1937Sn14)	112 (4)
DuBridge (1938Br47)	107 (4)
Krishnan (1941Kr12)	112 (2)
Huber (1943Hu33)	115 (4)
Blaser (1949Bl30)	112 (1)
Jarmie (1955Ja12)	111 (1)
Bendel (1958Be08)	109.8 (12)
Markowitz (1958Ma12)	112 (1)
Carlson (1959Ca63)	109.70 (54)
Yule (1960Yu15)	110,2 (2)
Rayburn (1961Ra53)	111.0 (22)
Mahony (1962Ma15)	109.74 (21)
Beg (1963Be31)	109.6 (6)
Hofmann (1964Ho09)	110.5 (6)
Mahony (1964Ma07)	109.72 (6)
Ebrey (1965Eb02)	109.87 (12)
Bormann (1965Bo38)	111 (2)
Kavanagh (1969Ka17)	109.87 (12)
Hogstrom (1973Ho21)	95 (7)
Rutledge (1980Ru02)	109.71 (2)
Katoh (1989Ka01)	109.48 (8)
Schrader (2004Sc00)	109.748(21)

The only outliers values are 107 (4) min (1938Br47), 115 (4) min (1943Hu33) and 95 (7) min (1973Ho21), which contributed with a statistical weight of just $0.378.10^{-5}$ % (1973Ho21) to $0.116.10^{-4}$ % (1938Br47 and 1943Hu33) to the weighted average. Our recommended half -life is the weighted average of 109.728 (19) min, or 1.8288 (3) h ($\chi^2/\nu = 1.98$).

b$^+$ **Transition and Electron capture transition**

The β^+ and electron capture probabilities shown in Tables 2.1 and 2.2, respectively, have been deduced using a K/β^+ ratio of $(3.00 \pm 0.18)\ 10^{-2}$ measured by Drever (1956Dr02), $P_K/P_{EC} = 0.9267$ (48) (see Section 2.2) and, normalizing to a total probability ($P_{\beta+} + P_{EC}$) of 100 %. This leads to $P_{\beta+}$ = 96.86(19) % and P_{EC} = 3.14(19) %, respectively. The uncertainties were calculated through their propagation on the above formulas.

The experimental K/β^+ ratio of Drever is close to the theoretical values:
a) 3.19 10^{-2} calculated with LOGFT program;
e) 3.31 10^{-2} given by Fitzpatrick (1973Fi13);
f) 3.14 10^{-2} given by Bambynek (1977Ba49);

Using the LOGFT program evaluators calculated a lg ft of 3.57 for this allowed transition. This value agrees with 3.554 suggested by Ajzenberg-Selove (1972Aj01, 1978Aj01 and 1987Aj01).

The partial sub shell capture probabilities given in Section 2.2 were calculated using the program EC - Capture for an allowed transition.

The weighted mean of the β^+ end-point energy has been calculated (with the Lweight program, version 3) using the following measured values (in keV):

Reference	Values (keV)
Blaser (1949Bl30)	635 (15)
Ruby (1951Ru40)	649 (9)
Hofmann (1964Ho09)	635 (2)
Alburger (1970Al17)	632.9 (7)
Fitzpatrick (1973Fi13)	633.3 (3)

The weighted average of these 5 values is 633.2 keV with an internal uncertainty of 0.3 keV and a reduced χ^2 of 1.4. This value is in agreement with $E_{\beta+}$ (633.5 (6) keV) deduced from the adopted Q value (1995Au04) in this evaluation.

3) Gamma-ray Emissions

The annihilation radiation emission intensity ($I_{\gamma 511}$) is $P_{\beta+}$ (=96.86(19) %), multiplied by 2, without the correction factor for the annihilation-in-flight process in the medium. That is, $I_{\gamma 511}$ = 193.72(27) %.

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^{22}Na - Comments on evaluation of decay data
M. Galán

No substantial differences with previous Helmer and Schönfeld ^{22}Na evaluation (1999BeZQ) are found. Only Q-value is changed and a new ε/β^+ experimental ratio (2009NA08) is available since 1997.

1) Decay Scheme

^{22}Na disintegrates by electron capture and β^+ emission to excited level of 1274-KeV in ^{22}Ne.
^{22}Na ground state has $J_\pi = 3^+$ from Helmer and Schönfeld evaluation (1997).

The level scheme is complete. A good agreement has been found between the total decay energy of 2843,0 (24) keV computed for this decay scheme by RADLST code and the Q value of 2843,02 (21) keV.

2) Nuclear Data

The Q value is from new value of 2009AuZZ: Q β^+ = 2843,02 (21) keV obtained from the most recent measurements of 2004Mu26 and 2008Mu05. Other: 2842,3 (4) (2003AU03).

The measured ^{22}Na half-life values, in years, are:

Reference	Value (a)	Comments
2002UN02, 1992UN01	2,6037 (3)	
1982RUZV	2,6018 (7)	
1980HO17	2,6019 (4)	
1965AN07	2,613 (11)	Rejected by Chauvenet's criterion
1965AN07	2,603 (1)	
1965AN07	2,602 (11)	
1961WY01	2,62 (2)	Rejected by Chauvenet's criterion
1957ME47	2,58 (3)	Rejected by Chauvenet's criterion

	Mean	Reduced χ^2
LWM	2,6029 (8)	3,32
NRM	2,6023 (3)	2,37
RT	2,6021 (3)	

1965AN07 reported a fourth value of 2,5917 (30) which has been omitted from the analysis as it is inconsistent with all of other values. The previous values of 2,6019 (3) in 1980RUZX (replaced by 1982RUZV) and that of 2,5775 (3) in 1982HOJZ (replaced by 1992UN01) have not been included.

The Lweight for Excel and AveTool computer codes have been used with these eight input values. The weighted mean of the Limitation of Relative Statistical Weight Method (LWM) was the same result in both codes. AveTool also estimates the weighted mean by two more methods: Normalised Residual Method (NRM) (1992JA06) and Rajeval Technique (RT) (1992RA08). Following the most conservative method of LWM the eight values have been considered.

As it was discussed by Helmer and Schönfeld in their previous ^{22}Na evaluation (see Comments on ^{22}Na evaluation, 1999BeZS), the value of 2002UN02 is inconsistent with the other recent values from 1982RUZV and 1980HO17 and one could exclude the values before the 70's.
The values in 1957ME47, 1961WY01 and 1965AN07 were rejected based on the Chauvenet's criterion. For the remaining values, the largest contribution to the weighted average comes from the value of Unterweger (2002UN02). The LWM method increased the uncertainty of this value 1,093 times in order to reduce its relative weight to 50 %. The final uncertainty is also expanded from 0,0004 to 0,0008 to include de most precise value of 2,6037.

The recommended value is the more conservative LWM mean, 2,6029 (8) a or 950,6 (3) d [1 a = 365,242 198 78 d (1999BeZQ)] with an internal uncertainty of 0,0002 and an external of 0,0004.

Level energy has been obtained from a least-squares fit to γ-ray energies (GTOL computer code).

2.1) Electron Capture and Positron Transitions

Many different ε/β^+ ratios for the 1274-keV level have been measured. They are reported in Table 1 and compared with theoretical estimations:

Reference	ε/β^+ (experimental)	ε/β^+ (theoretical)	Comments
1954KR**†	0,124 (12)		
1954SH**†	0,110 (6)	0,1135 (20)	
1954ZW**†		0,111	
1955AL**†	0,122 (10)		
1958KO75	0,109 (8)		
1959RA09	0,112 (4)		
1964WI04	0,1041 (7)		
1967LE07	0,1048 (7)	0,1138 (25) 0,100 (6)	omitting e^- exchange correction with e^- exchange correction
1968VA13	0,1042 (10)	0,1118 (25)	
1969MC06	0,1136 (97)		From K/β^+ = 0,1050 (90). The factor 1/1,0816 from 1977BO10 was used.
1976MA38	0,1077 (6)		
1977BA48		0,1117 (4)	
1977BO10	0,1128 (57)		
1978FI11		0,1152 (3)	
1983BA41	0,1079 (3)		
1990KU11	0,1050 (29)	0,1116 (3)	
2009NA08	0,1084 (27)		

† References not appear in NSR database. Nomenclature has been added by evaluator.

As can be seen in Table 1, experimental results present important discrepancies and they do differ substantially from theoretical predictions. Firestone et al. (1978FI11) discussed further about the anomalous ε/β^+ in ^{22}Na.

Statistical analyses of the experimental values have been done. In the experimental dataset the LWM method rejected 1954KR01 and 1955AL01 values based on Chauvenet's criterion. The uncertainty of 1983BA41 was changed to reduce its relative weight to 50 %. For the 12 input values the weighted mean is 0,1068 with an internal uncertainty of 0,0002 and a external of 0,0005 and a reduced χ^2 of 2,25. The adopted value is 0,1068 (11) with an uncertainty increased to include the most precise value of 0,1079. If data before 1960 are rejected the LWM is 0,1067 (12) with expanded uncertainty and reduced χ^2 of 2,8.

Experimental data and theoretical estimations are found to differ up to 10 %.

The P_{β^+} and P_ε were derived as follows: with $\frac{P_\varepsilon(1274)}{P_{\beta^+}(1274)} = 0{,}1068(11)$ from experimental results and with $\frac{P_{\beta^+}(1274)}{P_{\beta^+}(0)} = 1600(400)$ from 1953WR13, these ratios were introduced in the relationship $100 = P_{\beta^+}(1274) + P_\varepsilon(1274) + P_{\beta^+}(0)$ neglecting the electron capture branching to the ground state. Then one obtain, $P_{\beta+}(0) = 0{,}056\ (14)\ \%$.

Then, the LOGFT program (theory) was run considering $P_{\varepsilon+\beta+}(1274) = 99{,}944\ (14)\ \%$ and $P_{\varepsilon+\beta+}(0) = 0{,}056\ (14)\ \%$. The ε/β^+ for the ground state estimated by the code is 0,01782 (18). Thus one has:

$$100 = P_{\beta^+}(1274) + 0{,}1068(11) \times P_{\beta^+}(1274) + \frac{1}{1600(400)} \times P_{\beta^+}(1274) + 0{,}01782(18) \times \frac{1}{1600(400)} \times P_{\beta^+}(1274)$$

That gives:

$P_{\beta+}(1274) = 90{,}30\ (9)\ \%$
$P_\varepsilon\ (1274) = 9{,}64\ (9)\ \%$
$P_{\beta+}(0) = 0{,}055\ (14)\ \%$
$P_\varepsilon(0) = 0{,}00098\ (25)\ \%$

Using EC-Capture program we have: P_K= 0,9233 (35) and P_L=0,0767 (35)

2.2) γ-ray Transitions

Transition Probabilities

The γ-transition probability is $P_{\varepsilon+}(1274) + P_{\beta+}(1274) = 90{,}30\ (9) + 9{,}64\ (9) = 99{,}94\ (13)\ \%$

Internal conversion coefficients

The internal conversion coefficients (ICC) have been calculated using the BrIcc computer code, which interpolated ICC values from tables of Band et al. (2002BA85). Associated uncertainties are 1,4 %. The theoretical value of 6,71 (9) × 10^{-6} agrees with the value of 6,8 (4) × 10^{-6} from the analysis of experimental data (1985HAZA).

The theoretical α_π (1979SC31) interpolated for this E2 transition is found to be 2,34 (3) x 10^{-5}.

3) Atomic Data

3.1) Atomic values (ω_K, ϖ_L and η_{KL}) are from 1996SC06.

3.1.1) X-Radiations, 3.1.2) Auger electrons

The X-ray and Auger electron emission probabilities have been deduced from γ-ray and conversion electron data by using the computer code EMISSION. Results were verified with the RADLST computer code. Differences between both codes were less than 4 %.

4) Electron Emissions

The β^+ and the electron capture emission probabilities are discussed above.

5) Photon Emissions

Energies

γ-ray energy 1274,537 (7) is from 2000HE14. The level energy has been computed to account for the recoil energy in the daughter nucleus.

γ-ray emissions

The absolute P_γ is evaluated from $P_{\gamma + ce}$ and the total internal conversion coefficient $\alpha = (\alpha_\pi + \alpha_T)$:

$$P_\gamma = \frac{P_{\gamma+ce}}{1+\alpha} = \frac{99{,}94(13)}{1+3{,}01(4)\times 10^{-5}} = 99{,}94(13)\%$$

The annihilation radiation emission probability is taken to be 2 times $P_{\beta+}$, that is 180,7 (2) % without the correction factor for the annihilation-in-flight.

Additional reference:

R.G. Helmer, E. Schönfeld (1999BeZS) Evaluation and comments on evaluation of ^{22}Na. Table des Radionucléides, CEA-ISBN 2-7272-0211-3 (1999).

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Comments of ^{24}Na Evaluation
by R. G. Helmer and E. Schönfeld

1 Decay Scheme

The decay scheme is complete since the four levels populated in this decay are the only excited levels in ^{24}Mg below the decay energy.

The spins, parities, and half-lives of the excited levels are from the Endt evaluation 1990En08.

2 Nuclear Data

For the half-life, the following values are available (in hours):

14.90 (2)	1949Wi10, Wilson and Bishop (1949)	
15.10 (4)	1950Co69, Cobble and Atteberry (1950)	
14.97 (2)	1953Lo09, Lockett and Thomas (1953)	
14.90	1955To07, Tobailem (1955)	omitted - no uncertainty
14.959 (10)	1958Ca20, Campion and Merritt (1958)	
14.953 (13)	1960Wo07, Wolf(1960)	
15.05 (2)	1961Wy01, Wyatt et al. (1961)	superseded by 1972Em01
15.04 (5)	1962Mo21, Monahan et al. (1962)	
15.00 (2)	1968La10, Lagoutine et al. (1968)	superseded by 1982La25
15.16 (5)	1969Ke14, Kemeny (1969)	omitted - no background subtraction
15.030 (3)	1972Em01, Emery et al. (1972)	omitted - outlier
14.969 (12)	1974Ch25, Chakraborty (1974); average of 6 values with external uncertainty	
15.09 (6)	1976Ge06, Genz et al. (1976)	
15.010 (28)	1978Da21, Davis et al. (1978)	
14.9590 (12)	1980Ho17, Houtermans et al. (1980)	
14.964 (15)	1980Mu11, Muckenheim et al. (1980)	
14.965 (10)	1980RuZY, Rutledge et al. (1980)	superseded by 1982RuZY
14.965 (10)	1982RuZV, Rutledge et al. (1982)	
14.956 (3)	1982La25, Lagoutine, Legrand (1982);	originally σ=0.008 divided by 3
14.951 (3)	1982HoZJ, Hoppes et al. (1982)	superseded by 1992Un01
14.9575 (28)	1983Wa26, Walz et al. (1983)	
15.027 (2)	1989Ab05, Abzouzi et al. (1989)	omitted - outlier
14.90 (2)	1991Bo34, Bode et al. (1991)	
14.9512 (32)	1992Un01, Unterweger et al. (1992)	
14.86 (12)	1994Mi03, Mignonsin (1994)	

14.9574 (20) **adopted value**, LRSW weighted average

In the final weighted average, the values of 1972Em01 and 1989Ab05 have been omitted because they are outliers; both are over 30σ from the adopted value. If these values are included, the reduced-χ^2 value is about 80. For the 17 values included, the Limitation of Relative Statistical Weight, LRSW, method (1985ZiZY, 1992Ra08) increases the uncertainty of the value of 1980Ho17 from 0.001

to 0.0016 in order to reduce its relative weight from 73% to 50%. In addition to this relative weight, those of the values of 1982La25, 1983Wa34, and 1992Un01 are between 13 and 15%. For the final weighted average the internal uncertainty is 0.0012, the reduced-χ^2 value is 3.01, and the external uncertainty is 0.0020.

1974Ch25 have measured this half-life for solid NaCl and for an aqueous solution. No change of the half-life was observed, contrary to the report of 1969Ke14.

The Q_{β^-} value is taken from the 1995Au04 evaluation.

2.1 b- Transitions

The energies are calculated from the Q_{β^-} value and the level energies. In the following list, nine values of the experimentally determined β^- end-point energy (in keV) for the transition to the 4122-keV level are compared with the value derived from Q value.

1394 (4)	1957Po36, Porter et al. (1957)
1389 (4)	1958Da10, Daniel (1958)
1389 (2)	1961De23, 1965De25, Depommier and Chabre (1961)
1395	1963Pa20, Paul et al. (1963)
1393 (3)	1964Le09, Lehmann (1964)
1394 (2)	1965Be24, Beekhuis and De Waard (1965)
1389.2 (5)	1969Bo48, Booij et al. (1969)
1389 (2)	1972Gi17, Gils et al. (1972)
1390 (1)	1976Ge06, Genz et al. (1976)
1392.94 (16)	Q - E(4122)

The measured and calculated probabilities (in %) of the β^- transitions are:

Level (keV)	**1950Gr01** Grant(1950)	**1951Tu12** Turner (1951)	**Present evaluation**
5236			0.057 (7)
4239			<0.002
4122	100	100	99.939 (8)
1368	<0.01	0.003	0.003 (2)
0			$<5 \times 10^{-10}$

The 4th forbidden β^- branch to the ground state has not been observed. From the experimental limit on the number of counts in the β^- spectrum above 4140 keV, 1951Tu12 give lg *ft* > 15.1. The lg *ft* systematics of 1998Si17 lists four decays of this type with lg *ft* values of 22.5 to 24.3. Since this is a very small set of values, we have taken the lower limit of the ^{24}Na lg *ft* to be 20, which corresponds to $I_{\beta^-}(0) < 5\text{x}10^{-10}$ %; this value is adopted.

The β^- branch to the 4238 level is a 2nd forbidden transitions and the lg *ft* systematics (1998Si17) give lg *ft* > 10.6 which corresponds to $I_{\beta^-}(4238) < 0.002\%$; this value is adopted. This small value is supported by the adopted decay scheme for which the intensity of the 998-keV γ-ray feeding this level is more [0.00151(25)] than that depopulating it [0.00024(3) + 0.00084(10)]. An unobserved γ-ray of 116 keV could also depopulate this level.

No direct measurements are reported for the β^- transitions to the 4238- and 5236-keV levels. The adopted value for the transition to the 1368-keV level is based on the measurement of 1951Tu12 [Turner and Cavanagh (1951)] who gave no uncertainty. The adopted value for the transition to the 5236-keV level was calculated from probabilities of the two de exciting γ-rays and their internal and pair conversion.

The β^- branch to the 4122-keV level is 100% less the intensity of those to the levels at 0, 1368, 4238, and 5236 keV. The sum of the latter four is 0.061(8)%, so the former is 99.939(8)%.

2.2 Gamma Transitions

The transition probabilities of the 3866- and 4237-keV γ-rays are determined from the following measurements:

	3867 keV	4237 keV
1960Ar10, Artamonova *et al.* (1960)	0.09 (2)	0.0015 (5)
1962Mo21, Monahan *et al.* (1962)	0.075 (20)	0.008 (3)
1968Va06, van Klinken *et al.* (1968)	0.063 (6)	
1970Le12, Lebowitz (1970)	0.0489 (25)	<0.0033
1972Ra21, Raman *et al.* (1972)	0.061 (5)	0.00084 (10)
Adopted value	**0.056(7)**	**0.00084(10)**

For the 3866-keV γ-ray, the adopted value is the average of all five values, which gives an internal uncertainty of 0.0026, a reduced-χ^2 value of 2.46, and an external uncertainty of 0.0041, and the final uncertainty was expanded to include the most precise value. For the 4237-keV γ-ray, the value of 1972Ra21 is adopted as it is considered to be the most reliable and it is consistent with the limit of 1970Le12.

The 996- and 2869-keV γ-ray transitions are not observed in ^{24}Na decay, but their emission probabilities can be deduced from the relative probabilities in other decays or reactions. The transition probability of 996-keV γ-ray was calculated from the measured $P_\gamma(996)/P_\gamma(3866)$ ratio. For this ratio, the measured values are :

0.017 (5)	1972Me09, Meyer *et al.* (1972) from ^{23}Na(p,γ)
0.019 (2)	1973Le15, Leccia *et al.* (1973) from ^{23}Na(p,γ)
0.015 (3)	1975Bo43, Boydell *et al.* (1975) from ^{23}Na(p,γ)
0.0260 (17)	1981Wa07, Warburton *et al.* (1981) from ^{24}Al ε decay
0.030 (4)	1990En02, Endt *et al.* (1990) from ^{23}Na(p,γ)
0.022 (4)	**Adopted value**

The adopted value is the weighted average value of 0.0222 with an internal uncertainty of 0.0011, a reduced-χ^2 of 4.6 and an external uncertainty of 0.0024. The LRSW method increases the final uncertainty to 0.004 to include the most precise value of 0.0260. With the above value of $P_\gamma(3866)$, we obtain $P_\gamma(996) = 0.00123(27)$.

The ratio $P_\gamma(2869)/P_\gamma(4237)$ ratio has been measured as follows:

0.30 (3)	1972Me09, Meyer *et al.* (1972) from ^{23}Na(p,γ)

0.30 (3)	1972Ra21, Raman *et al.* (1972) from ^{24}Mg(n,n'γ)
0.299 (15)	1973Le15, Leccia *et al.* (1973) from ^{23}Na(p,γ)
0.267 (7)	1973Br16, Branford (1973) from ^{23}Na(p,γ)
0.299 (19)	1975Bo43, Boydell (1975) from ^{23}Na(p,γ)
0.304 (19)	1981Wa07, Warburton *et al.* (1981) from ^{24}Al ε decay
0.284 (7)	**Adopted value**

The adopted value is the weighted average of all six values after the uncertainty for the 1973Br16 value was increased from 0.007 to 0.009 to reduce its relative weight from 63% to 50%. This average has an internal uncertainty of 0.006, a reduced-χ^2 of 1.37, and an external uncertainty of 0.007. With the above adopted value of 0.00084(10) for $P_\gamma(4237)$, one obtains $P_\gamma(2869) = 0.00024(3)$.

If there are no direct feeding the ground state by ß$^-$ decay or the unobserved γ transitions of 4122 and 5236 keV, $T_\gamma(1368) = 100 - T_\gamma(4237) = 99.99916(10)$ where $T_\gamma = P_\gamma\,(1.0 + \alpha + \alpha_\pi)$. Upper limits for transition intensities of the 4122- and 5236-keV γ-rays can be determined from the ratios measured by 1981Wa07: $P_\gamma(4122)/P_\gamma(2754) < 0.00001$, or $P_\gamma(4122) < 0.001$ and $P_\gamma(5236)/P_\gamma(3867) < 0.004$, so $P_\gamma(5236) < 0.00023$ and by 1972Ra21 and 1967En05 which give $P_\gamma(4122) < 0.0009$ and $P_\gamma(5236) < 0.00002$. If the 4122- and 5236-keV transitions have intensities equal to the latter upper limits, the value of $T_\gamma(1368)$ would reduce from 99.99916 to 99.9983. Since it is unlikely that these two values will be at the limits, we have adopted the value of $T_\gamma(1368) = 99.9990(3)$ and $P_\gamma(1368) = 99.9935(5)$.

The 1114-keV transition between the 5236- and 4122-keV levels has not been observed in ^{24}Na decay. In the ^{24}Al decay, 1981Wa07 have found an upper limit of the ratio $P_\gamma(1114)/P_\gamma(3867) < 0.007$ which yields the value of $P_\gamma(1114) < 0.0004$.

The transition probability of the 2754-keV γ-ray is calculated from the balance condition $T_\gamma(2754) = T_\gamma(1368) - [T_\gamma(2869) + T_\gamma(3867) + P_{\beta^-}(1368)]$. This yields $T_\gamma(2754) = 99.9990(3) - 0.059(7) = 99.940(7)\%$, which gives $P_\gamma(2754) = 99.872(8)\%$.

From the intensity balance at the 4238-keV level, for a possible depopulating γ-ray of 116 keV, $P_\gamma(116) = 0.0004(3) + I_\gamma(4238)$. Since this γ-ray has not been observed, it is omitted from the scheme.

The internal-conversion coefficients are interpolated from the tables of theoretical values (Band *et al.*, 1976). The mixing parameters, δ, were based on the following information:

γ energy	1960Ba19	1963Br15	1973Le15	**adopted**
998			-5.1 (+8-12) or -0.47 (4)	**-0.47 (4)**
2869	+23 (9)		> 30	**+23 (9)**
3867		large	-0.21 (2) or >19	**pure E2**

The uncertainty of the interpolated conversion coefficients is assumed to be 3 %.

The internal-pair-formation coefficients (α_π) for the 1368- and 2754-keV γ-rays have been interpolated from calculated values of 1979Sc31 and are in reasonable agreement with measured values which are:

1368 keV	2754 keV	
	0.00116 (10)	1949Ra01
	0.00076 (19)	1950Mi82

	0.00067 (10)	1951Cl50
0.00006 (1)	0.00071 (2)	1952Bl53
0.00003	0.00080	1952Sl52

In summary, the γ-ray photon and transition intensities are:

Energy (keV)	Transition (%)	Photon (%)
998	0.00151 (25)	
1114	<0.0004	
1368	99.9990 (3)	99.9935 (5)
2869	0.00024 (3)	
2754	99.940 (7)	99.872 (8)
3867	0.056 (7)	
4122	<0.0009	
4238	0.00084 (10)	
5236	<0.00002	

If P_γ is not given, it is equal to T_γ.

3 Atomic Data

The values for ω_K, the mean ω_L, and η_{KL} are taken from 1996Sc06.

3.1 X Radiation

The mean energies of the K_α radiations have been calculated from the wave lengths given by 1967Be65.

3.2 Auger Electrons

The mean energy of the KLL Auger electrons is taken from 1977La19.

4 Radiation Emission

4.1 Electron Emission

The energies and emission probabilities of the particles are the same as those given already in sect. 2.1. The energies of the electron from internal conversion and internal-pair formation are calculated from the γ-ray energies. The number of electrons per disintegration for various processes are calculated from the γ-ray emission probabilities, α_π, α, and the atomic data.

4.2 Photon Emission

The energies of the two main γ-rays are from 2000He14. From the decay of ^{24}Na, the energies for the 3867- and 4238-keV γ-rays are 3867.5(3) from 1968Va06 and 1970Le12 and the 4237.4(10) keV from 1972Ra21. The energies of the 996- and 2869-keV γ-rays would then be calculated from the level energies. The adopted values for all four of these γ-rays have been taken from the decay of ^{24}Al (1981Wa07).

The number of photons per disintegration were calculated as described in sect. 2.2.

5 Main Production Modes

Taken from N. Coursol, Table de Radionucléides (1982).

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^{32}P – Comments on evaluation of decay data
by V. Chisté and M. M. Bé

1) Decay Scheme

^{32}P disintegrates by β^- emission (100 %) to the ground state of the stable nuclide ^{32}S.

2) Nuclear Data

The Q value (1710,66 (21) keV) is from Audi and Wasptra evaluation (1995Au04), and has been calculated with the formula:

Q = $M(A,Z) - M(A,Z+1)$,
where M(A,Z) and M(A,Z+1) are the measured atomic masses of ^{32}P and ^{32}S, respectively.

This value is in agreement with a weighted average value of 1708 (7) keV , which was calculated from measured values of the β^- end-point energy (see b$^-$ **Transition**).

The measured ^{32}P half-life values (in days) are given below:

$T_{1/2}$

Reference	Value (days)	Comments
Ambrosen (1934Am01)	17,5 (11)	Omitted from analysis
Preiswerk (1935Pr20)	15,0 (15)	″
Sizoo (1936Si10)	15,0 (1)	″
Newson (1937Ne19)	14,5 (3)	″
Capron (1938Ca08)	14,5 (3)	″
Cacciapuotu (1938Ca15)	14,30 (3)	
Mulder (1940Mu04)	14,07 (3)	Omitted, outlier
Klema (1948Kl06)	14,35 (5)	
Sinclair(1951Si26)	14,60 (5)	Omitted, outlier
Locket (1953Lo19)	14,50 (4)	Omitted, outlier
Bayly (1956Ba25)	14,30 (9)	
Anders (1957An57)	14,223 (30)	Original Uc × 2
Daniel (1958Da08)	14,2 (3)	
Robert (1959Ro24)	14,55 (6)	Omitted, outlier
Marais (1961Ma01)	14,282 (20)	Original Uc × 2
Goodier (1966Go17)	14,290 (28)	Original Uc × 2
Pernaa (1969Pe16)	14,32 (1)	
Lagoutine (1969La28)	14,268 (42)	
Belyaev (1977Be21)	12 (2)	Omitted, outlier
Mudhole (1977Mu15)	14,35 (5)	
Precker (1979Pr36)	14,28 (4)	
Coursey (1994Co26)	14,26 (1)	

The first five and less precise historical values were omitted from analysis. In several cases original uncertainties have been enlarged to take into account systematic uncertainties in measurements.
The Mulder, Sinclair, Locket, Robert and Belyaev values have been shown to be outliers by the Lweight program, based on the Chauvenet's criterion. With the remaining 12 values, the weighted average is 14,284 d ; with an internal uncertainty of 0,006 d ; an external uncertainty of 0,01 and a reduced $-\chi^2$ of 2,89.

The adopted value is the weighted average : *14,284 d*, with a final uncertainty expanded to include the most precise value of Coursey ((1994Co26), 14,26 (1) days)) and is *0,036 d*.

The large dispersion of the original set of data (reduced $-\chi^2$ = 31,4) is explained by the fact that ^{32}P is mainly produced by ^{32}S(n, γ)^{32}P reaction, then, resulting samples always contain ^{33}P as an impurity which could be not correctly taking into account.

b$^-$ Transition transition

Evaluators calculated, with LOGFT program, a *lg ft* of 7,9 for this allowed transition. The value agrees with those suggested by Endt (1967En01, 1973En01, 1978En01 and 1990En01).

The weighted mean of the β^- end-point energy (or Q) has been calculated (with the Lweight program, version 3) using the following measured values (in keV):

Reference	Values (keV)
Lyman (1937Ly11)	1690 (24)
Newson (1937Ne19)	1590 (30)
Capron (1938Ca08)	1680 (50)
Siegbahn (1946Si07)	1712 (8)
Langer (1949La21)	1689 (10)
Marshaw (1950Ma28)	1708 (8)
Agnew (1950Ag05)	1718 (10)
Jensen (1952Je12)	1704 (8)
Antoneva (1954An18)	1712 (8)
Pohm (1956Po01)	1712 (6)
Ricci (1957Ri32)	1695 (15)
Daniel (1958Da08)	1705 (4)
Johnson (1958Jo12)	1711 (3)
Nichols (1961Ni22)	1707 (1)
Fehrentz (1961Fe15)	1705 (4)
Bosch (1963Bo36)	1706 (11)
Canthy (1966Ca31)	1697 (2)
Fishbeck (1968Fi17)	1710(2)
Flothmann (1969Fl25)	1701,2 (4)
Persson (1971Pe07)	1707 (4)
Booij (1971Bo06)	1706 (4)
Zemann (1971Ze02)	1711 (2)
Moore (1976Mo13)	1712,0 (8)
Greenwood (1993Gr10)	1710,0(30)
Kojima (2001Ko20)	1708 (2)

Evaluators calculated the weighted average of these 25 values using the Lweight program (version 3) as 1705,0 keV with an uncertainty of 3,8 and a reduced $-\chi^2$ of 9,6. The Lyman (1937Ly11), Newson (1937Ne19), Capron (1938Ca08), Langer (1949La21), Agnew (1950Ag05), Ricci (1957Ri32) and Canthy (1966Ca31) values have been shown to be outliers by the Lweight program, based on the Chauvenet's criterion. For the remaining 18 values, the weighted average is is 1708,0 keV with an internal uncertainty of 0,36 keV, an external uncertainty of 1,1 keV and a reduced $-\chi^2$ of 8,6. The final uncertainty is 7,0 keV (expanded so range includes the most precise value of Flothmann (1969Fl25)). This value is in agreement with the adopted Q value (1995Au04) in this evaluation.

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^{33}P – Comments on evaluation of decay data
by V. Chisté and M. M. Bé

1) Decay Scheme

^{33}P disintegrates by β^- emission (100 %) to the ground state of the stable nuclide ^{33}S.

2) Nuclear Data

The Q value (248,5 (11) keV) is from Audi and Wapstra evaluation (1995Au04), and has been calculated with the formula:

Q = $M(A,Z) - M(A,Z+1)$,
where M(A,Z) and M(A,Z+1) are the measured atomic masses of ^{33}P and ^{33}S, respectively.

Q, calculated with the formula, is in agreement with a weighted average va lue of 248,5 (10) keV, which the evaluators have calculated from measured values of the β^- end-point energy (see b$^-$ **Transition**).

The measured ^{33}P half-life values (in days) are given below:

$T_{1/2}$

Reference	Value (days)
Sheline(1951Sh22)	25 (2)
Jensen (1952Je12)	24,8 (5)
Westermark (1952We01)	25 (2)
Nichols (1954Ni06)	24,4 (2)
Westermark (1954We03)	25,4 (2)
Russell (1958Ru07)	25 (1)
Fogelstrom-Fineman (1960Fo14)	25,2 (5)
Reynolds (1968Re20)	25,30 (5)
Lagoutine (1972La21)	25,56 (7)

Nichol's value (24,4 (2)) is an outlier (based on Chauvenet's criterion). The weighted average of the eight remaining values (excluding Nichol's value) is 25,383 days with an internal uncertainty of 0,040 days (χ^2 =1,6). Thus we recommend a half-life of *25,383 (40) d*.

b$^-$ **Transition**

Evaluators calculated, using the LOGFT program, a *lg ft* value of 5 for this allowed transition. This value agrees with those given by Endt (1967En01, 1973En01, 1978En01, 1990En01 and 1998En01).

The evaluators have calculated a weighted mean of the β^- end-point energy (or Q) from the following measured values (in keV):

Reference	Values (keV)
Sheline (1951Sh22)	270 (20)
Jensen (1952Je12)	260 (20)
Westermark (1952We01)	246 (5)
Nichols (1954Ni06)	249 (2)
Elbek (1954El07)	252 (5)
Elbek (1954El08)	250 (5)
Westermark (1954We03)	246 (5)
Russell (1958Ru07)	238 (5)
Polak (1984Po09)	248,3 (13)

Evaluators calculated the weighted average of these 9 values using the Lweight program (version 3) as 248,2 keV with an internal uncertainty of 1,0 and a reduced -χ^2 of 0,87. The 2 values of Elbek (1954El07 and 1954El08) are independents measurements. The Sheline (1951Sh22), Jensen (1952Je12) and Russell (1958Ru07) values have been shown to be outliers by the Lweight program, based on the Chauvenet's criterion. For the remaining 6 values, the largest contributions to the weighted average come from the values of Polak (1984Po09), with a relative statistical weight of 59 %.
The weighted average of the six remaining input values is 248,5 keV with an internal uncertaint y of 1,0 keV and a reduced -χ^2 of 0,23. This value is in agreement with the adopted Q value (1995Au04) in this evaluation.

Atomic Data

Atomic values (ω_K and n_{KL}) are from (96Sc33).

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^{35}S - Comments on evaluation of decay data
by V.P. Chechev and M.M. Bé

The first evaluation was completed by V. Chechev in 1998. It was updated in January 2012 to include the new Q(β^-) value of 167.33 (3) keV (2011AuZZ), compared to 167.14 (8) keV, used in the original evaluation. The literature available by January 2012 was included.

Nuclear Data

Half-Life

In literature there are many measurements of the ^{35}S half-life. They are listed in Table 1.

Table 1. Measurements results and recommended value of ^{35}S half-life.

Reference	Value (d)	Uncertainty (d)	Remarks
1940Le**	88	5	GM, omitted
1941Ka**	88	3	GM, omitted
1943He**	87,1	1,2	GM
1949Ma**	88		Omitted
1952Ru23	80		Omitted
1958Se49	87,16	0,10	PC
1959Ca12	88,8	1,0	PC
1959Co56	86,35	0,17	PC
1961Wy01	89,0	0,5	PC
1961Oz01	87,1	0,9	Calorimetry
1965Fl02	87,9	0,3	PC
1968Wo06	87,39	0,10	4πPC
1969La34	87,48	0,14	4πPC, original Uc/3
1999Pa18	87,38	0,03	Omitted, β-spectrometer
χ^2 /n-1 = 6,6			
χ^2 crit. = 2,5			
UWM =	87,59		
LWM = (recommended)	87,25	0,15	Uc_{int} = 0,06 ; Uc_{ext} = 0,15

Conventional designations in the fourth column:
Measurement of counting rate decrease by Geiger-Müller counter (GM), proportional counter (PC), calorimeter (calorimetry), 4π proportional counter (4πPC).

The two values without uncertainty and the two oldest ones with high uncertainty were omitted from statistical analysis.

The value of Palermo *et al.* (1999Pa18) has been omitted because the measurement was carried out to check a source preparation process, only the statistical uncertainty was taken into account; in the publication, the uncertainty bars associated to each result, are significantly greater that the claimed uncertainty, moreover an impurity was observed in the source. It was then difficult to assess a real uncertainty and this value was rejected.

Decay Energy and Characteristics of Electron Emission (β^-)

The decay energy of ^{35}S has been adopted using the evaluations of Audi *et al.* (2011).
The end-point of the ^{35}S β^--spectrum has been obtained from the correlation:
$E_{\beta^-} = Q_{\beta^-} - E_r$ where $E_r = 3$ eV is the maximum recoil energy of ^{35}Cl atom.
The average energy of the electrons per disintegration has been calculated for an allowed form of β^-- spectrum taking into account the adopted value of Q_{β^-}.

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1959Co56	R.D. Cooper and E.S. Cotton, Science 129 (1959) 1360	[$T_{1/2}$]
1961Wy01	E.I. Wyatt et al., Nucl.Sci.Eng. 11 (1961) 74	[$T_{1/2}$]
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1968Wo06	E.J. Woodhouse and T.H. Norris, J.Inorg.Nucl.Chem. 301 (1968) 1373	[$T_{1/2}$]
1969La34	F. Lagoutine et al., Intern.J.Appl.Rad.Isot. 20 (1969) 868	[$T_{1/2}$]
1999Pa16	L.Palermo et al., Nucl. Instrum. Methods Phys. Res. A423 (1999) 337	[$T_{1/2}$]
2011AuZZ	G. Audi and W. Meng, private communication (2011)	[Q_{β^-}]

^{36}Cl - Comments on evaluation of decay data
by M.-M. Bé and V.P. Chechev

This evaluation was completed in 1998, it was updated in January 2012. The literature available by this date was included. A new mean energy of the β decay is proposed.

1. Decay Scheme and total Decay Energy

^{36}Cl decay scheme is based on the measurements of Drever (1955Dr35) and Pierson (1967Pi04).
The Q-values taken from Audi *et al.* (2011AuZZ) are based on many measurements.

2. Half-Life

The following values of the ^{36}Cl half-life in relation to β^--decay to ^{36}Ar($T_{1/2\beta-}$) presented in Table 1 have been considered .

Table 1. Results of ^{36}Cl → ^{36}Ar decay half-life measurements

Reference NSRkeynumber	$T_{1/2}$ (β^-) (10^5 *a*)	Method and remarks
1949Re**	3,6	Microwave spectrometer, β G-M
1949Re**	2	Abundance by calculation from bombardment data
1949Wu15	4,4 (5)	Microwave spectrometer, β G-M
1955Ba93	3,08 (3)	Mass spectrometry, 4πβpc
1957Wr37	2,6 (4)	Cl(n,γ)Yield, β G-M.
1957Wr37	2,5 (4)	Mass spectrometry, β G-M. Same activity as above
1966Go07	3,10 (4)	Mass spectrometry, 4πβpc
1966Go07	3,06 (2)	Mass spectrometry, liq.scint. Same mass concentration as above

Wright *et al.* (1957Wr37) gave two results for ^{36}Cl half-life. The mass concentration of the samples was determined by two different methods, but the specific activity was determined only once and used to derive both half-life values, so, these values are not independent. Then, in this evaluation, the simple mean of the two results has been introduced for the statistical process.
Goldstein (1966Go07) published two results as well. However, in this work, they carried out one determination of the mass concentration and two separate measurements of the sample activity. Two half-life values were derived. Similarly, the simple mean is adopted, in this evaluation, with the highest experimental uncertainty because the author said that “he did not include any systematic error”.

The values used for the statistical analysis are:

Reference	$T_{1/2}$ (β^-), (10^5 *a*)	
1949Wu15	4,4 (5)	
1955Ba93	3,08 (3)	
1957Wr37	2,55 (40)	
1966Go07	3,08 (4)	
χ^2 crit. = 3,8		

χ^2 /n-1 = 2,9		
UWM	3,28	
LWM	3,08	Int. u_c = 0,024 ; Ext. u_c = 0,04

The adopted value is: 3,08 (4) 10^5 *a*.

From the basic relations:
$T_{1/2} = \ln 2 / (\lambda_{ec} + \lambda_{\beta-})$ and $\lambda_{ec}/\lambda_{\beta-} = P_{ec}/P_{\beta-}$

the total half-life of ^{36}Cl is obtained $T_{1/2}(\beta^-) \times 0{,}981$ (1) = 3,02 (4)$\cdot10^5$ *a*.

3. Electron Capture

An experimental value of the ratio $(P_L/P_K)_{exp}$ = 0,112 (8) was measured in 1962Do07, and a theoretical value $(P_L/P_K)_T$ was calculated, assuming an allowed transition or 1st forbidden, from the tables of Schönfeld to be 0,095 (5) and, 0,0944 by using the LOGFT program. Theoretical and measured values are not consistent.
On one hand, there is only one measured value; on the other hand, this transition was shown to be of a non-unique second forbidden order.
However, the energy involved is high (1142 keV) so the difference between a 1st and a 2nd forbidden transition should be expected to be low. Then, the theoretical results are preferred and a conservative uncertainty of 5 % was applied.

The probability of the electron capture P_{EC} = 1,9 (1) % was deduced from the measured ratio $P\varepsilon_K/P_{\beta}^-$ = 0,017 (1) (1955Dr35) and $P\varepsilon_K = 0{,}904 (5) \times P_{EC}$.

4. β+ Transition

The probability P_{β}+=1,57 (30) 10^{-3} % has been obtained by averaging the experimental data shown in Table 3.

Table 3. Measurement results for the probability of ^{36}Cl β^+ -decay ($P_{\beta+}$), per 100 ^{36}Cl disintegrations.

Reference	P_{β}+ (10^{-3}) %	Remarks
1962Do07	1,2 (5)	P_{β}+ = 1,7 (1) × 7(+3-1) 10^{-4} = 1,2 (+0,5-0,2) 10^{-3} %. The greatest uncertainty is adopted.
1962Be29, 1963Be38	2,3 (9)	
1965To05	1	No uncertainty, omitted
1967Pi04	1,66 (11)	Uncertainty increased to 0,40 to limit its weight
Recommended value	1,57 (30)	Reduced χ^2 =0,6 ; crit χ^2 = 4,6

The recommended value P_{β}+ has been obtained by using the LWM procedure with the three input values from (1962Do07, 1963Be38 and 1967Pi04). The set of data is consistent then, the adopted value is the weighted mean with the internal uncertainty.

5. β^- Transition

The probability P_{β}- = 98,1 (1) % was calculated from the balance relation:
$P_{\beta}- = 1 - P_{EC} - P_{\beta}+$

6. Atomic Data

The atomic constants ω_K, n_{KL} and relative emission probabilities of K X-ray components and K-Auger have been taken from Schönfeld (1996Sc06).
The energy values for Auger electrons have been taken from Larkins (1977La19).

7. Photon Emissions

The emission probabilities of K X-ray components and K-Auger electrons in sulfur were derived from the probability of the electron capture P_{EC} and the adopted values P_K and ω_K.

The emission probabilities of K X-ray components and Auger electrons of argon due to K-shell auto-ionization have been calculated using $P_{XK}(Ar)/P_{XK}(S)$ = 0,149 (22) from 1976Lj03 and atomic constants.

The number of photons per 100 disintegrations for the annihilation radiation was deduced from the $P_{\beta}+$ value as determined above.

8. Beta Emissions

The end-point of the ^{36}Cl β^- spectrum has been obtained from $E_{\beta}- = Q_{\beta}- - E_r$ where E_r = 18 eV is the maximum recoil energy of the ^{36}Ar atom.
The end-point energy of the ^{36}Cl β^+ spectrum has been calculated as $E_{\beta}+ = Q\varepsilon - E_{r'}$ – 1022,0 keV, where $E_{r'}$ = 2 eV is the maximum recoil energy of ^{36}S atom.

Several papers report measurements or calculations of the ^{36}Cl β^- spectrum (see as examples: 1949Wu18, 1972Ma72, 1974Re11, 1993Sa24, 2004Kr10, 2005Gr41, 2008Ro31, etc.).
When using the program BetaShape (2011MoZU), which is based on theoretical considerations, for the mean β^- energy, we obtain:
- with the hypothesis of an allowed transition: 251 keV,
- with the hypothesis of a 2nd non-unique forbidden order, accepted as 1st unique forbidden: 278 keV,
- with the hypothesis of a 2nd non-unique forbidden order, accepted as 2st unique forbidden: 303 keV.

Recently, Rotzinger *et al.* (2008Ro31) measured the ^{36}Cl β^- spectrum by mean of a magnetic calorimeter, they kindly provided us their original recorded data, from which a mean β^- energy value of 316 keV has been derived.
This latter value is adopted, an uncertainty of 5 % is supposed, however it is difficult to estimate it correctly.

The β^+ transition is also of a 2nd non-unique forbidden order. Similarly the mean β^+ energy was calculated as 50 keV for an allowed transition and 58 keV for a 1st unique forbidden transition by the BetaShape program. The adopted value is 54 keV with an uncertainty which covers both hypothesis.

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^{37}Ar - Comments on evaluation of decay data
by V.P. Chechev

Evaluated in March 2012 with a literature cut-off by the same date.

1. Decay Scheme and Decay Energy

^{37}Ar disintegrates by 100 % electron capture (EC) transition to the ground state of the stable nuclide ^{37}Cl. The decay scheme is complete as there are no excited levels of ^{37}Cl below the EC decay energy Q^+ (1998En04).
Q^+ value has been taken from atomic mass adjustment (2003Au03, 2011AuZZ) based on the precise spectrometric measurement of the Q-value for (p, n) reaction on ^{37}Cl (1998Bo30).

2. Half-Life

The following values of the ^{37}Ar half-life presented in Table 1 were considered.

Table 1. Results of ^{37}Ar half-life measurements (in days)

Reference	Author(s)	Value	Comments
1944We**	Weimer et al.	34.1 (3)	Omitted; ^{39}K (d,α), ^{37}Cl (d,2n) and ^{37}Cl (p,n), ionization chamber, t = 7 half-lives, possible source impurities, uncertainty strongly underestimated in an unknown amount
1952Mi**	Miskel and Perlman	35.0 (4)	Omitted; ^{40}Ca (n,α), proportional counter, no details, possible source impurities
1959Ki41	Kiser and Johnston	34.30 (14)	Omitted; ^{40}Ca (n,α), K Auger peak decay, proportional counter, t = 2 half-lives, possible source impurities, uncertainty strongly underestimated in an unknown amount
1965St09	Stoenner et al.	35.1 (1)	^{40}Ca (n,α), 5 proportional counters, t = 5 half-lives, declared uncertainty includes possible systematic errors
1973Co26	Colomer and Gauvain	35.06 (9)	^{37}Cl (p,n), 2 proportional counters, t = 5 and 3 half-lives; the authors reported the uncertainty of 0.18 d for 95% confidence level
1975Ki10	Kishore et al.	35.02 (2)	^{37}Cl (p,n), several proportional counters, numerous decay curves (over 1 to 3 half-lives), 28 measurements
2001Re01	Renne and Norman	34.95 (4)	^{40}Ca (n,α) and ^{40}Ca (n,nα), ^{37}Ar/^{36}Ar mass spectrometry; the authors reported the uncertainty of 0.08 d for 95% confidence level

The four input values (from 1965St09, 1973Co26, 1975Ki10, and 2001Re01) have been adopted for the statistical processing. The weighted average for this data set is 35.011 with an internal uncertainty of 0.017 and external uncertainty of 0.019 (χ^2/ν = 1.21). The smallest experimental uncertainty reported is 0.02.
The recommended value of the ^{37}Ar half-life is **35.01 (2) days**.

3. Electron Capture

The energy of the electron-capture transition 3/2+ → 3/2+ in the decay of ^{37}Ar → ^{37}Cl is equal to the adopted Q^+ value.
K, L, M-electron capture probabilities P_K, P_L, P_M were deduced using the EC-CAPTURE computer program (1998Sc28). It should be noted that according to theory L- and M-electron captures occur basically on L1 and M1 subshells (1972Dz09). Log ft value was calculated for the allowed electron-capture transition using the LOGFT computer code (NNDC Tools and Publications, Web programming: M. Emeric and A. Sonzogni, NNDC, Brookhaven National Laboratory).

4. Atomic Data, X-Ray and Auger Electron Emissions

Atomic values, ω_K, ϖ_L and n_{KL} are from Schönfeld and Janβen (1996Sc06).
The X-ray and Auger electron emission probabilities were calculated using the program EMISSION (2000Sc47). The calculation results including average energies per disintegration are given in Tables 2, 3.

Table 2. KX- and LX- rays in decay of ^{37}Ar

	Energy, keV	Number of photons per disintegration	Energy per disintegration, keV
X $K\alpha_2$	2.6208	0.0276 (7)	0.0723 (18)
X $K\alpha_1$	2.6224	0.0546 (14)	0.143 (4)
X Kβ	2.8156	0.0071 (4)	0.020 (1)
X Lβ	0.240	0.0020 (4)	0.00048 (10)
		Total	**0.236 (5)**

Table 3. Auger electrons in decay of ^{37}Ar

	Energy, keV	Number of electrons per disintegration	Energy per disintegration, keV
L-Auger	0.17-0.26	1.665 (8)	0.38 (4)
K-LL	2.31 (7)	0.689 (6)	1.59 (5)
K-LM	2.57 (4)	0.119 (6)	0.306 (5)
K-MM	2.8	0.0051 (5)	0.014 (2)
		Total	**2.29 (6)**

5. Internal Bremsstrahlung

The characteristics of the internal bremsstrahlung in the ^{37}Ar decay were calculated in 1986BrZQ (Table 4). The results of that calculation were taken for the evaluation of the average energy E_{IB} of internal bremsstrahlung per disintegration of ^{37}Ar: E_{IB} = 0.139 (14) keV (2011Ch65). The relative uncertainty of E_{IB} was set as 10 % based on that the theoretical estimation of the internal bremsstrahlung intensity for allowed electron capture transitions (1972Dz09) agrees with experimental data within less than 15 %.

Table 4. Internal bremsstrahlung in decay of ^{37}Ar

Energy (keV)	Number of photons per disintegration	Energy (keV) per disintegration
10-20	$1.31 \cdot 10^{-6}$	$2.0 \cdot 10^{-5}$
20-40	$3.8 \cdot 10^{-6}$	$1.17 \cdot 10^{-4}$
40-100	$2.4 \cdot 10^{-5}$	$1.8 \cdot 10^{-3}$
100-300	$1.63 \cdot 10^{-4}$	0.034
300-600	$2.0 \cdot 10^{-4}$	0.087
600-814	$2.5 \cdot 10^{-5}$	0.0164
Total		**0.139 (14)**

6. Total energy of non-neutrino radiation per disintegration

Decay of ^{37}Ar is accompanied by emissions of *X*-rays, internal bremsstrahlung, Auger electrons and monochromatic neutrinos with energies of 811.05 (20), 813.60 (20), and 813.85 (20) keV. The neutrino energies were deduced from the value of decay energy Q^+ = 813.87 (20) keV (see Section 1) and the values of *K*, *L*, *M*-electron binding energies (Cl, *Z* = 17) (1977La19).

The total energy of non-neutrino radiation per disintegration releasing in the form of (*X* + Auger) emissions and internal bremsstrahlung is obtained from Tables 2–4 of 2.67 (7) keV. This value was specified using the calculation of (*X* + Auger) - energy releasing in each act of ^{37}Ar electron capture by the relation of $E = W_K P_K + W_L P_L + W_M P_M$, where W_J - binding energy of electron in J-shell, P_J - probability of electron capture in J-shell, J = K, L, M. The more accurate value of the energy of non-neutrino radiation per disintegration is 2.709 (16) keV per disintegration (2011Ch65).

7. References

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^{40}K - Comments on evaluation of decay data
by X. Mougeot, R.G. Helmer

The initial evaluation was completed in 1998. This revised evaluation was done in 2009, taking into account the available literature by April 2009.

1 Decay Scheme

The decay scheme is complete since all of the levels in ^{40}Ar and ^{40}Ca below the decay energies are populated.

The J^{π} and half-life of the excited level are from 1990EN08 evaluation.

2 Nuclear Data

Q values are from Audi and Wapstra 2003 (2003AU03).

A full list of the half-life measurements available by April 2009, and the reasons why certain have been excluded by the evaluator, is given in Table 3.

Three types of measurements were carried out: $T_{1/2}(\beta^-)$ and $T_{1/2}$(EC, 1460 keV) which are partial half-lives, and $T_{1/2}$ which is the total half-life. Branching ratios are needed to evaluate the ^{40}K half-life from these measurements: $P_{\beta-}$ for the $^{40}K \rightarrow {}^{40}Ca$ transition, $P_{ec,1460}$ for the $^{40}K \rightarrow {}^{40}Ar^{2+}$(1460 keV) transition, $P_{\beta+}$ and $P_{ec,gs}$ for the $^{40}K \rightarrow {}^{40}Ar^{0+}$(ground state) transition. So, $T_{1/2}(\beta^-)$ and $T_{1/2}$(EC, 1460 keV) have been evaluated first and then, the branching ratios and the ^{40}K total half-life.

2.1 Partial half-lives

2.1.1 $T_{1/2}(b^-)$

Table 1: Partial measured β^- half-lives.

Reference	Partial $T_{1/2}(\beta^-)$ ($\times 10^9$ a)	Comments
1948Graf	1.48 (7)	
1948Hirzel	1.18 (19)	Excluded by LWEIGHT (Chauvenet's criterion)
1949Stout	1.29 (8)	
1950Smaller	1.76 (5)	Excluded by LWEIGHT (3σ criterion)
1951Delaney	1.24 (1)	Excluded by LWEIGHT (Chauvenet's criterion)
1951Good	1.46 (3)	
1955SU38	1.34 (3)	
1955KO21	1.36 (5)	
1956MC20	1.44 (1)	
1959KE26	1.46 (3)	
1960SA31	1.37 (4)	
1961GL07	1.400 (15)	
1962FL05	1.45 (40)	
1965BR25	1.36 (2)	
1965LE15	1.400 (2)	Uncertainty increased to 6.4 $\times 10^6$ a by LWEIGHT
1966FE09	1.41 (2)	
1966Egelkraut	1.40 (7)	
1971Venkataramaiah	1.31 (6)	

The statistical processing was done using the LWEIGHT program. For $T_{1/2}(\beta^-)$, the program turned up three statistical outliers: 1948Hirzel (Chauvenet's criterion), 1950Smaller (3σ criterion), and 1951Delaney (Chauvenet's criterion). From the resulting discrepant data set, with a reduced-χ^2 value of 2.62, a weighted average was deduced. LWEIGHT increased the uncertainty of the most precise measurement (1965LE15) from 2 to 6.4×10^6 a in order to have a maximum contribution of 50 %. The second main contribution is 1956MC20 amounting for 20 %. Finally, this evaluation leads to:

$$\mathbf{T_{1/2}(b^-) = 1.407\ (7)\ ´\ 10^9}\ \text{a}.$$

2.1.2 $T_{1/2}$(EC, 1460 keV)

Table 2: Partial measured EC half-lives.

Reference	Partial $T_{1/2}$(EC, 1460) ($\times 10^9$ a)	Comments
1947GL07	11 (2)	Excluded by LWEIGHT (Chauvenet's criterion)
1948Ahrens	11.6 (2)	
1950Sawyer	12 (1)	
1950Graf	12 (2)	
1953BU58	11.7 (5)	
1955SU38	13.4 (2)	Excluded by LWEIGHT (Chauvenet's criterion)
1955BA25	11.3 (5)	
1957WE43	11.7 (4)	
1960SA31	12.3 (6)	
1965LE15	12.2 (3)	
1966DeRuytter	12.2 (2)	
1966Egelkraut	11.8 (5)	

For the electronic capture (EC) part, all the partial half-lives, given in Table 2, were measured by detecting the 1460 keV gamma-ray in ^{40}Ar. In Table 3, a partial half-life for EC is listed, evaluated by 1956Wetherill: this evaluation used four measurements of the ^{40}Ar/^{40}K concentration ratio in young mica. Obviously, in this case, the total branching ratio of the $^{40}\text{K} \rightarrow {}^{40}\text{Ar}$ was determined. So, this result cannot be used to evaluate the partial $T_{1/2}$(EC, 1460 keV).

The statistical processing was done using the LWEIGHT program. It turned up two statistical outliers: 1947GL07 and 1955SU38 (Chauvenet's criterion). A weighted average was adopted from the resulting consistent data set, with a reduced-χ^2 value of 0.87. The main contributions are 30 % for 1966DeRuytter and 1948Ahrens, and 13 % for 1965LE15. Finally, this evaluation gives:

$$\mathbf{T_{1/2}(EC,\ 1460\ keV) = 11.90\ (11)\ ´\ 10^9}\ \text{a}.$$

2.2 Branching ratios

The branching ratios were calculated following Helmer's method (1999BeZS). From the decay scheme:

$$\mathbf{P_{ec,1460} + P_{b+} + P_{b-} + P_{ec,gs} = 1}.$$

In order to calculate each branching ratio, the following quantities: $P_{ec,1460}/P_{\beta-}$, $P_{\beta+}/P_{\beta-}$ and $P_{ec,gs}/P_{\beta+}$ must be known.

The $P_{ec,1460}/P_{\beta-}$ ratio comes from the $T_{1/2}(\beta^-)/T_{1/2}$(EC, 1460 keV) ratio. The partial half-lives evaluated above leads to: $\mathbf{P_{ec,1460}/P_{b-} = 0.1182\ (12)}$.

The β^+ transition of the ^{40}K is a difficult measurement, due to a very low intensity and the pair production which comes from the 1460 keV gamma-ray of ^{40}Ar. Few experiments were able to give more than an upper limit: 1959TI20 ($1.3\ (7) \times 10^{-5}$), 1962EN01 ($1.12\ (14) \times 10^{-5}$) and 1965LE15 ($1.5\ (5) \times 10^{-5}$). The experimental set-up of 1962EN01 minimized the pair production. Following Helmer's choice, the most precise result is used in the present evaluation: $\mathbf{P_{b+}/P_{b-} = 1.12\ (14)\ ´\ 10^{-5}}$.

The $P_{ec,gs}/P_{\beta+}$ ratio was calculated theoretically by Helmer, as described hereafter. The LOGFT program cannot calculate this ratio for this unique 3rd forbidden (3U) transition. But it can calculate the theoretical value for 1U and 2U transitions. For the former (1U), this ratio is 8.51 (9) and for the latter (2U), it is 45.20 (47). Making the assumption that the 3U ratio rises by the same factor (45.20/8.51), then $P_{ec,gs}/P_{\beta+} = 240$. Following Helmer's choice, a value of **200 (100)** for $\mathbf{P_{ec,gs}/P_{b+}}$ was adopted in the present calculation.

The following branching ratios are then deduced:

P_{b-} = 89.25 (17) %, $P_{ec,1460}$ = 10.55 (11) %, $P_{ec,gs}$ = 0.20 (10) %, P_{b+} = 0.00100 (12) %.

2.3 Total ^{40}K half-life

Table 3: Total half-lives used for the evaluation, determined from measurements and branching ratios.

Reference	Type of measurement	$T_{1/2}$ (×10^9 a)	Coefficient (%)	Total $T_{1/2}$ (×10^9 a)	Comments
1931Orban	Partial, EC 1460	0.5	-	-	Not used : no uncertainty
1947GL07	Partial, EC 1460	11 (2)	10.55 (11)	1.16 (21)	
1948Ahrens	Partial, EC 1460	11.6 (2)	10.55 (11)	1.224 (25)	
1948Graf	Partial, β^-	1.48 (7)	89.25 (17)	1.32 (6)	
1948Hirzel	Partial, β^-	1.18 (19)	89.25 (17)	1.05 (17)	Excluded by LWEIGHT (Chauvenet's criterion)
1949Stout	Partial, β^-	1.29 (8)	89.25 (17)	1.15 (7)	
1949Floyd	Total	1.54 (39)	100	1.54 (39)	Excluded by LWEIGHT (Chauvenet's criterion)
1950Sawyer	Partial, EC 1460	12 (1)	10.55 (11)	1.27 (11)	
1950Graf	Partial, EC 1460	12 (2)	10.55 (11)	1.27 (21)	
1950Faust	Total	1.14 (10)	100	1.14 (10)	
1950SA52	Total	1.27 (5)	100	1.27 (5)	
1950Spiers	Total	1.18	-	-	Not used : no uncertainty
1950Houtermans	Total	1.31 (7)	100	1.31 (7)	
1950Smaller	Partial, β^-	1.76 (5)	89.25 (17)	1.571 (45)	Excluded by LWEIGHT (3σ criterion)
1951Delaney	Partial, β^-	1.24 (1)	89.25 (17)	1.107 (9)	Excluded by LWEIGHT (Chauvenet's criterion)
1951Good	Partial, β^-	1.46 (3)	89.25 (17)	1.303 (27)	
1953BU58	Partial, EC 1460	11.7 (5)	10.55 (11)	1.23 (5)	
1955SU38	Partial, β^-	1.34 (3)	89.25 (17)	1.196 (27)	
1955SU38	Partial, EC 1460	13.4 (2)	10.55 (11)	1.414 (26)	Excluded by LWEIGHT (Chauvenet's criterion)
1955KO21	Partial, β^-	1.36 (5)	89.25 (17)	1.214 (45)	
1955BA25	Partial, EC 1460	11.3 (5)	10.55 (11)	1.19 (5)	
1956MC20	Partial, β^-	1.44 (1)	89.25 (17)	1.285 (9)	
1956Wetherill	Partial, EC and β^+	12.2 (6)	10.75 (15)	1.31 (7)	^{40}Ar/^{40}K in young mica
1957WE43	Partial, EC 1460	11.7 (4)	10.55 (11)	1.234 (44)	Direct measurement
1959KE26	Partial, β^-	1.46 (3)	89.25 (17)	1.303 (27)	
1960SA31	Partial, EC 1460	12.3 (6)	10.55 (11)	1.30 (6)	
1960SA31	Partial, β^-	1.37 (4)	89.25 (17)	1.223 (36)	
1961GL07	Partial, β^-	1.400 (15)	89.25 (17)	1.249 (14)	
1962FL05	Partial, β^-	1.45 (40)	89.25 (17)	1.29 (36)	
1965BR25	Partial, β^-	1.36 (2)	89.25 (17)	1.214 (18)	
1965LE15	Partial, EC 1460	12.2 (3)	10.55 (11)	1.287 (34)	
1965LE15	Partial, β^-	1.400 (2)	89.25 (17)	1.2495 (30)	

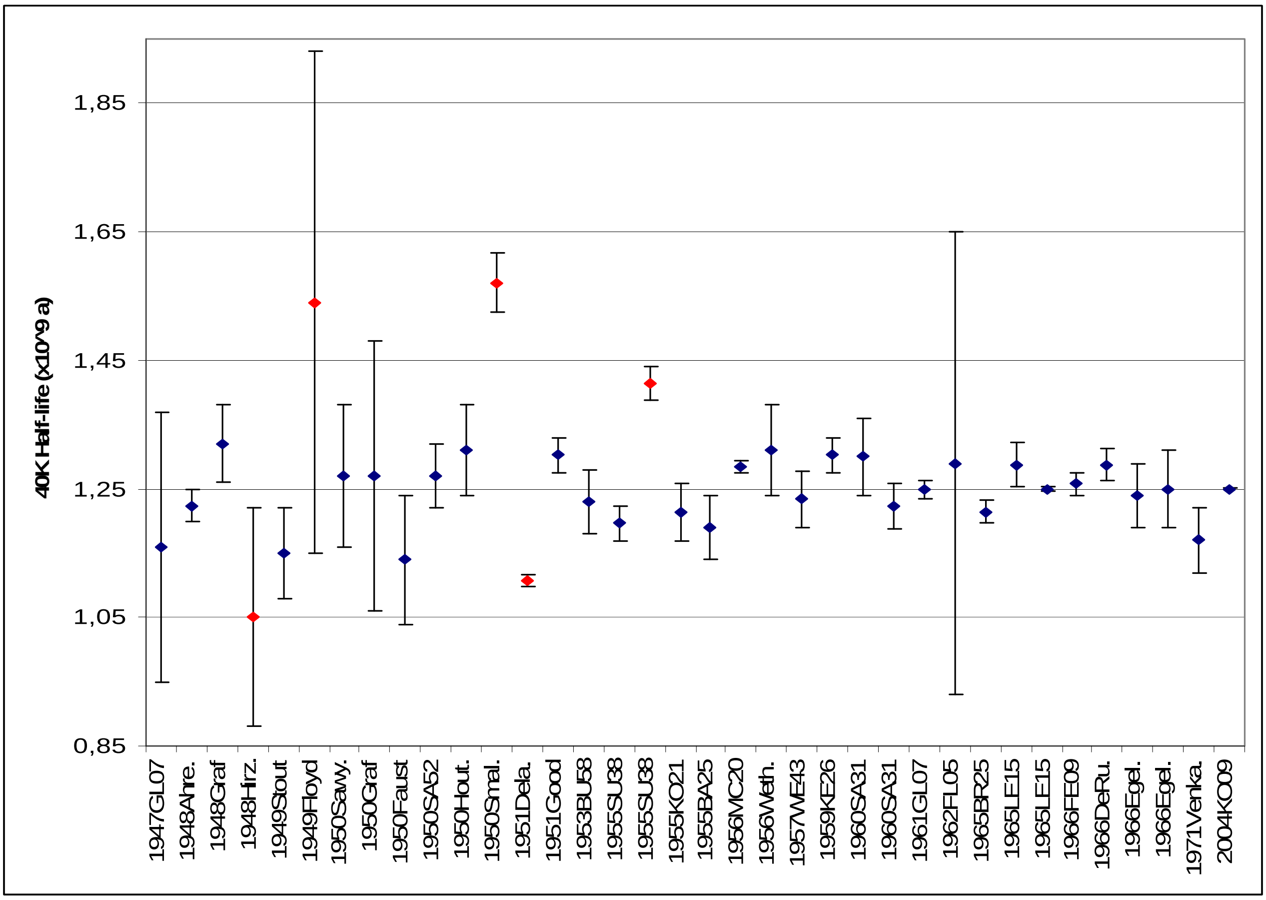
Reference	Type of measurement	$T_{1/2}$ (×10^9 a)	Coefficient (%)	Total $T_{1/2}$ (×10^9 a)	Comments
1966FE09	Partial, β^-	1.41 (2)	89.25 (17)	1.258 (18)	
1966DeRuytter	Partial, EC 1460	12.2 (2)	10.55 (11)	1.287 (25)	
1966Egelkraut	Partial, EC 1460	11.8 (5)	10.55 (11)	1.24 (5)	
1966Egelkraut	Partial, β^-	1.40 (7)	89.25 (17)	1.25 (6)	
1971Venkataramaiah	Partial, β^-	1.31 (6)	89.25 (17)	1.17 (5)	
1972Gopal	Partial, β^-	1.13 (6)	-	-	Not used : erroneous uncertainty, see also 2001BE81
1977CE04	Partial, EC 1460	12.30 (4)	-	-	Not used : erroneous uncertainty, see also 2001BE81
2004KO09	Total	1.248 (3)	100	1.2480 (30)	

In order to evaluate the ^{40}K half-life, each partial half-life was recalculated using the appropriate branching ratio. The corresponding uncertainty was also calculated.

The LWEIGHT program turned up five statistical outliers: four by Chauvenet's criterion (1948Hirzel, 1949Floyd, 1951Delaney, 1955SU38 (EC, 1460)) and one by 3σ criterion (1950Smaller). A weighted average was adopted from the resulting consistent data set, with a reduced-χ^2 value of 1.62. The data used for the evaluation of the ^{40}K half-life can be seen in Figure 1. The two main contributions come from 1965LE15 (β^-) and 2004KO09, each of them amounting by 43 %. The adopted value is: $T_{1/2} = 1.2504\ (25) \times 10^9$ a. Since these measurements are not all independent, the adopted uncertainty is the most precise uncertainty on measurement: 3.0×10^6 a, identical for 1965LE15 (β^-) and 2004KO09.

The recommended value for the ^{40}K half-life is then: **$T_{1/2}$ = 1.2504 (30) ´ 10^9 a**, in good agreement with the evaluations by Helmer (1.265 (13) × 10^9 a) (1999BeZS) and Chechev (1.258 (10) × 10^9 a) (2001Chechev).

Figure 1: $T_{1/2}$ measurements used for the present evaluation, recalculated with the branching ratios. The red ones are excluded by LWEIGHT.



2.4 Electron Capture Transitions

The evaluation of the branching ratios is described in Section 2.2. That is:
$P_{ec,1460}$ = 10.55 (11) % and $P_{ec,gs}$ = 0.20 (10) %.

The log *ft* value for the 1U transition ($^{40}K \rightarrow ^{40}Ar^{2+}$) was computed using the LOGFT program:
log *ft* = 11.55 (1).

LOGFT cannot calculate the log *ft* value for the 3U transition ($^{40}K \rightarrow ^{40}Ar^{gs}$). The evaluator chose the same method used in Section 2.2 to calculate the $P_{ec,gs}/\beta^+$ ratio.
So, log *ft* (1U) = 19.51 (5) and log *ft* (2U) = 20.41 (5) and then, log *ft* (3U) = 21.35 (10).

The P_K, etc. values were computed by the LOGFT program.

2.5 b- Transitions

The β^- branching ratio is 89.25 (17) %, as deduced in Section 2.2. The average energy is from the LOGFT program.

The log *ft* value for this 3U transition ($^{40}K \rightarrow ^{40}Ca$) is calculated with the same method as previously, then log *ft* (3U) = 20.58 (1).

2.6 Gamma Transitions

The internal conversion coefficients were calculated using the BrIcc program (2008KI07) for the K, L and M shells. The total internal conversion coefficient is: $\alpha = 10.28\ (15) \times 10^{-5}$.

From the theoretical tables of 1979SC31, the internal pair formation coefficient is:
$\alpha_\pi(1460, E2) = 7.3\ (5) \times 10^{-5}$.

So: $\alpha_T = \alpha + \alpha_\pi(1460, E2) = 17.6\ (5) \times 10^{-5}$

3 Atomic Data (Ar, Z=10)

3.1 X Radiations and Auger electrons

The X-ray and Auger electron data were computed using the EMISSION program with the atomic data of Schönfeld and Janßen (1996SC06).

4 Radiation Emissions

4.1 Electron Emission

The β^+ and β^- intensities were evaluated as described above in Section 2.

4.2 Photon Emissions

No new measurement was carried out for the 1460 keV gamma-ray energy in ^{40}Ar since 1998. The adopted value was evaluated by Helmer (1999BeZS): E_γ = 1460.822 (6) keV.

The gamma emission intensity is deduced from the electronic capture probability (see Section 2.2) and internal conversion coefficient (see Section 2.6):

$$I_\gamma(1460) = P_{EC}(1460)\ /\ [1 + \alpha_T] = 10.55\ (11)\ /\ 1.000176\ (5)\ \%.$$

So we have:

$$I_\gamma(1460) = 10.55\ (11)\ \%.$$

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^{41}Ar - Comments on evaluation of decay data
by V. Chisté and M. M. Bé

This evaluation was completed in February 2010. Literature by February 2010 was included.

1 Decay Scheme

^{41}Ar disintegrates 100 % by beta minus emissions to excited levels and to the ground state of ^{41}K.

A good agreement was found between the effective Q value (2492 (7) keV) calculated from the decay scheme data and the adopted and recommended value from the mass adjustment of Audi (2003Au03).

2 Nuclear Data

The Q value is from the atomic mass evaluation Audi and Wapstra (2003Au03).

Spin and parities are from evaluation of P. M. Endt (1990En08).

Level energies and half-life for the 1293-keV excited level are from the mass-chain evaluation of J. A. Cameron and B. Singh (2001Ca59).

Experimental ^{41}Ar half-life values (in min) are given in Table 1:

Table 1: Experimental values of ^{41}Ar half-life.

Reference	Experimental value (min)	Comments
A. H. Snell (1936Sn01)	110 (1)	
E. Bleuler (1946Bl28)	109.4 (10)	
H. Brown (1950Br29)	107 (3)	Outlier.
W. Hälg (1951Ha78)	109.6 (4)	
A. Schwarzschild (1956Sc91)	111 (1)	Outlier.
H. Paul (1964Pa03)	109.8 (12)	
M. Bormann (1969Bo11)	103.5 (24)	Outlier.
F. Jundt (1971Ju04)	109 (2)	
A. R. Rutledge (1986Ru09)	109.32 (12)	
A. Abzouzi (1990Ab06)	109.640 (38)	
Recommended value	109.611 (38)	χ^2 = 1.13

The values of H. Brown (1950Br29), Schwarzschild (1956Sc91) and Bormann (1969Bo11) have been shown to be outliers, based on the Chauvenet's criterion and thus were omitted in the final calculation. With the 7 remaining values (1936Sn01, 1946Bl28, 1951Ha78, 1964Pa03, 1971Ju04, 1986Ru09 and 1990Ab06), a weighted average was calculated using the LWEIGHT computer code (version 3). The largest contribution to the weighted average comes from the value of Abzouzi (1990Ab06), amounting to 89 %.

The adopted value is the weighted average of 109.611 min with an external uncertainty of 0.038 min. The reduced-χ^2 value is 1.13.

2.1 β- Transitions

The maximum energies of the β^- transitions in the decay of ^{41}Ar → ^{41}K have been obtained from the Q^- value (2003Au03) and the level energies given in Table 2 from J. A. Cameron (2001Ca59).

Table 2: ^{41}K levels populated in the decay of ^{41}Ar.

Level Number	Level energy (keV)	Spin and parity	Half-life
0	0	$3/2^+$	
1	1293.64 (4)	$7/2^-$	6.7 (5) ns
2	1677.0 (3)	$7/2^+$	

The transition probability of the β transition to the ground state of ^{41}K has been reported as (Table 3):

Table 3: Experimental values of β transition probability to the ground state of ^{41}K.

Reference	Experimental value (%)	Comments
A. Schwarzschild (1956Sc91)	0.88	Not used: no uncertainty.
G. R. Kartashov (1961Ka19)	0.78 (2)	
H. Paul (1964Pa03)	0.82 (6)	
Recommended value	0.784 (19)	$\chi^2 = 0.4$

The adopted probability value of the β transition to the ground state is the weighted average of 0.784 % with an internal uncertainty of 0.019 %. The reduced-χ^2 value is 0.4.

For the 1293- and 1677-keV levels, the adopted β^- transition probabilities and the associated uncertainties were deduced from the γ transition probability balance at each level of the decay scheme (see **4.2 γ Emissions**).

The values of log ft and average β^- energies have been calculated with the program LOGFT for the allowed, unique 1st forbidden and 1st forbidden β^- transitions.

2.2 γ Transitions

The transitions probabilities were calculated using the γ-ray emission intensities and the relevant internal conversion coefficients (see **4.2 Gamma Emissions**).

Multipolarity and mixing ratio of 1293-keV γ-ray transition are from H. H. Eggenhuisen (1978Eg01):
1293-keV γ-ray: M2 + E3, with $\delta = 0.118\ (12)$

The internal conversion coefficients (ICC's) for this γ-ray transition have been interpolated from theoretical values of I. M. Band (2002Ba85) using the BrIcc computer program (calculation for 'hole') (2008Ki07). The α_T theoretical value is compared with a measured value in Table 4. They are in agreement within the uncertainty limits.

Table 4: Experimental and recommended (calculated) values internal conversion coefficients.

	α_T (1293-keV)
G. R. Kartashov (1961Ka19)	$6.8\ (9)\ 10^{-5}$
BrIcc program (recommended values)	$7.44\ (11)\ 10^{-5}$

The internal pair formation coefficient α_π(1293 keV) is 4.92 (7) 10^{-6} (given by BrIcc computer program). So α_T, using to calculate the 1293-keV transition probability, is

$$\alpha_T = 4.92\ (7)\ 10^{-6} + 7.44\ (11)\ 10^{-5} = 7.93\ (11)\ 10^{-5}$$

3 Atomic Data

Atomic values, ω_K, n_{KL} and the X-ray relative probabilities are from Schönfeld and Janβen (1996Sc06).

4 Emissions

4.1 K x-rays

The X-ray absolute intensities were deduced from the decay data using the EMISSION computer code.

4.2 Photon emissions

The energies of the γ-rays given in section 5.2 are from J. A. Cameron (2001Ca59).

The experimental relative γ-ray emission intensities in ^{41}K have been obtained from all the available relative and absolute values.

The normalization factor to convert the relative emission intensities to absolute emission intensities is calculated using the formula:

$$N = \left(\frac{100 - P_\beta(0,0)}{(\Sigma(1 + \alpha_T)P_{rel})} \right) = \frac{100 - 0.784(19)}{(\Sigma(1+\alpha_T)P_{rel})} = 0.99157\ (20),$$

where the sum is over all the γ transitions to the ground state (1293- and 1677-keV) and α_T is the relevant coefficient. The uncertainty was calculated through the propagation on the formula given above.

The experimental γ-ray emission probabilities relative to 100 for the 1293-keV γ-ray are given in Table 5.

Table 5: Experimental data sets of the relative γ-ray emission intensities (%)

Reference / Energy (keV)	1293.64 (4)	1677.0 (3)
W. W. Pratt (1965Pr05)	100	5 (2) 10^{-2}
F. Jundt (1971Ju04)	100	5.2 (5) 10^{-2}
Evaluated value	100	5.19 (49) 10^{-2}
χ^2		0.0094

The adopted values are the weighted means calculated by the LWEIGHT program (version 3).

The adopted relative and absolute γ-ray emission probabilities are given in Table 6.

Table 6: Recommended relative and absolute γ-ray intensities (%).

Eγ (keV)	**Relative γ-ray intensity (%)**	**Absolute γ-ray intensity (%)**
1293.64 (4)	100	99.157 (20)
1677.0 (3)	5.19 (49) 10^{-2}	5.15 (49) 10^{-2}

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^{44}Sc – Comments on evaluation of decay data

by E. Browne

The *Limitation of Relative Statistical Weights* [1] (LWM) method, used for averaging numbers throughout this evaluation, provided a uniform approach for the analysis of discrepant data. The uncertainty assigned to the recommended value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

^{44}Sc ($T_{1/2}$ = 3.97 h) decays 94.27(5)% by β^+, and 5.73(5)% by electron capture (Q(EC)=3653.3(19) keV (95Au04)[2]) allowed transitions to levels at 1157.0-, 2656.5-, and 3301.5-keV in ^{44}Ca (stable). A β^+ transition from ^{44}Sc ($J^\pi = 2^+$) to the ground state of ^{44}Ca ($J^\pi = 0^+$) has not been observed. Such transition would be second-forbidden non unique, for which the systematic trend of log *ft* predicts a value > 10.6 (98Si17)[4]. For ^{44}Sc this value corresponds to a β^+ transition probability limit of < 0.005%. Therefore, I used no β^+ feeding to the ground state, and normalized the decay scheme using the sum of the relative transition probabilities of the 1157.0-, 2656.4-, and 3301.3-keV gamma rays. This procedure produced a normalization factor $N = (9.9875(3) \times 10^{-4})$, as it will be shown in below.

Nuclear Data

The recommended half-life of ^{44}Sc, 3.97(4) h, is a weighted average (LWM, σ_{int}=0.01, χ^2/ν= 8.0) of 3.927(8) h (69Ra16)[5], 4.00(2) h (66Ta01)[6], and 4.05(3) h [7]. Other values are: 4.04 h [8], 4.01 h [9], and 3.9 h [10], were not used because they have no uncertainties.

Gamma Rays

Tables Ia and Ib give gamma-ray energies and relative emission probabilities, respectively, reported by 90Me15[11], 83Gu11[12], 76Co06 [13], 74HeYW [14], 73Si05 [15], and 90Sc08 [16]. Recommended values (weighted averages (LWM)) are given on columns 5 and 7, respectively.

Table Ia - Gamma-Ray Energies

90Me15[11] & 76Co06[13] keV	83Gu11[12] keV	74HeYW[14] keV	73Si05[15] keV	Rec. Value keV	χ^2/ν
	646.55 (62)		646.5 (20)		
726.49	726.3 (15)		726.0 (15)		
	772.7 (12)		774		
1157.031 (15)	1157.015 (15)	1156.92 (15)	1156.9 (5)	1157.020 (15)	0.37
1499.489 (25)	1499.436 (15)	1499.20 (20)	1499.4 (3)	1499.460 (20)	1.3
2144.3 (1)	2144.43 (20)		2144.8 (8)	2144.33 (10)	0.34
2656.478 (30)	2656.435 (50)	2657.14 (20)	2656.4 (5)	2656.48 (7)	3.9
3301.3 (1)	3301.361 (55)	3301.6 (15)	3301.35 (6)	0.16	

Table Ib - Relative Gamma-Ray Emission Probabilities

Energy keV	90Me15[11] & 76Co06[13]	90Sc08[16]	83Gu11[12]	74HeYW[14]	73Si05[15]	Rec. Value	χ^2/ν
646.5			0.040		0.043 (18)		
726.3	=0.014		0.053 (10)		0.051 (21)		
772.7	=0.0067*		0.062 (16)		0.041 (23)		
1157.020	1000(3)	1000 (1)	1000 (3)#	1000 (50)	1000 (3)#	1000 (3)	
1499.46	9.0 (2)	9.12 (15)	9.22 (37)	9.0 (10)	9.1 (4)	9.09 (15)	0.10
2144.33	0.02 (2)		0.035 (10)#		0.039 (7)	0.036 (7)	0.41
2656.48	1.11 (4)	1.15 (6)	1.11 (3)	1.4 (5)	1.3 (1)	1.12 (3)	0.98
3301.35	0.0064 (8)		0.016 (2)		0.018 (3)	0.017 (2)&	0.31

* From ^{44}K decay, relative to 9.0 for the emission probability of 1499-keV gamma ray._

\# Estimated by evaluator.

& Weighted average of 0.016(2) and 0.018(3).

The 726- and 772-keV gamma rays reported by 83Gu11 [12] and 73Si05 [15] were not observed by 90Me15 [11] and 76Co06 [13], who reported upper limits four and nine times lower, respectively, for their relative emission probabilities. Therefore, they probably do not belong to the decay of ^{44}Sc.

The 646-keV gamma ray was observed with about the same relative emission probability by both 83Gu11 [12] and 73Si05 [15]. These authors placed this gamma ray de-exciting a 3301-keV level, which is also de-excited by the 2144- and 3301-keV transitions. 90Me15 [11] and 76Co06 [13] did not report the 646-keV gamma ray. However, 76Co06 [13] have seen it in the β^- decay of ^{44}K. Table II shows the relative emission probabilities of the 646-, 2144-, and 3301-keV gamma rays, which de-excite the 3301-keV level, from both ^{44}Sc electron-capture and ^{44}K β^- decay.

Table II - Relative Emission Probabilities for the 646-, 2144-, and 3301-keV Gamma Rays from the 3301-keV Level

Energy keV	83Gu11[12] P_γ	73Si05[15] P_γ	76Co06[13] P_γ
	From ^{44}Sc EC Decay		From ^{44}K β^- Decay
646.5	0.040	0.043 (18)	1.5 (5)
2144.33	0.035	0.039 (7)	12.9 (8)
3301.35	0.016 (2)	0.018 (3)	5.5 (9)
***			
R(646/2144)	1.1	1.1	0.12
R(2144/3301)	2.2	2.2	2.3

Table II shows that the ratio R(646/2144) is ten times lower from ^{44}K β^- decay than from ^{44}Sc electron-capture decay. Consequently, the 646-keV gamma-ray, observed from ^{44}K decay, does not de-excite the 3301-keV level, as 83Gu11 had suggested, and therefore, its existence is uncertain.

Multipolarities and Conversion Coefficients

A total measured conversion coefficient [17] α_t=6.3 (3)x10^{-5} for the 1157.020-keV gamma-ray suggests an E2 multipolarity for this gamma-ray. The 1499.46-keV gamma-ray has an M1+1.8 (4)% E2 multipolarity (δ = +0.137(7)), determined in a $\gamma\gamma(\theta)$ measurement (68Wa21)[3].The theoretical conversion coefficients in Table 2.3 (Tables Section) for these transitions are from 76Ba63 [18]. Conversion coefficients for pair creation are theoretical values from 79Sc31[30].

Absolute Emission Probabilities.

As mentioned before, the gamma-ray normalization factor *N* can be obtained as follows:

$$N = 1/[P_{\gamma(1157)}(1+\alpha_{1157}) + P_{\gamma(2256)} + P_{\gamma(3301)}] = 1/[1000\ (3)\ (1 + 6.68 \times 10^{-5}) + 1.12\ (3) + 0.064\ (8)]$$
$$= 9.9875(3) \times 10^{-4}$$

The internal pair conversion coefficients (from 79Sc31[19]) for these gamma-rays are: α_{IP}(1157, E2) = 4.0 × 10^{-6}, α_{IP}(2256, E2) = 5.9 × 10^{-4}, and α_{IP}(3301, E2) = 9.0 × 10^{-4}. These coefficients were not included in the calculation shown above because their effect is negligible.

The fractional uncertainty in *N* should be added in quadrature to those in the relative emission probabilities. For the 1157.020-keV gamma-ray, which dominates this normalization, the correct propagation of this uncertainty is as follows:

$$P_\gamma(abs,1157) = P_\gamma(rel,\ 1157) \times N = 1000\ (3)/[1000\ (3)\ (1 + 6.68 \times 10^{-5}) + 1.12\ (3) + 0.064\ (8)] =$$
$$= 1/\ [1.0000668 + 1.18\ (3)/1000\ (3)] = 1/[1.0000668 + 0.00118\ (3)] = 0.99875(3)$$

Notice that the fractional uncertainty of the relative emission probability is 0.3% , however, because of the effect of covariances, that in the absolute emission probability is just 0.003% . Table III shows the gamma-ray absolute emission probabilities.

Table III - Absolute Gamma-ray Emission Probabilities

Energy (keV)	P_γ(%)
1157.020 (15)	99.875 (3)
1499.460 (20)	0.908 (15)
2144.33 (10)	3.6 (7) × 10^{-3}
2656.48 (7)	0.112 (3)
3301.35 (6)	1.7 (2) × 10^{-3}

Electron-Capture and b$^+$ Transitions

The electron-capture plus β^+ probabilities shown in the decay scheme have been deduced from gamma-ray transition intensity balances at each level. For the transition to the 1157-keV level, the values of the individual β^+ and electron-capture probabilities (given in Tables 2.2 and 2.1, respectively) are based on the recommended ε/β^+ = 0.0499(5) ratio. This ratio is a weighted average of the experimental values 0.0499(5) (83Ba41) [20] and 0.0497(23) (76St21) [21]. Theory predicts 0.0489 [22].

Electron-capture probabilities to the various atomic sub-shells, i.e., P_K, P_L, P_{M+} in Table 2.1 are theoretical values (98Sc28)[23] calculated with the computer program EC-CAPTURE[24].

90Sc08 [16] measured the annihilation emission probability $P_{\gamma\pm}(511)$ = 1.88(3), which includes a 2.4% correction for positron annihilation-in-flight. I confirmed the value of this correction using the calculation procedure presented in Appendix D of the *Table of Radioactive Isotopes* [25], as described below in Table IV.

Table IV - Annihilation-in-flight Correction Factor

E(bin) keV	$<\beta^+>^*$ keV	β^+ (%)$^\#$ %	$E_{avg}{}^\&$ keV	$P(E_{avg})^\wedge$ %	$\beta^+_{fl}{}^@$ %
0-10	0.000434	0.0056	7.75		
10-20	0.0056	0.0355	15.77		
20-40	0.060	0.191	31.41		
40-100	1.12	1.50	74.67	0.5	0.0075
100-300	26.8	12.6	212.69	1.0	0.126
300-600	140.0	30.7	456.03	2.1	0.645
600-1300	418.0	48.6	860.0	3.4	1.652
1300-2497	10.8	0.80	1350.0	4.8	0.038
	Total β^+ branching	**94.0**		Correction factor	**2.47**

*Average β^+ energy per decay

$^\#$ β^+ bin probability

$^\&$ Average β^+ bin energy = 100 $< \beta^+>/\beta^+(\%)$

$^\wedge$ Positron annihilation-in-flight probability (from Fig.3, Appendix D, *Table of Radioactive Isotopes*)

$^@$ Fraction (in %) of β^+ transitions that annihilate in flight = $0.01 \mathrm{x} \beta^+(\%) \mathrm{x}\ P(E_{avg})$

The final result, 2.47%, agrees with 2.4%, used by 90Sc08 [16].

Then, the β^+ probability is $P_{\beta+}(1157) = 1.88(3)/2 = 0.940(15)$. The electron-capture probability, $P_{EC}(1157) = 0.9897(5) - 0.940(15) = 0.0497(15)$, although less accurate, is in agreement with the recommended value given in Table 2.1.

Levels half-life

The following half-life values: 2.61(14) ps (1157 -keV level), 30(3) fs (2656 -keV level), and 35 (18) fs (3301-keV level), shown on the level scheme, are from 90En08 [26].

Atomic Data

The X-ray and Auger-electron probabilities in Section 4 have been calculated with the computer program EMISSION[27], using the gamma -ray and electron -capture data from Section 2, and atomic data from 96Sc06[28]

Total Average Radiation Energy

The calculated (RADLST [29]) total average radiation energy of 3653.3(25) keV (which includes all the radiations emitted by ^{44}Sc), agrees very well with Q(EC) =3653.3(19) keV (1995Au04 [2]) and confirms the self consistency of the ^{44}Sc decay scheme.

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^{44}Ti – Comments on evaluation of decay data

by E. Browne

Evaluation Procedures

The *Limitation of Relative Statistical Weights* [1] (LWM) method, used for averaging numbers throughout this evaluation, provided a uniform approach for the analysis of discrepant data. The uncertainty assigned to the recommended value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

^{44}Ti ($T_{1/2}$= 60.0 y) decays 100% by electron capture (Q(EC)=267.5 (19) keV) to excited levels at 67.9- and 146.2 keV only in ^{44}Sc ($T_{1/2}$=3.93 h), which subsequently decays by EC+β^+ to ^{44}Ca (stable).

90Sc08 measured the relative emission probabilities of the 1157 -, 67.9- and 78.4-keV gamma rays from a ^{44}Ti - ^{44}Sc equilibrium source. Since the absolute emission probability of the 1157 -keV gamma ray from ^{44}Sc is well known (0.999) [2], this measurement provided values for the absolute emission probabilities of the 67.9- and 78.4 keV gamma rays as well, thus normalizing the decay scheme of ^{44}Ti.

Nuclear Data

^{44}Ti is of considerable interest in astrophysics, since it is one of the few long -lived gamma-ray-emitting nuclides expected to be substantially produced during a supernova explosion. Moreover, the solar system abundance of ^{44}Ca is believed to have originated from the nucleosynthesis of ^{44}Ti and the subsequent decays. The characteristic 1157 -keV gamma ray from ^{44}Sc, which was observed from the young supernova remnant Cassiopeia A [3], opened the possibility of deducing the mass of ^{44}Ti that was ejected in the explosion. For this calculation, however, it was needed (among other quantities) a reasonably precise knowledge of the ^{44}Ti half-life.

The recommended half-life of ^{44}Ti, 60.0 (11) y, is a weighted average (LWM, σ_{int}=0.5, χ^2/ν= 5.6) of:

- 60.7 (12) y [4] (method: decay of count rate),
- 59.0 (6) y (98Ah03[5], method: decay of count rate),
- 60.3 (13) y (98Go05[6], method: specific activity with beam fragmentation),
- 62 (2) y (98No06[7], method: decay of count rate),
- 66.6 (16) y (90Al11[8], method: decay of count rate), and
- 54.2 (21) y (83Fr27[9], method: specific activity with accelerator mass spectroscopy).

The following results have not been included in the averaging:

- Preliminary results: 58 (10) y [10] (method: specific activity with beam fragmentation), 39.0 (18) y [11] (method: specific activity with beam fragmentation), and 63 (3) y (97No06 [12], method: decay of count rate).
- Older measurements: 48.2 (9) y (65Mo07 [13], method: specific activity), and 46.4 (17) y (65Wi05[14], method: specific activity). These values significantly deviate from recent results, probably because of systematic errors.

Woosley and Diehl [15] have recommended a half-life of 60 (1) y for ^{44}Ti, based on the 1998 values.

Gamma Rays

Energies

^{44}Ti emits gamma rays of 67.9 -, 78.4-, and a very weak one of 146.2 keV. The precise gamma -ray energies for the 67.9 - and 78.4 -keV transitions given in Table 4.2 (and the values corrected for nuclear recoil, in Table 2.2) are weighted averages (LWM) of results from 63Kl06[16], 67Ri06[17], and 91We08[18] (See Table I). Other: 88Al27 [19] (superseded by 91We08 [18]). The energy of 146.22 (3) keV for the 146 - keV is from level-energy differences. A measured value is: 147.0 (15) keV (67Ri06[17]).

Table I - ^{44}Ti Gamma-ray Energies

	67.9 keV	78.4 keV
91We08[18]	67.8679 (14)	78.3234 (10)*
67Ri06[17]	67.85 (4)	78.38 (4)
63Kl06[16]	67.85 (7)	78.44 (7)
Average	67.8679 (14)	78.36 (3)
χ^2/ν	0.13	1.3

* The uncertainty of 0.0010 was increased to 0.035 to reduce the statistical weight of this measurement from 99.9% to 50%. Original $\chi^2/\nu = 2.4$.

Emission Probabilities

The relative emission probabilities are average values (LWM) from 88Al27[19], 90Sc08[20], and 67Ri06[17], as given in Table II below.

Table II - ^{44}Ti Relative Emission Probabilities

Energy keV	67Ri06[17] P_γ(rel.)	88Al27[19] P_γ(rel.)	90Sc08[20] P_γ(rel.)	W. Average (LWM) P_γ(rel.)	χ^2/ν
67.8679 (14)	0.942 (15)*	0.981 (11)	0.960 (15)	0.965 (16)@	2.3
78.36 (3)	1.000 (11)*	1.000 (11)	1.000 (13)	1.000 (11)&	
146.22 (3)	0.0010 (3)	0.00093 (6)	0.00095 (3)	0.00095 (3)	0.05

* Original uncertainties of 0.005 seemed unrealistically low. Evaluator has increased these values.

& Uncertainty is the smallest of the individual values.

@ Internal uncertainty σ_{int}=0.011

A factor to normalize relative to absolute emission probabilities was deduced as follows:

- N= 0.955 (15), from the average relative emission probabilities given in Table III column 2, the theoretical conversion coefficients from Section 2.2, and the condition that the total transition intensity to the ground state is 100%, as shown below.

$$[P_\gamma(67.8)(1+\alpha_{68}) + P_\gamma(146)(1+\alpha_{146})]\ N = 100\%$$

- N=0.974 (13), from the emission probability of the 78-keV gamma ray (0.974 (13)) relative to an absolute probability of 0.999 (1) for the 1157-keV gamma ray in the decay of ^{44}Sc in equilibrium with ^{44}Ti (90Sc08).

The (unweighted) average of these normalization factors is N_{avg}=0.964 (13) (smallest uncertainty from input values).

Table III gives recommended relative and absolute gamma-ray emission probabilities.

Table III - Recommended Relative and Absolute Gamma-Ray Emission Probabilities

E_γ (keV)	P_γ (rel.)*	P_γ (abs.) &
67.9	0.965 (16)	0.930 (15)
78.36 (3)	1.000 (11)	0.964 (11)
146.22 (3)	0.00095 (3)	0.00092 (3)

* From Table II, column 5.

& Values from column 2 multiplied by N_{avg} (=0.964 (13))

Multipolarities and Conversion Coefficients

The following experimental conversion coefficients: α_K = 0.123 (23) (67Ri06 [17]), α= 0.10 (5) (63Kl06[16]) for the 67.9-keV gamma ray, and α_K = 0.031 (5) (67Ri06[17]), α = 0.017 (8) (63Kl06[16]) for the 78.4-keV gamma ray, suggest E1 and M1 multipolarities for the 67.9- and 78.4-keV transitions, respectively. Spins of 0- (for the 146-keV level) and 1- (for the 67.9-keV level) require M1 multipolarity for the 78.4-keV gamma ray. The evaluator has assigned from decay scheme (0- to 2+)[M2] multipolarity to the 146-keV gamma ray.

Total conversion coefficients also may be deduced from the measured absolute gamma-ray emission probabilities of 90Sc08, by using 0.7 (3)% (88Al27, delayed -coincidence experiment) for the electron-capture feeding to the 67-keV level, and neglecting the very weak 146-keV transition. These calculations are:

α(67.9) = [1.0/0.935 (15)] -1.0 = 0.069 (17); α(78.4) = [(1.0 - 0.007 (3))/0.974 (13)] -1.0 = 0.019 (14), which agree with the measured values. Where 0.935 (15) and 0.974 (13) (90Sc08) are the experimental absolute emission probabilities of the 67.9- and 78.4-keV gamma rays, respectively. The absolute adopted emission probabilities were not used in this calculation because they are partially based on decay scheme considerations (that include the conversion coefficient of the 67.9-keV gamma ray.)
Table IV shows experimental and theoretical conversion coefficients for the 67.9-, 78.4-, and 146-keV gamma rays.

Table IV - Conversion Coefficients

E_γ keV	α_T@ From P_γ(%)	α_T Exp.	α_T* Theory	α_K Exp	α_K* Theory	Mult.
67.8679 (14)	0.069 (17)	0.10 (5)#	0.0845 (25)	0.123 (23)&	0.0766 (23)	E1
78.36 (3)	0.019 (14)	0.017 (8)#	0.032 (1)	0.031 (5)&	0.0273 (8)	M1
146.22 (3)			0.046 (1)		0.0414 (12)	M2

[*] Interpolated from 76Ba63[21]
[#] From 63Kl06[16]
[&] From 67Ri06[17]
[@] See text

The experimental conversion coefficients in Table IV are quite imprecise, therefore, the evaluator has adopted interpolated theoretical values as the recommended conversion coefficients. The interpolation was done with the computer program ICC[22].

Electron-Capture Transitions

The EC probability to the 146-keV level is given by:

$\varepsilon(146) = [P_\gamma(78.4)+e(78.4) + P_\gamma(146)+e(146)] \times 100 = 99.5\ (11)\% + 0.096\ (3)\% = 99.6\ (11)\%$.

For the EC probability to the 0+ ground state of ^{44}Sc (0+ to 2+, second forbidden) a log ft >10.6 is expected from the systematic trend for second forbidden transitions (98Si17), which corresponds to $\varepsilon(0) < 0.04\%$. Using $\varepsilon(0)=0.04\%$ and $\varepsilon(146) = 99.6\ (11)\%$ gives $\varepsilon(67.4) = 0.4\ (11)\%$. Experimental values for this quantity are 0.7 (3)% (88Al27 [19]), and 1.9 (15)% (67Ri06 [17]), both measured in γ-x ray coincidence experiments.

Electron-capture probabilities to the various atomic sub-shells, ie. P_K, P_L, P_{M+} in Table 2.1, are theoretical values (98Sc28[23]) calculated with the computer program EC-CAPTURE[24].

Levels half-life

Table V shows the experimental half-life values for the 67.3- and 78.4 keV levels, as well as their respective recommended (i.e., average) values.

Table V - ^{44}Sc Levels half-life

67.9 keV		78.4 keV	
153 (2) ns	(67Ri06[17])	50 (3) μs	(63Kl06[16])
153 (1) ns	(62Th12[25])	49.5 (10) μs	(64Br27[27])
180 (20) ns	(59Cy90[26])	51.2 (9)* μs	(88Al27[19])
166 (5) ns	(63Kl06[16])		
155 (2) ns	(75Gu24[28])		
154.8 (8) ns	(88Al27[19])		
Avg.(LWM) = 154.2 (8) ns		Avg. (LWM) = 50.4 (7) μs	
$\chi^2/\nu = 1.95$		$\chi^2/\nu = 0.77$	

[*] The uncertainty was increased from 0.3 ($\chi^2/\nu = 1.4$) to 0.9 to reduce its statistical weight from 91% to 50%.

Atomic Data

The X-ray and Auger-electron probabilities in Section 4 have been calculated using the gamma-ray and electron-capture data that are presented in Section 2, and using atomic data from 96Sc06[29].

Total Average Radiation Energy

Our calculated (RADLST [30]) total average radiation energy of 268 (3) keV (which includes all the radiations emitted by ^{44}Ti), agrees very well with Q(EC) = 267.5 (19) keV (95Au04 [31]) and confirms the quality and completeness of the ^{44}Ti decay scheme.

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^{45}Ca - Comments on evaluation of decay data
by M.M. Bé

This evaluation was completed in February 2012 with a literature cut-off by the same date.

Decay Scheme

^{45}Ca disintegrates by beta minus emission to the ^{45}Sc ground state mainly, with a very small branch of 0,002 % to the ^{45}Sc first excited level of 12,4 keV.
Level energies, spins and parities (J^{π}) were taken from the evaluation by Burrows (2008Bu01).

Nuclear Data

Half-life

The recommended value was derived from measurements listed in Table 1.

Table 1. Measurement results and recommended value of ^{45}Ca half-life.

Reference	Value (d)	Uncertainty (d)	Remarks
1952De01	163,5	4,0	GM, Stat. uc
1957Th**	153	2	
1959Ca12	167	3	PC
1961Wy01	165,1	0,7	PC
1965An07	162,63	0,11	4πpc
1970Si24	163	2	PC
1994Lo04	162,67	0,25	LSC
χ^2 /n-1 =	0,34		
χ^2 crit. =	0,38		
UWM =	162,95		
LWM = (recommended)	162,64	0,11	Uc_{int} = 0,10 ; Uc_{ext} = 0,018

Conventional designations in the fourth column:
Measurement of counting rate decrease by Geiger-Müller counter (GM), proportional counter (PC), 4π proportional counter (4πpc), Liquid Scintillation Counting (LSC).
Stat. uc: statistical uncertainty component.

Values from Thiry (1957Th**), Caswell (1959Ca12) and Wyatt (1961Wy01) have been found outliers due to Chauvenet's criterion. The set of the remaining four values is consistent, and then the adopted value is the weighted mean with the lowest of the experimental uncertainties.

Decay Energy and Characteristics of Electron Emissions

The decay energy of ^{45}Ca has been adopted from the evaluation of Audi *et al.* (2011AuZZ),
$Q_{\beta-}$ = 258,0 (7) keV.
It should be noted that in the previous evaluation (2003Au03) $Q_{\beta-}$ = 255,8 (8) keV. This difference seems due to a change of 2,5 keV in the ^{45}Sc mass.

Several papers report measurements of the ^{45}Ca β^- spectrum (1950Ma03, 1950Ke60, 1967Ha39); by using a Kurie plot, the nature of the transition gs → gs was determined to be allowed.
With this hypothesis, a mean beta energy of 76,8 keV was calculated with the BetaShape program (2011Mo**), which is based on theoretical considerations. It can be compared with the experimental value of 74,6 (30) keV obtained by Caswell (1952Ca10).
A weak β^- transition to the 12,4 keV level was deduced from the observation of K conversion electrons by Freedman *et al.* (1965Fr12). The ratio of the K conversion electrons over the total β emissions was measured being:
$I(ce_K)/I\beta = 1{,}4\times10^{-5}$ (+8 -3)
The adopted value for this ratio is $I(ce_K)/I\beta = 1{,}7\ (6) \times 10^{-5}$ in application of the method described in Audi (2003Au03, page 21) to experimental data with asymmetric uncertainties.
The internal conversion coefficients for a M2 transition were calculated with the BrIcc program in the “frozen orbital approximation” (Kibédi *et al.* - 2008Ki07), that is: α_T = 423 (9) and α_K = 362 (8).
Then, the probability of the β^- transition to the 12,4 keV level is 2,0 (7) $\times10^{-3}$ %.

Gamma-ray transition and emission

From the results above, the probability of the 12,4 keV gamma-ray transition is 2,0 (7) $\times 10^{-3}$ % and the gamma-ray emission intensity is negligible.

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^{46}Sc - Comments on evaluation of decay data
by R. G. Helmer

1 Decay Scheme

The only levels in ^{46}Ti below the decay energy are those populated in this ^{46}Sc β^- decay, so that portion of the decay scheme is complete. However, ^{46}Sc can also electron-capture decay, ε, to levels in ^{46}Ca with a decay energy of 1368 keV. The available levels are 0^+ at 0 keV and 2^+ at 1346 keV with ε branches that are 4th forbidden and 2nd forbidden, respectively. From systematics (1998Si17), the corresponding log *ft* limits are ≥ 22.5 and ≥ 10.6, and the deduced $P_{\varepsilon+\beta+}$ limits are ≤ 1.0×10^{-12} % and ≤ 2.5×10^{-6} %, respectively. Therefore, these ε branches are negligible.

The J^π values and half-lives for the excited levels are from Adopted Levels in Nuclear Data Sheets (2000Wu08).

2 Nuclear Data

Q value is from Audi and Wapstra 1995 (1995Au04).

The half-life values available are, in days:

85 (1)	(1940Wa01)	omitted from analysis
84.1 (3)	(1956Sc87)	omitted from analysis
83.89 (12)	(1957Ge07)	omitted from analysis
84.4 (2)	(1957Wr37)	omitted from analysis
83.80 (3)	(1965An07)	superseded by 1982HoZJ
84.34 (13)	(1974Cr05)	omitted as outlier
83.75 (3)	(1977MeZP)	superseded by 1980RuZY
83.819 (6)	(1980Ho17)	
83.79 (6)	(1980Ol03)	
83.752 (15)	(1980RuZY)	
83.79 (6)	(1982HoZJ)	superseded by 1992Un01
83.752 (15)	(1982RuZV)	same as 1980RuZY
83.73 (12)	(1983Wa26)	
83.83 (7)	(1992Un01)	
83.788 (22)	Adopted value	

This set of values is inconsistent which causes the adopted value to depend on the choice of the values used and the "averaging" method used. The values have decreased over time; the unweighted average of the four not superseded values before 1978 (1940Wa01, 1956Sc87, 1957Ge07, and 1957Wr37) is 84.18, whereas the same average for the five values after 1978 (1980Ho17, 1980Ol03, 1980RuZY, 1983Wa26, and 1992Un01) is 83.78. The values reported before 1960 were omitted from the analysis since it would have been difficult to determine the presence of a small amount of a longer-lived impurity with the spectroscopy methods then available.

The discrepancy among the values is illustrated by the values of 84.34(13) (1974Cr05), 83.819(6) (1980Ho17), and 83.752(15) (1980RuZY). The first two values differ by 0.52(13) and the last two by 0.067(16), or about 4σ in each case. The latter two values have the greatest weight in any weighted average, so the results will depend on how the analysis modifies their relative weight, and the first value will give the largest contribution to the χ^2 value. Of the remaining six values not superseded, that of 84.34(13) (1974Cr05) is considered an outlier and is omitted.

For the remaining five values not superseded, the following averages are obtained:

unweighted	83.784 (19)
weighted	83.810, σ_{int} =0.006, reduced-χ^2=4.46, σ_{ext} =0.013
RAJEVAL	83.776 (20)
Normalized residuals	83.793 (16)
LRSW - weighted average	83.788, σ_{int} =0.010, reduced-χ^2=1.67, σ_{ext}=0.022 and σ_{LRSW}=0.031

The RAJEVAL method (1992Ra08) increases both of the two smallest uncertainties, namely, 0.006 to 0.043 and 0.015 to 0.026, which causes the value of 1980RuZY to have the largest weight. The Normalized Residuals method (1992Ja06) also increases both of the two smallest uncertainties but by different amounts, namely, 0.006 to 0.022 and 0.015 to 0.028, which leaves the value of 1980Ho17 with the largest weight, but only by a small amount. In contrast, the Limitation of Relative Statistical Weight, LRSW, method (1985ZiZY, 1992Ra08) only increases the most precise uncertainty, namely that of 1980Ho17, from 0.006 to 0.014 in order to reduce its relative weight to 50% from its initial 84%. The LRSW method expands the final uncertainty to 0.031 in order to include the most precise value. [The LRSW method finally suggests the unweighted average of 83.96(14), but that choice is not accepted here.]

The results from the RAJEVAL, Normalized residuals, and LRSW methods all are in good agreement and the adopted value, 83.788(22) is taken as the latter value with its external uncertainty.

2.1 b$^-$ Transitions

The β^- branch to the ground state of ^{46}Ti is 4th forbidden with an expected log *ft* ≥ 22.5 (1998Si17) and a corresponding $P_{\beta-}(0) \leq 1 \times 10^{-11}$ %, the measured limit is $\leq 1 \times 10^{-4}$ % (1954Ke04).

Similarly, for the 2nd forbidden decay to the 889 level, the expected log *ft* ≥ 10.6 which corresponds to $P_{\beta-}$ (889) ≤ 0.8 %. The measured $I_{\beta-}$ to this level are 0.096(1) (1954Ke04), 0.0036(7) (1956Wo09), ≤ 0.06 (1950Mo62), and ≤ 0.05 (1950So57). Some previous evaluators (e.g., 1986Al19) have assigned $I_{\beta-}$ (889) = 0.0036(7) because it is consistent with the limits of 1950Mo62 and 1950So57. However, this evaluator has some reservations about the resulting precision for $I_{\beta-}$ (2009) and, therefore, has expanded the uncertainty and gives $I_{\beta-}$ (889) = 0.004 % (+36-4), which is consistent with the two limits and the value of 1956Wo09, and thus $I_{\beta-}$ (2009) = 99.996(+4-36).

If symmetric uncertainties are required, as in ENSDF, for these quantities, $I_{\beta-}$ (889) = 0.02(2) and $I_{\beta-}$ (2009) = 99.98(2), adopted values.

The β^- average energies and log *ft* values are from LOGFT code.

2.2 Gamma Transitions

The J^π assignments are from the Adopted Levels in the Nuclear Data Sheets (2000Wu08) and these imply the two γ–rays have E2 multipolarities.

The internal-conversion coefficients were interpolated from the Band tables (1976Ba63).

The internal-pair-formation coefficient was interpolated from the theoretical values (1979Sc31) and is IPFC(1120) = 0.0000022 (4). This value is only abut 2 % of the corresponding internal-conversion coefficient and, therefore, is negligible.

3 Atomic Data

The data are from 1996Sc06.

3.1 and 3.2

None

4 Radiation Emissions

4.1 Electron Emission

The emission intensities are calculated from the atomic data and the decay data.

4.2 Photon Emission

The γ-ray energies are from 2000He14 for the 889 and 1120 lines and the 2009 energy is the sum of these values corrected for nuclear recoil.

The relative γ-ray emission probability of the 2009-keV γ-ray is from 1980Fu07.

The emission probability of the 889 -keV γ-ray is $[100.0 - P_{\gamma}(2009)] / [1.0 + \alpha(889)] = 99.999987(10)/1.000167(5) = 99.9833(5)$ where the uncertainty is 5 ppm from the $(1.0 + \alpha)$ term. That of the 1120 -keV γ-ray is $[I_{\beta-}(2009)-P_{\gamma}(2009)]/[1.0 + \alpha(1120)] = 99.996(+4 -36)/1.000095(3) = 99.986(+4-36)$, with symmetric uncertainties 99.98 (2). Here, α(2009) has been neglected.

6 References

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^{51}Cr - Comments on evaluation of decay data
by E. Schönfeld and R. G. Helmer

1 Decay scheme

The decay scheme is complete since there is only one excited level in ^{51}V below the decay energy and it is populated in this decay.

The J^{π} and half-life of the excited level are from the 1997Zh09 evaluation.

See 1973De60 for a very complete evaluation of the nuclear and atomic data related to this decay.

2 Nuclear Data

Q value is from Audi and Wapstra (1995Au04).

The half-life data, in days, are as follows:

26.0 (10)	1940Wa02	
26.5 (10)	1940Wa02	
26	1948Ho04	
27	1948Mi12	
27.75 (30)	1952Ly17	
27.9 (2)	1956Ka33	
27.8 (1)	1956Sc87	
27.85 (2)	1957Ka65	
28.04 (16)	1957Ka65	
27.75 (30)	1957Wr37	
27.82 (20)	1963Ho17	
27.701 (6)	1964Ma56	
27.5	1965Sa09	
27.7 (2)	1967LaZZ	superseded by 1975La16
27.80 (51)	1968Bo25	
27.704 (3)	1969MeZV	superseded by 1982RuZV
27.679 (17)	1970WaAA	superseded by 1983Wa26
27.76 (15)	1972Em01	
28.1 (17)	1973ArZI	
27.721 (26)	1973LaAA	superseded by 1975La16
27.750 (9)	1973Vi13	
27.703 (8)	1974Ts01	
27.72 (3)	1975La16	
27.690 (5)	1980Ho17	
27.71 (1)	1982ChZF	
27.705 (12)	1982DeYX	superseded by 1983Wa26
27.73 (1)	1982HoZJ	superseded by 1992Un01
27.704 (3)	1982RuZV	
27.71 (3)	1983Wa26	
27.7010 (12)	1992Un01	
27.703 (3)	**Adopted value**	

Three sets of half-life values were analyzed with the Limitation of Relative Statistical Weight, LRSW, method (1985ZiZY,1992Ra08) ; these sets had 21, 20, and 9 values. In all three cases the LRWS analysis increases the uncertainty of the 1992Un01 value from 0.0012 to 0.0021 in order to reduce its relative weight from 76% to 50%.

For all 21 values with uncertainties and not superseded, the LRSW weighted average is 27.7034 with an internal uncertainty of 0.0015, a reduced -χ^2 = 5.06, and an external uncertainty of 0.0034. The largest contribution to this reduced-χ^2 is 2.7 from the first value from 1957Ka65. If this value is removed from the data, the remaining 20 values give an LRSW weighted average is 27.7026 with an internal uncertainty of 0.0015, a reduced-χ^2 = 2.49, and an external uncertainty of 0.0024.

The third analysis was done with the nine values from the set of twenty which have uncertainties of ≤ 0.03 (namely, 1964Ma56, 1973Vi13, 1974Ts01, 1975La16, 1980Ho17, 1982ChZF, 1982RuZV, 1983Wa26, and 1992Un01). In this case the LRSW analysis gives a weighted average of 27.7025, an internal uncertainty of 0.0015, a reduced-χ^2 of 4.48, and an external uncertainty of 0.0032.

The adopted value of 27.703 (3) is consistent with all three of these results.

2.1 Electron Capture Transitions

The capture branching is determined from the P_γ(320) value (see sec. 4.2).

The P_K etc. values from LOGFT and EC-CAPTURE codes agree quite well, namely

	LOGFT			EC-CAPTURE		
Level	P_K	P_L	P_{M+N}	P_K	P_L	P_M
0	0.892	0.0927	0.0154	0.8919 (17)	0.0934 (14)	0.0144 (6)
320	0.891	0.0935	0.0156	0.8910 (17)	0.0941 (14)	0.0145 (6)

The EC-CAPTURE values have been adopted.

2.3 Gamma Transitions

The internal-conversion coefficient of α = 0.00169 (5) and α_K = 0.00154 (3) are from the analysis of experimental data in 1985HaZA. These results are based on α = 0.00169 (5) (1973Wi10) and α_K values of 0.00157 (8) (1969KaAA, as quoted in 1985HaZA), 0.00156 (8) (1970Ca17), 0.00146 (13) (1970Ri11), and 0.00153 (4) (1973Wi10). From K/L = 11.3 (6) and L/M = 5.1 (6) from 1969Dr01, one obtains α_L = 0.000136 (8) and α_M = 0.000027 (4). [An earlier evaluation by 1973De60 had available the latter three α_K values and deduced α_K = 0.00153 (4) and from the above K/L and L/M ratios α = 0.00169 (5).] Other measured values of α are 0.00162 (16) (1955Bu01), 0.0031 (2) (1955Es15), 0.0015 (2) 1956Of03), and 0.0016 (2) (1962Gu09) and those of α_K are 0.0029 (2) (1955Es15), 0.00138 (13) (1955Of01), 0.00146 (10) (1968Ri17, superseded by 1970Ri11), and 0.001527 (36) (1969WiAA, as quoted in 1985HaZA, superseded by 1973Wi10).

The mixing ratio, δ, deduced from these α_K and α_L and the conversion coefficients interpolated from the tables of 1976Ba63 is 0.40 (4). This compares reasonable well with the value of +0.465 (20) from the evaluation of 1997Zh09 which is based on the measured values of +0.43 (3) from (γ,γ'), +0.52 (7) from Coulomb excitation, and 0.49 (3) calculated from the adopted B(E2) and half-life values.

3, 3.1, and 3.2 X Radiations and Auger Electrons

Data are from 1996Sc06.

4.1 Electron Emissions

The data are from the γ-ray and atomic data in sec. 2.1, 2.2, and 3. A comparison of these intensities (in %) and those from RADLST gives :

	EMISSION	RADLST
L Auger	147.6 (10)	146.17 (16)
K Auger	66.4 (6)	66.32 (5)
K-320	0.0152 (3)	0.0166 (13)
L-320	0.00134 (8)	0.0016 (10)

The adopted values are from Emission.

4.2 Photon Emissions

The energy is from 2000He14.

The LRSW analysis of 9 P_γ values gives the weighted average of 9.87% (5) with a reduced $\chi^2 = 0.96$. The input values are: 9.8 6 (1955Bu01), 9 1 (1955Co56), 9.72 15 (1963MeZZ), 10.20 63 (1965Dh01), 9.75 20 (average of 2 values of 1965Le24), 10.2 10 (1970Ri11), 9.85 9 (1980Sc07), 10.30 19 (1984Fi10), and 9.86 8 (1991Ba11). Others: ≈ 2 (1940Wa02), 3 (1945Br02), 8 (1952Ly17), 21 (1952Ma49), 9.8 (1955Bi29), 7 (1955Co56), and 10.1 3 (1970ScAA, replaced by 1980Sc07). [From a set of five values, the evaluation of 1973De60 gives a result of 9.83% (14).]

The number of X rays was calculated, by the Emission program, from the γ-ray probabilities and atomic data in sec. 2.1, 2.2, and 3.

7. References

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^{54}Mn - Comments on evaluation of decay data
by R. G. Helmer and E. Schönfeld

1 Decay scheme

The decay scheme is complete since the only level in ^{54}Cr below the decay energy is populated in this decay. The β^- decay to ^{54}Fe is negligible.

The J^π and half-life of the excited level are from the 1993Hu04 evaluation.

2 Nuclear Data

Q value is from Audi and Wapstra 1995 (1995Au04) evaluation.

The half-life data, in days, are as follows:

291 (1)	1955Ba10	omitted from analysis
290 (6)	1956Ka33	omitted from analysis
278 (5)	1956Sc87	omitted from analysis
313.5 (7)	1961Wy01	
300	1964Be26	omitted from analysis
303 (1)	1964Ma14	omitted from analysis
311.9 (2)	1965An07	
311.9 (2)	1965An07	
312.6 (4)	1965An07	
314	1965Sa09	omitted from analysis
312 (5)	1968Ha47	
312.2 (3)	1968La10	quoted σ of 0.9 divided by 3
312.99 (5)	1968Zi01	quoted σ of 0.10 divided by 2, omitted from analysis
312.2 (9)	1969BoZX	
312.16 (11)	1973MeYE	superseded by 1982RuZV
315.40 (3)	1973Vi13	omitted from analysis
312.6 (8)	1974Cr05	
312.21 (5)	1979MeZY	superseded by 1980RuZY
312.21 (3)	1980RuZY	superseded by 1982RuZV
312.02 (4)	1982HoZJ	superseded by 1992Un01
312.21 (3)	1982RuZV	
312.19 (13)	1982RyZX	
312.15 (23)	1982RyZX	
312.028 (34)	1992Un01	
312.11 (5)	1997Ma75	
312.13 (3)	**Adopted value**	

The three values from before 1960 were omitted because it would have been difficult to determine the presence of impurities in the samples with the spectrometry methods available then. The two values without uncertainties were omitted. The quoted uncertainty for the value of 1968La10 was divided by 3 to convert it to a 1 σ value. The values of 1964Ma14, 1968Zi01, and 1973Vi13 were omitted since they are outliers; with the latter two both included the reduced-χ^2 is 21.7 and with only 1968Zi01 included, it is 7.4.

Adopted value of 312.13 (3) is from the Limitation of Relative Statistical Weight analysis (1985ZiZY, 1992Ra08) of the 13 remaining values. For this fit, the internal uncertainty is 0.020, the reduced-χ^2 =2.06, and the external uncertainty is 0.029. In this analysis, the three values from 1992Un01, 1982RuZV, and 1997Ma75 contribute 94% of the relative weight, and the latter two which are from the same laboratory contribute 60% of the relative weight.

2.1 and 2.2 Electron-Capture and b$^+$ Transitions

The unique 2nd forbidden $\varepsilon+\beta^+$ transition to the ^{54}Cr ground state has not been observed, but an upper limit can be determined from the log *ft* systematics (1998Si17) as well as from searches for the positrons. From these log *ft* systematics, log $f_{2u}t > 13.9$ which corresponds to $\varepsilon+\beta^+$ branch of < 0.0007%. The experimental limits on the β^+ intensity come from searches for the 511 -keV annihilation radiation. These limits are ≤ 8×10^{-5}% (1968Be01), ≤ 4.4×10^{-6}% (1989Su08), and ≤ 5.7×10^{-7}% (1993Da20). From the latter value and the theoretical ε/β^+ ratio of 638(11), one has a capture probability of ≤ 0.0004%. Since this limit is lower than that from the log *ft* systematics, it is adopted.

The P_K etc. values for the branch to the 834keV level from the LOGFT and EC-CAPTURE codes agree quite well, namely

	P_K	P_L	P_M
LOGFT	0.8895	0.0942	0.0163
EC-CAPTURE	0.8895 (17)	0.0950 (15)	0.0150 (16)

The EC-CAPTURE values have been adopted.

2.3 b$^-$ Transitions

This unique 2nd forbidden β^- transition to the ^{54}Fe ground state has not been observed. A limit on its probability can be calculated from the log *ft* systematics (1998Si17) which give $\log f_{2u}t \geq 13.9$ and this corresponds to $I(\beta^-) \leq 0.0005\%$.

From cosmic-ray data and a model of galatic transport of cosmic rays, 1996Du15 deduce the partial half-life for β^- decay to be between 1×10^6 and 2×10^6 years, which corresponds to a β^- branch intensity between 0.00004% and 0.00009%.

2.4 Gamma Transitions and Internal-Conversion Coefficients

The α and α_K are from the analysis of the experimental data in 1985HaZA and, are based only on the data of 1966Ha07. The corresponding theoretical values interpolated from the tables of 1976Ba63 are 0.000252(8) and 0.000224(7) were α has been computed as $\alpha_K + 1.33 \times \alpha_L$.

3, 3.1 and 3.2 Atomic Data

Data are from 1996Sc06.

4.1 Electron Emissions

The data are deduced from the γ-ray probabilities and atomic data in sec. 2.1, 2.2, and 3.

A comparison of these intensities with those from the RADLIST code for this decay scheme is:

	Radlist	EMISSION
L Auger	143.3 (4)	143.0 (6)
K Auger	63.21 (12)	63.3 (5)
K-834	0.0224 (13)	0.0224 (11)
L-834	0.002199	0.00220 (13)

4.2 Photon Emissions

The energy is from the 2000He14 evaluation.

The γ-ray emission probability is computed as $I_{\varepsilon}(834) / [1.0 + \alpha(834)] = 99.9997(3) / 1.000251(11) = 99.9746(11)$. The dominant component in the final uncertainty is from the uncertainty in α.

A comparison of the computed X-ray emission probabilities is:

	RADLST	EMISSION
$K_{\alpha2}$	7.659 (15)	7.66 (13)
$K_{\alpha1}$	15.04 (3)	15.0 (3)
K_{β}	3.056 (6)	3.05 (6)
K	25.76 (3)	25.7 (3)

And, the measured Cr K X ray emission probabilities include:

25.7 (4)	1963Ta19
24.3 (12)	1965Le21
25.14 (17)	1967Ba50
24.90 (53)	1967PeZZ
24.92 (17)	1968Ha47
24.4 (3)	1973KoAA
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which are slightly lower than the calculated values, but generally are within the uncertainties.

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^{55}Fe - Comments on evaluation of decay data
by M. M. Bé and V. Chisté

The initial evaluation was completed in April 1998. This revised evaluation was carried out in 2005, the literature available by December 2005 was taking into account.

1. Decay scheme

An Internal Bremsstrahlung electron capture spectrum was measured by **Isaac *et al.***, the intensity was found to be 3.24 (6) × 10^{-5} relatively to K capture.
The J^{π} value and level energy are from **NDS 64,4** (1991). From other decay modes, the excited level energy has been determined to be 125.949 (10) keV.

2. Nuclear Data

- The Q value is from **Audi and Wapstra** (2003)
- The half-life values taking into account are, in days :

(1)	977.9	2.3	**Lagoutine** 1982 (DSA PC)[a]
(2)	1000.4	1.3	**Houtermans** 1980 (PC)
(3)	1009.0	1.7	**Hoppes** 1982 (PC, Si(Li))
(4)	996.8	6.0	**Morel** 1994 (Planar Ge)
(5)	995.0	3.0	**Karmalitsyn** 1998 (PC)
(6)	1003.5	2.1	**Schötzig** 2000 (Si(Li))
(7)	1005.2	1.4	**Van Ammel** 2006 (DSA PC)

[a] (Method of measurement, PC = Proportional counter, DSA = Defined Solid Angle)

The (1) value is rejected because it is discrepant by Chauvenet's criterion.
With this value deleted, none of the other values has a relative weight greater than 50 %.
The Lweight calculation gives, for the six remaining values, a weighted mean value of 1003.4 d, with an external uncertainty of 1.7, an internal uncertainty of 0.7 and a reduced -χ^2 of 5.4.
This set of value is inconsistent, the three values with lower uncertainties (2, 3 and 7) are not compatible within their uncertainty limits. No trend can be distinguished.
So, the external uncertainty has been expanded so range to include the most precise value of 1000.4 d.

The adopted value is *1003.4 (30) d* or *2.747 (8) a*.

Other references not used in this evaluation due to their discrepancy or their great uncertainty comparing with the set of recent values above :

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2.1. Electron Capture transitions

- The EC transition energies are from Q(EC) = 231.21 (18) and from the individual level energies.
- The transition probabilities are deduced from the total gamma-ray transition probability balances at each level.
- The electron capture coefficients, for this allowed transition, were calculated by using the EC-capture program :

  $P_K = 0.8853$ (16) ; $P_L = 0.0983$ (13) ; $P_M = 0.0157$ (6) ; $P_N = 0.0006$ (2)

  The LOGFT program gives :

  $P_K = 0.885$ (9) ; $P_L = 0.0974$ (10) ; $P_M = 0.0161$ (2) ; $P_{N+} = 0.00106$ (1)

  Measurements were carried out by **Pengra *et al.*** :

  $P_K = 0.881$ (4) ; $P_L = 0.103$ (4) ; $P_{M+} = 0.0161$ (8)

Results from calculations and measurements are in good agreement, nevertheless the measured values are dependent on ω_K (= 0.314) and on the intensity of the Kα X-ray (= 0.89). So, the recommended values are those of the EC-capture program.

- Several measurements or calculations were done to study the double K-shell ionization process. One can quoted **Campbell *et al.***; where the total probability for double vacancies in the K shell was found to be 1.3 (2) 10^{-4}, or **Kitahara *et al.*** where the probability for the ejection of another K electron during the K-capture decay was estimated to be 1.01 (27) 10^{-4}. As these phenomena have very small probabilities, these results are only quoted here as a matter of interest.

2.2. Gamma transitions

A weak gamma transition is deduced from the observation of a 126 keV gamma emission. The energy is derived from the level energy.

3. Atomic Data

Several data for ω_K are deduced from measurements :
- from **Smith**, $\omega_K = 0.320$ (3) ($P_K = 0.885$ (2))
- from **Konstantinov et al.**, $\omega_K = 0.312$ (3)
- from **Dobrilovic et al.**, $\omega_K = 0.322$ (5)
- from **Kuhn et al.**, $\omega_K = 0.310$ (23)
- from **Hubbell et al.**, $\omega_K = 0.321$ (7) (deduced from photoionization cross-section measurements)

A theoretical value was also calculated by **Chen** : $\omega_K = 0.323$.
These values are in good agreement (except **Konstantinov et al.** and **Khun et al.**) with the recommended value of ω_K = *0.321 (5)* from the semi-empirical fit of **Bambynek 1984**.

ϖ_L and η_{KL} are from **Schönfeld *et al.***

3.1.1. X Radiations

- The X-ray energies were obtained by conversion of the wavelength values from **Bearden** into energies with 1 Å = 1.000 014 81 (92) 10^{-10} m.
- The emission intensities are calculated by the EMISSION program from PTB with ω_K , ϖ_L and η_{KL} quoted above and, Kβ/Kα = 0.1359 (14) , Kα_2 / Kα_1 = 0.5099 (25) (**Schönfeld *et al.***).
- With P_K = 0.8853 (16) for this allowed transition, and ω_K = *0.321 (5)* the total K X-ray emission intensity is then $P_K \times \omega_K = 0.284$ (5) which can be compared with the experimental values of 0.279 (8) (**Schötzig**) and of 0.283 (2) (**Smith**).

The value given by **Smith** was obtained in an international activity measurement exercise where six laboratories reported results for $P_K \times \omega_K$. The deduced weighted mean is in good agreement with the calculated value and has a better uncertainty. However, as pointed out by **Smith**, this uncertainty is probably underestimated. So, the value of $I_K = P_K \times \omega_K \times 100$ = 28.4 (5) % is adopted.

3.1.2. Auger Electrons

Complete measurements of the K Auger spectrum of manganese was performed by **Kovalik *et al.***, they found for the relative intensities of the K Auger groups :
KLM/KLL = 0.26 (2)
KMM/KLL = 0.018 (2)
These values are in good agreement with the recommended values calculated with the EMISSION program:
KLM/KLL = 0.272 (3)
KMM/KLL = 0.0185 (4)

The energies were taken from **Larkins** or, for the missing lines, calculated from the electron binding energies. **Kovalik *et al.*** also measured the energies and found a good agreement for the KLM spectrum but observed discrepancies for the KLL and KMM groups.

4.2. Gamma emissions

A weak gamma emission superimposed on the intense inner -bremsstrahlung was observed by **Zlimen *et al.*** and interpreted as the deexcitation of the first excited state of Mn -55. The γ-ray energy is given as 126.0 (1) keV and the γ-ray intensity as 1.3 (1) × 10^{-7} %.
From the level energy 125.949 (10) keV and with a recoil energy of 0.2 eV, the retained γ-ray energy is 125.949 (10) keV.

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Mn-56 – Comments on evaluation of decay data
by A. L. Nichols

Evaluated: November 1999
Re-evaluated: January 2004

Evaluation Procedures

Limitation of Relative Statistical Weight Method (LWM) was applied to average numbers throughout the evaluation. The uncertainty assigned to the average value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

A reasonably simple and consistent decay scheme has been constructed from the gamma-ray measurements of 1967Au01, 1968Sh07, 1973Ar15, 1974Ti01, 1974Ho25 and 2004MiXX. Ten distinct gamma-ray emissions were identified with ^{56}Mn decay in these studies. An additional gamma ray at 3119.3 keV was identified by 1968Sh01, but this emission has been discarded due to a lack of evidence from the other studies.

Nuclear Data

The gamma-ray emissions of ^{56}Mn are reasonably well-defined, and this radionuclide has suitable decay characteristics for use as a calibrant over the gamma-ray energy range 840 to 2550 keV.

Half-life

Half-life adopted from the evaluation of Woods for the IAEA-CRP: Update of X- and Gamma-ray Decay Data Standards for Detector Calibration. The measurements of 1968Sh07, 1971GoYM, 1972Em01, 1973La12, 1980RuZY, 1992An13 and 1994Ya02 were considered.

Reference	Half-life (days)
1968Sh07	0.10771(4)
1971GoYM	0.10742(33)
1972Em01	0.10779(25)
1973La12	0.107438(8)
1980RuZY	0.107350(33)
1992An13	0.107454(4)§
1994Ya02	0.1040(20)*
Evaluated value	0.107449(18)

§ Uncertainty increased to ± 0.000008 to ensure weighting factor not greater than 0.50.
* Method development study: removed from data set due to uncharacteristically large uncertainty.

Woods evaluation for IAEA-CRP (2004WoZZ): recommended half-life of 0.107449(19) days or 2.57878 (46) h (using above data set, but also excluding 1994Ya02 data), adopted for this evaluation.

Gamma Rays

Energies

A number of well-defined gamma-ray energies were adopted from the recommended standards of 2000He14. All other gamma-ray energies were calculated from the structural details of the proposed decay scheme and the nuclear level energies of 1999Hu04 (as derived from the energy measurements of 1973Ar15, 1974Ho25 and 1974Ti01). An additional gamma ray with an energy of 3119.3(5) keV was only detected by 1968Sh01, and has been discarded due to a lack of evidence in all of the other studies.

Emission Probabilities

Weighted mean relative emission probabilities were determined for all of the gamma rays assigned to the decay scheme, using the relevant data from the measurements of 1967Au01, 1968Sh07, 1973Ar15, 1974Ho25, 1974Ti01 and 2004MiXX. All gamma-ray emissions were expressed relative to the 846.7638 keV transition, which was arbitrarily assigned an uncertainty of 3% (100(3)%).

Gamma-ray Emission Probabilities: Relative to P_g(846.7638 keV) of 100%

E_g(keV)	P_g^{rel}						
	1967Au01	1968Sh07	1973Ar15	1974Ho25	1974Ti01	2004MiXX	Recommended Values*
846.7638(19)†	100(3)	100(3)	100(3)	100(3)	100(3)	100.000(103)	100(3)
1037.8333(24)†	-	-	0.06(1)	0.03(1)	0.040(5)	-	0.040(4)§
1238.2736(22)†	-	-	0.14(3)	0.13(1)	0.10(1)	0.097(2)	0.098(2)§
1810.726(4)†	30(3)	29.4(16)	28.6(15)	26.9(13)	27.5(8)	26.610(72)	27.2(4)
2113.092(6)†	17.4(17)	16.0(9)	16.0(8)	14.3(7)	14.5(4)	13.956(53)	14.4(3)§
2523.06(5)‡	1.10(15)	1.6(5)	1.14(5)	1.01(5)	1.00(3)	1.025(9)	1.03(2)
2598.438(4)†	-	-	0.026(5)	0.02(1)	0.019(2)	-	0.020(2)
2657.56(1)‡	0.60(10)	0.66(6)	0.71(4)	0.66(7)	0.66(2)	0.648(8)	0.652(7)§
2959.92(1)‡	0.31(6)	0.26(3)	0.30(2)	0.32(3)	0.31(1)	0.314(6)	0.311(5)§
3119.3(5)#	-	0.08(4)	-	-	-	-	-
3369.84(4)‡	0.22(5)	0.20(4)	0.15(2)	0.16(2)	0.17(1)	-	0.17(1)

† Energy adopted from 2000He14.

‡ Energy calculated from the nuclear level energies specified by 1999Hu04.

\# Energy from 1968Sh07, but transition not included in proposed decay scheme.

* Weighted mean values adopted using LWEIGHT, unless stated.

§ Recommended values adopted from a combination of the normalised residuals and Rajeval methods (see 2004MaYY).

The normalisation factor for the gamma-ray emission probabilities was calculated from the proposed decay scheme via two routes:

(a) beta population of all ^{56}Fe nuclear levels derived from gamma-ray depopulation/population and summed, assuming β decay to ^{56}Fe ground state is zero (spin and parity considerations ($3^+ \rightarrow 0^+$)).

for all nuclear levels populated by β decay $\Sigma P_{\beta i} = (101.163 \pm 1.479) \times NF = 100$

$NF = 0.989 (15)$

(b) population of ^{56}Fe ground state by gamma transitions, assuming β decay to ^{56}Fe ground state is zero.

$\Sigma P_{\gamma i} (1 + \alpha_i)$ NF = [P_γ (3369.84 keV) + P_γ(2959.92 keV) + P_γ(2657.62 keV) + P_γ(846.7638 keV) $(1 + \alpha_i)$] × NF = 100

101.163(23) × NF = 100

NF = 0.9885(3)

Hence, a normalisation factor of 0.9885(3) was adopted on the basis of the more accurate determination.

Multipolarities and Internal Conversion Coefficients

The nuclear level scheme specified by 1999Hu04 has been used to define the multipolarities of the gamma transitions on the basis of known spins and parities. Studies of the internal conversion coefficients of the some of these gamma transitions support the proposed transition types: (97%M1 + 3%E2) for the 1810.726 keV gamma rays (taken from 1989Co01); (99.96%M1 + 0.04%E2) and 100%E2 for the 1037.8333 and 1238.2736 keV gamma rays, respectively (taken from 1974Ho25).

Multipolarity Assignments

Reference	E_g (keV)	Multipolarity
1974Ho25	1037.83	99.96%M1 + 0.04%E2
	1238.27	E2
	1810.726(4)	96.5%M1 + 3.5%E2
	2113.092(6)	93.4%M1 + 6.6%E2
	2523.06(5)	94.1%M1 + 5.9%E2
	2598.438(4)	93.4%M1 + 6.6%E2
1989Co01	1810.726(4)	97%M1 + 3%E2
	2113.092(6)	96%M1 + 4%E2

Beta-particle Emissions

Energies

All beta-particle energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 1999Hu04 and the Q-value were used to determine the energies and uncertainties of the beta-particle transitions to the various levels.

Emission Probabilities

The beta-particle emission probabilities were calculated from the recommended gamma-ray emission probabilities and the theoretical internal conversion coefficients of 1976Ba63 (latter estimated by interpolation of the data). Log *ft* systematics can be applied to the beta-particle transition to the ground state of ^{56}Fe (ΔJ=3, $\Delta\pi$ = no), with a lower limit for log *ft* of 13.9 (1998Si17), to give a beta-particle emission probability of < 0.0005 (set to zero).

Beta-particle Emission Probabilities

E_b(keV)	P_b
	Recommended Values*
250.2(3)	0.00020(2)
325.7(3)	0.0120(3)
572.6(3)	0.00040(4)
735.6(3)	0.145(3)
1037.9(3)	0.275(4)
1610.4(3)	0.00057(6)
2848.7(3)	0.566(7)

* Recommended emission probabilities derived from evaluated gamma-ray emission probabilities and theoretical internal conversion coefficients.

Atomic Data

The x-ray data have been calculated using the evaluated gamma-ray data, and the atomic data from 1996Sc06, 1998ScZM and 1999ScZX.

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^{56}Co - Comments on evaluation of decay data by C.M. Baglin and T. D. MacMahon

This current evaluation was carried out in 2004. The literature available by September 2004 was included.

Evaluation Procedures

The *Limitation of Relative Statistical Weight* (LWM) [1985ZiZY] method, used almost exclusively for averaging numbers throughout this evaluation, provided a uniform approach for the analysis of discrepant data. In the few instances when an alternative technique was used, this fact has been noted.The uncertainty assigned in this evaluation to the recommended value is always greater than or equal to the smallest uncertainty in any of the experimental values used in the calculation.

1 Decay Scheme

^{56}Co decays 19.58 (11) % by positron (β^+) emission and 80.42 (11) % by electron capture (ε) to ^{56}Fe (Q(ε) = 4566.0 (20) keV (2003Au03)). Altogether, 46 γ rays de-exciting 15 nuclear levels in ^{56}Fe have been reported. Except for the strong 847 -keV transition, emission of conversion electrons is very low and negligible compared to that of γ rays (photons) because of the low atomic number (Z=26) of the daughter nucleus (^{56}Fe) and the high energy (> 700 keV) of the most intense γ-ray transitions. Consequently, neither conversion coefficients (most of them $< 2 \times 10^{-4}$) nor conversion electron energies and intensities have been tabulated in this evaluation. Pair production is also possible for transitions with $E_\gamma \geq 1022$ keV, but the internal-pair-formation coefficients (based on 1979Sc31) do not exceed 10^{-3} and are tabulated only for those transitions for which the coefficients exceed 4 x 10^{-4} or for which their omission would affect the deduced branching.

The evaluator has normalized the decay scheme assuming zero $\varepsilon+\beta^+$ feeding from the 4^+ ^{56}Co parent to the 0^+ ^{56}Fe ground state. Then Σ(I(γ+ce) to ground state) = 100%. Based on the decay scheme, only the 847γ, 2657γ and 3370γ feed the ground state. The 847 keV transition conversion coefficient is taken as $3.03(9) \times 10^{-4}$ (from Band *et al.*, 1976Ba63, assuming $\alpha = \alpha_K + 1.33\ \alpha_L$ and a 3% uncertainty). The normalization factor N is then given by:

$$N = 100 / [I(847\gamma)\ (1+\alpha(847\gamma)) + I(2657\gamma) + I(3370\gamma)]$$

Where: I(847γ), I(2657γ) , I(3370γ) are the relative values given in Table 2

$$= 100 / [100.0303\ (9) + 0.0195\ (20) + 0.0103\ (8)]$$

$$= 100 / [100.0601\ (23)]$$

$$= 0.999399\ (23)$$

With this normalization, the probability of the 847 keV transition is : P(847)(γ+ce) = 99.9702(23)%.

Electron-capture and β^+ transition probabilities to excited states in ^{56}Fe were determined from γ-ray transition intensity balance at each level and theoretical ε/β^+ ratios. It should be noted that the 2$^{\text{nd}}$-forbidden transitions to the 2690 and 3370 levels, though weak, are probably overestimated since log *ft* values for these branches are significantly lower than expected from log *ft* systematics.

The evaluator has included level half -life data from the evaluation by Huo (1999Hu04) in the decay scheme drawing given here. The level energies shown in the drawing result from a least-squares adjustment of the γ-ray energies recommended in this evaluation.

2 Nuclear Data

The recommended value for the half-life of ^{56}Co is 77.236 (26) days, taken from the evaluation by Woods *et al.* (2004WoAA). This supersedes an earlier evaluation by two of these authors (2004Wo02) in which 77.20 (8) days ($\chi^2/\nu = 0.9$) was recommended. Measured values and their respective sources are:

Half-life (days)	Reference	Comments
77.2 (8)	1954Bu58	
77.3 (3)	1957Wr37	
78.76 (12)	1972Em01	statistical outlier
78.4 (5)	1974Cr05	statistical outlier
77.12 (10)	1977An13	
77.12 (7)	1978La21	
77.30 (9)	1989Al24	
77.08 (8)	1989Le17	
77.28 (4)	1989Sc17	
77.29 (3)	1990Al29	
77.210 (28)	1992Fu02	
77.29 (4)	1992Fu02	

The weighted average of all data published from 1977 onwards is 77.245 (23) days ($\chi^2/\nu = 2.2$), where the uncertainty shown is the external uncertainty (the internal uncertainty is 0.015 days).

$Q(\varepsilon) = 4566.0$ (20) keV is adopted from 2003Au03.

2.1 b+ Transitions

The positron end-point energies, calculated from $E_{\beta^+} = Q(\varepsilon) - E(\text{lev}) - 1022$, are the evaluator's values deduced using $Q(\varepsilon) = 4566.0$ (20) keV (2003Au03) and level energies (E(lev)) from the decay scheme. Absolute β^+ emission probabilities are from γ-ray intensity balance at each nuclear level and theoretical $I_{\beta i}^{+}/\varepsilon_i$ ratios. Note that the latter may not be reliable for the 2nd-forbidden branches.

2.2 Electron Capture Transitions

ε-transition energies, calculated from $E(\varepsilon) = Q(\varepsilon) - E(\text{lev})$, are evaluator's values deduced using $Q(\varepsilon) = 4566.0$ (20) keV (2003Au03) and level energies (E(lev)) from the decay scheme. Absolute ε transition probabilities are from γ-ray intensity balance at each nuclear level and theoretical $I_{\beta i}^{+}/\varepsilon_i$ ratios. These sum to 80.42(11)%, implying $I(\beta^+)$=19.58(11)%. Fractional atomic shell electron-capture probabilities (P_K, P_L, P_M) are evaluator's values calculated using the EC-CAPTURE computer program [2] for the relevant nuclear level energies.

3 Atomic Data

Emission probabilities are evaluator's values calculated using the EMISSION program (Version 3.04) [3], atomic data from 1996Sc06, and the γ-ray emission probabilities recommended here. The K X-ray and K-Auger electron energies are taken from Schönfeld and Rodloff [5] and [4], respectively; L X-ray and L-Auger electron energies are from Larkins [6].

4 Photon Emissions

4.1 Energies

γ-ray energies shown in boldface in Table 1 are from 2000He14. These values are based on a revised energy scale that uses the new adjusted fundamental constants and wave lengths deduced from an updated value of the lattice spacing of Si crystals [Cohen and Taylor [1]]. Helmer *et al.* (2000He14) fitted the adjusted γ-ray energy measurements for ^{56}Co to a level scheme, and deduced recommended γ-ray energy values from level-energy differences. Less precise energies are from 1990Me15, 1989Al25 (one transition only) and 1980St20. The latter authors adopted energies from the literature for the strongest transitions (shown in square brackets in Table 1) and made the general statement that the uncertainties in the other transition energies range from 0.05 keV to 0.8 keV; the evaluator has, therefore, assigned uncertainties of 0.8 keV to the four energies adopted from this study. The uncertainties in the γ-ray energies given in this evaluation are statistical only, as reported by authors. See Table 1.

4.2 Emission Probabilities

a. Relative intensities

Relative emission probability measurements are given in Table 2, panels a); panels b) show the results fo several different analyses of those data along with the intensities recommended in the present evaluation. In cases where the authors indicated an uncertainty in the relative intensity of the 847-keV reference line, that uncertainty was combined in quadrature with the statistical uncertainty for each of the other transitions prior to all analyses of the data.

The analysis of these data is complicated on account of two factors:

(i) Discrepant data sets. Of the approximately 770 data points, successive runs of the program LWEIGHT identify a total of 87 statistical outliers based on the Chauvenet criterion; this seems an unusually large fraction. Most outliers, though by no means all, arise from the earlier measurements.

(ii) The use by some authors of Ge detector efficiency calibration curves which are inadequate at the highest energies. This problem was first identified by McCallum and Coote (1975Mc07) and is discussed further by Baglin *et al.* in 2002Ba38.

One prescription for dealing with discrepant data is the limitation of relative statistical weight method proposed by Zijp (1985ZiZY) and incorporated in the program LWEIGHT. The program identifies a set of data as ‘discrepant’ whenever its reduced chi-squared value exceeds the critical reduced chi-squared value for the relevant number of data points. For those cases, it then increases the uncertainty for any datum whose statistical weight exceeds 50% until it no longer does so, then recalculates the weighted mean. If the weighted mean overlaps the unweighted mean, the weighted mean will be adopted. The uncertainty used is usually the internal uncertainty; however, the uncertainty will be expanded to include the most precise datum, if necessary, and the external uncertainty will be used if the internal uncertainty is less than the uncertainty in the most precise datum. Otherwise, the unweighted mean will be adopted; this does not seem to be a particularly useful number since it could so easily be skewed by the least reliable data.

Two additional techniques that might reasonably be applied to the analysis of these data are the Normalised Residuals (1991JaXX) and the Rajeval (1992Ra08) techniques. Both are iterative techniques which increase the uncertainties of any deviant data, but they use different prescriptions for identifying and adjusting the deviant data. The results of these analyses are also shown in Table 2.

Another logical approach would be to use the results from LWEIGHT after all statistical outliers have been eliminated from the dataset. Table 2 also gives the results from this analysis.

The second problem could be approached by considering data from only the eight experiments (2002MoZP, 2000Ra36, 1990Me15, 1980St20, 1978Ha53, 1977Ge12, 1974BoXX and 1971Si29) in which the detector efficiency has been *measured* (not extrapolated) up to at least the highest ^{56}Co transition energy (3611 keV). (Details of the efficiency calibrations for many measurements are sketchy at best, and some rely partially or totally on Monte Carlo calculations.) However, this approach greatly decreases the number of data points, so one should resort to this measure only at energies where significant problems are anticipated. The high precision data from 1971Ca14, based on a linear extrapolation to high energy of a log(efficiency) *versus* log(energy) plot, have received considerable scrutiny in the literature, and 2002Ba38 deduced a multiplicative correction factor ($F = 1.116 - 0.155\ E_\gamma + 0.0397 E_\gamma^2$, where E_γ is in MeV) to correct ^{66}Ga intensity data in 1971Ca14; this formula implies intensity correction factors of 0.98, 1.01 and 1.06, respectively, at $E_\gamma = 2.5$, 3.0 and 3.5 MeV. These factors apply equally to the ^{56}Co data from 1971Ca14 and to those from 1970Ph01 and 1974Ho25, all tied to the intensity scale in 1971Ca14. This situation suggests that data from only the eight selected references should be considered for $E_\gamma > 3000$ keV. However, although used only for $E_\gamma > 3000$ keV, the analysis of data from the selected references is shown in Table 2 for transitions of all energies, for the sake of completeness.

b. Absolute Intensities

Absolute emission probabilities are based on experimental results and decay -scheme normalization arguments as follows:

- $I_{ce}(847\gamma, E2)/I_\gamma(847\gamma) = 3.03\ (9) \times 10^{-4}$ (Theory (Band *et al.*, 1976Ba63), assuming $\alpha = \alpha_K + 1.33\ \alpha_L$ and 3% uncertainty).
- No $\varepsilon+\beta^+$ branch to ground state, so $\Sigma(I(\gamma+ce)$ to ground state) = 100%.

The recommended absolute γ-ray emission probabilities are the relative values recommended in Table 2 multiplied by 0.999399 (23).

c. Annihilation radiation intensity

The 511-keV γ-ray intensity has not been experimentally determined but may be estimated from:

$$I(\gamma^\pm) = 2 \times [100 - I(\varepsilon) + I(\text{pair production})]$$
$$= 2 \times [19.58\ (11) + 0.024]$$
$$= 39.21(22)\ \%$$

4.3 Transition Multipolarities and Mixing Ratios

The transition multipolarities and mixing ratios have been taken directly from the evaluation by Huo (1999Hu04). Several additional transition multipolarities, deduced from the decay scheme, are shown enclosed by square brackets.

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Table 1. ^{56}Co Gamma-Ray Energies

2000He14	1990Me15	1989Al25	1980St20	Adopted
E_g (keV)	E_g (keV)	E_g (keV)	E_g (keV)[a]	E_g (keV)
	263.41 (10)		263.34	263.41 (10)
	411.38 (8)		410.94	411.38 (8)
	486.54 (11)		485.2	486.54 (11)
			655.0 (8)[a]	655.0 (8)
			674.7 (8)[a]	674.7 (8)
733.5085 (23)	733.72 (15)		733.6	**733.5085 (23)**
787.7391 (23)	787.88 (7)		787.77	**787.7391 (23)**
846.7638 (19)	846.772 (8)		[846.764]	**846.7638 (19)**
		852.78 (5)		852.78 (5)
896.503 (7)	896.56 (20)		896.55	**896.503 (7)**
977.363 (4)	977.485 (60)		977.39	**977.363 (4)**
996.939 (5)	997.33 (16)		996.48	**996.939 (5)**
1037.8333 (24)	1037.840 (6)		[1037.844]	**1037.8333 (24)**
	1089.03 (24)		1089.31	1089.03 (24)
1140.356 (7)	1140.28 (10)		1140.52	**1140.356 (7)**
1159.933 (8)	1160.08 (16)		1160.0	**1159.933 (8)**
1175.0878 (22)	1175.102 (6)		[1175.099]	**1175.0878 (22)**
	1198.78 (20)		1198.77	1198.78 (20)
1238.2736(22)	1238.282 (7)		[1238.287]	**1238.2736(22)**
	1272.2 (6)		1272.20	1272.2 (6)
1335.380 (29)	1335.56 (8)		1335.56	**1335.380 (29)**
1360.196 (4)	1360.215 (12)		[1360.206]	**1360.196 (4)**
	1442.75 (8)		1442.65	1442.75 (8)
	1462.34 (12)		1462.28	1462.34 (12)
1640.450 (5)	1640.54 (13)		1640.38	**1640.450 (5)**
1771.327 (3)	1771.351 (16)		[1771.350]	**1771.327 (3)**
1810.726 (4)	1810.714 (35)		[1810.722]	**1810.726 (4)**
1963.703 (11)	1963.99 (6)		[1963.714]	**1963.703 (11)**
2015.176 (5)	2015.181 (16)		[2015.179]	**2015.176 (5)**
2034.752 (5)	2034.755 (15)		[2034.159]	**2034.752 (5)**
2113.092 (6)	2113.185 (115)		[2113.107]	**2113.092 (6)**
2212.898 (3)	2212.96 (15)		[2212.921]	**2212.898 (3)**
	2276.36 (16)		2276.09	2276.36 (16)
	2373.7 (4)		2373.71	2373.7 (4)
	2523.86 (20)		2523.0	2523.0 (8)[b]
2598.438 (4)	2598.458 (13)		[2598.460]	**2598.438 (4)**
			2657.4 (8)[a]	2657.4 (8)
3009.559 (4)	3009.591 (22)		[3009.596]	**3009.559 (4)**
3201.930 (11)	3201.962 (16)		[3201.954]	**3201.930 (11)**
3253.402 (5)	3253.416 (15)		[3253.417]	**3253.402 (5)**
3272.978 (6)	3272.990 (15)		[3272.998]	**3272.978 (6)**
	3369.69 (30)		3369.97	3369.69 (30)
3451.119 (4)	3451.152 (17)		[3451.154]	**3451.119 (4)**
	3547.93 (6)		3548.27	3547.93 (6)
	3600.49 (40)		3600.85	3600.7 (4)
			3611.8 (8)[a]	3611.8 (8)

[a] Authors took energies for the strongest lines from the literature (shown in square brackets) and stated that uncertainties varied from 0.05 to 0.8 keV for the others. The evaluator has conservatively assigned 0.8 keV to those lines whose energies are adopted in the present evaluation from this reference.

[b] The datum from 1980St20 is adopted in preference to the more precise datum from 1990Me15 because the latter value fits its level-scheme placement poorly and is almost 1 keV higher than the γ-ray energy of 2522.88 (6) adopted in an evaluation (1999Hu04) which included information from sources other than ^{56}Co ε decay.

Table 2: ^{56}Co Relative Gamma-Ray Emission Probabilities[@], a) Experimental Data

Ref./Eg	**263.4**g	**411.4**g	**486.5**g	**655.0**g	**674.7**g	**733.5**g	**787.7**g	**846.8**g	**852.8**g	**896.5**g
65Pe18							1.04* (21)	100		
66Do07								100		
66Hu17								100		
66Sc01								100		
67Au01						0.10* (5)	0.4 (2)	100		
67Ba75								100		
68Sh07						0.13 (6)	0.2 (1)	100		
67Ch20							0.36 (5) (8)	100 (15) (0)		
69Ar04								100		
69Au09								100		
69Sc09							0.37 (4)	100		0.14* (4)
70Ph01	0.03 (1)		0.066 (6)			0.21 (4)	0.31 (6)	100		0.06 (1)
71Ca14	0.021 (4)	0.025 (5)	0.041 (7)			0.193 (3)	0.308 (8)	100		0.071 (4)
71Ge07								100		
71Ge08	0.05* (1)	0.024 (7)	0.050 (12)		0.03 (1)	0.18 (3)	0.28 (4)	100	0.04 (1)	0.08 (2)
71Si29[S]							0.21 (6)	100		
72Pe20[d]								100.0 (60) (0) 100.0 (56) (0) 100.0 (57) (0)		
74BoXX[S]								100		
74Ho25	0.020 (6)	0.025 (9)	0.07 (2)		0.03 (1)	0.165 (8)	0.29 (3)	100		0.062 (6)
75Ka06						0.219 (7)	0.311 (12)	100		0.089 (11)
77Ge12[S]								100 (1) (0)		
78Ha53[S]						0.143 (13)	0.34 (3)	100		0.077 (10)
80St20[S]	0.022 (4)	0.031* (4)	0.069 (7)	0.038 (8)	0.038 (7)	0.195 (14)	0.320 (7)	100		0.063 (6)
80Sh28	0.031[c] (9)	0.026 (8)	0.065 (11)		0.045 (20)	0.166 (12)	0.28 (1)	100		0.089 (13)
80Yo05			0.061 (10) (10)			0.193 (12) (12)	0.305 (13) (13)	100.0 (3) (0)		0.095 (18) (18)
82Gr10								100		
89Al25								100	0.050 (3)	
90Me15[S]	0.022 (4)	0.025 (5)	0.055 (5)			0.20 (1)	0.31 (1)	100		0.070 (5)
92ScZZ						0.190 (7) (7)	0.315 (10) (10)	100.00 (26) (0)		0.086 (20) (20)
00Ra36[S]								100		
02MoZP[S]								100.0 (2) (0)		

Table 2: ^{56}Co Relative Gamma-Ray Emission Probabilities[@]
b) Analysis

Eg	**263.4**g	**411.4**g	**486.5**g	**655.0**g	**674.7**g	**733.5**g	**787.7**g	**846.8**g	**852.8**g	**896.5**g
All Data										
# data points, N	7	6	8	1	4	13	17	33	2	12
χ^2/(N-1)	1.5	0.31	1.7	N/A	0.31	4.2[b]	2.0[b]	N/A	0.92	1.4
Iγ; UWM	0.028 (4)	0.0260 (10)	0.060 (4)	-	0.036 (4)	0.176 (9)	0.350 (45)	100	0.045 (5)	0.082 (6)
Iγ; WM	0.0234 (20)	0.0269 (23)	0.0583 (27)	-	0.035 (5)	0.1909 (22)	0.309 (3)	100	0.049 (3)	0.0704 (22)
Iγ; LWM	= WM	= WM	= WM	-	= WM	0.176 (17)[X]	0.309 (11)[X]	100	= WM	= WM
Iγ; Norm Res	0.0234 (20)	0.0269 (23)	0.0583 (27)	-	0.035 (5)	0.1905 (37)	0.310 (4)	100	0.049 (3)	0.0704 (22)
Iγ; Rajeval	0.0227 (20)	0.0269 (23)	0.0602 (29)	-	0.035 (5)	0.1914 (24)	0.311 (4)	100		0.0704 (22)
Statistical Outliers Excluded			N/A	N/A	N/A				N/A	
# data points, N	6	5	-	-	-	12	16	33	-	11
χ^2/(N-1)	0.36	0.01	-	-	-	4.3[b]	1.4	N/A	-	1.3
UWM	0.0243 (20)	0.0250 (3)	-	-	-	0.182 (8)	0.307 (13)	100	-	0.077 (4)
WM	0.0223 (21)	0.0250 (28)	-	-	-	0.1911 (22)	0.309 (3)	100	-	0.0701 (22)
LWM	= WM	= WM	-	-	-	0.1909 (48)[e]	= WM	100	-	= WM
Selected Data										
# data points, N	2	2	2	1	2	3	4		0	3
χ^2/(N-1)	0	0.88	2.7	N/A	0.43	6.6[b]	1.5	N/A	N/A	0.83
Iγ; UWM	0.022 (0)	0.028 (3)	0.062 (7)	-	0.034 (4)	0.179 (18)	0.295 (29)	100	-	0.070 (4)
Iγ; WM	0.022 (3)	0.029 (3)	0.060 (4)	-	0.035 (6)	0.183 (7)	0.317 (6)	100	-	0.068 (4)
Iγ; LWM	= WM	= WM	= WM	-	= WM	0.183 (18)[e]	= WM	100	-	= WM
Iγ; Norm Res										
Iγ; Rajeval										
Adopted Ig	0.0234 (20)	0.0269 (23)	0.058 (3)	0.038[a] (8)	0.035 (5)	0.191 (4)	0.310 (4)	100	0.049 (3)	0.0704 (22)
Source	All; WM	All; WM	All; WM	1980St220	All; WM	All; NR	All; NR	N/A	All; WM	All; WM

Table 2: ^{56}Co Relative Gamma-Ray Emission Probabilities (continued)[@], a) Experimental Data

Ref./Eg	977.4g	996.9g	1037.8g	1089.0g	1140.4g	1159.9g	1175.1g	1198.8g	1238.3g	1272.2g
65Pe18	1.73* (35)		14.1 (15)				2.1 (6)		66.8 (40)	
66Do07			12.4 (5)						71.2 (26)	
66Hu17			14.5 (15)				2.8* (5)		70.5 (70)	
66Sc01			14.0 (20)				1.4* (2)		66.3 (60)	
67Au01	1.36 (36)		12.8 (9)				2.4 (2)		69.5 (35)	
67Ba75	1.62* (10)		13.7 (8)				2.03* (14)		72.1 (50)	
68Sh07	1.01* (30)		12.1* (8)				2.2 (1)		70.2 (25)	
67Ch20	1.50* (23) (32)		14.0 (21) (30)		0.170 (26) (36)		1.60* (24) (34)		64 (10) (14)	
69Ar04	1.1 (1)		9.6*[f] (6)				1.9* (2)		69.6 (35)	
69Au09			13.08 (35)				1.73* (13)		68.3 (14)	
69Sc09					0.17 (3)					
70Ph01	1.35 (5)		14.0 (7)		0.24* (4)	0.11 (2)	2.25 (5)		68.5 (12)	
71Ca14	1.448 (14)	0.112 (6)	14.24 (14)	0.048 (9)	0.142 (9)	0.100 (9)	2.300 (25)	0.050 (7)	67.64 (68)	0.019 (1)
71Ge07			12.9 (5)				2.26 (23)		67.8 (15)	
71Ge08	1.42 (14)	0.13 (3)	14.4 (9)	0.04 (1)	0.16 (3)	0.11 (2)	2.29 (22)	0.06 (2)	69.6 (35)	0.024 (7)
71Si29[S]	1.21* (6)		12.44 (31)				2.11 (5)			
72Pe20[d]			13.45 (190) (206) 13.03 (172) (187) 12.72 (153) (169)				1.99* (27) (30) 2.18 (34) (36) 1.93* (25) (27)		70.9 (77) (88) 68.2 (72) (81) 66.9 (75) (84)	
74BoXX[S]			13.7 (6)				2.3 (1)		66.2 (10)	
74Ho25	1.37 (4)	0.17 (5)		0.07 (2)	0.13 (2)	0.078 (7)	2.25 (11)	0.028 (9)		0.022 (3)
75Ka06	1.386 (15)		13.922 (116)		0.107 (3)	0.095 (6)	2.180 (24)		66.37 (74)	
77Ge12[S]	1.426 (15) (21)		14.04 (14) (20)				2.28 (2) (3)		66.4 (7) (10)	
78Ha53[S]	1.38 (4)	0.170 (14)	13.5 (2)	0.06 (2)	0.117 (13)	0.08 (1)	2.11 (10)	0.044 (8)	65.1 (4)	0.035* (4)
80St20[S]	1.41 (2)	0.092 (14)	14.11 (19)	0.050 (7)	0.125 (6)	0.074 (8)	2.30 (32)	0.04 (1)	68.47 (87)	0.038* (6)
80Sh28	1.38 (3)	0.11 (1)	14.06 (28)	0.075 (9)	0.11 (1)	0.079 (9)	2.22 (5)	0.035 (10)	67.59 (131)	0.022 (8)
80Yo05	1.435 (16) (16)	0.129 (14) (14)	14.16 (5) (7)	0.05 (3) (3)	0.131 (21) (21)	0.095 (14) (14)	2.241 (12) (14)	0.051 (9) (9)	66.06 (21) (29)	0.025 (8) (8)
82Gr10			13.85 (35)						65.8 (16)	
89Al25										
90Me15[S]	1.440 (15)	0.112 (6)	14.0 (1)	0.05 (1)	0.15 (1)	0.10 (1)	2.28 (2)	0.05 (1)	67.6 (4)	0.020 (2)
92ScZZ	1.450 (15) (15)		14.18 (13) (13)		0.137 (5) (5)		2.289 (21) (21)		66.96 (60) (60)	0.024 (10) (10)
00Ra36[S]			14.11 (22)				2.25 (4)		66.6 (10)	
02MoZP[S]	1.424 (6) (7)		14.07 (4) (5)				2.252 (9) (10)		66.20 (11) (17)	

Table 2: ^{56}Co Relative Gamma-Ray Emission Probabilities (continued)[@]
b) Analysis

Eg	**977.4**g	**996.9**g	**1037.8**g	**1089.0**g	**1140.4**g	**1159.9**g	**1175.1**g	**1198.8**g	**1238.3**g	**1272.2**g
All Data:										
# data points, N	20	8	30	8	13	10	29	8	29	9
χ^2/(N-1)	2.7[b]	3.0[b]	4.5[b]	1.3	5.3[b]	1.6	2.8[b]	0.92	1.8[b]	3.1[b]
Iγ; UWM	1.39 (3)	0.128 (10)	13.51 (18)	0.055 (4)	0.145 (10)	0.092 (4)	2.15 (5)	0.045 (4)	67.84 (36)	0.0254 (22)
Iγ; WM	1.423 (4)	0.116 (3)	14.018 (31)	0.054 (4)	0.1204 (21)	0.088 (3)	2.249 (6)	0.044 (3)	66.42 (12)	0.0206 (8)
Iγ; LWM	1.423 (7)[e]	0.116 (6)[e]	13.51 (56)[X]	= WM	0.145 (38)[X]	= WM	2.15 (10)[X]	= WM	67.8 (16)[X]	0.025 (6)[X]
Iγ; Norm Res	1.423 (7)	0.114 (4)	14.04 (5)	0.054 (4)	0.131 (4)	0.088 (3)	2.250 (9)	0.044 (3)	66.45 (16)	0.0205 (9)
Iγ; Rajeval	1.425 (5)	0.113 (4)	14.055 (31)	0.051 (4)	0.133 (3)	0.088 (3)	2.254 (6)	0.044 (3)	66.44 (12)	0.0199 (8)
Statistical Outliers Excluded:		N/A		N/A		N/A		N/A	N/A	
# data points, N	14	-	28	-	11	-	21	-	-	7
χ^2/(N-1)	1.7	-	2.6[b]	-	4.0[b]	-	1.6	-	-	0.36
UWM	1.406 (9)	-	13.70 (11)	-	0.137 (7)	-	2.240 (16)	-	-	0.0223 (8)
WM	1.424 (4)	-	14.03 (3)	-	0.1164 (23)	-	2.252 (6)	-	-	0.0196 (8)
LWM	= WM	-	13.70 (37)[X]	-	0.137 (30)[X]	-	= WM	-	-	= WM
Selected Data:										
# data points, N	6	3	8	3	3	3	8	3	7	3
χ^2/(N-1)	3.1[b]	9.1[b]	4.9[b]	0.12	2.8	2.1	1.9	0.25	4.4[b]	8.5[b]
Iγ; UWM	1.382 (35)	0.125 (23)	13.75 (20)	0.053 (3)	0.131 (10)	0.085 (8)	2.24 (3)	0.045 (3)	66.65 (41)	0.031 (6)
Iγ; WM	1.422 (6)	0.117 (5)	14.01 ((4)	0.0508 (55)	0.130 (5)	0.083 (5)	2.254 (8)	0.045 (5)	66.31 (14)	0.0242 (17)
Iγ; LWM	1.422 (12)[e]	0.122 (21)[e]	13.98 (11)[e]	= WM	= WM	= WM	= WM	= WM	66.36 (36)[e]	0.028 (8)[X]
Iγ; Norm Res										
Iγ; Rajeval										
Adopted Ig	1.423 (7)	0.116 (6)	14.04 (5)	0.054 (4)	0.132 (4)	0.088 (3)	2.250 (9)	0.044 (3)	66.45 (16)	0.0202 (8)
Source	All; LWM	All; LWM	All; NR	All; WM	All; NR-Raj	All; WM	All; NR	All; WM	All; NR	All; NR-Raj

Table 2: ^{56}Co Relative Gamma-Ray Emission Probabilities (continued)$^{@}$, Experimental Data

Ref./Eg	1335.4g	1360.2g	1442.8g	1462.3g	1640.5g	1771.3g	1810.7g	1963.7g	2015.2g	2034.8g
65Pe18		4.0 (8)				16.2 (14)		0.75 (27)	4.1* (12)	9.2* (17)
66Do07		3.8 (3)				15.6 (13)			3.8* (7)	7.8 (10)
66Hu17		4.5 (7)				12.5* (13)	0.70* (14)	0.80 (15)	3.7* (6)	8.3 (15)
66Sc01		3.8 (4)				13.5* (14)		1.10* (15)	3.5* (4)	6.5* (8)
67Au01		4.5 (3)				16.1 (8)	0.4* (2)	0.59 (9)	2.7 (2)	7.4 (6)
67Ba75		4.8* (3)				16.9 (10)	1.3* (6)	1.1* (2)	2.93 (30)	7.37 (50)
68Sh07		4.2 (4)				16.7 (10)	0.5* (3)	0.63 (20)	2.9 (4)	7.7 (5)
67Ch20		4.0 (6) (8)				14.0* (21) (30)		0.68 (10) (14)	2.6 (4) (6)	6.6* (10) (14)
69Ar04		4.6 (3)				16.2 (10)		0.9* (2)	3.9* (3)	8.2 (5)
69Au09		4.15 (12)				14.95 (40)			2.78 (14)	7.56 (21)
69Sc09	0.12 (2)		0.23* (3)	0.12* (3)			0.65 (6)	0.63 (5)		
70Ph01	0.15* (2)	4.37 (13)	0.20 (2)	0.08 (2)	0.05 (2)	16.0 (5)	0.62 (6)	0.74 (3)	3.13 (10)	8.1 (2)
71Ca14	0.123 (3)	4.340 (45)	0.200 (8)	0.077 (1)	0.065 (9)	15.78 (16)	0.641 (8)	0.721 (15)	3.095 (31)	7.95 (8)
71Ge07		4.16 (21)				16.5 (8)			2.99 (20)	8.2 (6)
71Ge08	0.11* (2)	3.96 (40)	0.14* (2)	<0.02	0.07 (1)	14.9 (9)	0.55* (6)	0.67 (7)	2.83 (30)	7.7 (6)
71Si29^{S}		4.42 (8)					0.47* (6)	0.58 (5)	2.60 (12)	7.0* (3)
72Pe20^{d}		4.08 (51) (57) 4.4 (6) (6) 5.30* (78) (84)				15.36 (174) (197) 15.98 (180) (201) 14.55 (166) (186)			2.88 (42) (45) 2.28* (27) (30) 2.59 (45) (47)	6.25* (88) (96) 6.8* (8) (9) 6.85* (80) (89)
74BoXX^{S}		4.4 (1)				15.9 (3)			3.1 (1)	7.8 (1)
74Ho25	0.120 (12)	4.35 (12)	0.177 (9)	0.065 (12)	0.063 (6)		0.63 (3)	0.71 (3)		
75Ka06	0.120 (3)	4.189 (52)	0.172 (4)	0.078 (3)	0.062 (3)	15.369 (241)	0.665 (23)	0.667 (21)	3.025 (72)	7.694 (146)
77Ge12^{S}		4.24 (4) (6)				15.65 (16) (22)	0.650 (7) (10)	0.724 (8) (11)	3.09 (5) (6)	7.95 (12) (14)
78Ha53^{S}	0.12 (2)	4.24 (15)	0.195 (10)		0.05 (1)	15.26 (15)	0.59* (3)	0.70 (2)	2.97 (3)	7.64 (6)
80St20^{S}	0.128 (6)	4.32 (6)	0.173 (7)	0.091 (13)	0.062 (7)	15.5 (4)	0.629 (13)	0.719 (15)	3.182 (66)	8.14 (17)
80Sh28	0.124 (10)	4.29 (8)	0.182 (11)	0.086 (3)	0.055 (9)	15.61 (30)	0.62 (2)	0.71 (2)	2.95 (6)	7.74 (2)
80Yo05	0.130 (6) (6)	4.265 (17) (21)	0.172 (7) (7)	0.084 (6) (6)	0.070 (11) (11)	15.49 (5) (7)	0.657 (23) (23)	0.707 (11) (11)	3.026 (14) (17)	7.766 (28) (36)
82Gr10		4.27 (15)				15.11 (38)			2.97 (11)	7.60 (19)
89Al25										
90Me15^{S}	0.125 (5)	4.33 (4)	0.20 (1)	0.077 (5)	0.06 (1)	15.70 (15)	0.64 (1)	0.720 (15)	3.08 (3)	7.89 (7)
92ScZZ	0.118 (6) (6)	4.29 (4) (4)	0.185 (7) (7)	0.065 (8) (8)	0.072 (12) (12)	15.48 (14) (15)	0.638 (8) (8)	0.724 (10) (10)	3.04 (5)(5)	7.90 (13) (13)
00Ra36^{S}		4.23 (7)				15.42 (25)			3.03 (5)	7.835 (120)
02MoZP^{S}		4.22 (15) (15)				15.24 (8) (9)	0.641 (5) (5)	0.698 (3) (3)	2.976 (14) (15)	7.69 (3) (3)

Table 2: ^{56}Co Relative Gamma-Ray Emission Probabilities (continued)$^{@}$

a) Analysis

Eg	**1335.4**g	**1360.2**g	**1442.8**g	**1462.3**g	**1640.5**g	**1771.3**g	**1810.7**g	**1963.7**g	**2015.2**g	**2034.8**g
All Data										
# data points, N	12	31	12	10	11	29	19	23	30	30
χ^2/(N-1)	0.57	0.90	2.5^{b}	1.8	0.44	1.3	1.2	1.9^{b}	2.5^{b}	1.7
Iγ; UWM	0.124 (3)	4.29 (5)	0.186 (6)	0.082 (5)	0.0617 (23)	15.43 (17)	0.64 (4)	0.738 (27)	3.06 (7)	7.64 (11)
Iγ; WM	0.1229 (16)	4.283 (13)	0.1797 (23)	0.0779 (9)	0.0621 (21)	15.46 (4)	0.639 (3)	0.7030 (25)	3.015 (9)	7.746 (13)
Iγ; LWM	= WM	= WM	0.180 (8)^{X}	= WM	= WM	= WM	= WM	0.7060 (42)^{e}	3.015 (39)^{X}	=WM
Iγ; Norm Res	0.1229 (16)	4.283 (13)	0.1797 (36)	0.0779 (9)	0.0621 (21)	15.46 (4)	0.639 (3)	0.7038 (37)	3.019 (14)	7.746 (18)
Iγ; Rajeval	0.1229 (16)	4.283 (13)	0.1792 (25)	0.0774 (9)	0.0621 (21)	15.49 (4)	0.640 (3)	0.7094 (37)	3.025 (10)	7.744 (14)
Statistical Outliers Excluded					N/A					
# data points, N	10	29	10	9	-	26	12	20	24	23
χ^2/(N-1)	0.45	0.80	2.3	1.7	-	1.2	0.43	1.6	2.3^{b}	1.6
UWM	0.1228 (12)	4.24 (4)	0.186 (4)	0.078 (3)	-	15.67 (11)	0.640 (4)	0.694 (12)	2.94 (4)	7.82 (5)
WM	0.1228 (16)	4.282 (13)	0.1799 (23)	0.0779 (9)	-	15.47 (4)	0.641 (3)	0.7028 (25)	3.014 (9)	7.748 (14)
LWM	= WM	= WM	= WM	= WM	-	= WM	= WM	= WM	2.94 (4)^{X}	= WM
Selected Data										
# data points, N	3	8	3	2	3	7	6	6	8	8
χ^2/(N-1)	0.12	0.89	3.1	1.0	0.50	2.0	115^{b}	2.9	4.7^{b}	3.5^{b}
Iγ; UWM	0.1243 (23)	4.300 (28)	0.189 (8)	0.084 (7)	0.057 (4)	15.52 (9)	0.60 (3)	0.690 (22)	3.00 (6)	7.74 (12)
Iγ; WM	0.126 (4)	4.309 (24)	0.185 (5)	0.079 (5)	0.059 (5)	15.40 (6)	0.590 (3)	0.7008 (28)	3.001 (11)	7.727 (23)
Iγ; LWM	= WM	= WM	= WM	= WM	= WM	= WM	0.59 (5)^{X}	= WM	3.006 (30)^{X}	7.736 (48)^{e}
Iγ; Norm Res								0.701 (5)	2.999 (22)	7.727 (44)
Iγ; Rajeval								0.713 (6)	2.997 (14)	7.713 (24)
Adopted Ig	0.1229 (16)	4.283 (13)	0.180 (4)	0.0779 (9)	0.0621 (21)	15.46 (4)	0.639 (3)	0.706 (4)	3.019 (14)	7.746 (13)
Source	All; WM	All; WM	All; NR	All; WM	All; WM	All; WM	All; WM	All; LWM	All; NR	All; WM

Table 2: ^{56}Co Relative Gamma-Ray Emission Probabilities (continued)$^{@}$ Experimental Data

Ref./Eg	**2113.1g**	**2212.9g**	**2276.4g**	**2373.7g**	**2523.0g**	**2598.4g**	**2657.4g**	**3009.6g**
65Pe18						17.4 (15)		1.3* (4)
66Do07						16.0* (27)		1.9* (8)
66Hu17	0.40 (9)	0.43 (9)	0.12 (3)	0.15* (3)	<0.03	20.0* (20)		1.25* (25)
66Sc01						17.4 (17)		1.5* (2)
67Au01	0.29 (5)					17.3 (9)		0.9 (2)
67Ba75	0.4 (1)	0.4 (1)				15.0* (13)		0.8 (3)
68Sh07	0.32 (15)	0.20*^{f} (2)				17.0 (6)		1.0 (1)
67Ch20	0.56* (8) (12)	0.60* (9) (13)				14.0* (21) (30)		0.60* (9) (13)
69Ar04	0.3 (1)					18.7* (11)		0.9 (5)
69Au09						16.55 (44)		
69Sc09	0.32 (4)	0.46* (5)	0.14 (2)	0.11 (2)	0.09 (3)			
70Ph01	0.39 (3)	0.40 (3)	0.15 (2)	0.12 (2)	0.054 (15)	17.2 (4)		0.93 (6)
71Ca14	0.387 (4)	0.377 (10)	0.106 (5)	0.055 (12)	0.060 (5)	16.85 (17)		1.010 (11)
71Ge07						18.0* (9)		
71Ge08	0.26* (3)	0.28* (3)	0.10 (2)	0.08 (2)	0.07 (2)	16.5 (10)	~0.02	0.92 (10)
71Si29^{S}	0.34 (4)	0.30* (6)						1.55* (12)
72Pe20^{d}						15.65* (204) (224) 17.3 (22) (24) 14.44* (175) (193)		
74BoXX^{S}						17.3 (4)		1.0 (2)
74Ho25	0.37 (2)	0.36 (2)	0.128 (8)	0.059 (12)	0.044 (10)		0.016 (5)	0.98 (9)
75Ka06	0.0.375 (17)	0.387 (18)	0.146 (7)			16.64 (22)		0.922 (29)
77Ge12^{S}	0.387 (8) (9)	0.406 (9) (10)				17.34 (26) (31)		1.06 (3) (3)
78Ha53^{S}	0.34 (2)	0.39 (2)	0.15 (2)	0.050 (6)	0.084 (9)	17.19 (15)	0.029 (4)	1.05 (3)
80St20^{S}	0.375 (14)	0.42 (2)	0.117 (9)	0.097 (12)	0.079 (11)	17.40 (38)	<0.05	0.84 (4)
80Sh28	0.35 (1)	0.35 (1)	0.115 (10)	0.079 (10)	0.14*^{f} (1)	16.41 (33)	0.015 (3)	1.02 (2)
80Yo05	0.363 (7) (7)	0.389 (8) (8)	0.124 (7) (7)	0.083 (11) (11)	0.068 (11) (11)	16.96 (6) (8)	0.021 (6) (6)	
82Gr10								
89Al25								
90Me15^{S}	0.385 (5)	0.35 (1)	0.110 (5)	0.08 (1)	0.060 (5)	17.29 (15)		1.05 (1)
92ScZZ	0.376 (10) (10)	0.395 (14) (14)	0.128 (19) (19)	0.082 (22) (22)		17.26 (28) (28)		1.16 (3) (3)
00Ra36^{S}						17.1 (3)		
02MoZP^{S}	0.372 (4) (4)	0.388 (4) (4)				16.82 (7) (8)		1.033 (11) (11)

Table 2: ^{56}Co Relative Gamma-Ray Emission Probabilities (continued)$^{@}$
a) Analysis

Eγ	**2113.1γ**	**2212.9γ**	**2276.4γ**	**2373.7γ**	**2523.0γ**	**2598.4γ**	**2657.4γ**	**3009.6γ**
All Data								
# data points, N	21	19	13	12	10	28	4	23
$\chi^2/(N-1)$	2.5^b	7.6^b	2.8^b	3.6^b	7.6^b	1.3	2.8	4.9^b
Iγ; UWM	0.365 (13)	0.383 (18)	0.126 (5)	0.087 (8)	0.075 (8)	16.89 (22)	0.020 (3)	1.07 (6)
Iγ; WM	0.3764 (21)	0.3795 (27)	0.1192 (24)	0.071 (3)	0.0687 (27)	16.97 (4)	0.0195 (20)	1.029 (5)
Iγ; LWM	0.376 (11)^X	0.380 (8)^X	0.119 (13)^X	0.087 (37)^X	0.069 (9)^X	= WM	= WM	1.029 (21)^X
Iγ; Norm Res	0.3761 (31)	0.385 (5)	0.1179 (36)	0.077 (6)	0.064 (4)	16.97 (4)	0.0184 (22)	1.030 (9)
Iγ; Rajeval	0.3756 (22)	0.387 (3)	0.1187 (28)	0.079 (4)	0.062 (3)	16.96 (4)	0.0168 (23)	1.029 (6)
Statistical Outliers Excluded			N/A				N/A	
# data points, N	19	14	-	11	9	20	-	17
$\chi^2/(N-1)$	1.9	2.8^b	-	3.3^b	1.7	1.2	-	4.4^b
UWM	0.360 (8)	0.389 (6)	-	0.081 (7)	0.068 (5)	17.06 (7)	-	0.975 (22)
WM	0.3769 (21)	0.3835 (27)	-	0.070 (3)	0.0631 (28)	16.96 (4)	-	1.028 (5)
LWM	= WM	0.384 (5)^e	-	0.070 (20)^X	= WM	= WM	-	0.975 (75)^X
Selected Data								
# data points, N	6	6	3	3	3	7	1	7
$\chi^2/(N-1)$	1.9	4.4^b	2.0	7.8^b	3.4	2.2	N/A	7.5^b
Iγ; UWM	0.367 (9)	0.376 (18)	0.126 (12)	0.076 (14)	0.074 (7)	17.21 (7)	0.029 (4)	1.08 (8)
Iγ; WM	0.3770 (29)	0.386 (3)	0.113 (4)	0.064 (5)	0.067 (4)	17.01 (6)	-	1.039 (7)
Iγ; LWM	= WM	0.385 (9)^e	= WM	0.068 (18)^X	= WM	= WM	-	1.039 (19)^e
Iγ; Norm Res	0.3770 (29)	0.389 (6)	0.113 (4)	0.080 (7)	0.072 (5)	17.13 (8)	-	1.043 (11)
Iγ; Rajeval	0.3773 (35)	0.390 (4)	0.112 (4)	0.082 (8)	0.080 (7)	17.20 (8)	-	1.043 (7)
Adopted Iγ	0.376 (3)	0.385 (5)	0.118 (4)	0.078 (6)	0.063 (4)	16.97 (4)	0.0195 (20)	1.039(19)
Source	All; NR	All; NR	All; NR	All; NR-Raj	All; NR-Raj	All; WM	All; WM	Sel; LWM

Table 2: ^{56}Co Relative Gamma-Ray Emission Probabilities (continued)$^{@}$, Experimental Data

Ref./Eg	**3201.9g**	**3253.4g**	**3273.0g**	**3369.7g**	**3451.1g**	**3547.9g**	**3600.7g**	**3611.8g**
65Pe18	3.2 (5)	8.5 (6)	1.5 (4)		0.95 (15)			
66Do07	2.9 (11)	5.8* (22)	1.2 (5)		0.7 (3)	0.2 (1)		
66Hu17	3.80* (45)	9.2* (9)	2.1 (4)		1.1 (2)	0.16 (3)	0.010 (5)	<0.005
66Sc01	3.4 (4)	8.3 (8)	1.9 (3)		0.7 (1)	0.21 (3)		
67Au01	3.4 (2)	7.8 (4)	1.5 (3)		0.87 (9)	0.15 (3)		
67Ba75	2.9 (3)	6.6 (6)	1.35 (20)		0.63* (15)	0.11* (5)		
68Sh07	2.8 (4)	7.3 (5)	1.5 (4)		0.83 (10)	0.15 (5)	0.02 (1)	
67Ch20	2.9 (4) (6)	7.2 (11) (15)	1.60 (24) (34)		0.72 (11) (15)	0.20 (3) (4)		
69Ar04	3.0 (2)	7.1 (4)	1.3 (1)		0.8 (1)	0.1* (1)		
69Au09	3.03 (14)	7.35 (21)	1.72 (13)		0.85 (7)			
69Sc09							0.024* (4)	0.007 (3)
70Ph01	3.10 (11)	7.5 (2)	1.72 (5)		0.89 (3)	0.18 (1)	0.014 (4)	0.011 (3)
71Ca14	3.03 (3)	7.390 (75)	1.755 (18)	0.011 (2)	0.875 (9)	0.178 (3)	0.015 (1)	0.0065 (10)
71Ge07	3.20 (35)	7.7 (9)	1.71 (25)		0.93 (20)	0.2 (1)		
71Ge08	2.81 (28)	7.0 (6)	1.69 (17)	0.015 (3)	0.82 (1)	0.15 (2)	0.014 (3)	0.007 (2)
71Si29^{S}			1.71 (9)		0.94 (2)	0.20 (3)		
72Pe20^{d}	2.86 (34) (38) 3.03 (36) (40) 2.55* (33) (36)	6.98 (86) (96) 7.4 (8) (9) 6.52 (78) (86)	- 1.57 (21) (23) 1.25 (20) (21)		0.98 (24) (25) 1.03 (14) (15) 0.84 (13) (14)			
74BoXX^{S}	3.2 (1)	8.2 (4)	1.9 (1)		1.00 (4)	0.20 (2)		
74Ho25				0.008 (2)	0.89 (4)	0.178 (9)	0.016 (2)	0.008 (2)
75Ka06	3.067 (157)	7.45 (43)	1.697 (103)		0.936 (84)	0.164 (18)		
77Ge12^{S}	3.18 (10) (10)	7.79 (24) (25)	1.85 (6) (6)		0.93 (3) (3)	0.190 (6) (6)	0.0165 (7) (7)	0.0085 (4) (4)
78Ha53^{S}	3.24 (3)	7.97 (11)	1.84 (3)	0.010 (1)	0.95 (2)	0.196 (5)	0.012 (3)	0.005 (2)
80St20^{S}	3.03 (7)	7.60 (15)	1.815 (36)	0.011 (2)	0.90 (2)	0.196 (6)	0.015 (2)	0.010 (2)
80Sh28	3.04 (6)	7.52 (15)	1.77 (4)	0.007 (2)	0.90 (2)	0.19 (5)	0.015 (3)	0.007 (2)
80Yo05								
82Gr10								
89Al25								
90Me15^{S}	3.24 (3)	7.937 (65)	1.89 (2)	0.011 (2)	0.954 (10)	0.198 (5)	0.018 (1)	
92ScZZ	3.32 (7) (7)	8.13 (17) (17)	1.93 (4) (4)		0.973 (20) (20)	0.200 (5) (5)		
00Ra36^{S}	3.16 (6)	7.815 (160)	1.84 (4)		0.93 (3)	0.19 (1)		
02MoZP^{S}	3.196 (17) (18)	7.85 (4) (4)	1.854 (12) (13)		0.94 (1) (1)	0.196 (2) (2)		

Table 2: ^{56}Co Relative Gamma-Ray Emission Probabilities (continued)$^{@}$, Analysis

Eg	**3201.9**g	**3253.4**g	**3273.0**g	**3369.7**g	**3451.1**g	**3547.9**g	**3600.7**g	**3611.8**g
All Data								
# data points, N	27	27	27	7	29	24	12	9
χ^2/(N-1)	2.4^b	2.8^b	3.7^b	1.1	5.8^b	2.2^b	1.2	1.1
Iγ; UWM	3.10 (5)	7.55 (13)	1.68 (4)	0.0104 (10)	`0.888 (19)	0.179 (6)	0.0158 (11)	0.0078 (6)
Iγ; WM	3.172 (11)	7.776 (27)	1.826 (8)	0.0100 (7)	0.905 (4)	0.1914 (13)	0.0162 (4)	0.0081 (3)
Iγ; LWM	3.10 $(10)^X$	7.55 $(30)^X$	1.68 $(17)^X$	= WM	0.905 $(30)^X$	0.179 $(17)^X$	= WM	= WM
Iγ; Norm Res	3.188 (16)	7.82 (4)	1.838 (13)	0.0100 (7)	0.931 (7)	0.1934 (14)	0.0162 (4)	0.0081 (3)
Iγ; Rajeval	3.194 (12)	7.825 (28)	1.837 (9)	0.0100 (7)	0.932 (5)	0.1939 (14)	0.0162 (5)	0.0080 (4)
Statistical Outliers Excluded			N/A	N/A				N/A
# data points, N	25	25	-	-	28	22	11	-
χ^2/(N-1)	2.4^b	2.9^b	-	-	5.8^b	2.2^b	0.99	-
UWM	3.089 (34)	7.56 (10)	-	-	0.897 (18)	0.185 (4)	0.0150 (8)	-
WM	3.173 (11)	7.775 (27)	-	-	0.905 (4)	0.1914 (13)	0.0161 (4)	-
LWM	3.09 $(11)^X$	7.56 $(29)^X$	-	-	0.905 $(30)^X$	0.185 $(11)^X$	= WM	-
Selected Data								
# data points, N	7	7	8	3	8	8	4	3
χ^2/(N-1)	1.6	1.1	1.1	0.17	1.2	0.22	1.7	1.8
Iγ; UWM	3.178 (27)	7.88 (7)	1.837 (21)	0.0107 (3)	0.943 (10)	0.1958 (14)	0.0154 (13)	0.0078 (15)
Iγ; WM	3.205 (13)	7.868 (31)	1.856 (9)	0.0103 (8)	0.943 (6)	0.1957 (16)	0.0167 (5)	0.0084 (4)
Iγ; LWM	= WM	=WM	=WM	=WM	= WM	=WM	= WM	= WM
Iγ; Norm Res	3.205 (13)	7.868 (31)	1.856 (9)	0.0103 (8)	0.943 (6)	0.1957 (16)	0.0167 (5)	0.0084 (4)
Iγ; Rajeval	3.209 (13)	7.871 (31)	1.853 (10)		0.944 (6)	0.1957 (16)	0.0166 (6)	0.0085 (4)
Adopted Ig	3.205 (13)	7.87 (3)	1.856 (9)	0.0103 (8)	0.943 (6)	0.1957 (16)	0.0167 (5)	0.0084 (4)
Source	Sel; WM	Sel; WM	Sel; WM	Sel; WM	Sel; WM	Sel; WM	Sel; WM	Sel; WM

[@] Experimental data are listed along with the authors' statistical uncertainty in the least significant digits (given in parentheses). If two numbers are shown in parentheses, the second is the uncertainty after any uncertainty in the reference line (847γ) has been combined in quadrature with the former uncertainty. Note that reference codes are given with the leading two digits of the code omitted. In the 'Analysis' section, the following abbreviations have been used: UWM= unweighted mean; WM= weighted mean; LWM= values recommended by the program LWEIGHT; Norm Res = result from Normalised residuals analysis; Rajeval = result from Rajeval technique analysis; N-Raj = mean of values from Normalised Residuals and Rajeval technique analyses, using the larger of the two uncertainties 'Sel' referrers to data from eight selected references in which the detector efficiency curves were well-characterised to at least 3600 keV (2002MoZP, 2000Ra36, 1990Me15, 1980St20, 1978Ha53, 1977Ge12, 1974BoXX and 1971Si29).

[*] This γ-ray intensity datum is identified by LWEIGHT as a statistical outlier based on the Chauvenet criterion.

[a] Transition reported in one study only.

[b] Exceeds critical value for $\chi^2/(N-1)$ so LWEIGHT considers the data in this dataset to be discrepant.

[c] Reported as 0.310 in 1980Sh28, but this is clearly a typographical error; the value from the literature with which it is compared is also an order of magnitude too large.

[d] 1972Pe20 took data using three different detectors (cylindrical, rectangular and trapezoidal), each calibrated using Monte Carlo calculations; data from these detectors are shown separately.

[e] Weighted mean, external uncertainty recommended by LWEIGHT.

[f] Datum rejected by Rajeval analysis.

[S] Data from this reference included in ‘selected data’ analysis.

[X] LWEIGHT has expanded the uncertainty to encompass the most precise datum.

^{57}Co - Comments on evaluation of decay data

by V. P. Chechev and N. K. Kuzmenko

1. Decay Scheme

The 2nd forbidden electron capture (EC) transitions to the 3/2$^-$ excited levels of 14,413 keV and 366,74 keV have not been observed, as well as the 2nd forbidden unique EC transition to the 1/2$^-$ ground state of ^{57}Fe. From the log ft systematics the log ft of the 2nd forbidden transitions should be greater than 11,1 and 10,8, respectively, and for the 2nd forbidden unique transition, greater than 12,9. From these, the upper limits on the EC branch probabilities to the 14,413 keV level and ground state of ^{57}Fe are obtained as < 0,003 % and < 0,00035 %, and for the EC branch to the 366,74 keV level ≤ 0,002%. The calculations of the level probability balance in the decay scheme of ^{57}Co were made not taking into account the first two unobserved transitions. The EC branch probabilities to the levels of 136,47 keV, 366,74 keV and 706,42 keV were obtained from an probability balance of the gamma transitions.

2. Nuclear Data

Q value is from Audi and Wapstra (1995Au04).
There are available eight measurement results of the half-life of ^{57}Co (Table 1).

Table 1. Measurement results and evaluation of the half-life of ^{57}Co

Reference	Data set "1" χ^2 =39,2 $(\chi^2)_7^{0,05}$ =14,1	Data set "2" χ^2 =14,5 $(\chi^2)_6^{0,05}$ = 12,6	Data set "3" χ^2 =14,5 $(\chi^2)_6^{0,05}$ =12,6
1997Ma75	271,68(9)	271,68(9)	271,68(9)
1992Un01	272,11(26)	272,11(26)	272,11(26)
1983Wa26	271,84(4)	271,84(4)	271,84(4)
1981Va11	271,90(9)	271,90(9)	271,90(9)
1980Ho17	271,77(5)	271,77(5)	271,77(5)
1972La14	271,23(21)	271,23(21)	271,23(21)
1972Em01	269,8(4)	Omitted	Omitted
1965An07	271,65(13)	271,65(13)	271,65(13)
Evaluated value 271,80(5) d			

The value of 269,8(4) days from 1972Em01 was omitted on statistical considerations (because of a large contribution to χ^2 and also on the Chauvenet's criterion).This leads to the data set "2" of the seven values which coincides with the final data "3" as the LRSW method in statistical processing of the set "2" does not change the relative statistical weights.

The computer program EV1NEW 2000Ch01 has chosen the weighted mean of 271,80(5) days with the tS (or MBAYS) uncertainty as $(\chi^2)^{0,05}{}_{n-1}<\chi^2<10(\chi^2)^{0,05}{}_{n-1}$ (see evaluation technique in 2000Ch01). Other statistical procedures give, UWM -271,74(10), WM-271,80(3), CHV-271,83(7), UINF-271,80(4), PINF-271,80(4), BAYS-271,80(5), LWM-271,80(4), IEXW-271,75(8), NORM-271,80(4), RAJ-271,80(3). The computer program LWEIGHT leads to 271,80(3) days, the weighted mean with the internal uncertainty (the external uncertainty is 0,042). (The other evaluations of half-life of ^{57}Co see in 1990Ni03 and 1998Bh11).

The adopted value for the half-life of ^{57}Co is 271,80(5) days.

Half-life of excited levels in ^{57}Fe

The half-life of the excited levels (136 and 14 keV) have been evaluated being : **8,8(5)** ns [using 1989Ra17 and 1978AlZX] and **98,0(3)** ns [from 1961Cl11, 1965Ki03, 1967Ec05, 1969Ho28, 1978AlZX, 1995Ah04], respectively.

2.1. Electron Capture Transitions

The energies of the electron capture, ε, transitions have been calculated from the Q value and the level energies deduced from gamma transition energies.

The P_K, P_L and P_M values have been obtained from the tables of Schönfeld (1998Sc28). The experimental P_K values are available for $\varepsilon_{0,2}$ EC transitions to the level of 136,47 keV: 0,885(9) in 1968Ru04 ; 0,87(2) in 1969Bo49 ; 0,922(10) in 1973 Mukerji and 0,89(4) in 1990Si03.

The electron capture probabilities of $\varepsilon_{0,2}$, $\varepsilon_{0,3}$ and $\varepsilon_{0,4}$ have been calculated from the balance of the evaluated Pγ+ce values for the136,47 keV, 366,74 keV and 706,42 keV levels, respectively, assuming negligible EC transitions to the 14,4 keV level and the ground state of ^{57}Fe.

The calculated value of the sum of $P_{\gamma+ce}$ for the 4 gamma transitions to the ground state of ^{57}Fe is 99,996 (19) %.

2.2. Gamma Transitions and Internal Conversion Coefficients

The evaluated energies of gamma transitions are the energies of the gamma rays plus the recoil energy.

The probabilities of gamma transitions $P_{\gamma+ce}$ have been computed using the evaluated absolute gamma ray emission intensities and the total internal conversion coefficients (ICC). The ICC have been evaluated using the experimental information on the multipolarity admixture coefficients (see below) and the theoretical values from 1976Ba63.

The values of δ(E2/M1) have been adopted from the analysis of 1978Kr19 except for $\gamma_{2,1}$ which is obtained by weighting the 4 values of +0,120 from 1972Fo05, +0,116(1) from 1973Sc15, +0,1195(10) from 1975Co22 and +0,120(4) from 1972Kr15 (see also the evaluation of 1998Bh11). The weighted average of δ(E2/M1) for $\gamma_{2,1}$ is +0,1180(12).

The adopted values of δ(E2/M1) for other gamma transitions are 0,00223(18) for $\gamma_{1,0}$, +0,02 for $\gamma_{3,2}$, +0,083(5) for $\gamma_{4,3}$, +0,025(9) for $\gamma_{3,1}$,-0,45(5) for $\gamma_{3,0}$,+0,097(8) for $\gamma_{4,2}$ and -0,465(8) for $\gamma_{4,1}$.

There are many experimental values of ICC and the ratios of the fractional intensities of conversion electrons for $\gamma_{1,0}$, $\gamma_{2,1}$ and $\gamma_{3,0}$ which, with the exception of 1996Me11, support the adopted values of ICC:

$\gamma_{1,0}$ α_K=7,76(23), α_L=0,804 (24) from 1976Ba63
α_K=7,35(19) from 1985HaZA
K:L:M+=100:9,59(13):1,48(15) from 1971Po05

$\gamma_{2,1}$ α_K=0,0214(12), K/L+ =8,2(6) from 1967Ha06
K:L:M+ =100:9,0:1,5 from 1955Co31

$\gamma_{3,0}$ α_K=0,122(13), K/L+ =8,6(5), α_T/α_K =1,118(5) from 1967Ha06

There are 6 experimental values for the total ICC (α_T) of the low-energy gamma transition $\gamma_{1,0}$(14,413 keV): 9,0(5) and 8,9(6) from 1965Ki03 ; 8,26(22) from 1965Mo22 ; 8,25(46) from 1966Sp06 ; 8,26(22) from 1968Ru04 and 8,19(18) from 1970Jo30. They can be compared to the adopted value of α_T=8,58(18).

3. Atomic Data

3.1. Fluorescence yields

The fluorescence yields are taken from 1996Sc06 (Schönfeld and Janβen).

3.2. X Radiations

The X-ray energies are based on the wavelengths in the compilation of 1967Be65 (Bearden).

The relative Kβ/Kα emission probability is taken from 1998Be and 1997Lepy. They have shown that taking into account double-electron transitions with a simultaneous emission of a photon and Auger electron (the radiative Auger effect RAE) increases the value of Kβ/Kα = from 0,1368(14) (1996Sc06) to 0,1419(19) (1998Be) or 0,1423(17) (1997Lepy). From these we have adopted Kβ/Kα = 0,142(2).

The ratio $K\alpha_2/K\alpha_1$ is from 1996Sc06

3.3. Auger Electrons

The energies of Auger electrons are from 1977La19 (Larkins).

The ratios P(KLX)/P(KLL) and P(KXY)/P(KLL) are taken from 1996Sc06.

4.Photon Emissions

4.1 X-Ray Emissions

The total absolute emission intensity of KX-rays (P_{XK}) has been computed using the adopted value of ω_K, the evaluated total absolute emission probabilities (sums) of K conversion electrons (Pce_K) and K electron capture ($P\varepsilon_K$).

The absolute emission intensities of the KX -ray components have been computed from the total P_{XK} using the relative probabilities from sect. 3.2.

Below the measured values of $P_{K\alpha}$ and P_{XK} are compared to our calculated (evaluated) values:

	Measured		*Calculated*
	1989 Debertin	1994Ar22	(evaluated)
P_{Ka}, %	50,6(9)	50,1(5)	50,0(6)

	Measured				*Calculated*
	1968Ru04	1973 Mukerji	1978 Vylov	1989 Debertin	(evaluated)
P_{XK}, %	56,9(8)	58,4(17)	55,3(15)	56,0(11)	57,1(9)

The total absolute emission intensity of LX -rays has been computed using absolute sums Pce_L, Pce_K, $P\varepsilon_K$, $P\varepsilon_L$ and atomic data of section 3.1 (ω_K, ϖ_K, n_{KL}).

4.2. Gamma Emissions

The energies of the gamma rays $\gamma_{2,1}$ and $\gamma_{3,0}$ have been adopted from 1976Bo16 and 2000He14. The energies of other gamma rays have been obtained as the weighted means of measurement results listed in Table 2 or calculated from the decay scheme of ^{57}Co. The corrections to the revised energetic scale in 2000He14 (lowering the values by 5,80 ppm) do not change these values.

The evaluator has assumed no EC feeding to the ground and first excited states and used the total gamma-ray transition probabilities to these two states (except that for the 14,4 -keV transition) to normalize the decay scheme (using adopted relative photon intensities from Table 3, conversion coefficients from Section 2.2). This procedure has produced a normalization factor of 0,8551(6).

The absolute gamma ray emission intensity for $\gamma_{1,0}$ (14,413 keV) has been computed as follows: $P'_{\gamma}(\gamma_{1,0}) = P'_{\gamma+ce}(\gamma_{1,0})/(1+\alpha_T(\gamma_{1,0}))$, where $P'_{\gamma+ce}(\gamma_{1,0}) = 87,57(16)$ comes from decay-scheme probability balance at the 14,4 -keV level, and $\alpha_T(\gamma_{1,0})=8,58$. The deduced value of $P_\gamma(\gamma_{1,0})=9,15(17)$ % can be compared with the experimental values, such as 9,5(2) % (1978Vylov), 9,54(12) % (1992ScZZ) and 9,16(15) % (1989Debertin). It agrees extremely well with the CRP experimental result from 1989 Debertin.

It should be noted also that the evaluated sum $P_\gamma(\gamma_{2,0})+P_\gamma(\gamma_{1,0})==19,86(23)$ % agrees well with the measured value of 19,84(17)% in 1971Ko19.

Table 2 - Measured and adopted energies of gamma-rays in the decays of ^{57}Co → ^{57}Fe and ^{57}Mn → ^{57}Fe

	1965Ki03	1965Sp06	1970Gr13	1971Ko19	1972He42	1974Ti01[a]	1976Bo16	1980Ve05	WM	Adopted
$\gamma_{1,0}$			14,408(5)		14,41247(29)	14,410(6)			-	14,41295(31)[b]
$\gamma_{2,1}$			122,07(3)	122,06(2)		122,063(4)	122,06065(12)		-	122,06065(12)
$\gamma_{2,0}$			136,473(4)	136,47(3)		136,473(4)	136,47356(29)		-	136,47356(29)
$\gamma_{3,2}$	229,8(10)	230,6(6)	230,4(5)	230,4(6)		230,25(4)		230,29(2)	230,27(3)	230,27(3)
$\gamma_{4,3}$	339,7(4)	339,7(5)	339,7(3)	339,68(28)		339,60(6)		339,54(18)	339,61(9)	339,67(3) [b]
$\gamma_{3,1}$	352,5(4)	352,4(5)	352,5(3)	352,23(27)		352,32(3)		352,36(1)	352,34(2)	352,34(2)
$\gamma_{3,0}$	366,8(5)	366,7(5)	336,8(4)	367,0(5)		366,73(4)		366,75(1)	366,74(3)	366,74(3) [b]
$\gamma_{4,2}$	570,0(4)	570,3(4)	570,1(3)	570,04(28)		569,93(5)		569,92(4)	569,94(4)	569,94(4)
$\gamma_{4,1}$	692,1(3)	692,1(3)	692,1(2)	692,44(6)		692,00(3)		692,03(2)	692,02(2)	692,01(2)[b]
$\gamma_{4,0}$	706,4(4)	706,8(4)	706,6(3)	706,46(34)		706,54(22)		706,40(20)	706,50(20)	706,42(2)[b]

a Experimental values from the decay of ^{57}Mn

b Calculated from decay scheme using the energies of $\gamma_{2,1}$, $\gamma_{2,0}$, $\gamma_{3,2}$, $\gamma_{3,2}$, $\gamma_{4,2}$

Table 3 - Relative emission probabilities of gamma rays in the decay of ^{57}Co

γ	E_γ	1965Ki03	1965Ma38	1971Ko19	1974 HeYW	1980Sc07 [a]	1982Gr10	Average	Adopted
$\gamma_{1,0}$	14			$1,14(5) \cdot 10^4$					10,70(20) [b]
$\gamma_{2,1}$	122	10^5	10^5	10^5	10^5	10^5	10^5	10^5	100
$\gamma_{2,0}$	136	1,25(8) 10^4	1,20(1) 10^4	1,30(4) 10^4	1,29(7) 10^4	1,236(9) 10^4	1,245(30) 10^4	1,253(18) 10^4 [c]	12,53(18)
$\gamma_{3,2}$	230		0,2(2)	0,5(5)					4(4) 10^{-4}
$\gamma_{4,3}$	340		2,9(3)	4,5(4)					0,0045(4) [d]
$\gamma_{3,1}$	352		2,0(2)	3,7(4)					0,0037(4) [d]
$\gamma_{3,0}$	367		0,7(1)	1,5(4)					0,0015(4) [d]
$\gamma_{4,2}$	570		16(1)	19,4(11)	10(10)			18(2) [e]	0,018(2)
$\gamma_{4,1}$	692		188(5)	183(11)	190(30)			186(7) [f]	0,186(7)
$\gamma_{4,0}$	706		5,5(6)	6,2(6)				5,8(6) [g]	0,0058(6)

[a] In 1980Sc07 the absolute gamma-ray emission probabilities are reported: $P\gamma_{2,0}$(136)=10,58(8)% and $P\gamma_{2,1}$(122)=85,59(19)%. Their ratio is 0,1236(9).

[b] Calculated as described in the text

[c] The LWEIGHT program (version 1.2) has used an unweighted average and expanded the uncertainty so range includes the most precise value of 1980Sc07 . It is reasonable choice because of disagreement of the experimental values some uncertainties of which are only statistical.

[d] Adopted from 1971Ko19.

[e] LWEIGHT has used a weighted average and expanded the uncertainty so range includes the most precise value of 1965Ma38.

[f] The method of Limitation of Relative Statistical Weights (LRSW) increased the uncertainty of 1965Ma38 to 10,3.

[g] The experimental uncertainty is adopted as the uncertainty of the evaluated value.

5. Electron emissions

The energies of the conversion electrons have been calculated from the gamma transition energies given in sect. 2.2 and the electron binding energies.

The emission intensities of the conversion electrons have been calculated using the transition probabilities given in sect. 2.1and 2.2, the atomic data given in sect. 3, and the internal conversion coefficients given in sect. 2.2.

The low energy electron spectrum from the decay of ^{57}Co has been analysed in 1997KoZJ using a combined electrostatic spectrometers. They obtained the following intensity ratios for the main spectrum components: (LMM+LXY) / KLL / KLX / KMX / K-14,4 / L-14,4 / (M+N)-14,4 = 49,3(38): 59,6(23): 15,2(6): 1,2(2): 49,9(18): 5,1(3): 0,80(4). These values agree mainly with our evaluated data on electron emissions apart from the intensity of L Auger electrons. Perhaps, the latter is connected with difficulties of the electron spectrum measurement in the energy region of 0,6 -0,7 keV. The discrepancy takes place also for the L/(M+N) and K/(M+N) ratios.

Also in 1997KoZJ L_1/L_2 = 15,7(5), L_1/L_3=39,3(16), $M_{2,3}/M_1$=0,076(4) have been measured for the gamma transition $\gamma_{1,0}$ (14,4 keV).

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^{57}Ni – Comments on evaluation of decay data
by Shiu-Chin Wu

The *Limitation of Relative Statistical Weight* (1988WoZO) (LWM) method, used for averaging numbers throughout this evaluation, provided a uniform approach for the analysis of discrepant data. For two discrepant values, the method chooses the unweighted average. The uncertainty assigned to the recommended values was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

1. Decay Scheme

^{57}Ni decays by EC + β^+ to ^{57}Co states at 1377.65, 1504.81, 1757.58, 1919.55 and 2804.27 keV. The total β^+ branching has been measured by 1967Li08, 1962Ch20, 1958Ko60 and 1964Ru06. The weighted average of the results gives (45.9 ± 1.0) %, in agreement with the value of 43.5% predicted by theory [1; 1957Zw01].

2. Nuclear Data

The following values of the half-life of ^{57}Ni have been used to deduce a recommended value:

1	35.54(5) h	Dickens (1986)
2	35.65(5) h	Grutter (1982)
3	36.16(11) h	Rothman et al. (1974)
4	35.99(12) h	Ebrey and Gray (1965)
5	35.7(2) h	Rudstam (1964)
6	36.4(7) h	Friedlander et al. (1950)
7	35.7(10) h	Maienschein and Meem (1949)

The recommended half-life of ^{57}Ni, 35.9(3) h, is an average (χ^2/N-1=5.83, LWM) of the seven values listed above. The LWM method changed the uncertainty of the averaged value from 0.1 h to 0.3 h, in order to overlap with the most precise value of 35.54 h. The value of 43.7(9) h by Rayburn (1961Ra06) differs from the average by about 8 σ, and was not included. Rudstam (1956Ru45) had previously reported a value of 37.6(5) h, which has been superseded by the more precise value of 35.7(2) h (1964Ru06) given above.

2.1 Electron Capture Transitions

Electron-capture energies given in Tables 2.2 have been deduced from the Q value and the level energies. EC + β^+ feedings to the levels are from gamma-ray emission probability balances. The electron-capture and positron emission probabilities to the individual levels are based on theoretical [1] β^+/EC ratios. The fractional atomic shell electron-capture probabilities are theoretical values [1977Ba48] calculated with the EC-CAPTURE computer program [2]. EC decay to the ground state of ^{57}Co has not been observed. This transition would be 2nd forbidden non-unique, with a systematic *lg ft* value of 11.0 or higher. Its corresponding probability, calculated with the LOGFT computer program [3], is less than 0.01%. Similarly, the EC decay to the 1st excited state has a probability of less than 0.001%.

2.2 Positrons Transitions

Electron-capture and β^+ end-point energies given in Tables 2.1 and 2.2 are equal to Q_{EC} = 3264.2(26) keV (1995Au04) minus the individual level energies, and to the electron -capture energies minus 2 m_0c^2 (1022 keV), respectively.

2.3 Gamma Rays

Gamma-ray energies were measured with Ge(Li) detectors by Scardino *et al.* (1990Sc23); Rothman *et al.* (1974HeYW); Gatrousis *et al.* (1969Ga14); Lingeman *et al.* (1967Li08) and Piluso *et al.* (1966Pi01). The energies adopted here are the LWM averages, which are usually dominated by the values of 90Sc23.

Adopted	1990Sc23	1974HeYW	1969Ga14	1967Li08	1966Pi01	χ^2_R
127.164(3)	127.164(3)	127.192(25)	127.1(1)	127.6(5)**	127.2(1)	0.59
161.86(3)	161.86(3)		161.8(3)			0.04
304.1(1)	304.1(1)					
379.94(2)	379.94(2)		380.0(2)			0.09
541.9(1)	541.9(1)					
673.44(4)	673.44(4)		673.4(2)			0.04
696.0(4)	696.0(4)					
755.3(1)	755.3(1)					
906.98(5)	906.98(5)		906.8(3)			0.35
1046.54(14)#	1046.68(3)		1046.4(2)			0.98
1223.8(3)#	1224.00(4)		1223.5(4)			0.78
1279.99(6)	1279.99(6)					
1350.52(6)	1350.52(6)					
1377.62(4)	1377.63(3)	1377.59(4)	1377.6(2)	1378.0(5)	1378.1(2)	1.7
1603.28(6)	1603.28(6)					
1730.45(6)	1730.44(6)		1730.6(3)			0.27
1757.55(3)	1757.55(3)	1757.48(8)	1757.6(2)	1758.2(6)**	1757.7(2)	0.45
1897.0(5)#	1897.42(4)		1896.5(4)			2.6
1919.62(14)	1919.52(5)	1919.43(8)	1919.5(2)	1919.9(6)	1920.2(1)	11
2133.04(5)	2133.04(5)		2132.9(3)			0.21
2730.76(14)	2730.91(4)		2730.6(2)	2731(2)		0.61
2804.08(15)	2804.20(3)		2803.9(2)	2805.1(9)		1.2
3177.27(5)	3177.28(5)		3176.9(3)	3177.3(12)		0.78

** Statistical outlier, omitted.

The LWM chose the unweighted average for these discrepant values.

Gamma-ray emission probabilities relat ive to that of the 1377.62 keV γ-ray measured with Ge(Li) detectors were reported by Scardino *et al.* (1990Sc23); Grutter (1982Gr10); Rothman *et al.* (1974HeYW); Gatrousis *et al.* (1969Ga14); Lingeman *et al.* (1967Li08) and Piluso *et al.* (1966Pi01). The LWM averages have been adopted here.

E_γ keV	Adopted	1990Sc23	1982Gr10	1974HeYW	1969Ga14	1967Li08	1966Pi01	χ^2_R
127.164(3)	19.8(6)	20.4(4)	20.3(2)	16.6(10)	20.0(6)	17.6(9)	15.0(9)	10
161.86(3)	0.025(3)#	0.0278(8)			0.022(11)			14
304.1(1)	0.0024(7)	0.0024(7)						
379.94(2)	0.089(7)#	0.082(2)			0.10(5)			4.2
541.9(1)	0.0045(6)	0.0045(6)						
673.44(4)	0.0600(18)	0.0601(18)1)			0.06(3)			0.38
696.0(4)	0.0011(8)	0.0011(8)						
755.3(1)	0.0066(8)	0.0066(8)						
906.98(5)	0.092(18)#	0.075(2)			0.110(6)			20
1046.54(14)	0.163(4)	0.164(4)			0.16(1)			0.20
1223.8(3)	0.094(16)#	0.077(3)			0.110(6)			18
1279.99(6)	0.0118(9)	0.0118(9)						
1350.52(6)	0.0024(12)	0.0024(12)						
1377.62(4)	100(2)	100	100	100	100	100	100	
1603.28(6)	0.0048(8)	0.0048(8)						
1730.45(6)	0.068(4)#	0.064(3)2)			0.072(4)			2.5
1757.55(3)	7.5(5)	7.04(20)	7.63(20)	9.1(8)	7.7(2)	9.5(5)	6.9(3)	6.1
1897.0(5)	0.031(3)#	0.034(3)			0.028(14)			2.0
1919.62(14)	15.4(7)	15.0(3)	17.0(4)	18.9(12)	17.0(5)	22.4(11)3)	14.7(2)	10
2133.04(5)	0.041(6)#	0.035(2)2)			0.047(24)			13
2730.76(14)	0.024(4)	0.0243(6)			0.03(2)	0.015(2)		18
2804.08(15)	0.126(21)	0.120(4)			0.17(1)	0.088(9)		23
3177.27(5)	0.019(5)	0.0136(7)			0.024(1)	0.021(3)		21

1) The relative intensity of the 673.44 -keV γ-ray was listed in 1990Sc23 as 0.0601(15), and corrected as 0.0601(8) by Bhat (1992Bh05). However, a relative uncertainty of 1% for such a weak peak seems too low, it is probably a typographical error. We used 0.0601(18) here.

2) As suggested by Bhat (1992Bh05), the intensity given in 1990Sc23 for the 1730.44 keV γ-ray (0.0614(3)) was changed to 0.064(3); and the uncertainty of the 2133.04 keV γ-ray (0.0350(2)) was increased by a factor of 10 here (possible typographical errors).

3) Statistical outlier, omitted.

The LWM chose the unweighted average for these discrepant values.

EC + β^+ feeding to the ground state of ^{57}Co has not been observed. A systematic *lg ft* ≥ 11.0 for a second forbidden non-unique transition corresponds to $I_{EC} \leq 0.01\%$ for a possible EC transition to the ground state of ^{57}Co. Thus, we used the sum of the relative emission probabilities of the 1224.00 keV, 1377.63 keV, 1757.55 keV, 1897.42 keV, 1919.52 keV, 2133.04 keV, 2730.91 keV, 2804.20 keV and 3177.28 keV γ-rays to normalize the decay scheme. The 1377.62 keV gamma ray is the strongest transition, for which we used a fractional uncertainty of 2%, suggested by 1992Bh05. Similarly, for the first excited state at 1224 keV, a possible EC + β^+ transition would have a systematic *lg ft* ≥ 12.6, which corresponds to an intensity $I_{EC} \leq 0.001\%$. Conversion coefficients used in these calculations are those of Band *et al.* [1976Ba63].

3. Atomic Data

The X-ray and Auger electron emission probabilities given in section 3 are values calculated by using the computer program EMISSION [4], the electron capture probabilities from section 2.2, and atomic data from 1996Sc06.

4. Radiation Emission

4.1 Electron Emission

The emission probabilities of the Auger electrons have been calculated here using the adopted nuclear and atomic electron capture transition data, and the program EMISSION [4]. The emission probabilities of conversion electrons were calculated using the adopted γ-ray emission probabilities and conversion coefficients (section 2.2).

4.2 Photon Emission

The emission probabilities of X-rays were calculated using the adopted nuclear and atomic electron capture transition data, and the program EMISSION [4]. The evaluation of the gamma -ray emission probabilities was discussed in section 2.3.

Total Average Radiation Energy

The total released average radiation energy (electron capture, neutrinos, nuclear recoil, photons and electrons) in the EC + β^+ decay of ^{57}Ni (calculated by using the computer program RADLST [5]) is 3264(32) keV. This value agrees well with 3264.2(26) keV from mass differences (1995Au04), and thus confirms the quality and completeness of the decay scheme.

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^{59}Fe – Comments on evaluation of decay data
by M.M. Bé and V. Chisté

1. Decay scheme

This decay scheme was well studied (Bérényi, Béraud, Collin, Ferguson, Heath, Pancholi, Metzger, Raman, etc.) so that the existence of beta transitions and the spin and parity of the ^{59}Co levels are clearly established. Some authors (Mukerji, Raman) carried out experiments in order to measure the weak β- branches. No clear evidence of a β-branching to the 1190 keV level was found, if this transition exists its branching ratio has an upper limit of 1×10^{-4}.

2. Nuclear Data

^{59}Fe half-life (in days)

Author	NSR	Value	Uc	Method
Metzger	52Me53	45.0	3.0	NaI
Keene	58Ke26	44.56	0.03	ionisation chamber
Pierroux	59Pi43	45.60	0.08	Electrometer à lames vibrantes
Fuschini	60Fu03	63.1	0.8	
Heath	60He06	45.0	5.0	NaI
Subba Rao	60Su10	46.5	1.0	
Wortman	63Wo01	45.0	3.0	
Emery	72Em01	44.5	0.2	NaI
Visser	73Vi13	44.75	0.04	NaI (s x 3)
Alstad	75Al02	45.3	0.3	Gas flow proportional counter
Houtermans	80Ho17	44.496	0.007	4π-γ
Walz	83Wa26	44.53	0.07	4π–γ ionisation chamber
Unterweger	92Un01	44.5074	0.0072	
Martin	97Ma75	44.472	0.008	4π–γ ionisation chamber

The value from Fuschini was omitted due to its large deviation from the others.
The values from Subba Rao, Pierroux were rejected as outlier (Chauvenet' s criteria).
With this set of eleven remaining values, the reduced χ^2 is 6.4 and the Lweight program recommends the unweighted mean and expanded the uncertainty : 44.74 ± 0.24.
With these eleven values the weighted mean and the external uncertainty are :
44.498 ± 0.011.

Taking into account the most precise values (Keene, Visser, Houtermans, Walz, Unterweger and Martin) :
- the value from Visser was rejected as outlier;
- then the reduced $\chi^2 = 4$;
- the weighted mean is 44.495 with an external uncertainty of 0.008.

Regarding the fact that the four more recent measurements are compatible with this value and (for three of them) have a similar uncertainty, the recommended value is :
44.495 ± 0.008 d

Half-lives of ^{59}Co excited levels

Level 1100 keV

- Sidhu : ≤ 50 ps
- Béraud < 14 ps

Level 1291 keV (in ns)

Author	NSR	Value	Uc
Sidhu :	67Si01	0.60	0.05
Agarwal :	67Ag03	0.59	0.02
Béraud :	67Be60	0.575	0.011
Garg :	72Ga39	0.538	0.004
Green :	72Gr05	0.564	0.020
Arens :	71Ar07	0.564	0.005

The value from Chauhan (0.516 (6)) was not taken into account : it seems that the experiment is the same as those described in Garg *et al.*
For the six values above the reduced χ^2 is 5.45 and the critical χ^2 = 3. Then, the uncertainty on the value given by Garg was increased by 1.08 in order to reduce its relative weight to 50 %. The reduced χ^2 is 5.10. This set of value is not consistent and the unweighted mean is adopted : **0.572 (34) ns**.

Level 1434 keV

Arens : 210 (20) ps

2.1 Beta Transitions

Beta transition energies

The adopted Q-value 1565.2 (6) keV is from Audi and Wapstra. It was determined from the measurements of Wortman and Metzger (see Table below)
The adopted energies and uncertainties of beta transitions are deduced from the Q-value and the levels energies and their uncertainties.

Measured beta energies are summarized in the following table :

keV	**1565**	**475**	**273**	**132**	**85**
Wortman	1573 ± 3	475 ± 3	273 ± 5		
Berenyi		455 ± 5	275 ± 5		
Metzger	1560 ± 8	462 ± 3	271 ± 3		
Mukerji	1566			132	85
Subba Rao	1580 ± 20	470 ± 6	280 ± 6	150 ± 10	
Raman	1575 ± 20	461 ± 10	268 ± 10	128	80
Evaluated	*1572 ± 3*	*463.4 ± 2.2*	*273.0 ± 2.1*	*137 ± 8*	*82.5 ± 2.5*
Adopted	**1565.2 ± 0.6**	**465.9 ± 0.6**	**273.6 ± 0.6**	**130.9 ± 0.6**	**83.6 ± 0.6**

The 1565 keV transition is second forbidden non unique, with the shape factor given by Wortman (see below) the mean energy is 521 keV ; with the shape factor from Raman the mean energy is 584 keV ; these calculations were done with the SPEBETA program. In the Russian book Kolobachkin *et al.* the mean energy was calculated to be 523 keV.
Expecting a confirmation, the adopted value is 522 (2) keV.

Beta transition probabilities

The emission probabilities are calculated from gamma transition probability imbalance on each level. That was done for all the transitions, except for the weak 1565-keV to the ground state, the resulting values are in agreement with the experimental values (see Table below).

Taking into account the consistency of the decay scheme :
- the sum of all the transitions to the Co-59 ground state must be equal to 100 ; this leads to an intensity value of 0.12 (32) for the 1565 keV transition. This important uncertainty comes from the propagation of the uncertainties on the gamma transitions.
- the sum of all the beta transitions leaving from Fe-59 must be equal to 100 ; this gives a value of 0.13 (34) for the 1565 transition.

However, several authors measured this transition intensity and found values from 0.18 (4) % to 0.3 (1) % (Table below).
It must also be pointed out that the authors gave measured gamma emission probabilities after corrections, with a value of the $I_{\beta-}$(gs) taken as :
- 0.3% by Legrand, Béraud, Pancholi ;
- 0.18% by Miyahara.

From the previous remarks, it follows that the $I_{\beta-}$(gs) intensity is certainly greater than 0.10% (decay scheme) and less than 0.40% (experiments).
The adopted value is then : 0.25 (15) %.

Table : Measured Iβ

Metzger (52Me53)			
1573 keV	Iβ = 0.3 (1)%	lg ft = 10.9	
475 keV	Iβ = 54.8 (20)%	lg ft = 6.7	
273 keV	Iβ = 44.9 (20)%	lg ft = 5.9	
Wortman. (63Wo01) (No uncertainty given)			
1573 keV	Iβ = 0.30%	lg ft = 10.96	shape factor $p^2 + 3.3\, q^2$
475 keV	Iβ = 51.2%	lg ft = 6.74	
273 keV	Iβ = 48.5%	lg ft = 5.92	
Raman (74Ra13)			
1573 keV	Iβ = 0.18 (4)%	lg ft = 11.15 ± 0.11	shape factor $p^2 + 1.7\, q^2$
475 keV	Iβ = 51 (3)%		
273 keV	Iβ = 47 (4)%		
(80-128)	Iβ = (1.4)%		
Berényi (60Be06) (No uncertainty given)			
1573 keV	Iβ < 0.5 %		
475 keV	Iβ = 55.4%	lg ft = 6.1	
273 keV	Iβ = 44.6%	lg ft = 5.3	

β–γ circular polarization asymmetry coefficients

Behrens (70BeZx) recommends :
For 466β- 1099γ : A= -0.164 (7)
For 273β- 1292γ : A= -0.15 (2)

2.2 Gamma transitions and internal conversion coefficients

1291 keV transition

Assuming a pure E2 transition, the theoretical ICC (from Band's tables) a_T **= 1.22 10^{-4}** is consistent with the experimental one from Metzger (52Me53) $\alpha_T = 1.35$ (6) 10^{-4}.
Other measurements :
Metzger (52Me53), $\alpha_K = 1.19$ (6) 10^{-4}
Hinman (53Hi02), $\alpha_T = 1.06$ (16) 10^{-4}
Collin (64Co34), $\alpha_T = 1.07$ (8) 10^{-4}

K.S.Krane *et al.* (1976Kr10) suggests a M3/E2 mixture of $\delta = -0.033$ (30), that does not change the ICC value significantly.

1099 keV transition

Assuming a pure E2 transition, the theoretical ICC (from Band's tables) a_T **= 1.75 10^{-4}** is consistent with the experimental one from Metzger (52Me53) $\alpha_T = 1.87$ (7) 10^{-4}.
Other measurements :
Metzger(52Me53), $\alpha_K = 1.35$ (6) 10^{-4}
Hinman(53Hi02), $\alpha_T = 1.84$ (27) 10^{-4}
Collin(64Co34), $\alpha_T = 1.36$ (10) 10^{-4}

334 keV transition E2/M1

The measured values of the mixing ratio are the following :

Author	**Delta**
Pancholi	– 0.12 (6)
Eriksson	– 0.12 (4)
Arens	+ 0.05 + 0.03 – 0.07 or – 1.8 + 0.4 – 0.6
Adopted value	– 0.12 (6)
ICC (Band)	**0.002 (1)**

142 keV transition E2/M1

The measured values of the mixing ratio are the following :

Author	**Delta**
Pancholi	-0.15 (6) $< \delta < 0.026$
Eriksson	– 0.006 (12)
Arens	0.028 + 0.009 – 0.014 or – 1.78 + 0.15 – 0.20
Adopted value (from Krane 1977Kr13)	– 0.008 (7)
ICC (Band)	**0.0160 (1)**

192 keV transition E2/M1

The measured values of the mixing ratio are the following :

Author	**Delta**
Pancholi	– 0.22 (2)
Eriksson	0.21 (2)
Arens	– 0.21 (2) or $\delta > 14$
Bajaj	0.22 (2)
Collin	– 0.296 (23)
Adopted value	0.21 (1)
ICC (Band)	**0.00899 (15)**

Gamma emissions

Gamma emission energies
The gamma emission energy of the following lines are from Helmer (2000He14) :
142.651 ± 0.002
192.349 ± 0.005
1099.245 ± 0.003
1291.590 ± 0.006
Others are from Pancholi.

Gamma emission intensities

Eight published papers describe measurements of the gamma emission intensities, all the values are given in absolute values.

Heath *et al.* do not give uncertainty, therefore these values are omitted.

The results given by Béraud *et al.* are with uncertainties of the order of 10%, they are not omitted but their relative weight is generally weak, as well as those of the values given by Mukerji *et al.*

J.Legrand *et al.* (70Le03), carried out $\beta-\gamma$ coincidences measurements and deduce d $I\gamma$ absolute values, assuming that the β branching to the ground state is 0.3%. The uncertainty adopted by Legrand is the sum of the statistical uncertainty assessed at 3σ and the systematic uncertainty at 1σ; consequently, the standard deviation cannot be obtained dividing the original uncertainty by 3 and we divided the given uncertainties by 2 only.

Pancholi *et al.* (73Pa18), measured the relative values and normalized them such as I(*1099* + *1292* + *1481*) = 99.7 %, assuming $I\beta(gs)$ = 0.3%.

Miyahara *et al.*(1989Mi07), carried out activity measurements and deduced absolute values. This paper is the most recent one and gives the most precise values which contribute more than 50% in the adopted result for the two intense lines : 1099 and 1291 keV.

The following table summarizes all the values taken into account and the adopted results.

These different set of data are consistent, except for the original set of seven data for the 335 keV line where two values are outliers and are omitted (o). The adopted values are the weighted means.

keV	**142**	**192**	**335**	**381**
Mukerji	1.1 ± 0.16	3.3 ± 0.3	0.27 ± 0.03	
Legrand	0.98 ± 0.02	2.95 ± 0.04	0.24 ± 0.02	0.023 ± 0.002
Béraud	0.79 ± 0.8	2.50 ± 0.25	0.25 ± 0.05	0.022 ± 0.005
Collin	0.8 ± 0.2	2.8 ± 0.3	0.7 ± 0.3 (o)	
Miyahara	0.955 ± 0.030	2.851 ± 0.048	0.262 ± 0.016	
Ferguson	0.85 ± 0.15	2.4 ± 0.4	0.34 ± 0.07 (o)	
Pancholi	1.02 ± 0.04	3.08 ± 0.1	0.27 ± 0.01	0.018 ± 0.003
χ**2/N-1(critical)	1.5 (2.8)	1.9 (2.8)	0.5	0.97
Adopted value	**0.972** ± **0.015**	**2.918** ± **0.029**	**0.264** ± **0.007**	**0.0215** ± **0.0016**

keV	**1099**	**1291**	**1481**
Mukerji	57.5 ± 3	42.4 ± 2.3	0.052 ± 0.006
Legrand	55.5 ± 0.8	44.1 ± 0.6	0.09 ± 0.01
Béraud	56.2 ± 5.6	43.5 ± 4.3	0.056 ± 0.012
Collin	56.5 ± 1.5	43.2 ± 1.5	
Miyahara	56.68 ± 0.22	42.99 ± 0.30	
Ferguson	56 ± 3	44 ± 3	
Pancholi	56.5 ± 1.5	43.2 ± 1.1	0.059 ± 0.006
χ**2/N-1(critical)	0.4	0.5	3.6 (3.8)
Adopted value	**56.59** ± **0.21**	**43.21** ± **0.25**	**0.0603** ± **0.0037**

Angular correlation coefficients

Several authors determined the angular correlation coefficients. Some of them are summarized here as a matter of interest.

192γ - 1099γ, $3/2^-$(M1+E2)$3/2^-$(E2)$7/2^-$:

Author	NSR	A2	uc	A4	uc
Heath	60He06	0.024	0.005		
Rao	70Ra00	0.028	0.003	0.008	0.007
Arens	71Ar07	0.008	0.007		
Bajaj	72Ba**	0.008	0.004	0.004	0.008
Eriksson	73Er11	0.011	0.004	– 0.003	0.004

335γ - 1099γ, $1/2^-$(M1+E2)$3/2^-$(E2)$7/2^-$:

Author	A2	uc	A4	uc
Rao	– 0.043	0.003	– 0.004	0.003
Arens	– 0.064	0.011	– 0.008	0.025
Eriksson	– 0.040	0.010	– 0.006	0.0006
Bajaj	– 0.099	0.012		

143γ - 1292γ, $1/2^-$(M1+E2)$3/2^-$(E2)$7/2^-$:

Author	A2	uc	A4	uc
Heath	– 0.069	0.005		
Rao	– 0.065	0.004	– 0.006	0.005
Arens	– 0.065	0.004		
Bajaj	– 0.070	0.005	0.014	0.015
Subrahmanyam	– 0.09	0.01		
Eriksson	– 0.070	0.003		

Conversion electrons

Conversion electron intensities were calculated from the gamma transition probabilities and the internal conversion coefficients.

Hinman(53Hi02) gives the ratio of the number of conversion electrons from the 1099 keV transition to the number of conversion electrons from the 1291 keV transition, to be equal to 1.91 (9).

There is a good agreement with the ratio (1.87) obtained from the calculated values in this evaluation.

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^{59}Ni - Comments on evaluation of decay data
M. Galán

1) Decay Scheme

^{59}Ni disintegrates mainly by electron capture (2nd forbidden non-unique) to the ground state of ^{59}Co.
^{59}Co ground state has $J_\pi = 7/2^-$ (2002BA42).

2) Nuclear Data

The Q value is from new values of 2009AuZZ: Q_ε = 1072,76 (19) keV. Other: 1075,1 (13) keV (1976BE02).

Only one direct measurement has been performed for the ^{59}Ni half-life. The value of 7,6 (0,5) × 10^4 years given by 1981Ni08 from two samples by absolute activity measurement has been adopted as the recommended value.
Some other indirect measurements from nuclear reactions have been performed.

The measured ^{59}Ni half-life values, in years, are:

Reference[a]	Value (a) ($\times 10^4$)	Procedure	Comments
2008WAZW	9,7 (0,7)	^{60}Ni(n,2n)^{59}Ni reaction	Corrected 1994Ru19 result with newest $\sigma_{thermal}$ and K_α yield. E(n) = 17-19 MeV
1994RU19	10,8 (1,3)	^{58}Ni(n,γ)^{59}Ni and ^{54}Fe(n,γ)^{55}Fe reactions	E(n) = 14.8 MeV
1991NO08	29 (10)	^{60}Ni(n,2n)^{59}Ni reaction	Authors used σ = 104 (25) mbarn measured by 1988BO31 (very poor statistics)
1981NI08	7,6 (0,5)	Absolute activity measurement	Recommended value
1956SA32	10,0 (2,5)	^{58}Ni(n,γ)^{59}Ni reaction	E(n)= thermal. $T_{1/2}$ was not the purpose of the work
1951BR05	7,5 (1,3)	^{58}Ni(n,γ)^{59}Ni and ^{59}Co(n,γ)^{60}Co reactions	E(n)= thermal. Data used for these reactions σ = 4.2 and σ = 34.5 respectively
1951WI14	75	^{58}Ni(n,γ)^{59}Ni reaction	No uncertainty given

[a] Evaluator used the NSR (Nuclear Science References, Brookhaven Lab.) keynumbers.

The only absolute activity measurement has been performed by 1981NI08. This value was deduced from 2 samples prepared by means of the reaction ^{59}Co(p,n)^{59}Ni, purified by ion-exchange columns in order to remove ^{58}Co activity. 6,93 keV Co K_α X-rays were measured by a Xe filled proportional counter. The value of 7,6 (5) ×10^4 years estimated by 1981NI08 has been adopted as the recommended value as it comes from a direct measurement.
The five other measurements were all made in a very similar way. After neutron irradiation ^{59}Ni atoms are counted by mass spectrometry. Purification is performed to avoid iron or cobalt impurities. The induced activity in the samples has been counted via the Co K X-ray after the ^{59}Ni K capture.

2008WAZW corrected the half-life result given by 1994RU19 using the recently published thermal cross-section of ^{58}Ni (2004RA23) of 4,13 (5) barns instead of the old value of 4,6 (3) barns from 1981MUZQ. The ^{59}Ni half-life is reduced about 10 % but still higher than the recommended value. 2008WAZW analyzed the contribution to the uncertainty of the ^{59}Ni half-life mainly from the uncertainties in the cross-sections.
1991NO08 used the cross-section of ^{60}Ni(n,2n) measured by 1988BO30 but this value was obtained with very poor statistics (as mentioned by authors of 1991NO08).
The oldest value (with uncertainty) given by 1951BR05 was estimated using thermal-neutron cross-sections for ^{58}Ni(n,γ) and ^{59}Co(n,γ) of 4,17 and 34,5 barns respectively.

If a statistical analysis is made for the five indirect measurements, the Lweight code rejects 1991NO08 datum based on Chauvenet's criterion. For the other four values, the weighted mean with external uncertainty is 9,5 (6) ×10^4 years.
Due to the high discrepancy of the results depending on the technique used, new experimental direct measurements are needed.

2.1) Electron Capture and Positron Transitions

Experimental β^+/K ratios are reported in Table 2 and compared with theoretical estimations:

Reference	β^+/K		β^+/EC	
	experimental	theoretical	experimental	theoretical
1991JA02	4,2 (13) ×10^{-7}			
1976Be02			1,5 ×10^{-7}	
Theory (Logft Code)		1,75 ×10^{-5}		1,55×10^{-5}

The LOGFT program (theory) was used with the recent published Q value from 2009AuZZ.

For a 2nd forbidden ε the Logft code gives a theoretical value of $P_{\beta+}$ (1072,76) = 0,001 55 (4) % and P_{ε} (1072,76) = 99,998 44 (4) %with a logft of 11,89 (3). Notice that the theoretical β^+/ε branching is in complete disagreement with the experimental results of 1,5 × 10^{-7} (1976Be02) and 4,2 (13) × 10^{-7} (1991Ja02). The reason for this discrepancy remains unknown.

The EC-Capture program gives: P_K= 0,8870 (16), P_L= 0,0966 (13), P_M= 0,0156 (5), P_N= 0,0008 (2)

From the experimental value β^+/K = 4,2 (13) × 10^{-7} and assuming K/EC = 0,8870 (16) then we have
β^+/EC = 3,7 (12) × 10^{-7}.

And from β^+ + EC = 100 we obtain:

$P_{\beta+}$ = 3,7 (12) × 10^{-5} %
Pε = 99,999 96 (1) %

Which are the adopted values.

3) Atomic Data

3.1) Atomic values (ω_k, ϖ_L and η_{KL}) are from 1996SC06.

3.1.1) X-Radiations, 3.1.2) Auger electrons

The X-ray and Auger electron emission probabilities have been estimated by using the computer code EMISSION. Results were verified with the RADLST computer code.

Good agreement has been found between the total decay energy of 1072,56 (19) keV computed for this decay scheme by RADLST code and the Q value of 1072,76 (19) keV.

4) Gamma emissions

The annihilation radiation emission probability ($I_{\gamma 511}$) is computed as 2 × $P_{\beta +}$, without the correction factor for the annihilation-in-flight process in the medium, that is $I_{\gamma 511}$= 7,4 (24) × 10^{-5} %.

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^{60}Co - Comments on evaluation of decay data
by R. G. Helmer

This evaluation was originally completed in September 1996 with minor editing in February 1997 and post-review editing in January 2006 ; the literature available by January 2006 was included by M.-M.Bé (LNE-CEA/LNHB).

1 Decay scheme

In addition to the levels reported in this decay, there are levels in ^{60}Ni below the decay energy at 2284 keV (0+) and 2626 (3+). However, based on the limits on the β^- branches to these levels (see sect. 2.1), this scheme is considered complete. The scheme is internally consistent since the total decay energy computed from the decay scheme is 2823.0 (5) keV compared to the Q value of 2823.07 (21) keV.

2 Nuclear Data

Q value is from Audi *et al.* (2003Au03).

The half-life values available, in days, are listed. If the value was published in years, it is shown here in years and also converted to days (365.242 days/year).

	Years	Days	Uc	Remarks
1940Li01	5,3 ± 0,7	1936	256	As quoted in 1963Go03 - Outlier (CHV)
1949Se20	5,08 ± 0,08	1855	29	As quoted in 1963Go03 - Outlier (3*S)
1950Br76	5,26 ± 0,17	1921	62	
1951Si25	5,25 ± 0,02	1917,5	7,3	As quoted in 1963Go03
1951To25	5,27 ± 0,07	1925	26	As quoted in 1963Go03
1953Ka21	5,21 ± 0,04	1903	15	Outlier (CHV)
1953Lo09	4,95 ± 0,04	1808	15	Omitted from analysis
1957Ge07	5,24 ± 0,03	1914	11	
1958Ke26	5,33 ± 0,04	1947	15	As quoted in 1965An07 - Outlier (CHV)
1963Go03	5,263 ± 0,003	1922,3	1,1	
1965An07	5,242 ± 0,008	1914,6	2,9	
1968La10	5,270 ± 0,007	1924,8	2,6	
1970Wa19	5,2719 ± 0,0011	1925,5	0,4	Replaced by 1983Wa26
1973Ha60	5,24 ± 0,21	1914	77	
1977Va30	5,283 ± 0,003	1929,6	1,1	
1980Ho17		1925,2	0,4	
1982HoZJ	5,282 ± 0,007	1929,2	2,6	Replaced by 1992Un01
1982RyZX		1924,8	1,0	
1982RyZX		1925,5	0,3	Omitted – unpublished result
1983Ru04		1925,02	0,47	
1983Wa26		1925,5	0,4	
1992Un01		1925,12	0,46	Replaced by 2002Un02
2002Un02		1925,20	0,25	
Adopted	**5,2710 ± 0,0008**	**1925,21**	**0,29**	

One input value (1949Se20) is outlier by 3 sigma, three others are outlier due to Chauvenet criterion (1940Li01, 1953Ka21, 1958Ke26).
For the remaining 14 values, the critical χ^2 is 2.1 ; the reduced χ^2 is 3 ; no value contributes over 50 % of the relative weight. The weighted average is 1925.21 with an internal uncertainty of 0.17 and an external uncertainty of 0.29.

2.1 b$^-$ Transitions

In addition to the main decay to the $J^{\pi} = 4^+$ level at 2505 keV, there is the possibility of β^- decay from the 5^+ parent to the 0^+ levels at 0 and 2284 keV, the 2^+ levels at 1332 and 2158 keV, and the 3^+ level at 2626 keV.

The β^- decay to the 0+ levels at 0 and 2284 keV are unique 4th forbidden with expected log *ft* values (1973Ra10)> 23 and corresponding $P_{\beta-} < 1 \times 10^{-10}$% and $< 1 \times 10^{-13}$%, respectively. The decay to the 3+ level at 2626 is 2nd forbidden with an expected log *ft* > 11 and a corresponding $P_{\beta-} < 0.01$%. This level decays mainly by γ's of 467 and 1293 keV; the $P_\gamma(467)$ has been reported as <0.00023% (1976Ca18) and <0.0004% (1969Va20), which indicates $P_{\beta-}(2626) < 0.001$%.

The β^- decay to the 1332 level is unique 2nd forbidden with an expected log *ft* ≥ 12.8 and a corresponding $P_{\beta-} \leq 12$%. The measured values are (in %): 0.15 (1) (1954Ke04), 0.010 (2) (56Wo09), 0.12 (61Ca05), and 0.08 (2) (1968Ha03). The average of 0.12% (3) is adopted.

The decay to the 2158-keV level is unique 2nd forbidden with an expected log *ft* ≥ 12.8 and a corresponding $P_{\beta-} \leq 0.02$%. This branch is given as 0.000% (2) from 1969Ra23. (Value is given as 0.18% (3) in 1968Ha03, but this is apparently from a misinterpretation of the γ-ray spectrum.)

The decay to the 2505-keV level is then 100.0 - $P_{\beta-}$ (1332) - $P_{\beta-}$(2158) = 0.12(3) - 0.000(2) = 99.88(3)%.

The β^- energies and log *ft* values are from the program LOGFT.

2.2 Gamma Transitions

The multipolarities are from the adopted γ data in the Nuclear Data Sheets (1993Ki10).
The total and K-shell internal-conversion coefficients, α and α_K, for the 1173- and 1332-keV γ rays are from the evaluation of the experimental measurements (1985HaZA) and the remaining values were interpolated from the Band tables (2002Ba85).

The internal-pair-formation coefficients were interpolated from the theoretical values of 1979Sc31 and are $\alpha_\pi(1173) = 0.000\,006\,2\ (7)$ and $\alpha_\pi(1332) = 0.000\,034\ (4)$. The former is negligible since it is only about 5% of the corresponding α, but the latter is about 25% of the α, so it needs to be taken into account.

3 Atomic Data (Ni, Z=28)

The data are from Schönfeld and Janßen (1996Sc06).

3.1 and 3.2 X Radiation and Auger Electrons

The data were computed by RADLIST with the Schönfeld atomic data.

4 Radiation Emission

4.1 Electron Emission

Data were computed by the program RADLIST.

4.2 Photon Emissions

The γ-ray energies are from 2000He14 for the 1173-keV and 1332-keV lines and the others are deduced from the level energies resulting from a fit to the γ-ray energies. Besides the 1173 and 1332 values, the input to this fit included:

346.93 (7) from 1976Ca18 where the authors average their result and that of 1969Va20;
other: 346.95 (10) (1969Va20);

826.06 (3) from ^{59}Co(p,γ)^{60}Ni (1975Er05); others: 826.18 (20) (1969Va20) and 826.28 (9) (1976Ca18, but includes value of 1969Va20);

2158.57 (10) from ^{59}Co(p,γ) (1975Er05); others: 2158.8 (4) (1970Di01) from ^{60}Co decay and 2158.9 (2) (1969Ra07) and 2159.6 (8) (1969Ho22) from ^{60}Cu decay.

For the relative γ-ray emission probabilities, the following data were used.

Relative γ-ray emission probability

γ energy (keV) =	347	467	826	1173/1332	2158	2505
Reference						
1949Fl				100		<2.5x10^{-5}
1955Wo44	<0.005			100	0.0012 (2)	
1959Mo				100		-4x10^{-5}
1968Ha03			0.19 (2)	100		
1969Ra23			<0.02	100	<0.002	
1969Va20	0.0078 (12)	<0.0004	0.0055(47)	100		
1970Di01	<0.006		<0.04	100	0.0092 (16)	<4x10^{-5}
1972Le14			0.003 (2)	100	0.0005 (2)	
1973Fu15				100	0.0020 (13)	9(7) 10^{-6}
1976Ca18	0.00758 (50)	<0.00023	0.00762(80)	100.0	0.00111 (18)	
1977HaXC				100		<0.001
1977Lo01	0.0069 (10)	<0.0012		100		
1978Fa03				100		<1.0x10^{-5}
1978Fu05				100		2.0(4)x10^{-6}
1988Se09				100		5.2(20)10^{-6}
Adopted	0.0075 (4)		0.0076 (8)	100	0.0012 (2)	2.0(4)10^{-6}

These relative emission probabilities were normalized by requiring that the total β^- emission probability is 100%. For the 1332-keV γ ray, this means :

$$
\begin{aligned}
P_\gamma(1332) &= \{100.00 - P_\gamma(2158)\times[1+\alpha(2158)] - P_\gamma(2505)\times[1+\alpha(2505)]\}\ /\ [1.00+\alpha(1332)+\alpha_\pi(1332)] \\
&= [100.00 - 0.0012(2) - 0.0000020(4)]\ /\ [1.000 + 0.000128(5) + 0.000034(4)] \\
&= 99.9988(2)\ /\ 1.000162(6) = 99.9826(6)\%.
\end{aligned}
$$

In the evaluation 1991BaZS, this value is computed in the same fashion, but is given as 99.983 (6)% ; the origin of the larger uncertainty is not clear. Similarly, for the 1173-keV γ ray, this means :

$$
\begin{aligned}
P_\gamma(1173) &= \{P_{\beta\text{-}}(2505) - P_\gamma(347)\times[1+\alpha(347)] - P_\gamma(2505)\times[1+\alpha(2505)]\}\ /\ [1.00+\alpha(1173)+\alpha_\pi(1173)] \\
&= [99.88(3) - 0.0075(4) - 0.0000020(4)]\ /\ [1.000 + 0.000168(4) + 0.0000062(7)] \\
&= 99.87(3)\ /\ 1.000174(4) = 99.85(3)\ \%.
\end{aligned}
$$

6 References

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^{63}Ni - Comments on the Evaluation of Decay Data
by K. B. Lee

This evaluation was completed in August 2005.

1. Decay Scheme

^{63}Ni disintegrates by β^- emission (100%) to the ground state of the stable nuclide ^{63}Cu.

2. Nuclear Data

The Q value (66.980 (15) keV) is from the measured value of Holzschuh (1999Ho09). This value is in agreement with 66.975 (15) keV from the atomic mass table of Audi et al. (2003Au03).

The measured ^{63}Ni half-life values are given below.

Reference	Values (years)	Comments
Brosi (1951Br)	85 (20)	Omitted from analysis
Wilson (1950Wi)	61	Omitted from analysis
McMullen (1956Mc)	125 (6)	Omitted from analysis
Horrocks (1962Ho)	93.9 (20)	Revised by Collé (1996Co25)
Barnes (1971Ba89)	101.21 (20)	Revised by Collé (1996Co25)
Collé (1996Co25)	101.06 (197)	

The first three older and less precise historical values were omitted from the analysis. The Horrocks (1962Ho) and Barnes (1971Ba89) values were revised by Collé (1996Co25) using more accurate nuclear data and thereby more rigorously calculated liquid scintillator detection efficiencies. The weighted average for the last three values is 98.7 years; with an internal uncertainty of 1.1 years; an external uncertainty of 2.4 years and a reduced-χ^2 of 4.38.

The evaluator's recommended value is the weighted average : 98.7 (24) years.

2.1 b$^-$ Transitions

The evaluator has calculated (using the LOGFT program) a *log ft* of 6.7 for this allowed transition.

The various measured β^- end-point energy values (or Q-values) are summarized below.

Reference	Values (keV)	Comments
Preiss (1957Pr)	67.0 (5)	Omitted
Hsue (1966Hs01)	65.87 (15)	Omitted
Hetherington (1987He14)	66.946 (20)	Omitted
Kawakami (1992Ka29)	66.9451 (39)	Omitted
Ohshima (1993Oh2)	66.9459 (54)	Omitted
Ohshima (1993Oh2)	66.9433 (126)	Omitted
Holzschuh (1999Ho09)	66.980 (15)	Adopted value

Uncertainties given in 1993Oh2 include systematic values combined in quadrature with statistical uncertainties.

Holzschuh et al. (1990Ho09) pointed out that in the previous measurements of end-point energies the excitation of atomic electrons was not taken into account. That means that all the other values are biased by an amount of the order of the mean electron excitation energy (85 eV). Therefore the evaluator has recommended the value given in 1990Ho09. Besides, a second end-point energy given in 1993Oh2 was obtained under the assumption of the existence of a 17 keV neutrino.

3. Atomic Data

The fluorescence yield is from the compilation of 1996Sc33.

4. Radiations

The mean energy of beta particles has been computed as 17.434 (4) keV using the LOGFT program.

4. Main Production Modes

^{62}Ni(n,γ)

6. References

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1950Wi	Wilson H. W., Phys. Rev. **79** (1950) 1032-1033 [$T_{½}$]
1956Mc	McMullen C. C., Pate B. D., Tomlinson R. H. and Yaffe L. , Can. J. Chem. **33** (1956) 1742-1746 [$T_{½}$]
1957Pr	Ivor L. Preiss, R. W. Fink and B. L. Robinson, J. Inorg. Nucl. Chem. **4** (1957) 233-236 [End-point energy]
1962Ho	Horrocks D. L. and Harkness A. L., Phys. Rev. **125** (1962) 1619-1620 [$T_{½}$]
1966Hs01	S. T. Hsue, L. M. langer, E. H. Spejewski and S. M. Tang, Nucl. Phys. **80** (1966) 657 [End-point energy]
1971Ba89	I.L. Barnes, S. B. Garfinkel and W. B. Mann, Int. J. Appl. Radiat. Isotop. **22** (1971) 777 [$T_{½}$]
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^{64}Cu - Comments on evaluation of decay data
by M.M. Bé and R.G. Helmer

This evaluation was completed in September 2010. To compare with the previous evaluation of R.G. Helmer in 2002, it includes several results published since this date (2002We02, 2007Qa02, 2010Wanke) and others obtained in the context of an Euramet exercise (2010 Bé).
Several procedures can be followed to determine the decay scheme of ^{64}Cu. In this evaluation we tried to introduce results coming from methods other than ionizing radiation measurements, in order to minimize the inherent correlation of the results.

1 Decay Scheme

The only levels in ^{64}Zn and ^{64}Ni below the decay energies are those populated in this decay, so the decay scheme is complete.

The J^{π} values and half-lives for the excited levels are from Adopted Levels in Nuclear Data Sheets (2007Si04).

2 Nuclear Data

Q values from 2003Au03 are 579.4 (7) keV for β^- decay and 1675.03 (20) keV for $\varepsilon\beta^+$decay.

The change in the half-life as a function of the chemical form or electron environment has been studied by several authors. These results are tallied after those used for the half-live evaluation.

The results of half-life measurements are listed below, in hours.

Not included in the evaluation			
	$T_{1/2}$	u_c	
(1935Am01)	10		omitted, no uncertainty
(1937He05)	12.5		omitted, no uncertainty
(1944Hu05)	11.9	1	omitted, same data as 1943Hu03
(1957Wr37)	12.87	0.05	superseded by 1972Em01
(1965He08)	13.9		omitted, no uncertainty
(1967Vi08)	12.8		omitted, no uncertainty
(1972WyZZ)	12.72	0.04	superseded by 1972Em01

The half-life values considered are, in hours:

	$T_{1/2}$	u_c	
(1936Va02)	12.8	0.1	
(1938Ri)	12.8	0.3	as cited in 1968Ke12
(1939Sa02)	12.8	0.3	as cited in 1968Ke12
(1943Hu03)	11.9	1	
(1950Ra62)	12.8	0.04	as cited in 1968Ke12

	$T_{1/2}$	u_c	
(1951Sc56)	12.74	0.07	
(1951Si91)	12.88	0.03	
(1955To07)	12.80	0.03	as cited in 1968Ke12
Rudstam	12.90	0.06	as cited in 1968Ke12
(1959Po64)	12.85	0.05	
(1965Pa18)	12.86	0.03	
(1966Fu14)	12.70	0.03	
(1966Li09)	12.86	0.03	
*(1968He20)	12.701	0.011	as cited in 1973De56
(1968Ke12)	12.80	0.04	
(1969Bo11)	12.65	0.17	
*(1972Em01)	12.715	0.007	
*(1972MeZM)	12.701	0.007	as cited in 1996Si12
(1973ArZI)	12.6	1	
*(1973De56)	12.699	0.002	
(1973Ne02)	12.82	0.04	
*(1974Ry01)	12.704	0.006	
*(1980RuZY, 1982RuZV)	12.701	0.003	
*(1989Ab22)	12.700	0.003	
*(2010Wanke)	12.705	0.005	
*(2010Bé - IFIN)	12.696	0.012	

The set of 25 unsuperseded values with uncertainties is inconsistent. The unweighted average is 12.76 (2) hours and the weighted average is 12.7025 with an internal uncertainty of 0.0013, a reduced-χ^2 of 6.3, and an external uncertainty of 0.003. It has been suggested that many of the older measurements give longer half-lives due to the presence of unidentified impurities. The value of 12.699 (2) used here for 1973De56 is the simple mean of their 22 measured values. The input value of 12.715 (7) is the evaluator's weighted average of the three values given in the paper of 1972Em01. The uncertainty given by 1989Ab22 has been increased to 0.003 to include systematic uncertainty components, but due to the very brief description of the process given in this paper, it is very difficult to assess them.

From the original set of 25 values, the most accurate ones (*) with uncertainties less than 0.012 hour have been accepted for statistical processing. In this set of nine values (1968He20, 1972Em01, 1972MeZM, 1973De56, 1974Ry01, 1980RuZY, 1989Ab22, 2010Wanke and 2010Bé - IFIN), the value of 1972Em01 was found outlier by the Chauvenet's criterion.

The adopted half-life is then the weighted average of the 8 remaining values. This average is 12.7003 with an internal uncertainty of 0.0013; an external uncertainty of 0.0007 and a reduced-χ^2 of 0.3.

As noted below, changes in this half-life of the order of 1 part in 10^4 have been reported depending on the chemical form. Since these changes are comparable to the calculated uncertainty, the adopted uncertainty has been increased to 0.0020.

This half-life has been measured, and reported, many times primarily to identify the radionuclide observed, for example, in the process of cross section measurements. Some of these values, which are not included above are: 13 (1948Mi12); 12.8 (1950Ho26); and 13.8 (14), 13.6 (7), and 12.4 (17) (1972Cr02).

Since ^{64}Cu decays, in part, by electron capture, there have been several measurements of the variation in the decay constant with the chemical form or atomic environment. The results from 1968 to 1975 are tallied in 1976Ha66 and given in the following table.

Reference and first author	**Forms compared**		**$\Delta\lambda/\lambda \cdot 10^4$**
1972Au Auric	Cu phtalocyanine in two forms		10.0 (16)
1972Em01 Emery	Cu metal	$Cu(NO_3)_2$	15 (15)
1973Ha60 Harbottle	Cu metal	CuO	0 (3)
1973De56 Dema	Cu phtalocyanine in two forms		0.4 (20)
1974Je	Cu metal	$Cu(H_2O)_6SO_4$	0.12 (9)
Jenschke	Cu metal	$Cu(H_2O)_4(NO_3)_2$	0.81 (10)
	Cu metal	Cu(2)	2.94
	Cu metal	Cu(3)	1.86
1974Jo17	Cu phtalocyanine in two forms		1.4 (23)
Johnson	Cu phtalocyanine in two forms		3.7 (58)
	Cu metal	CuO	0.0 (23)
1975MaXN	Cu metal	Cu_2S	2.3 (10)
	Cu metal	$CuInS_2$	1.5 (10)
	Cu metal	Cu_2SnS_3	1.5 (10)
	$CuInS_2$	Cu_2SnS_3	0 (1)
1979Eh01	Cu metal	atom % Cu in Ag	
Ehrhart		2	1.7 (3)
		5	1.6 (4)
		25	0.9 (4)
		50	0.7 (5)
		75	0.2 (4)
1979Ko31	Cu metal	atom % Cu in Au	
Koran		2	3.1 (4)
		5	3.0 (4)
		25	1.4 (4)
		50	0.7 (5)
		75	-0.2 (9)

The earliest measurements gave larger values of $\Delta\lambda/\lambda$, but the values beginning in 1973 range from 0 to 0.000 37 (6). These values are similar in magnitude to the uncertainty of 1.5 parts in 10^4 assigned to the adopted value. A set of measurements is also given in 1968Ke12, but the units of the results are not clear.

No dependence of the half-life with the temperature has been observed (2008Fa12).

2.1 β^-, β^+ and Electron Capture Transitions

The probabilities of the β^-, β^+ and ε branches were determined by a series of separate, but partially correlated, measurements by 1983Ch47, 1986Ka03 and 2007Qa02. These measurements included the β^- spectrum, β^+ spectrum, $4\pi\beta$-γ coincidences, liquid scintillation counting, and X- , γ- ray spectrum. Then, in 1983Ch47 their analysis contained a least-squares fit to the various measured quantities and ratios of quantities, taking the covariances into account.

Another kind of investigation made by mass spectrometry measurements of the number of atoms of ^{64}Ni and ^{64}Zn produced in the decay of a ^{64}Cu sample (2002We02) led to the determination of the $P_{\beta-}$ branching ratio.

- **β^- Transition**

The published measured probabilities of the β^- transition are:

References	**$P_{\beta-}$ (%)**	**uc (%)**	**Comments**
1983Ch47	39.04	0.33	4πβ(LS)–γ coincidence counting
1986Ka03	38.34	0.56	deduced
2002We02	38.06	0.3	Mass spectrometry
2007Qa02	38.4	1.2	2π PC – anti coincidence counting
χ^2 /n – crit χ^2	1.6	3.8	
UWM	38.46	0.21	
WM	**38.48**	**0.26**	**Adopted**

From P_β^- = 38.48 (26) %, then **$P(_\beta^+$ +ec) = 61.52 (26) %.**

- **β^+ Transition**

Two methods are possible to derive the $P(_\beta^+)$ value:

- From published measured probabilities of the β^+ transition:

References	**$P_{\beta+}$ (%)**	**uc (%)**	**Comments**
1983Ch47	17.86	0.14	Ge(Li) spectrometry
1986Ka03	17.93	0.20	HPGe γ spectrometry
2007Qa02	17.8	0.4	γ-γ coincidence counting
2010Wanke	17.56	0.16	HPGe γ spectrometry
2010Bé - CMI	17.69	0.19	HPGe γ spectrometry
2010Bé - LNHB	17.55	0.15	HPGe γ spectrometry
2010Bé – IFIN	17.65	0.60	HPGe γ spectrometry
χ^2 /n – crit χ^2	0.7	2.8	
UWM	17.72	0.06	
WM	17.71	0.07	

- From theoretical calculations, using the LOGFT program, the ratio Pec/ $P(_\beta^+)$ is: 2.485 (25), from the $P(_\beta^+ +ec_{0,0})$ = 61.05 (26) % below, the $P(_\beta^+)$ value is derived being $P(_\beta^+)$ = 17.52 (15) %.

The latter value has been obtained by an independent method and it is less correlated than the results of direct measurements. Moreover, it can be noted that the weighted mean of the four 2010 values, listed in the above table, of 17.59 (9) is very close to 17.52 (15). Thus, **$P(_\beta^+)$ = 17.52 (15) %** has been adopted in this evaluation.

- **Electron Capture Transitions**

The adopted $P_{ec0,1}$ value is deduced:

From P_{g1345} = 0.4744 (33) % (§ 2.4), then **$P_{ec0,1}$ = 0.4744 (33) %,**

and with $P(_\beta^+$ +ec) = 61.52 (26) %, **$P(_\beta^+ +ec_{0,0})$ = 61.05 (26)%.**

From the two values of P($_\beta$$^+$) as determined above two $P_{ec0,0}$ can be derived:

- With P($_\beta$$^+$) = 17.71 (7), P($ec_{0,0}$) = 43.34 (27) %,
- With P($_\beta$$^+$) = 17.52 (15), P($ec_{0,0}$) = 43.53 (20) %.

These values can be compared with the three experimental results obtained for the total P_{ec} (1983Ch47, 1986Ka03, 2007Qa02):

References	**Total P_{ec}**	**uc (%)**	**Comments**
1983Ch47	43.10	0.46	4πβ(LS)–γ coincidence counting
1986Ka03	43.73	0.52	4πβγ(PC)–γ coincidence counting + HPGe γ spectrometry + 4πβ–γ coincidence counting
2007Qa02	43.8	1.4	Si(Li) X-ray spectrometry
χ^2 /n – crit χ^2	0.5	4.6	
UWM	43.54	0.22	P($ec_{0,0}$) = 43.07 (33)
WM	43.40	0.33	P($ec_{0,0}$) = 42.93 (33)

The unweighted and the weighted means above are consistent, within the uncertainty limits, with P($ec_{0,0}$) = 43.34 (27) % calculated from experimental $P_{\beta+}$ values. This was expected since they were derived from the same sets of measurements.

The set of two values: **P($_\beta$$^+$) = 17.52 (15) % and P($ec_{0,0}$) = 43.53 (20) %** has been adopted in this evaluation because it was derived from another different method (using theoretical Pec/ P($_\beta$$^+$) ratio).

The average particle energies to the ^{64}Ni and ^{64}Zn ground states are 278.2 (9) and 190.7 (3) keV, respectively, and are from the LOGFT code. The log ft values to the ^{64}Ni ground state and level of 1345 keV are 4.973 (3) and 5.501 (6), respectively, and to the ^{64}Zn ground state - 5.302 (3), all of which are consistent with allowed transitions from the 1$^+$ parent state.

2.2 Gamma Transitions

The J$^\pi$ assignments are from the Adopted Levels in the Nuclear Data Sheets (2007Si04) and these imply the γ-ray has E2 multipolarity.

The internal-conversion coefficients (ICC) were interpolated from the tables of Band *et al.* (2002Ba85) by using the computer code BrIcc (2008Ki07) with the so called "Frozen orbital" approximation.

The internal-pair-formation coefficient was interpolated from the theoretical values and it is IPFC(1345) = 0.000 039.

From the ICC values and gamma ray emission intensity I_{g1345} = 0.4743 (33) % (§ 4.2), the 1345 keV gamma transition probability and electron capture probability to the first excited level in ^{64}Ni are deduced being: P_{g1345} = $P_{ec0,1}$ = 0.4744 (33) %.

3 Atomic Data

The data are from 1996Sc06.

4 Radiation Emissions

4.1 Electron Emissions

Auger electron emission intensities are deduced from the evaluated data set.

4.2 Photon Emissions

X-ray emission intensities are deduced from the evaluated data set.

The γ-ray energy is 1345.77 (6) keV from 1974HeYW.

The intensity of the 1345 keV gamma ray is deduced from the measured values:

Reference	$I_{\gamma 1345}$ (%)	uc (%)	Comments
1983Ch47	0.471	0.011	HPGe γ spectrometry
1986Ka03	0.487	0.020	HPGe γ spectrometry
2007Qa02	0.54	0.03	HPGe γ spectrometry
2010Wanke	0.474	0.005	HPGe γ spectrometry
2010Bé - CMI	0.476	0.006	HPGe γ spectrometry
2010Bé - LNHB	0.467	0.011	HPGe γ spectrometry
2010Bé- IFIN	0.481	0.017	HPGe γ spectrometry
χ^2 /n – crit χ^2	0.24	3	
UWM	0.476	0.0029	
WM	0.4743	0.0033	Adopted

5 Various comparisons

The following tables summarize values of some ratios measured or deduced in the publications compared with those derived from the present data set. Both are in agreement within the uncertainty limits.

- P_{β^-} / P_{β^+} ratio

Reference	P_{β^-} / P_{β^+}	uc	Remark
1946Br03	2.1		
1949Bo16	2.00	0.15	
1983Ch47	2.187	0.007	
1986Ka03	2.138	0.032	
χ^2 /n – crit χ^2	2.2	6.6	
UWM	2.163	0.025	Value deduced from the present adopted data set: 2.196 (24)
WM	2.185	0.010	

- $I_{\gamma 1345}$ / P(β^+) ratio

Reference	$I_{\gamma 1345}$ / P(β^+)	uc	Remark
1956Dz26	0.020 7		
1952Vl03	0.023	0.004	Omitted, outlier
1959Sc71	0.028 0	0.002 4	Omitted, outlier
1983Ch47	0.026 4	0.000 6	
1986Ka03	0.027 2	0.001 2	
2007Qa02	0.030 3	0.001 8	Omitted, outlier
2010Wanke	0.026 99	0.000 38	
2010Bé - CMI	0.026 91	0.000 45	
2010Bé - LNHB	0.026 6	0.000 7	
χ^2 /n – crit χ^2	0.23	3.3	
UWM	0.026 82	0.000 14	Value deduced from the present adopted data set: 0.027 06 (30)
WM	0.026 84	0.000 24	

6 Main production modes

They are taken from: Table de Radionucléides, F; Lagoutine, N. Coursol, J. Legrand. ISBN 2 7272 0078-1

7 Other earlier publications not used in the evaluation

- H. von Bradt (1946Br03)
$P_{\beta^-} / P_{\beta^+} = 2.1$

- R. Bouchez (1949Bo16)
$P_{\beta^-} / P_{\beta^+} = 2.00$ (15)

- Reynolds (1950Re51)
$P(_{\beta^+ + ec}) / P_{\beta^-} = 1.62$ (11)
$P(_{ecK}) / P(_{\beta^+}) = 2.32$ (28)

- Vlaar (1952Vl03)
$I_{\gamma 1345} / P(_{\beta^+}) = 0.023$ (4)

- Dzelepov *et al.* (1956Dz26)
$I_{\gamma 1345} / P(_{\beta^+}) = 0.0207$

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^{65}Zn - Comments on evaluation of decay data
by M.M. Bé, V. Chisté and R. G. Helmer

1 Decay scheme

This evaluation was originally completed in September 1996. New evaluation was completed in January 2005 taking into account results obtained as a part of a specific exercise dedicated to the ^{65}Zn activity and emission intensity measurements managed by the Euromet organization.

The decay scheme is complete since only two excited levels in ^{65}Cu below the decay energy are populated. Also, there is excellent agreement between the total decay energy of 1352.1 (19) keV computed from the evaluated decay scheme and the Q value of 1352.1 (3) keV.

2 Nuclear Data

Q = 1352.1 (3) value is from Audi *et al.* (2003Au03).

The measured ^{65}Zn half-life values, in days, are as follow:

245.0 (8)	1953To17	
243.5 (8)	1957Ge07	
246.4 (22)	1957Wr37	outlier
243.1 (7)	1965An07	replaced by 1982HoZJ
244.12 (12)	"	replaced by 1982HoZJ
242.78 (19)	"	omitted from analysis
243 (4)	1968Ha47	
258 (4)	1972Cr02	omitted from analysis
246 (5)	"	"
251 (6)	"	"
252 (6)	"	"
244.0 (2)	1972De24	replaced by 2004Va02
244.52 (7)	1973Vi13	Uncertainty given per 3 σ
244.3 (4)	1974Cr05	
243.75 (12)	1975La16	replaced by 2003Lu06
244.2 (1)	1982HoZJ	replaced by 1992Un01
243.97 (8)	1982DeYX	replaced by 1983Wa26
243.9 (3)	1983Wa26	replaced by 2004Sc04
244.16 (10)	1992Un01	(or 2002Un02)
244.15 (10)	2003Lu06	
243.66 (9)	2004Sc04	
243.8 (3)	2004Va02	
244.01 (9)	**Adopted**	

The four values of 1972Cr02 were omitted because they were not intended as $T_{1/2}$ measurements, but rather to determine the origin of certain γ-rays.

The very small uncertainty, 0.07 (3.3 σ), given by 1973Vi13 appears unrealistic when compared to the other quoted uncertainties at the same period of time, at least this uncertainty value should be increased. Moreover, this result is far from the mean and the published paper not detailed enough, so this result is omitted from analysis.

The value of 1957Wr37 was found outlier according to the Chauvenet's criterion.

As a rule, only one result per laboratory is retained in order to avoid possible correlation.

Then, the weighted average of the remaining eight values is 244.01 with an internal uncertainty of 0.05, an external uncertainty of 0.09 and, a reduced-χ^2 of 3.11 (the critical reduced-χ^2 is 2.60), no input value has more than 50% of the weight. The Lweight program suggested to expand the uncertainty to 0.31 in order to include the most precise value of 243.66 within its range.

But a small increased of the uncertainty given by 2004Sc04 from 0.09 to 0.11 leads to a reduced-χ^2 of 2.48 less than the critical one, then the Lweight program recommended the internal uncertainty as final uncertainty.

With these results in mind, the evaluator has chosen the weighted average and the external uncertainty.

2.1 Electron Capture Transitions

The ε branch to the 770-keV level is 2nd forbidden. From the log *ft* systematics (1973Ra10), the expected log *ft* value is > 11.0 and the corresponding $I_\varepsilon(0)$ is < 0.003%.

The P_K etc. values are computed from the Schönfeld tables (1995ScZY) for allowed transitions.

Level energy (keV) =	0	1115
P_K (S)	0.8853 (16)	0.8794 (17)
P_L (S)	0.0977 (15)	0.1027 (16)

The total branching ratios to each level were computed from the measured Iγ and adopted theoretical conversion coefficients.

The total branching (ε + β^+) to the ground state is 49.77 (11) %. From the 511-keV gamma emission intensity measurements, the β^+ transition probability is deduced as 1.421 (7) % (see § Photon emissions).

The LOGFT program gives the theoretical ε/β^+ ratio as 34.03 (18). Using the (ε + β^+) branching to the ground state as 49.77 (11) % ; the β^+ transition probability is then 1.42 (1)%. This value is in good agreement with the experimental observations.

From the LOGFT program, the theoretical ε_K/β^+ ratio is calculated as 29.86. This value can be compared with the corresponding experimental values of:

28.0 (32)	1953Pe14
30.3 (12)	1963Ta04
27.7 (15)	1968Ha47
31.3 (20)	1977Bo10
30.7 (11)	1984ScZP
30.3 (10)	1990Ku11

The measured 1115 γ/β^+ ratio is 35.1 (17) (1968Ha47).

For comparison with the adopted value for the β^+ transition probability of 1.421 (7)%, the measured values are :

	$I_{\beta+}$ (%)
1959Gl55	1.70 (10)
1962Be28	1.2 (3)
1963Ta04	1.40 (4)
1972De24	1.46 (2)

2.2 Gamma Transitions

The multipolarities are from the adopted γ-ray data (deduced from Coulomb excitation study and angular correlation data) in the journal Nuclear Data Sheets (1993Bh04).
The internal-conversion coefficients are interpolated from the tables of Band (2002Ba85). Mixing ratio of the 1115-keV transition is from Krane (1976Kr09). The ICC values for this high energy transition is very low so the influence of the uncertainty for the mixing ratio is negligible.
For the 1115-keV transition, the total and K-shell values of 1.85 (7) × 10^{-4} and 1.66 (6) × 10^{-4} respectively, evaluated by Hansen (1985HaZA) from measured values are in excellent agreement with the theoretical ones.

From the theoretical tables of 1979Sc31, the internal-pair-formation coefficients are α_π(1115, M1) = 1.2 × 10^{-6} and α_π(1115,E2) = 1.6 × 10^{-6}, so α_π(1115) =1.3 × 10^{-6}. This value is about 1% of the internal-conversion coefficient and therefore is negligible.

3 Atomic Data (Cu, Z=29)

Data are from 1996Sc06.

4.1 Electron Emission

The β^+ intensity to the ground state was deduced from the measured intensity of the 511-keV gamma ray.

4.2 Photon Emissions

The γ-ray energies are from the evaluation of Helmer *et al.* (2000He14) for the 1115-keV line where the values are on a scale on which the strong line from the decay of ^{198}Au is 411.80205 (17); from level energy differences for the 344-keV line; and from ^{65}Cu Adopted γ data in Nuclear Data Sheets (1993Bh04) and based on data from ^{65}Ni β^- decay for 770-keV line.

Photon emission intensities are deduced from the Euromet exercise results (2005Be**) and from other published values.

Absolute measured intensities of the 1115-keV line

	I (1115) (%)	Uc	
1959Gl55	51.3	3.0	
1960Go	46		
1963Ta04	50.7	0.5	
1966Ra21	51.3	1.5	
1968Ha47	52.4	1.0	Outlier
1972De24	50.75	0.10	Replaced by Euromet participant
1973Po10	49.3	0.8	
1982DeYX	50.39	0.26	replaced by 1990Sc08
1990Sc08	50.2	0.4	Replaced by Euromet participant
2003Lu06	49.76	0.21	Replaced by Euromet participant
Euromet-01	50.15	0.28	
Euromet-02	50.10	0.33	
Euromet-03	50.60	0.29	
Euromet-04	50.34	0.25	
Euromet-05	49.84	0.25	
Euromet-06	50.05	0.57	
Euromet-07	49.62	0.65	
Euromet-08	50.7	0.5	
Euromet-09	50.3	0.5	
Adopted	**50.22**	**0.11**	

The first part of the above Table lists the results published in various journals and the second part lists the values obtained as a part of the Euromet exercise (2005Be*).
The value from 1968Ha47 is omitted as outlier due to application of the Chauvenet's criterion. The results from 1972De24, 1990Sc08 and 2003Lu06 have been superseded by the results obtained by laboratories which have participated in the present Euromet exercise.

The LRSW analysis of the remaining 13 values gives a reduced χ^2 of 0.77 so the weighted mean of 50.22 and the internal uncertainty of 0.11, are adopted as final result.

344- and 770-keV Relative g-ray emission intensities :

γ-ray energy (keV)	I(344)	I(770)	I(1115)
1960Ri06	≤ 0.5	≤ 1	100
1968St05	0.0060 (6)		100
Euromet-02	0.005067 (365)	0.005358 (439)	100
Euromet-09	0.00220 (86)	0.003 (17)	100
Adopted relative	0.005067 (365)	0.005358 (439)	100
Adopted absolute	0.00254 (18)	0.00269 (22)	50.22 (11)

The adopted relative values are those given by the participant 2 in the Euromet exercise. This participant activated Zinc (99.99 %) foil by thermal neutrons and obtained a Zn-65 activity of the order of 10 MBq, so he had a better counting statistic and then a better uncertainty.

511-keV photon emission

This particular emission is due to the annihilation of the β^+ positrons in the source and in the surrounding material (annihilation-in-flight). In γ-ray spectrometry, this phenomenon has the effect of removing, from the 511-keV peak, a fraction of the annihilation photons, the magnitude of this effect depends on the material in which the β^+ are stopped and then must be calculated by each experimentalist.

reference	Intensity (%)	Uc	Correction for annihilation, in %
1990Sc08	2.84*	0.04	0.5
Euromet-01	2.81 *	0.03	0.2
Euromet-02	2.841 *	0.027	Wider peak region
Euromet-03	2.75	0.017	
Euromet-04	3.00	0.018	
Euromet-05	2.848 *	0.020	0.34
Euromet-07	2.86	0.04	
Euromet-09	2.88 *	0.04	0.5

(*) taking annihilation-in-flight into account, magnitude given in the last column.

Reference 1990Sc08 is superseded by one of the Euromet participant. The weighted mean and standard uncertainty of the four values taking annihilation-in-flight into account, are : 2.842 ± 0.013 %.

The emission of additional 511-keV photons created by electron-positron pair creation is negligible (see § Gamma transitions).

X-ray emissions and Auger electron emissions

From the gamma-ray emission intensities, the internal conversion coefficients, the electron capture probabilities and electron capture sub shell probabilities, the X-ray and Auger electron emission intensities have been deduced.

Calculated K X-ray are compared with the measured values in the following table.

	Kα		Kβ		KX	
Reference	Intensity	Uc	Intensity	Uc	Total	Uc
1963Ta19					40.0	0.6
1968Ha47					39.27	0.26
1968Ba**					38.66	0.17
1973Mu**					38.0	1.0
Euromet-05	32.1	1.6	4.50	0.023	36.6	1.6
Euromet-09	39	3.5	5.2	0.47	44.2	3.5
Weighted mean					38.87	0.22
Calculated	34.7	0.4	4.82	0.07	39.5	0.4

The weighted mean of the KX measured values (except Euromet-09 which is outlier) is lower than the calculated value deduced from the decay scheme. They barely agree within their uncertainty limits.

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^{66}Ga – Comments on evaluation of decay data
by E. Browne

1. Statistical Analysis of Data

The ***Limitation of Relative Statistical Weight*** (LWM) [1985ZiZY] method, used for averaging numbers throughout this evaluation, provided a uniform approach for the analysis of discrepant data. The uncertainty assigned in this evaluation to the recommended value is always greater than or equal to the smallest uncertainty in any of the experimental values used in the calculation.

2. Decay Scheme

^{66}Ga decays 56 (4) % by positron (β^+) emission and 44 (4) % by electron capture (ε) to ^{66}Zn ($Q(\varepsilon)$ = 5175(3) keV (1995Au04)). About 140 γ-rays de-exciting 31 nuclear levels in ^{66}Zn are known. Emission of conversion electrons is very low and negligible compared to that of γ rays (photons) because of the low atomic number (Z = 30) of the daughter nucleus (^{66}Zn) and the high energy (> 1000 keV) of the most intense γ-ray transitions. Consequently, neither conversion coefficients (most of them < 2×10^{-4}) nor a list of conversion electrons is given in this evaluation.

Evaluator has normalized the decay scheme using experimental results from 1960Sc06, decay-scheme information, and theory. As expected from the spins and parities of ^{66}Ga (0+) and ^{66}Zn (0+), there is a significant $\varepsilon+\beta^+$ feeding (51(4)%) to the ground state of ^{66}Zn. Electron-capture and β^+ transition probabilities to excited states in ^{66}Zn given in Section 2.1 are from γ-ray transition probability balance at each level and theoretical ε/β^+ ratios. The decay scheme shown here is that of 1998Bh02 with the addition of levels half-lives from 2002Ga20.

3. Nuclear Data

The recommended half-life of ^{66}Ga, 9.49(7) hours, is a weighted average (LWM, χ^2/ν=2.9) of 9.57(6) hours (1956Ru45), 9.50(10) hours (1959Ca15), and 9.33(8) hours (1964Ru06). Other values are: 9.45 hours (1950La55), and 9.35 hours (1967Va13).

$Q(\varepsilon)$=5175(3) keV is from 1995Au04.

4. Gamma Rays

Energies

γ-ray energies in Table 1 given in boldface are from 2000He14. These values are based on a revised energy scale that uses the new adjusted fundamental constants and wave lengths deduced from an updated value of the lattice spacing of Si crystals [Cohen and Taylor [1]]. Helmer and van der Leun (2000He14) fitted the adjusted γ-ray energies of ^{66}Ga to a level scheme, and deduced their recommended values from level-energy differences. Less precise energies are from 1993Al15 and 1994En02, but adjusted to those of 2000He14 using a least-squares procedure. Evaluator has considered the difference between these two energy scales to be a systematic adjustment that he applied to the recommended energies given here. Thus, the uncertainties in the γ-ray energies given in this evaluation are just statistical, as reported by authors. See Table 1.

Emission Intensities

The relative emission probabilities of the most intense γ rays (given in boldface) in Table 2 are values recommended in 2002Ba38 and in this evaluation. These are weighted averages (LWM) of results from Berkeley, Budapest, and of 2000Ra36. Some of the uncertainties given in 2002Ba38, however, may be smaller than those given here, which are always greater than or equal to the smallest uncertainty in any of the experimental values used in the calculation.

Relative emission probabilities of other γ rays are weighted averages (LWM) of values from 1970Ph01, 1971Ca14, and 1994En02, each corrected by evaluator for a systematic error in the detector efficiency above ~ 1100 keV. This error was caused by an inadequate extrapolation of the detector efficiency to higher energies, and affected its value by as much as 30% at 4806 keV (1975Mc07).

The correction factor ($F = 1.116 - 0.155\ E_\gamma(\mathrm{MeV}) + 0.0397\ E_\gamma^2(\mathrm{MeV})$) given in 2002Ba38 has been used here. Uncertainties in the recommended relative emission probabilities are only statistical and have been deduced from those given in the individual measurements (see Table 2).

Absolute emission intensities given here are based on experimental results and decay-scheme normalization arguments as follows:

$I_{ce}(1039\ \gamma)/I_{\beta+}(gs) = 2.08(10) \times 10^{-4}$ (1960Sc06)

$I_{\beta+}(gs)/\Sigma\ I_{\beta i}^{+} = 0.8697$ (1960Sc06)

$I_{ce}(1039\ \gamma, E2)/I_\gamma(1039\ \gamma) = 2.69(8) \times 10^{-4}$ (Theory, 1978Rö22).

Therefore,

$I_\gamma(1039\ \gamma)/\Sigma\ I_{\beta i}^{+} = 2.08(10) \times 10^{-4} \times 0.8697/2.69(8) \times 10^{-4} = 0.67(4)$.

Also $\Sigma\ I_{\beta i}^{+}/\Sigma\ I_{\varepsilon i} = 1.265$ from decay scheme and theoretical values of $I_{\beta i}^{+}/\varepsilon_i$ for each level. Using

$\Sigma\ I_{\beta i}^{+} + \Sigma\ I_{\varepsilon i} = 100$ %, gives $\Sigma\ I_{\beta i}^{+} = 55.8(24)$ %, and

$I_\gamma(1039\ \gamma) = 0.67(4) \times 55.8(24) = 37(3)$ %.

Absolute γ-ray emission intensities given in Section 5.2 are relative values multiplied by 0.37(3).

5. Positron (b^{+}) Transitions

Positron end-point energies given in section 2.1.1 ($E_\beta^{+} = Q(\varepsilon) - E(\mathrm{keV}) - 1022$) are evaluator's values deduced using Q(ε) = 5175(3) keV (1995Au04) and level energies (E(keV)) from decay scheme. Absolute β^{+} emission probabilities are from γ-ray intensity balance at each nuclear level and theoretical $I_{\beta\iota}^{+}/\varepsilon_i$ ratios.

6. Electron Capture (e) Transitions

ε transition energies (E(ε) = Q(ε) – E(keV)) are evaluator's values deduced using Q(ε) = 5175(3) keV (1995Au04) and level energies (E(keV)) from decay scheme. Absolute ε transition probabilities are from γ-ray probability balance at each nuclear level and theoretical $I_{\beta i}^{+}/\varepsilon_i$ ratios. Fractional atomic shell electron-capture probabilities (P_K, P_L, P_M) are evaluator's values calculated using the EC-CAPTURE computer program [2] and the nuclear level energies presented here.

7. Atomic Data

The X-ray and Auger electron energies given in sections 3, 4 are from Schönfeld and Rodloff [4] and [5], respectively. Emission intensities are evaluator's values calculated using the EMISSION (Version V.3.04) [3] program, atomic data from 1996Sc06, and the recommended γ-ray emission intensities from section 5.2.

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Table 1. ^{66}Ga Gamma-Ray Energies

1993Al15, 1994En02	1993Al15	2000He14	2000He14	Fitted
E$_g$ (keV)	DE$_g$ (keV)	E$_g$ (keV)	DE$_g$ (keV)	E$_g$ (keV)
171.9	0.2			171.9 (2)
283.87	0.03			283.87 (3)
290.808	0.011			290.8105(11)
347.77	0.05			347.77 (5)
375.396	0.017			375.398 (17)
410.177	0.012			410.178 (12)
412.915	0.016			412.916 (16)
442.872	0.014			442.873 (14)
448.725	0.02			448.73 (2)
459.682	0.014			459.683 (14)
494.336	0.013			494.336 (13)
499.59	0.006			499.590 (6)
551.284	0.022			551.284 (22)
554.28	0.03			554.28 (3)
557.13	0.05			557.13(5)
562.241	0.01			562.241 (10)
578.54	0.019			578.540 (19)
600.789	0.021			600.788 (21)
653.569	0.014			653.568 (14)
658.57	0.03			658.57 (3)
670.252	0.014			670.251 (14)
680.56	0.1			680.56 (10)
686.084	0.007	**686.080**	0.006	**686.080 (6)**
705.033	0.015			705.031 (15)
708.36	0.05			708.36 (5)
718.97	0.05			718.97 (5)
723.17	0.05			723.17 (5)
749.68	0.1			749.68 (10)
763.64	0.03			763.64 (3)
796.21	0.05			796.21 (5)
800.13	0.05			800.13 (5)
833.537	0.003	**833.5324**	0.0021	**833.5324 (21)**
853.046	0.009	**853.038**	0.008	**853.038 (8)**
856.53	0.01			856.527 (10)
857.096	0.009			857.093 (9)
862.929	0.013			862.926 (13)
867.93	0.03			867.93 (3)
873.395	0.021			873.392 (21)
885	0.05			885.00 (5)
907.394	0.019			907.390 (19)
914.392	0.014			914.388 (14)
929.68	0.03			929.68 (3)
953.93	0.09			953.93 (9)
954.12	0.07			954.12 (7)
963.896	0.015			963.892 (15)
980.938	0.013			980.934 (13)
1008.593	0.012			1008.588 (12)
1010.962	0.019			1010.957 (19)
1015.086	0.018			1015.081 (18)
1039.231	0.006	**1039.22**	0.003	**1039.220 (3)**

1993Al15, 1994En02 **E_g (keV)**	**1993Al15** **DE_g (keV)**	**2000He14** **E_g (keV)**	**2000He14** **DE_g (keV)**	**Fitted** **E_g (keV)**
1060.056	0.011			1060.051 (11)
1065.31	0.009			1065.305 (9)
1066.455	0.012			1066.450 (12)
1082.754	0.02			1082.75 (2)
1106.54	0.24			1106.53 (24)
1129.929	0.018			1129.923 (18)
1135.48	0.09			1135.47 (9)
1147.9	0.012	**1147.896**	0.010	1147.896 (10)
1190.297	0.008	**1190.287**	0.007	1190.287 (7)
1195.33	0.09			1195.32 (9)
1232.271	0.008			1232.264 (8)
1232.487	0.015			1232.480 (15)
1248.786	0.022			1248.779 (22)
1274.51	0.03			1274.50 (3)
1298.96	0.07			1298.95 (7)
1305.815	0.021			1305.807 (21)
1333.12	0.006	**1333.112**	0.005	**1333.112 (5)**
1356.112	0.009			1356.104 (9)
1356.328	0.015			1356.320 (15)
1357.258	0.012			1357.250 (12)
1409.36	0.24			1409.35 (24)
1418.763	0.006	**1418.754**	0.005	**1418.754 (5)**
1425.256	0.02			1425.25 (2)
1433.64	0.04			1433.63 (4)
1458.67	0.012	**1458.662**	0.012	**1458.662 (12)**
1468.98	0.05			1468.97 (5)
1508.175	0.011	**1508.158**	0.007	**1508.158 (7)**
1515.172	0.02			1515.162 (20)
1523.289	0.015			1523.279 (15)
1534.61	0.04			1534.60 (4)
1554.63	0.03			1554.62 (3)
1559.637	0.01			1559.627 (10)
1577.318	0.02			1577.308 (20)
1634.47	0.07			1634.46 (7)
1703.6	0.05			1703.59 (5)
1713.614	0.012			1713.602 (12)
1740.918	0.018	**1740.904**	0.016	1740.904 (16)
1787.45	0.09			1787.44 (9)
1797.95	0.09			1797.94 (9)
1868.118	0.02			1868.105 (20)
1872.753	0.006			1872.740 (6)
1898.832	0.009	**1898.823**	0.008	**1898.823 (8)**
1918.341	0.006	**1918.329**	0.005	**1918.329 (5)**
1927.97	0.04			1927.96 (4)
2009.643	0.016			2009.628 (16)
2026.031	0.025			2026.016 (25)
2065.792	0.008	**2065.778**	0.007	**2065.778 (7)**
2085.88	0.04			2085.86 (4)
2089	0.013			2088.985 (13)
2173.334	0.018	**2173.319**	0.015	**2173.319 (15)**
2189.631	0.009	**2189.616**	0.006	**2189.616 (6)**

1993Al15, 1994En02	**1993Al15**	**2000He14**	**2000He14**	**Fitted**
E$_{g}$ (keV)	**DE$_{g}$ (keV)**	**E$_{g}$ (keV)**	**DE$_{g}$ (keV)**	**E$_{g}$ (keV)**
2213.19	0.011	**2213.181**	0.009	**2213.181 (9)**
2265.86	0.24			2265.84 (24)
2292.188	0.013			2292.171 (13)
2341.691	0.011			2341.673 (11)
2393.153	0.01	**2393.129**	0.007	**2393.129 (7)**
2422.544	0.009	**2422.525**	0.007	**2422.525 (7)**
2433.826	0.018			2433.807 (18)
2467.99	0.07			2467.97 (7)
2492.44	0.03			2492.42 (3)
2537.11	0.05			2537.09 (5)
2588.573	0.013			2588.553 (13)
2631.46	0.09			2631.44 (9)
2698.94	0.05			2698.92 (5)
2713.75	0.05			2713.73 (5)
2751.852	0.006	**2751.835**	0.005	**2751.835 (5)**
2780.12	0.018	**2780.095**	0.016	**2780.095 (16)**
2785.7	0.3			2785.7 (3)
2802.8	0.5			2802.8 (5)
2843.153	0.016			2843.130 (16)
2933.395	0.017	**2933.358**	0.009	2933.358 (9)
2977.12	0.05	**2977.083**	0.043	2977.083 (43)
2993.25	0.04	**2993.208**	0.032	2993.208 (32)
3046.697	0.011	**3046.684**	0.009	3046.684 (9)
3085.4	0.4			3085.4 (4)
3212.526	0.019			3212.499 (19)
3228.824	0.009	**3228.800**	0.006	**3228.800 (6)**
3256.048	0.009			3256.021 (9)
3331.379	0.014			3331.351 (14)
3380.882	0.01	**3380.850**	0.006	**3380.850 (6)**
3422.075	0.012	**3422.040**	0.008	**3422.040 (8)**
3432.343	0.01	**3432.309**	0.007	**3432.309 (7)**
3738.13	0.05			3738.10 (5)
3766.893	0.018	**3766.850**	0.009	**3766.850 (9)**
3791.036	0.008			3791.004 (8)
3810.62	0.05			3810.59 (5)
4085.875	0.012	**4085.853**	0.009	**4085.853 (9)**
4295.224	0.01			4295.187 (10)
4461.247	0.013	**4461.202**	0.009	**4461.202 (9)**
4806.06	0.018	**4806.007**	0.009	**4806.007 (9)**
4865.91	0.04			4865.87 (4)
5005.62	0.23			5005.6 (3)

$Y = A + BX$ and input energies (X) from 1994En02.

Table 2: ^{66}Ga Relative Gamma-Ray Emission Intensities

Eg (keV)	1970Ph01 Ig	1970Ph01* Ig(Corr.)	1971Ca14 Ig	1971Ca14* Ig(Corr.)	1994En02 Ig	1994En02* Ig(Corr.)	2000Ra00 Ig	Berkeley Ig	Budapest Ig	Recomm. Ig	Remarks
171.9 (2)	0.028 (1)	0.028 (1)								0.028 (1)	O
283.87 (3)					0.0097 (21)	0.0097 (21)				0.0097 (21)	I
290.8105 (11)	0.150 (10)	0.150 (10)	0.131 (2)	0.131 (2)	0.146 (6)	0.146 (6)				0.133 (4)	A
347.77 (5)					0.0048 (15)	0.0048 (15)				0.0048 (15)	I
375.398 (17)					0.0058 (16)	0.0058 (16)				0.0058 (16)	I
410.178 (12)	0.300 (20)	0.300 (20)	0.172 (24)	0.172 (24)	0.177 (7)	0.177 (7)				0.177 (7)	I
412.916 (16)					0.0091 (13)	0.0091 (13)				0.0091 (13)	I
442.873 (14)					0.042 (3)	0.042 (3)				0.042 (3)	I
448.73 (2)	0.290 (10)	0.290 (10)	0.279 (58)	0.279 (58)						0.290 (10)	C
459.683 (14)	0.240 (10)	0.240 (10)	0.206 (35)	0.206 (35)						0.237 (10)	C
494.336 (13)					0.0152 (20)	0.0152 (20)				0.0152 (20)	I
499.590 (6)					0.013 (3)	0.013 (3)				0.013 (3)	I
551.284 (22)					0.0189 (16)	0.0189 (16)				0.0189 (16)	I
554.28 (3)					0.0122 (13)	0.0122 (13)				0.0122 (13)	I
557.13(5)					0.0166 (17)	0.0166 (17)				0.0166 (17)	I
562.241 (10)					0.0179 (17)	0.0179 (17)				0.0179 (17)	I
578.540 (19)	0.160 (10)	0.160 (10)	0.156 (20)	0.156 (20)						0.159 (10)	C
600.788 (21)					0.0365 (23)	0.0365 (23)				0.0365 (23)	I
653.568 (14)					0.0036 (12)	0.0036 (12)				0.0036 (12)	I
658.57 (3)					0.0203 (21)	0.0203 (21)				0.0203 (21)	I
670.251 (14)					0.0110 (18)	0.0110 (18)				0.0110 (18)	I
680.56 (10)					0.0040 (11)	0.0040 (11)				0.0040 (11)	I
686.080 (6)	0.690 (20)	0.690 (20)	0.645 (40)	0.645 (40)						0.681 (20)	C
705.031 (15)					0.0102 (11)	0.0102 (11)				0.0102 (11)	I
708.36 (5)					0.0234 (19)	0.0234 (19)				0.0234 (19)	I
718.97 (5)					0.0268 (20)	0.0268 (20)				0.0268 (20)	I
723.17 (5)					0.0093 (13)	0.0093 (13)				0.0093 (13)	I
749.68 (10)					0.0037 (11)	0.0037 (11)				0.0037 (11)	I
763.64 (3)					0.0240 (20)	0.0240 (20)				0.0240 (20)	I
796.21 (5)					0.0079 (17)	0.0079 (17)				0.0079 (17)	I
800.13 (5)					0.0027 (14)	0.0027 (14)				0.0027 (14)	I
833.5324 (21)	16.2 (7)	16.2 (7)	15.92 (17)	15.92 (17)			16.02 (24)	15.94 (14)	15.92 (6)	**15.93 (6)**	K
853.038 (8)			0.200 (5)	0.200 (5)	0.232 (12)	0.232 (12)				0.205 (5)	D
856.527 (10)			0.315 (10)	0.315 (10)	0.280 (12)	0.280 (12)				0.301 (17)	D

Recomm. Eg (keV)	1970Ph01 Ig	1970Ph01* Ig(Corr.)	1971Ca14 Ig	1971Ca14* Ig(Corr.)	1994En02 Ig	1994En02* Ig(Corr.)	2000Ra00 Ig	Berkeley Ig	Budapest Ig	Recomm. Ig	Remarks
857.093 (9)					0.040 (12)	0.040 (12)				0.040 (12)	I
862.926 (13)					0.0410 (20)	0.0410 (20)				0.0410 (20)	I
867.93 (3)					0.0117 (14)	0.0117 (14)				0.0117 (14)	I
873.392 (21)					0.046 (3)	0.046 (3)				0.046 (3)	I
885.00 (5)					0.0051 (13)	0.0051 (13)				0.0051 (13)	I
907.390 (19)	0.300 (20)	0.300 (20)	<0.034 (10)		0.059 (4)	0.059 (4)				0.059 (4)	E
914.388 (14)	0.190 (10)	0.190 (10)	<0.030 (10)		0.073 (4)	0.073 (4)				0.073 (4)	E
929.68 (3)					0.0123 (15)	0.0123 (15)				0.0123 (15)	I
953.93 (9)					0.0027 (3)	0.0027 (3)				0.0027 (3)	I
954.12 (7)					0.0121 (17)	0.0121 (17)				0.0121 (17)	I
963.892 (15)					0.039 (3)	0.039 (3)				0.039 (3)	I
980.934 (13)	0.150 (20)	0.150 (20)	0.130 (5)	0.130 (5)						0.131 (5)	C
1008.588 (12)	0.183 (10)	0.183 (10)	0.138 (4)	0.138 (4)						0.160 (20)	C
1010.957 (19)					0.073 (4)	0.073 (4)				0.073 (4)	I
1015.081 (18)					0.033 (8)	0.033 (8)				0.033 (8)	I
1039.220 (3)	100	100	100	100	100	100	100.0 (16)	100.0 (9)	100.0 (3)	**100.0 (3)**	K
1060.051 (11)			0.033 (10)	0.033 (10)	0.043 (3)	0.043 (3)				0.042 (3)	F
1065.305 (9)					0.0063 (12)	0.0063 (12)				0.0063 (12)	I
1066.450 (12)					0.0064 (12)	0.0064 (12)				0.0064 (12)	I
1082.75 (2)					0.036 (2)	0.0358 (20)				0.0358 (20)	I
1106.53 (24)					0.0033 (10)	0.0033 (10)				0.0033 (10)	I
1129.923 (18)					0.0370 (21)	0.0367 (21)				0.0367 (21)	I
1135.47 (9)					0.0128 (13)	0.0128 (13)				0.0128 (13)	I
1147.896 (10)	0.22 (3)	0.22 (3)	0.211 (17)	0.211 (17)						0.212 (17)	C
1190.287 (7)	0.42 (4)	0.42 (4)	0.34 (1)	0.34 (1)						0.345 (19)	C
1195.32 (9)					0.0025 (9)	0.0025 (9)				0.0025 (9)	I
1232.264 (8)	1.14 (20)	1.12 (20)	1.38 (4)	1.36 (4)						1.35 (5)	C
1232.480 (15)	0.4 (2)	0.4 (2)	0.14 (4)	0.14 (4)						0.15 (5)	C
1248.779 (22)					0.0027 (9)	0.0027 (9)				0.0027 (9)	I
1274.50 (3)					0.0192 (15)	0.0189 (15)				0.0189 (15)	I
1298.95 (7)					0.0105 (12)	0.0103 (12)				0.0103 (12)	I
1305.807 (21)					0.0109 (12)	0.0107 (12)				0.0107 (12)	I
1333.112 (5)	3.28 (5)	3.21 (5)	3.25 (4)	3.18 (4)			3.17 (5)	3.20 (3)	3.171 (13)	**3.175 (13)**	K
1356.104 (9)	0.83 (30)	0.81 (30)	1.00 (10)	0.98 (10)						0.96 (10)	C
1356.320 (15)	0.3 (1)	0.29 (10)	0.35 (5)	0.34 (5)						0.33 (5)	C

Recomm. **Eg (keV)**	**1970Ph01** **Ig**	**1970Ph01*** **Ig(Corr.)**	**1971Ca14** **Ig**	**1971Ca14*** **Ig(Corr.)**	**1994En02** **Ig**	**1994En02*** **Ig(Corr.)**	**2000Ra00** **Ig**	**Berkeley** **Ig**	**Budapest** **Ig**	**Recomm.** **Ig**	**Remarks**
1357.250 (12)	0.7 (2)	0.69 (20)	0.39 (10)	0.38 (10)						0.44 (13)	C
1409.35 (24)					0.0044 (18)	0.0043 (18)				0.0043 (18)	I
1418.754 (5)	1.65 (3)	1.61 (3)	1.700 (27)	1.659 (27)				1.640 (23)	1.659 (8)	**1.657 (8)**	M
1425.25 (2)					0.0167 (13)	0.0163 (13)				0.0163 (13)	I
1433.63 (4)					0.0050 (10)	0.0050 (10)				0.0050 (10)	I
1458.662 (12)	0.25 (7)	0.24 (7)	0.268 (6)	0.261 (6)						0.261 (6)	C
1468.97 (5)					0.0038 (10)	0.0037 (10)				0.0037 (10)	I
1508.158 (7)	1.48 (9)	1.44 (9)	1.520 (24)	1.478 (24)				1.503 (23)	1.496 (7)	**1.497 (7)**	M
1515.162 (20)					0.0172 (15)	0.0167 (15)				0.0167 (15)	I
1523.279 (15)					0.0152 (13)	0.0148 (13)				0.0148 (13)	I
1534.60 (4)					0.016 (4)	0.0155 (40)				0.016 (4)	I
1554.62 (3)					0.051 (3)	0.049 (3)				0.050 (3)	I
1559.627 (10)					0.061 (4)	0.059 (4)				0.059 (4)	I
1577.308 (20)					0.0111 (16)	0.0108 (16)				0.0108 (16)	I
1634.46 (7)					0.0098 (15)	0.0095 (15)				0.0095 (15)	I
1703.59 (5)					0.015 (5)	0.015 (5)				0.015 (5)	I
1713.602 (12)					0.068 (3)	0.066 (3)				0.066 (3)	I
1740.904 (16)	0.19 (4)	0.18 (4)	0.0800 (10)	0.0773 (10)						0.0773 (10)	G
1787.44 (9)					0.025 (2)	0.0240 (20)				0.0240 (20)	I
1797.94 (9)					0.0053 (14)	0.0051 (14)				0.0051 (14)	I
1868.105 (20)					0.0076 (15)	0.0073 (15)				0.0073 (15)	I
1872.740 (6)					0.064 (4)	0.062 (4)				0.062 (4)	I
1898.823 (8)	1.15 (3)	1.11 (3)	1.09 (4)	1.05 (4)				1.062 (23)	1.050 (8)	**1.051 (8)**	M
1918.329 (5)	5.65 (2)	5.45 (2)	5.625 (80)	5.427 (80)			5.33 (8)	5.44 (6)	5.360 (23)	**5.368 (23)**	K
1927.96 (4)					0.0063 (20)	0.0061 (20)				0.0061 (20)	I
2009.628 (16)					0.0086 (17)	0.0083 (17)				0.0083 (17)	I
2026.016 (25)					0.0073 (16)	0.0070 (16)				0.0070 (16)	I
2065.778 (7)	0.098 (16)	0.095 (16)	0.086 (4)	0.083 (4)						0.084 (4)	C
2085.86 (4)					0.006 (4)	0.0058 (40)				0.006 (4)	I
2088.985 (13)					0.032 (7)	0.031 (7)				0.031 (7)	I
2173.319 (15)	0.38 (3)	0.37 (3)	0.236 (12)	0.228 (12)						0.228 (12)	G
2189.616 (6)	15.0 (3)	14.5 (3)	15.06 (18)	14.56 (18)			14.54 (21)	14.50 (13)	14.39 (6)	**14.42 (6)**	K
2213.181 (9)	0.38 (5)	0.37 (5)	0.365 (12)	0.353 (12)						0.354 (12)	C
2265.84 (24)					0.0038 (14)	0.0037 (14)				0.0037 (14)	I
2292.171 (13)			0.110 (10)	0.107 (10)	0.047 (3)	0.046 (3)				0.046 (3)	H

Recomm. E_g (keV)	1970Ph01 I_g	1970Ph01* I_g(Corr.)	1971Ca14 I_g	1971Ca14* I_g(Corr.)	1994En02 I_g	1994En02* I_g(Corr.)	2000Ra00 I_g	Berkeley I_g	Budapest I_g	Recomm. I_g	Remarks
2341.673 (11)					0.0089 (17)	0.0086 (17)				0.0086 (17)	I
2393.129 (7)	0.64 (2)	0.62 (2)	0.670 (20)	0.651 (20)						0.635 (20)	C
2422.525 (7)	5.06 (10)	4.93 (10)	5.16 (5)	5.023 (5)			5.12 (8)	5.15 (6)	5.072 (24)	**5.085 (24)**	K
2433.807 (18)					0.0206 (17)	0.0201 (17)				0.0201 (17)	I
2467.97 (7)					0.0234 (19)	0.0228 (19)				0.0228 (19)	I
2492.42 (3)			0.063 (6)	0.061 (6)	0.061 (4)	0.060 (4)				0.060 (4)	F
2537.09 (5)					0.014 (3)	0.014 (3)				0.014 (3)	I
2588.553 (13)			0.073 (7)	0.072 (7)	0.072 (4)	0.071 (4)				0.071 (4)	F
2631.44 (9)					0.008 (3)	0.008 (3)				0.008 (3)	I
2698.92 (5)					0.0101 (17)	0.0100 (17)				0.0100 (17)	I
2713.73 (5)					0.017 (5)	0.017 (5)				0.017 (5)	I
2751.835 (5)	60.9 (8)	60.3 (8)	61.2 (6)	60.6 (6)			61.2 (8)	61.5 (6)	61.34 (26)	**61.35 (26)**	K
2780.095 (16)	0.33 (2)	0.33 (2)	0.337 (8)	0.334 (8)						0.334 (8)	C
2785.7 (3)					0.0081 (14)	0.0080 (14)				0.0080 (14)	I
2802.8 (5)					0.0040 (11)	0.0040 (11)				0.0040 (11)	I
2843.130 (16)					0.0045 (9)	0.0045 (9)				0.0045 (9)	I
2933.358 (9)	0.57 (3)	0.57 (3)	0.574 (8)	0.576 (8)						0.576 (8)	C
2977.083 (43)			0.062 (6)	0.062 (6)						0.062 (6)	N
2993.208 (32)			0.084 (8)	0.085 (8)						0.085 (8)	N
3046.684 (9)	0.17 (2)	0.17 (2)	0.150 (6)	0.152 (6)						0.154 (6)	C
3085.4 (4)					0.0052 (13)	0.0053 (13)				0.0053 (13)	I
3212.499 (19)					0.0049 (10)	0.0050 (10)				0.0050 (10)	I
3228.800 (6)	3.85 (6)	3.96 (6)	3.96 (4)	4.08 (4)			4.06 (8)	4.07 (4)	4.087 (22)	**4.082 (22)**	K
3256.021 (9)	0.31 (3)	0.32 (3)	0.241 (5)	0.249 (5)	0.270 (14)	0.279 (14)				0.254 (10)	A
3331.351 (14)					0.0059 (8)	0.0061 (8)				0.0061 (8)	I
3380.850 (6)	3.68 (4)	3.85 (4)	3.78 (4)	3.95 (4)			3.96 (8)	3.99 (4)	3.950 (23)	**3.960 (23)**	K
3422.040 (8)	2.10 (9)	2.21 (9)	2.18 (4)	2.29 (4)				2.29 (3)	2.321 (16)	**2.314 (16)**	M
3432.309 (7)	0.73 (3)	0.77 (3)	0.740 (10)	0.778 (10)						0.777 (10)	C
3724.8 (10)			0.0060 (10)	0.0065 (10)						0.0065 (10)	N
3738.10 (5)			0.032 (3)	0.035 (3)	0.0353 (20)	0.0385 (20)				0.0374 (20)	F
3766.850 (9)	0.37 (2)	0.41 (2)	0.364 (14)	0.399 (15)						0.403 (15)	C
3791.004 (8)	2.63 (11)	2.89 (11)	2.675 (32)	2.940 (35)			2.96 (5)	2.96 (4)	2.929 (24)	**2.941 (24)**	K
3806.3 (10)			0.0060 (10)	0.0066 (10)						0.0066 (11)	N
3810.59 (5)			0.0210 (20)	0.0231 (22)	0.025 (3)	0.028 (3)				0.0248 (22)	F
3827.5 (8)			0.0170 (20)	0.0190 (22)						0.0190 (22)	N

Recomm. Eg (keV)	1970Ph01 Ig	1970Ph01* Ig(Corr.)	1971Ca14 Ig	1971Ca14* Ig(Corr.)	1994En02 Ig	1994En02* Ig(Corr.)	2000Ra00 Ig	Berkeley Ig	Budapest Ig	Recomm. Ig	Remarks
4085.853 (9)	2.91 (6)	3.33 (7)	3.07 (4)	3.52 (5)			3.38 (8)	3.42 (4)	3.455 (20)	**3.445 (20)**	K
4295.187 (10)	9.2 (2)	10.88 (24)	9.17 (11)	10.84 (13)			10.24 (26)	10.54 (15)	10.25 (7)	**10.30 (8)**	K, L
4461.202 (9)	1.84 (4)	2.23 (5)	1.875 (22)	2.277 (27)				2.20 (4)	2.275 (23)	**2.26 (3)**	M
4806.007 (9)	3.96 (6)	5.10 (6)	3.82 (4)	4.92 (4)			4.93 (11)	5.00 (7)	5.04 (3)	**5.03 (3)**	K
4865.87 (4)					0.0058 (5)	0.0075 (6)				0.0075 (6)	I
5005.6 (3)					0.0025 (3)	0.0033 (4)				0.0033 (4)	I

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*γ-ray intensities (Iγ) corrected for a systematic inaccuracy in the detector efficiency curve above 1050 keV.

Correction factor f = 1.116 - 0.155 Eγ (MeV) + 0.0397 Eγ x Eγ (2002Ba38). Uncertainties are statistical values given by authors.

A: Weighted average of values from 1970Ph01, 1971Ca14, and 1994En02

B: Weighted average of values from 1971Ca14 and 1994En02. Value from 1970Ph01 is too high (peak may contain impurities).

C: Weighted average of values from 1970Ph01 and 1971Ca14.

D: Weighted average of values from 1970Ph01 and 1994En02.

E: From 1994En02. Value from 1970Ph01 is too high (peak may contain impurities).

F: Weighted average of values from 1971Ca14 and 1994En02.

G: From 1971Ca14. Value from 1970Ph01 is too high (peak may contain impurities).

H: From 1994En02. Value from 1971Ca14 is too high (peak may contain impurities).

I: From 1994En02.

K: Weighted average (in boldface) of values from 2000Ra36, from Berkeley, and from Budapest, as given in 2002Ba38
(except for the recommended uncertainties, which are never smaller than the smallest experimental uncertainty).

L: After correction for single-escape contribution from the 4806-keV line.

M; Weighted average (in boldface) of values from Berkeley and Budapest, as given in 2002Ba38

N: From 1971Ca14

O: Reported only by 1970Ph01.

^{67}Ga – Comments on evaluation of decay data
by X. Mougeot and V.P. Chechev

The initial evaluation was completed in March 2000. This revised evaluation was done in 2011, taking into account the available literature by March 2011.

1. Decay Scheme

The spins and parities of the ground state of ^{67}Ga and of the levels of ^{67}Zn are from the evaluation of 2005HU18.

The main difficulty in the evaluation of the ^{67}Ga decay scheme is connected with the lack of measurements of the absolute intensity of the internal conversion electron component P($ce_{1,0}$) from the 93 keV gamma transition (2000SI03). This value determines directly the probability P($\varepsilon_{0,0}$) of the allowed electron capture transition to the ground state of ^{67}Zn. In many evaluations, including 1991BH06, P($\varepsilon_{0,0}$) was adopted equal to zero. In a more recent evaluation (2005HU18), a value of 0,9 (9) % was adopted.

In this evaluation of the ^{67}Ga decay scheme, four measurements of P($ce_{1,0}$) were taken into account: 1998AT04, 2000SI03, 2005YA01 and 2007BO. The analysis led to the evaluated value of P($ce_{1,0}$) = 0,3254 (40) and to the probability of the electron capture transition to the ^{67}Zn ground state P($\varepsilon_{0,0}$) = 3,3 (32) % (see Section 4.2.2). The large uncertainty of P($\varepsilon_{0,0}$) mainly comes from the uncertainty of the evaluated mixing ratio δ(184 keV).

Among the adopted levels in 2005HU18, three levels are placed below the decay energy and are not taken into account in this evaluation: the $9/2^+$ at 604,48 (5) keV, the $7/2^-$ at 814,90 (6) keV and the $5/2^+$ at 979,85 (5) keV. These levels could be fed respectively by 3rd, 2nd and 1st transitions. As all the other electronic capture transitions are allowed, the branch intensities for these three levels must be much lower, and precisely the corresponding gamma-rays were never observed.

2. Nuclear Data

Q value is from 2003AU03: $Q^+(^{67}Ga)$ = 1000,8 (12) keV.

2.1 ^{67}Ga half-life

The measured half-life values of ^{67}Ga are summarized in Table 1. The values from 1948HO04 and 1950HO26 were not used in the evaluation because no experimental uncertainty was reported. The values from 1982HOZJ and 2002UN02 are the same values as respectively 1978ME10 and 1992UN01, and were not used in the evaluation.

1972CR02 gives eight measurements using the same method. As this data set is discrepant, an unweighted mean was chosen, calculated using the LWEIGHT program: $T_{1/2}(^{67}Ga)$ = 3,38 (9) d.

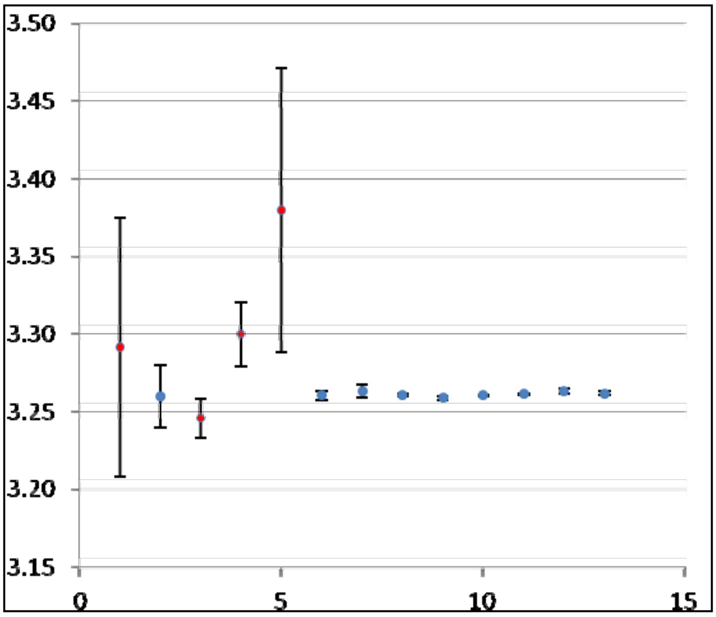
The measured half-life values used in this evaluation are summarized in Figure 1. The statistical processing was done using the LWEIGHT program. Four statistical outliers are excluded according to Chauvenet's criterion: 1938MA01, 1955TO27, 1964RU06 and 1972CR02, in red in Figure 1. A weighted average is 3,26125 (35) d from the resulting consistent data set, with a reduced-χ^2 value of 0,74. The statistical weights are 44 % for 1992UN01 and 20 % for 1980HO17, the two most precise measurements. As there are less than ten values, and as the most precise measurements use the same method, the smallest experimental uncertainty was preferred. Finally, the adopted value is:

$$\mathbf{T_{1/2}(^{67}Ga) = 3,2613\ (5)\ d}.$$

Table 1: ^{67}Ga half-life measurements. The excluded values are crossed out.

Reference	$T_{1/2}(^{67}Ga)$ measurements	$T_{1/2}(^{67}Ga)$ in d	Comments
~~1938MA01~~	~~79 (2) h~~	~~3,29 (8)~~	Excluded by Chauvenet's criterion
~~1948HO04~~	~~83 h~~	~~3,46~~	Not used: no uncertainty
1948MC32	3,26 (2) d	3,26 (2)	
~~1950HO26~~	~~80 h~~	~~3,33~~	Not used: no uncertainty
~~1955TO27~~	~~77,9 (3) h~~	~~3,246 (13)~~	Excluded by Chauvenet's criterion
~~1964RU06~~	~~79,2 (5) h~~	~~3,300 (21)~~	Excluded by Chauvenet's criterion
1972CR02	78,5 (15) h	3,27 (6)	
	78,2 (12) h	3,26 (5)	
	84,7 (23) h	3,53 (10)	
	79,1 (14) h	3,30 (6)	
	69,7 (36) h	2,90 (15)	
	84,2 (11) h	3,508 (46)	
	90,7 (42) h	3,78 (18)	
	83,8 (44) h	3,49 (18)	
~~1972CR02~~	**~~LWEIGHT~~**	**~~3,38 (9)~~**	Unweighted mean, excluded by Chauvenet's criterion
1972LE37	78,26 (7) h	3,2608 (29)	
1978LA21	78,33 (10) h	3,2638 (42)	
1978ME10	3,261 (1) d	3,261 (1)	
1979DE42	3,2594 (12) d	3,2594 (12)	
1980HO17	3,2607 (8) d	3,2607 (8)	
~~1982HOZJ~~	~~3,261 (1) d~~	~~3,261 (1)~~	Not used: same as 1978ME10
1992UN01	3,2615 (5) d	3,2615 (5)	
~~2002UN02~~	~~3,2615 (5) d~~	~~3,2615 (5)~~	Not used: same as 1992UN01
2004DA05	3,2634 (16) d	3,2634 (16)	
2004SC04	3,2623 (15) d	3,2623 (15)	
Adopted		**3,2613 (5) d**	

Figure 1: $T_{1/2}$ measurements used for the present evaluation. The red ones are excluded by LWEIGHT according to Chauvenet's criterion.



2.2 Half-lives of ^{67}Zn 93 keV and 184 keV metastable states

The measured half-life values of the first excited state of ^{67}Zn, at 93 keV, are given in Table 2. The value from 1953KE was not used because of the lack of uncertainty. The value from 1972LE37 comes from the same author as 1973LE18. 1973LE18 reports two consistent measurements, obtained with two independent methods. A weighted mean was chosen: $T_{1/2}$(^{67}Zn, 93 keV) = 9,15 (14) μs.

No outlier was found by the LWEIGHT program in the consistent data set. A weighted average was 9,002 (41) μs with a reduced-χ^2 value of 2,2. The statistical weight is 85 % for the most precise value from 1996HW03. For the same reasons as $T_{1/2}$(^{67}Ga), the smallest experimental uncertainty was preferred. Finally, the adopted value, with its external uncertainty, is:

$T_{1/2}$(^{67}Zn, 93 keV) = 9,00 (4) μs.

Table 2: $T_{1/2}$ half-life measurements of the 93 keV level of ^{67}Zn.
The excluded values are crossed out.

Reference	$T_{1/2}$ in μs	Comments
~~1953KE~~	~~8,5~~	Not used: no uncertainty
1953ME52	9,5 (10)	
1957BU39	9,4 (3)	
1969IV02	8,8 (18)	
1971SU18	8,7 (1)	
~~1972LE37~~	~~9,10 (15)~~	Not used: same as 1973LE18
1973LE18	9,20 (20)	
	9,10 (20)	
1973LE18	**9,15 (14)**	Consistent set, same author, independent methods: weighted mean chosen
1975RO25	9,1 (4)	
1996HW03	9,01 (3)	
1998AT04	9,34 (20)	

The measured half-life values of the second excited state of ^{67}Zn, at 184 keV, are given in Table 3. The value from 1964AL28 is given with asymmetric uncertainties, and was symmetrised according to the method described in 2003AU02.

The LWEIGHT program found two statistical outliers, excluded according to Chauvenet's criterion: 1961HO05 and 1962RI09. A weighted average was 1,028 (13) ns in the resulting consistent data set, with a reduced-χ^2 value of 0,3. The statistical weight is 83 % for the most precise value from 1972EN08. For the same reasons as $T_{1/2}$(^{67}Ga), the smallest experimental uncertainty was preferred. Finally, the adopted value, with its internal uncertainty, is:

$T_{1/2}$(^{67}Zn, 184 keV) = 1,028 (14) ns.

Table 3: $T_{1/2}$ half-life measurements of the 184 keV level of ^{67}Zn.
The excluded values are crossed out.

Reference	$T_{1/2}$ in ns	Comments
~~1961HO05~~	~~1,45 (15)~~	Excluded by Chauvenet's criterion
~~1962RI09~~	~~2,2 (7)~~	Excluded by Chauvenet's criterion
1964AL28	1,1 (5)	Symmetrised according to method of 2003AU02
1968LI02	1,01 (5)	
1972EN08	1,026 (14)	
1975RO25	1,06 (4)	

2.3 Electron Capture Transitions

The energies of the electron capture (ε) transitions were calculated from the Q value and the level energies deduced from gamma transition energies. The log *ft* values were computed using the LOGFT program.

The electron capture probabilities were calculated from the balance of the evaluated $P_{\gamma+ce}$ values taking into account the evaluated absolute intensity P($ce_{1,0}$) = 0,3254 (26) (see Section 4.2.2) that allows normalizing the total ground state gamma transition probability to 96,7 (31) per 100 disintegrations.

The experimental values of P_K are available for $\varepsilon_{0,2}$ and $\varepsilon_{0,3}$ from 1988BE55: $P_K(\varepsilon_{0,2})$ = 0,89 (4) and $P_K(\varepsilon_{0,3})$ = 0,88 (3). They were obtained using an old value of ω_K = 0,430 (7).

The P_K, P_L, P_M and P_N values were computed using the EC-capture program. The P_{L2}/P_{L1} ratios were computed by the LOGFT program and were used to determine the P_{L1} and P_{L2} values.

2.4 Gamma Transitions and Internal Conversion Coefficients

The evaluated energies of gamma transitions are the energies of gamma-rays with adding the recoil energy (see Section 4.2.1).

2.4.1 Mixing ratios and multipolarities

The multipolarities of the 93 keV ($\gamma_{1,0}$) and 794 keV ($\gamma_{4,1}$) transitions are pure E2. For the 794 keV transition, the admixture of M3 is possible and was evaluated. The other gamma transitions have an M1 + E2 multipolarity. Only the absolute values of the mixing ratios were evaluated to deal with the inconsistency of the signs. The mixing ratios measurements are given in Table 4.

Table 4: Mixing ratios measurements of the gamma transitions in ^{67}Zn. The excluded values, by the evaluator or by Chauvenet's criterion during the statistical process, are crossed out. The mixtures are M1 + E2 for all the transitions, except for the 794 keV transition which has an E2 + M3 mixture.

Reference	91 keV	184 keV	209 keV	300 keV	393 keV	494 keV	703 keV	794 keV	887 keV
1961HO05		~~δ^2 = 0,15~~							
1962RI09	$\lvert\delta\rvert \leq 0{,}07$	0,51 (7)							
1964AL28		0,43 (8)							
1968LI02		0,41 (6)							
1969BO41			~~0,40 (15)~~						
1971SU18	-0,11 (5)	0,38 (3)		~~pure M1~~	~~0,5 (1)~~	0,18 (6)			
1973BA54			0,034 (21)	-0,181 (8)	0,043 (10)		0,090 (28)		
1974NI01		$\delta \begin{cases} > -0{,}8 \\ < -0{,}1 \end{cases}$	0,02 (4)	-0,21 (5)	0,11 (6)	~~2,2 (6)~~		0,04 (17)	
1975TH01	0,06 (5)	0,48 (11)	0,01 (20)	0,05 (7)	-0,02 (17)	-0,22 (20)		0,47 (11)	0,8 (6)
1975WE08	-0,15 (3)	-0,17 (7)	0,08 (5)	-0,11 (4)	0,09 (2)	0,06 (4)			
	~~2,6 (3)~~		~~-5,7 (20)~~	~~2,3 (3)~~	~~3,2 (3)~~	~~2,8 (4)~~			
1978DU04		0,08 (4)	-0,10 (6)	0,20 (8)	-0,17 (8)	-0,17 (8)		-0,1 (1)	0,9 (3)
		~~-5,0 (8)~~	~~3,6 (8)~~	~~-3,1 (4)~~	~~-2,4 (3)~~	~~-1,7 (6)~~			
1978LO06						0,14 (3)		0,04 (4)	-0,96 (9)

Some values are given with asymmetric uncertainties: δ(184 keV) from 1964AL28 ; δ(300 keV) from 1973BA54 ; δ(794 keV) and δ(494 keV) from 1974NI01; δ(393 keV), δ(494 keV), δ(794 keV) and δ(887 keV) from 1975TH01. They were symmetrised according to the method described in 2003AU02.

The excluded values are crossed out in the table. For the 91 keV transition, the result from 1962RI09 rules out the second possibility from 1975WE08. For the 184 keV transition, the result from 1974NI01 rules out the second possibility from 1978DU04, and there is no uncertainty with the result of 1961HO05. For the 209 keV, 300 keV, 393 keV and 494 keV transitions, the second possibilities from 1975WE08 and 1978DU04 are ruled out by comparison with the other results. For the 300 keV transition, the result from 1971SU18 is ruled out by comparison with the other results. For the 494 keV transition, the second possibility from 1974NI01 is ruled out by comparison with the most precise measurement from 1978LO06.

The other values that are crossed out were excluded according to Chauvenet's criterion during the statistical processing with the LWEIGHT program: 1969BO41 for 209 keV and 1971SU18 for 393 keV. All the data set are consistent except for the 184 keV and 794 keV transitions which are discrepant. The existence of only one measurement from 1973BA54 for the 703 keV transition should be underlined. A weighted average was used for each gamma transition. The adopted values are given in Table 5. Internal uncertainty was chosen by the LWEIGHT program for the red adopted values, external uncertainty for the green ones and expanded uncertainty for the blue one.

Table 5: Adopted mixing ratios and the corresponding multipolarity.
Internal uncertainty was chosen by LWEIGHT for the red adopted values,
external uncertainty for the green ones and expanded uncertainty for the blue one.

	Adopted |δ|	**Multipolarity**	**Comments**
91 keV	0,123 (25)	M1 + 1,5 (6) % E2	Consistent, weighted average
184 keV	0,31 (7)	M1 + 8,8 (36) % E2	Discrepant, weighted average
209 keV	0,042 (17)	M1 + 0,18 (14) % E2	Consistent, weighted average
300 keV	0,178 (10)	M1 + 3,07 (33) % E2	Consistent, weighted average
393 keV	0,051 (16)	M1 + 0,26 (16) % E2	Consistent, weighted average
494 keV	0,110 (34)	M1 + 1,2 (7) % E2	Consistent, weighted average
703 keV	0,090 (28)	M1 + 0,8 (5) % E2	Only one measurement
794 keV	0,09 (11)	E2 + 0,8 (19) % M3	Discrepant, weighted average
887 keV	0,95 (9)	M1 + 47,4 (47) % E2	Consistent, weighted average

2.4.2 Internal conversion coefficients

The internal conversion coefficients measurements of the gamma transitions of ^{67}Zn are summarized in Table 6.

The adopted values are calculated with the BrIcc program (2008KI07) and can be seen in Table 7. They were calculated using the mixing ratios evaluated previously. These values agree satisfactorily with the measured ones. For the 794 keV transition, the two possible multipolarities were tested and the calculated internal conversion coefficients agree well inside the uncertainties. The possible admixture of M3 is kept.

Table 6: Internal conversion coefficients measurements of the gamma transitions of ^{67}Zn.

Reference	91 keV	93 keV	184 keV	209 keV	300 keV	393 keV	494 keV	887 keV
1938AL02	α_K ~ 0,07							
1953KE	α_K = 0,074	α_K = 0,63	α_K = 0,011	α_K = 0,029	α_K = 0,0029	α_K = 0,0019		
1953ME52		α_T = 0,54 (5)						
1966FR12		α_K = 0,77 (8)	α_K = 0,0156 (10)	α_K = 0,0075 (7)	α_K = 0,00337 (30)	α_K = 0,00192 (15)	α_K = 0,00119 (15)	α_K = 0,00034 (7)
1969LI04	α_K = 0,066 (10) α_{L1} = 0,0069 (11) $\alpha_{L2,3}$ = 0,00069 (30)							
1988BE55			α_K = 0,89 (4)			α_K = 0,883 (28)		

Table 7: BrIcc calculations for the internal conversion coefficients of the gamma transitions of ^{67}Zn.

	α_T	α_K	α_{Ltot}	Comments
91 keV	0,091 (6)	0,081 (5)	0,008 7 (7)	
93 keV	0,854 (12)	0,748 (11)	0,092 2 (13)	
184 keV	0,016 9 (21)	0,015 1 (19)	0,001 58 (20)	
209 keV	0,009 01 (14)	0,008 06 (13)	0,000 827 (13)	
300 keV	0,003 88 (6)	0,003 48 (6)	0,000 354 (6)	
393 keV	0,001 93 (3)	0,001 728 (25)	0,000 174 8 (25)	
494 keV	0,001 149 (18)	0,001 030 (16)	0,000 103 8 (17)	
703 keV	0,000 524 (8)	0,000 470 (7)	0,000 047 0 (7)	
794 keV E2+M3	0,000 54 (6)	0,000 48 (5)	0,000 049 (6)	Adopted
794 keV pure E2	0,000 523 (8)	0,000 469 (7)	0,000 047 3 (7)	
887 keV	0,000 354 (7)	0,000 318 (6)	0,000 031 8 (6)	

3. Atomic Data

3.1 Fluorescence yields

The fluorescence yields are taken from 1996SC06.

3.2 X Radiations and Auger electrons

The X-ray energies are based on the wave lengths in the compilation of 1967BE65 (Bearden). The energies of Auger electrons are from the SAISINUC software (see also 1977LA19 (Larkins) and 1987Table (Table de Radionucléides)).

The X-ray and Auger electron probabilities were computed using the EMISSION program with the atomic data from 1996SC06.

4. Photon Emissions

4.1 X-Ray Emissions

The total absolute emission probabilities of the K and L X-rays were computed using the EMISSION program with the atomic data from 1996SC06, the evaluated electron capture probabilities and the evaluated conversion electron probabilities.

The authors of 1979DE42 measured the following ratios: P(XK$_\alpha$)/P(184keV) = 2,37 (5) and P(XK$_\beta$)/P(184keV) = 0,331 (7). The absolute intensity measurements from 2005YA01 are:
P(XK$_{\alpha2}$) = 17,1 (8) %, P(XK$_{\alpha1}$) = 32,3 (14) %, P(XK$_{\beta1,3}$) = 6,44 (28) % and P(184 keV) = 21,4 (9) %. The relative uncertainties were increased to 4,4 % (see Section 4.2.2). This leads to the consistent ratio P(XK$_\alpha$)/P(184 keV) = 2,31 (12) and the discrepant ratio P(XK$_\beta$)/P(184 keV) = 0,301 (18).

With the previous calculations and the evaluated value of P(184 keV) (see Section 4.2.2), these ratios become: P(XK$_\alpha$)/P(184 keV) = 2,39 (8) and P(XK$_\beta$)/P(184 keV) = 0,338 (14). They are summarized in Table 8.

Table 8: Comparison of the P(XK$_\alpha$)/P(184 keV) and P(XK$_\beta$)/P(184 keV) ratios.

	1979DE42	2005YA01	Evaluated
P(XK$_\alpha$)/P(184 keV)	2,37 (5)	2,31 (12)	2,39 (8)
P(XK$_\beta$)/P(184 keV)	0,331 (7)	0,301 (18)	0,338 (14)

4.2 Gamma Emissions

4.2.1 Gamma-ray energies

The gamma-ray energy measurements are given in Table 9. The excluded values are crossed out. The values from 1978ME10 come from the same author as 1990ME15. The most recent data set was preferred, even if it corresponds to the less precise measurements of the two publications. The other values that are crossed out were excluded according to Chauvenet's criterion during the statistical process by the LWEIGHT program. All the data set are consistent and a weighted average was used each time. The adopted values are in red or in green when respectively the internal or the external uncertainties were chosen. The reduced-χ^2 are also mentioned.

Table 9: E$_\gamma$ measurements of γ–rays in ^{67}Zn.
The excluded values are crossed out. The values from 1978ME10 come from the same author as 1990ME15. The other values were excluded according to Chauvenet's criterion. Internal uncertainty was chosen by LWEIGHT for the red adopted values, external uncertainty for the green ones.

Reference	E$_{\gamma2,1}$ (keV)	E$_{\gamma1,0}$ (keV)	E$_{\gamma2,0}$ (keV)	E$_{\gamma3,2}$ (keV)	E$_{\gamma3,1}$ (keV)
1958CH08	91,22 (4)	93,26 (4)	184,46 (27)		
1966FR12	91,275 (20)	93,317 (20)	184,595 (40)	208,96 (6)	300,24 (7)
1969RA15	91,26 (10)	93,25 (10)	184,53 (10)	208,95 (10)	300,22 (10)
1971SU18	~~91 (2)~~	~~93 (2)~~	184 (2)	~~208 (2)~~	~~299 (2)~~
1974AR22		~~93,2 (2)~~	184,0 (2)		
1974HEYW	91,31 (5)	93,32 (2)	184,56 (2)	208,93 (2)	~~300,18 (2)~~
1977AB02			184 (1)		
1978DU04		93,3 (5)	184,63 (3)	208,91 (4)	300,24 (5)
~~1978ME10~~	~~91,266 (5)~~	~~93,311 (5)~~	~~184,577 (10)~~	~~208,951 (10)~~	~~300,219 (10)~~
1990ME15	91,237 (35)	93,291 (30)	184,569 (30)	208,970 (30)	300,230 (25)
Adopted	91,263 (15)	93,307 (12)	184,577 (17)	208,939 (15)	300,232 (21)
χ^2	0,74	0,54	1,7	0,48	0,02

Reference	$E_{\gamma 3,0}$ (keV)	$E_{\gamma 4,3}$ (keV)	$E_{\gamma 4,2}$ (keV)	$E_{\gamma 4,1}$ (keV)	$E_{\gamma 4,0}$ (keV)
1966FR12	393,65 (6)	494,31 (10)	703,6 (2)	794,7 (2)	888,0 (2)
1969RA15	393,60 (10)				
1971SU18	393 (2)	~~493 (2)~~	701 (2)	794 (2)	~~886 (2)~~
1974HEYW	393,47 (3)	494,19 (8)		794,49 (20)	887,68 (15)
1977AB02	393 (3)				~~884 (12)~~
1978DU04	393,54 (5)	494,1 (6)	703,2 (3)	794,39 (8)	887,67 (7)
~~1978ME10~~	~~393,529 (10)~~	~~494,169 (15)~~	~~703,110 (15)~~	~~794,386 (15)~~	~~887,693 (15)~~
1990ME15	393,539 (25)	494,132 (30)	703,08 (5)	794,38 (5)	887,664 (40)
Adopted	393,528 (20)	494,143 (28)	703,11 (8)	794,400 (41)	887,676 (33)
χ^2	1,5	1,3	2,5	0,67	0,91

The energies of the gamma transitions were then deduced by adding the recoil energy of the nucleus. The proton and neutron masses come from 2008MO18. The mass excess of ^{67}Zn comes from 2003AU02. The largest recoil energy is for the 887 keV transition, with a value less than 6,3 eV.

4.2.2 Gamma-ray emission probabilities

The measurements of gamma-ray emission probabilities are summarized in Table 10. The excluded values are crossed out. 1953KE was not used because of the lack of uncertainty. The intensity of the doublet from 1967VR03 is not useful. In 1975TH01, the intensities are normalized by level. With the 184 keV emission as reference, only the measurement of the 91 keV intensity can be used. In 1978LO06, the reference is the complete decay of the 888 keV level. As there is no value for the 184 keV emission, these values were not used. The values from 1978ME10 come from the same author as 1990ME15. The most recent data set was preferred.

Table 10: Measurements of gamma-ray emission probabilities from the decay of ^{67}Ga.
The values that are crossed out were excluded by the evaluator. The energies are in keV.
Values from 1969LI04, 2005YA01 and 2007BO are absolute emission probabilities measurements.
The relative uncertainties of the values from 2005YA01 were increased up to 4,4 %.

Reference	91	93	184	209	300	393	494	703	794	887
~~1953KE~~	~~2,7~~	~~63,9~~	~~29,6~~	~~1~~	~~20,2~~	~~4,9~~	~~0,4~~		~~0,2~~	~~0,4~~
1953ME52	7,0 (5)	93,0 (5)	44,1 (30)	3,0 (8)	27,5 (10)	9,7 (10)				
1966FR12	1,5 (4)	73 (7)	23,1 (16)	2,50 (25)	16,2 (16)		0,100 (15)	0,015 (2)	0,06 (1)	0,160 (16)
1967VR03	~~$\gamma_{2,1}+\gamma_{1,0}$ 229 (20)~~		100	10,9 (5)	75,6 (50)	20,4 (12)	0,24 (3)	0,05 (1)	0,23 (2)	0,58 (6)
1969LI04	3,27 (45)	38,4 (38)	23,7 (27)							
1969RA15	~~155 (11)~~	~~360 (25)~~	~~1000 (70)~~	~~2,4 (3)~~	~~15,7 (12)~~	~~4,3 (4)~~				
1974HEYW	13 (1)	100 (5)	62 (3)	7,1 (4)	50 (3)	14 (1)	3,7 (3)		0,15 (2)	0,43 (4)
1975TH01	13,1 (4)		86,9 (25)	~~9,6 (3)~~	~~70,3 (21)~~	~~20,1 (6)~~	~~23,8 (11)~~	~~4,8 (4)~~	~~18,4 (7)~~	~~53,2 (16)~~
~~1978LO06~~							~~25 (2)~~	~~5 (2)~~	~~21 (2)~~	~~49 (2)~~
1978ME10	~~80,0 (3)~~	~~1000 (3)~~	~~552 (2)~~	~~62,8 (3)~~	~~448 (1)~~	~~125,4 (5)~~	~~1,83 (2)~~	~~0,292 (9)~~	~~1,37 (5)~~	~~3,88 (2)~~
1979DE42	15,0 (5)	185 (6)	100,0 (11)	11,35 (13)	79,9 (9)	22,0 (3)	0,322 (7)	0,060 (5)	0,251 (7)	0,712 (11)
1990ME15	30 (2)	366 (14)	217 (9)	24 (1)	166 (4)	45 (1)	0,7 (1)	0,10 (1)	0,53 (3)	1,49 (5)
2005YA01	3,11 (14)	38,8 (17)	21,4 (9)	2,46 (11)	16,6 (7)	4,6 (2)				
2007BO	3,11 (3)	38,61 (35)	21,13 (10)	2,396 (13)	16,74 (8)	4,642 (25)	0,0657 (33)		0,0565 (24)	0,1522 (35)

The value from 1966FR12 for the 91 keV emission is given with asymmetric uncertainties, and was symmetrised according to the method described in 2003AU02. 2005YA01 and 2007BO measured absolute emission probabilities. The uncertainties from 2005YA01 are too low. They should be at least about 4,4 % according to the authors, and they were expanded.

In this evaluation, the data were normalized to the 184 keV emission, used as reference. They are given in Table 11. The crossed out values were excluded according to Chauvenet's criterion during the statistical process by LWEIGHT. All the data sets are consistent and a weighted average was used each time. Red adopted values stand for internal uncertainty, green ones stand for external uncertainty. The reduced-χ^2 are also mentioned.

Table 11: Measurements of gamma-ray emission probabilities used in this evaluation,
normalized to the 184 keV emission used as reference.
The values that are crossed out were excluded according to Chauvenet's criterion
during the statistical process by LWEIGHT.
Red values stand for internal uncertainty, green ones stand for external uncertainty.

Reference	**91 keV**	**93 keV**	**184 keV**	**209 keV**	**300 keV**	**393 keV**	**494 keV**	**703 keV**	**794 keV**	**887 keV**
1953ME52	15,9 (16)	~~211~~ ~~(14)~~	100	~~6,8~~ ~~(19)~~	~~62,4~~ ~~(48)~~	22,0 (27)				
1966FR12	~~6,5~~ ~~(18)~~	~~316~~ ~~(37)~~	100	10,8 (13)	~~70~~ ~~(8)~~		0,43 (7)	0,065 (10)	0,260 (47)	0,69 (8)
1967VR03			100	10,9 (5)	76 (5)	20,4 (12)	0,24 (3)	0,05 (1)	0,23 (2)	~~0,58~~ ~~(6)~~
1969LI04	13,8 (25)	162 (24)	100							
1974HEYW	~~21,0~~ ~~(19)~~	161 (11)	100	11,5 (9)	81 (6)	22,6 (19)	~~6,0 (6)~~		0,242 (34)	0,69 (7)
1975TH01	15,1 (6)		100							
1979DE42	15,0 (5)	185 (6)	100	11,35 (18)	79,9 (13)	22,00 (39)	0,322 (8)	0,060 (5)	0,251 (8)	0,712 (14)
1990ME15	13,8 (11)	169 (10)	100	11,1 (7)	76,5 (37)	20,7 (10)	0,32 (5)	0,046 (5)	0,244 (17)	0,687 (37)
2005YA01	14,53 (6)	181 (8)	100	11,5 (5)	77,7 (34)	21,3 (11)				
2007BO	14,72 (16)	182,7 (19)	100	11,34 (8)	79,2 (5)	21,97 (16)	0,31 (16)		0,267 (11)	0,720 (17)
Adopted	14,74 (14)	181,8 (19)	100	11,33 (7)	79,22 (48)	21,92 (14)	0,318 (12)	0,0539 (42)	0,252 (6)	0,712 (10)
χ^2	0,34	1,3	-	0,20	0,32	0,61	2,4	1,8	0,67	0,21

These evaluated relative emission probabilities were used with the absolute emission probability of the 93 keV level P(93 keV) to calculate the absolute gamma-ray emission probabilities. P(93 keV) was determined using the total internal conversion coefficient α_T(93 keV) calculated with the BrIcc program in Section 2.4.2, and the evaluated value of P($ce_{1,0}$).

Four values of P($ce_{1,0}$) were used in this evaluation: 0,3285 (40) from 1998AT04; 0,3198 (40) from 2000SI03; 0,331 (15) from 2005YA01; 0,330 (6) from 2007BO. The first value was recalculated by 2000SI03. The second value is an unweighted mean of the two results 0,3213 (14) and 0,3182 (27). The authors of 2000SI03 precise that the uncertainties are only 1σ statistical uncertainties. The final uncertainty of P($ce_{1,0}$) was increased to be at least the second lowest uncertainty, the one from 1998AT04. The values from 2005YA01 and 2007BO were calculated with the measured absolute intensities and with α_T(93 keV). The relative uncertainty of 2005YA01 was increased to 4,4 %, as explained above.

No outlier was found by the LWEIGHT program in the consistent data set. A weighted average was 0,3254 (26) with a reduced-χ^2 value of 1,1. The statistical weight is 40 % for the two most precise values from 1998AT04 and 2000SI03. As there are only four useful values, the smallest experimental uncertainty was preferred. Finally, the adopted value, with its external uncertainty, is:

$P(ce_{1,0})$ = 0,3254 (40).

With α_T(93 keV) = 0,854 (12) (see Table 7 in Section 2.4.2), the absolute intensity of the 93 keV gamma-ray transition was found to be:

P(93keV) = 0,381 (7).

With the absolute gamma-ray emission probabilities and the adopted total internal conversion coefficient of each transition, the transition probabilities $P_{\gamma+ce}$ were determined. They are given in Table 12. The resulting probabilities of the electron capture transitions were found to be: **$P(\varepsilon_{0,4})$ = 0,280 (8) %**; **$P(\varepsilon_{0,3})$ = 23,60 (47) %**; **$P(\varepsilon_{0,2})$ = 22,3 (27) %**; **$P(\varepsilon_{0,1})$ = 50,5 (17) %**. It leads to the probability of the electron capture to the ground state of ^{67}Zn: **$P(\varepsilon_{0,0})$ = 3,3 (32) %**. The large uncertainty of $P(\varepsilon_{0,0})$ mainly comes from the uncertainty of the evaluated mixing ratio δ(184 keV).

Table 12: The absolute gamma-ray emission probabilities,
calculated with the evaluated value of $P(ce_{1,0})$ and the adopted α_T(93 keV).
The transition probabilities were calculated from the P_γ and the α_T of each transition.

Transition	Relative intensity	P_γ (%)	$P_{\gamma+ce}$ (%)
$\gamma_{2,1}$ (91 keV)	14,74 (14)	3,09 (7)	3,37 (24)
$\gamma_{1,0}$ (93 keV)	181,8 (19)	38,1 (7)	70,6 (16)
$\gamma_{2,0}$ (184 keV)	100	20,96 (44)	21,3 (27)
$\gamma_{3,2}$ (209 keV)	11,33 (7)	2,37 (5)	2,40 (6)
$\gamma_{3,1}$ (300 keV)	79,22 (48)	16,60 (37)	16,67 (45)
$\gamma_{3,0}$ (393 keV)	21,92 (14)	4,59 (10)	4,60 (12)
$\gamma_{4,3}$ (494 keV)	0,318 (12)	0,0666 (29)	0,0667 (31)
$\gamma_{4,2}$ (703 keV)	0,0539 (42)	0,0113 (9)	0,0113 (9)
$\gamma_{4,1}$ (794 keV)	0,252 (6)	0,0528 (17)	0,053 (6)
$\gamma_{4,0}$ (887 keV)	0,712 (10)	0,1492 (38)	0,1493 (48)

5. Electron Emissions

The energies of the conversion electrons were calculated from the gamma-transition energies given in Section 4.2.1 and the electron binding energies.

The emission probabilities of the conversion electrons were calculated using the internal conversion coefficients given in Section 2.4.2. The emission probabilities of K-Auger electrons were calculated using the transition probabilities given in Sections 2.3 and 2.4, the atomic data given in Section 3, and the internal conversion coefficients given in Section 2.4.2.

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1992UN01	M.P. Unterweger, D.D. Hoppes, F.J. Schima, Nucl. Instrum. Methods Phys. Res. A 312, 349 (1992) [$T_{1/2}$]
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^{68}Ga - Comments on evaluation
by M.-M. Bé and E. Schönfeld

This evaluation was completed in 1996, it was reviewed in November 2011. The literature available by this date was included.

1 Decay Scheme

The decay scheme of Ga-68 is taken from Vo *et al.* (1994Vo15) who discovered 5 very weak transitions between already known levels in the decay scheme established by Lange *et al.* (1973La01). From other excitation modes, the existence of levels with energy (J^{π}): 2370,3 (15); 2417,44 (6) $(4)^+$; 2510,2 (15); 2750,38 (8) keV (3^-) was shown, however radiations originating from these levels were not observed in the Electron Capture decay of Ga-68 (1994Vo15). Transitions to the 2417 and 2510 keV levels would be third and second forbidden and therefore if they exist, their intensities would be very weak.
The values of the half- lives of the excited states of ^{68}Zn are taken from Burrows (2002Bu29).

2 Nuclear Data

The Q^+ value is from Audi *et al.* (2003Au03), adopted from Slot (1972Sl03) measurement, Q^+ = 2921,1 (12) keV.
A value of 2912 (10) keV was also measured by Kojima *et al.* (2001Ko07).

The following values of the half-life of ^{68}Ga have been taken into consideration:

Reference	**$T_{1/2}$ (min)**	Remarks
M. L. Perlman	68,0	omitted
G. L. Gleason (1960Gl04)	67,7 (3)	
L. A. Rayburn (1961Ra06)	69,2 (14)	outlier
T. G. Ebrey (1965Eb01)	68,33 (9)	Coin. Count. NaI(Tl), statistical uncertainty only
M. Borman (1965Bo42)	68,2 (1)	
J. M. Ootukalam (1971Oo01)	68,5 (5)	NaI, brief note, statistical uncertainty only
Smith and Williams (1971Sm02)	67,80 (8)	IC
Iwata et al. (1983Iw02)	67,629 (24)	Ge(Li)
Luca et al. (2012Lu*)	67,87 (10)	IC
Adopted	**67,83 (20)**	χ^2 crit = 2,8 ; χ^2 = 11

The set of 7 values used in the averaging process is not consistent with a reduced χ^2 of 11. The limitation of relative statistical weight procedure has then increased the Iwata's uncertainty to 0,05 in order to reduce the relative weight of this value to 50 %.
Therefore, the resulting (and adopted) weighted mean is 67,83 min with an expanded uncertainty of 0,20 to cover the most precise value.

2.1, 2.2 Electron Capture Transitions and β^+ Transitions

The sum of the EC + β^+ transition probabilities were deduced from the sum of the gamma transition probabilities populating and depopulating each level of the decay scheme. The EC/β^+ ratios were calculated by using the Logft program, a relative uncertainty of 5 % was assumed. For level 0, the theoretical value is quite close to the experimental values of 0,10 (2) (1959Ra04) ; for level 1, it lies between 1,28 (12) and 1,63 (11), experimentally determined by Ramaswamy (1959Ra04) and Sykora (1992Sy**) respectively.
The individual EC and β^+ probabilities have then been derived.

	P(EC+β^+) %	EC/β^+	P(EC) %	P(β^+) %
Level 0	96,62 (3) %	0,102 (5)	8,94 (41)	87,68 (41)
Level 1	3,00 (3) %	1,51 (7)	1,80 (5)	1,20 (4)
Level 2	0,0338 (23) %	127,5 (64)	0,0335 (23)	0,00026 (2)

From the values above, the sum of P(β^+) amounts for 88,88 (41) %, it corresponds to a 511 keV photon intensity of 177,8 (8) %, this result can be compared with experimental values.
Several authors measured the 511 keV photon emission, I_{511}, relatively to the 1077 emission:

Reference	I_{511}/I_{1077}	u_c	
Horen (1959Ho85)	5460	600	
Craseman (1956Cr29)	2880	340	Omitted
Carter (1968Ca15)	5930	600	
Ramaswamy (1959Ra04)	3900	420	Outlier
Schönfeld (1994Sc44)	5537	52	Uc increased to 220 to limit its weight to 50 %
Luca (2012Lu*)	5569	264	
Weighted mean ; internal uncertainty	5570	160	With I_{g1077} = 3,235 (30) %, the total I_{511} is 180 (5) %.

Moreover, two authors measured directly the I_{511} in absolute values: Schönfeld (1994Sc44), 178,29 (22) % and Luca (2012Lu*), 181 (6) %.
All these results are consistent within the uncertainty limits.

The energies are derived from the *Q* value and the level energies. The fractional probabilities for EC are calculated using the "Tables for Calculation of Electron Capture" (E. Schönfeld, PTB-Laboratory report 6.33-95-2 (1995)). These values are based on wave functions of Mann and Waber (1973) with exchange and overlap corrections of Bahcall and Vatai; see W. Bambynek et al., *Rev. Mod. Phys.* 49(1977)77. Note that the sum $P_K+P_L+P_M$ is not equal to 1 because of a very small fraction of capture from the N shell.

2.3 Gamma Transitions

The level differences (as well as the gamma-ray energies in Section 4.2) are taken from a compilation of Helmer (1997HeZZ) which takes into account also data from sources other than the Ga-68 decay.

The transition probabilities were derived from the emission intensities and the conversion coefficients.
The conversion coefficients are interpolated from Band’s tables by using the program BrIcc with the “frozen orbital approximation” (Kibédi *et al.* 2008Ki07). The adopted mixing ratios are derived from the experimental results as summarized below. For the 1261 keV transition where the values are discrepant the adopted value comes from the γ-γ directional correlation measurements of Vo *et al.(*1994Vo15). Eight transitions are pure E2 because the initial or the final level has J = 0.

Experimental mixing ratios δ :

Eγ (keV) Reference	483	805	938	1261	1744
1960Ra06				-1,8 (2)	
1962Ko01		+4 (+3 -2)			
1963Ta03				-2,25 (30)	
1971Ot01		-1,45 (15)		-0,21 (+6 -4)	0,24 (13)
1973La01		-1,46 (14)		0,14 (4)	0,29 (5)
1994Vo15	-0,12 (16) -1,7 (9)	-1,55 (5)	-0,7 (3)	-0,15 (2)	0,27 (2)
Adopted	1,0 (5) ^{e}	-1,53 (5) ^{w}	-0,7 (3)	-0,15 (2) ^{v}	0,272 (18) ^{w}
M1 / E2 (%)	50 (25)	70 (1)	33 (8)	2,2 (1)	6,9 (1)

^{e} : estimated ; ^{w} : weighted mean ; ^{v}: 1994Vo15.

3 Atomic Data

All these data are taken from E. Schönfeld and H. Janssen, *Nucl. Instr. and Methods in Phys. Res.* A 369(1996)527.

3.1 X Radiations

The energies are based on the wavelengths compiled by J. A. Bearden, *Rev. Mod. Phys.* 39(1967)78. The relative probabilities for K_{α} radiation are based on $P(K_{\beta})/P(K_{\alpha})$ and $P(K_{\alpha 2})/P(K_{\alpha 1})$ values as given in the above cited paper of Schönfeld and Janßen (1994). The relative probabilities for L quanta are derived from the corresponding absolute values (Section 4.2) setting $P(K_{\alpha 1})$ = 100.

3.2 Auger Electrons

The energies of KLL and KLX Auger electrons are taken from the paper of F. P. Larkins, Atomic Data and Nuclear Data Tables 20 (1977) 313. The relative emission probabilities of K Auger electrons are taken from the above cited paper of Schönfeld and Janßen (1994). The relative emission probabilities of L Auger electrons are derived from the corresponding absolute probabilities (Section 4.1) setting *P*(KLL) = 100.

4. Electron Emissions

The energies of the Auger electrons are the same as above. The energies of the conversion electrons are calculated from the energies of the gamma rays and the corresponding electron binding energies. The emission intensities of the Auger electrons are calculated from the transition probabilities of the EC transitions (2.1) and gamma transitions (2.3) using the atomic data given in Sections 3 and 3.2, the fractional electron capture probabilities and the conversion coefficients. The emission intensities of conversion electrons are calculated from the transition probabilities and conversion coefficients given in Section 2.3.

5. Photon Emissions

The X ray energies are the same as in 3.1. The energies of the gamma rays are taken from Helmer (1997HeZZ). The emission intensities of X rays were calculated from the decay scheme data.

Schönfeld *et al.* (1994Sc44) measured the ratio R of K x-ray intensities following the decay of Ge-68 and Ga-68, they obtained R = 9,57 (8). From the evaluation of Ge-68 decay data and the present one, a value R = 9,36 (26) is derived. They are in agreement within the uncertainty limits.

To determine the relative gamma-ray emission intensities the following values have been considered:

	Vaughan 1969Va16	Carter 1968Ca15	Lange 1973La01	Vo 1994Vo15	Schönfeld 1994Sc44	Luca 2012Lu*	χ^2 /n-1	Adopted
227	-	-	-	0,0037 (15)				0,0037 (15)
483	-	-	-	0,0082 (9)				0,0082 (9)
579	0,7 (1) *	1,1 (2)	1,00 (12)	1,05 (15)	1,14 (15)	1,35 (30) *	0,2	1,06 (7)
683	-	-	-	0,0097 (6)		-		0,0097 (6)
806	2,2 (2) *	2,8 (2)	2,95 (12)	2,81 (14)	2,90 (31)	2,68 (34)	0,3	2,87 (8)
939	-	-	-	0,0055 (5)		-		0,0055 (5)
1077	100	100	100	100	100	100		
1166	-	-	-	0,0005 (3)		-		0,0005 (3)
1261	3,1 (2)	2,9 (2)	3,00 (7)	2,75 (14)	3,06 (31)	2,60 (28)	1	2,95 (6)
1744	0,5 (1)	0,28 (4)	0,30 (4)	0,295 (15)		-	1,4	0,297 (16)
1883	4,8 (3)	4,1 (4)	4,33 (12)	4,6 (2)	3,86 (59)	3,94 (42)	1,1	4,39 (10)
2338	<0,1	0,04 (2)	0,050 (6)	0,031 (3)		-	4	0,035 (5)
2821	-	-	0,015 (2)	0,0139 (11)				0,0144 (11)

* Omitted from statistical processing

Where there are only values from Vo *et al.*, these results have been adopted unchanged. In all other cases weighted means were calculated by using the Lweight program, the adopted uncertainty being the highest of the internal or external uncertainty.

Two published papers report absolute measurements of the gamma intensities, for the 1077 keV emission, they are:

- Schönfeld *et al.* (1994): 3,22 (3) %
- Luca *et al.* (2012): 3,25 (11) %

From these two results, an absolute value of the 1077 keV intensity is adopted which is the simple mean with the lowest experimental uncertainty, that is: I_{g1077} = 3,235 (30) %.

All the other absolute intensity values were derived from I_{g1077} and the relative values as determined above.

A possible 1656 keV transition was observed only indirectly via conversion electrons by Slot *et al.* (1972Sl03) ($P_{\mathrm{ce}}(1656)/P_{\mathrm{ce}}(1077) = 0,010\ (2)$).

The absolute emission intensity of the annihilation photon (having 511 keV energy) is deduced from the decay scheme data and the theoretical EC/β⁺ ratios as described in § 2.1

7. References

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^{68}Ge - Comments on evaluation
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This evaluation was completed in 1996, it was updated to include the most recent *Q* value evaluation in December 2011. The literature available by this date was included.

Decay Scheme

The first excited state in Ga-68 is at 175 keV. As can be seen from the *Q* value an energy of this amount is not available. Thus, the decay scheme of Ge-68 is complete.

Nuclear Data

The Q^+ = 106,9 (24) keV is from 2011AuZZ, which supersedes the value of 106 (6) keV (2003Au03).

The following values of the half-life of ^{68}Ge have been taken into account:

Reference	**$T_{1/2}$ (*d*)**	
H. H. Hopkins, Jr.	250	omitted
G. Rudstam	288 (6)	
B. Crasemann *et al.*	275 (20)	
Waters *et al.* 1981	270,82 (27)	
Schönfeld *et al.* 1994	270,99 (19)	
Adopted	**270,95 (26)**	χ^2 crit = 3,8 ; χ^2 = 2,8

The set of four data is consistent, the weighted mean is adopted. Due to their large uncertainties, the values of Rudstam and Crasemann have practically no weight. The external uncertainty of 0,26 *d* is adopted, whereas the internal uncertainty is 0,15 *d*.

Electron Capture Transition

The energy is derived from the *Q* value. The fractional probabilities for EC are calculated using the "Tables for Calculation of Electron Capture" (E. Schönfeld, PTB-Laboratory report 6.33-95-2 (1995)). These values are based on wave functions of Mann and Waber (1973) with exchange and overlap corrections of Bahcall and Vatai; see W. Bambynek et al., *Rev. Mod. Phys.* 49(1977)77.

Atomic Data

All these data are taken from E. Schönfeld and H. Janssen, *Nucl. Instr. and Methods in Phys. Res.* A 369(1996)527.

X Radiations

The energies are based on the wavelengths compiled by J. A. Bearden, *Rev. Mod. Phys.* 39(1967)78. The relative probabilities for K_{α} radiation are based on $P(K_{\beta})/P(K_{\alpha})$ and $P(K_{\alpha 2})/P(K_{\alpha 1})$ values as given in the paper of Schönfeld and Janßen (1994).

Auger Electrons

The energies of KLL and KLX Auger electrons are taken from the paper of F. P. Larkins, (Atomic Data and Nuclear Data Tables 20 (1977) 313).
The relative emission probabilities of K Auger electrons are taken from the paper of Schönfeld and Janßen (1994). The relative emission probabilities of L Auger electrons are derived from the corresponding absolute probabilities setting *P*(KLL) = 100.

Radiation Emissions

Electron Emissions

The energies of the Auger electrons are the same as above. The emission intensities are calculated from the transition probability of the EC transition, the fractional electron capture probabilities and by using the atomic data given in sections above.

Photon Emissions

The X ray energies are the same as described above. The emission intensities are calculated from the transition probability of the EC transition, the fractional electron capture probabilities and by using the atomic data given in sections above.

Main Production Mode

Zn-66(α, 2n)Ge-68

References

1950Ho**	H.H.Hopkins Jr. Phys. Rev. 77 (1950) 717. Half-life
1956Ru45	G.Rudstam. Thesis U. Uppsala (1956). Half-life
1956Cr25	B.Crasemann, D..E.Rehfuss, H.T.Easterday. Phys.Rev. 102 (1956) 1344. Half-life
1981Wa26	S.L.Waters, G.R.Forse, P.L.Horlock, M.J.Woods. Int. J. Appl. Radiat. Isotop. 32 (1981) 757. Half-life
1994Sc44	E.Schönfeld, U.Schötzig, E.Günther, H.Schrader. Int. J. Appl. Radiat. Isotop. 45 (1994) 955. Half-life, Electron Capture/Beta plus Ratio, Gamma emission and annihilation probabilities
2002Bu29	T.W.Burrows. Nucl. Data Sheets 97 (2002) 1. Spin and parity
2003Au03	G.Audi, A.H.Wapstra, C.Thibault. Nucl. Phys. A729 (2003) 337. Q value
2011AuZZ	G.Audi, W.Meng. private communication (2011) Q

^{75}Se - Comments on evaluation of decay data
by V. Chisté and M. M. Bé

1 Decay Scheme

^{75}Se disintegrates 100 % by electron capture to excited levels and to the ground state of ^{75}As.

A good agreement was found between the effective Q value (860 (18) keV) calculated from the decay scheme data and the adopted and recommended value from the mass adjustment of Audi (2003Au03).

2 Nuclear Data

The Q value is from Audi and Wapstra (2003Au03).

Level energies, spins and parities are from the mass-chain evaluation of A. R. Farhan and B. Singh (1999Fa05).

Experimental ^{75}Se half-life values (in days) are given in Table 1:

Table 1: Experimental values of ^{75}Se half-life.

Reference	Experimental value (d)	Comments
H. N. Friedlander (1947Fr08)	115 (5)	Outlier
W. S. Cowart (1948Co07)	127 (7)	Outlier
J. M. Cork (1950Co58)	128	Not used: no uncertainty.
H. M. Wright (1957Wr37)	119.9 (6)	Outlier
H. T. Easterday (1960Ea02)	120.4 (2)	Outlier
F. Lagoutine (1975La16)	118.45 (25)	Outlier
M. J. Martin (1976MaZW)	120 (1)	Outlier
H. Houtermans (1980Ho17)	119.779 (4)	
U. Schötzig (1980Sc07)	119.76 (5)	
D. D. Hoppes (1982HoZJ)	119.80 (7)	
A. Iwahara (1994Iw04)	119.0 (5)	Outlier
M. He (2002He19)	115.0 (117)	Not used
M. P. Unterweger (2002Un02)	119.809 (66)	
Recommended value	119.781 (24)	χ^2 = 0.14

The value in 2002He19 was omitted because this value is just a verification of how good their experimental set-up was. The first 6 values (1947Fr08, 1948Co07, 1957Wr37, 1960Ea02, 1975La16, 1976MaZW) and the Iwahara value (1994Iw04) have been shown to be outliers, based on the Chauvenet's criterion and thus were omitted in the final calculation. With the 4 remaining values (1980Ho17, 1980Sc07, 1982HoZJ and 2002Un02), a weighted average was calculated using the LWEIGHT computer code (version 3). The largest contribution to the weighted average comes from the value of Houtermans (1980Ho17), amounting to 63 %. The LWEIGHT increases the uncertainty of 1980Ho17 value from 0.004 to 0.034 in order to reduce its relative weight from 63 % to 50 %.

The adopted value is the weighted average of 119.781 d with an internal uncertainty of 0.024 d. The reduced-χ^2 value is 0.14.

2.1 Electron Capture Transitions

The energies of the electron capture transitions have been obtained from the Q(EC) value (2003Au03) and the level energies given by A. R. Farhan (1999Fa05).

The adopted electron capture transition probabilities and associated uncertainties were deduced from the γ transition probability balance at each level in the decay scheme.

The partial sub-shell capture probabilities given in this section were calculated using the computer program EC-Capture.

2.2 γ Transitions

The γ transition probabilities were deduced using the γ-ray emission intensities and the relevant internal conversion coefficients (see **5.2 Gamma Emissions**).

Table 2 shows the multipolarities (no mixing ratios given) of γ transitions, deduced from the conversion coefficient (1999Fa05) analysis.

Table 2: Multipolarities of γ transitions.

Multipolarity	E_γ (keV)
E1	121.1155 (11), 136.0001 (6), 400.6572 (8),
[E2]	80.9365 (15), 373.61 (24), 556.90 (18), 821.56 (18)
E2	96.7340 (9)
E3	303.9236 (10)
[M1, E2]	249.3 (3), 419.1 (4), 468.6 (4), 542.02 (18), 617.8 (4)
M1 (+E2)	14.8847 (13)
M2 + (E3)	24.3815 (14)

For (M1 + E2) γ transitions (66-, 198-, 264-, 279- and 572-keV), the mixing ratios (δ) are given in Table 5, they were deduced by comparison between experimental values of K internal conversion coefficients and the theoretical values calculated using the BrIcc computer code (2008Ki07).

Since the γ transitions with E_γ = 121- and 136-keV were determined to be pure E1, their α_K coefficients can be interpolated from theoretical values and then used to deduce the α_K coefficient of the 264-keV γ-ray which has been used as the reference line in all the measurements. Then:

$$\alpha_k(264) = \frac{\alpha_k(136) \times I_\gamma(136)}{I_{CEK}(136)}$$

and

$$\alpha_k(264) = \frac{\alpha_k(121) \times I_\gamma(121)}{I_{CEK}(121)} \quad \text{(see Table 4)}$$

where:

– I_{CEK} is the weighted average of the experimental values of the relative conversion electron intensities shown in Table 3a (2nd and 3rd columns, respectively);

– I_γ is the weighted average of the experimental values of the relative γ-ray emission intensities given in Table 8 (see **5.2 Gamma Emission**).

Table 3a: Experimental and recommended values of relative conversion electron intensities (I_{CEK}) and photon (I_γ) intensities for (M1 + E2) γ-rays.

Energy (keV) Reference	121	136	66	198	264	279	572
1955Sc09	173 (14)	420 (34)	68 (10)	6.4 (9)	100	53 (7)	
1959Me76		377 (20)			100	53.6 (16)	
1960De06	180 (12)	450 (30)	80 (12)	6.8 (10)	100	63 (5)	
1960Gr03	154 (5)	384 (13)	73.7 (49)	7.30 (37)	100	49.2 (33)	0.055 (22)
1961Ed02	187 (15)	378 (30)	99 (12)	7 (1)	100	53 (5)	
1965Br19	167 (26)	520 (70)		7.0 (12)	100	52 (7)	
1970Pa25	174 (17)	399 (32)	72.3 (10)	7.36 (41)	100	52.5 (23)	0.0099 (9)
2005Ra29	169.91 (27)	377.94 (41)	88.47 (20)	6.41 (5)	100	42.93 (22)	0.0103 (34)
Recommended I_{CEK}	169.88 (42)	377.95 (41)	81 (8)	6.44 (7)	100	53.2 (12)	0.0100 (13)
χ^2	2.4	0.08	7.5	1.9		0.05	2.1
Recommended I_γ	28.7 (6)	97.8 (34)	1.792 (34)	2.48 (10)	100	42.36 (6)	0.06165 (49)
χ^2	4.16	5.08	6.07	4.43		0.51	1.43

Table 3b: Experimental and recommended values of relative conversion electron intensities I_{CEK} and photon (I_γ) intensities for additional (M1 + E2) γ-rays.

Energy (keV) Reference	24	80	96	303	400	419	556	617
1955Sc09		~ 8.1 (7)*	~ 720 (60)*	15.6 (13)	3.6 (5)			
1959Me76				15.4 (9)	3.6 (4)			
1960De06		14 (3)	940 (60)	16 (1)	3.8 (3)			
1960Gr03	1250 (150)	7 (1)	645 (32)	16.1 (9)	3.76 (28)			
1961Ed02			753 (60)	17.2 (17)	3.8 (3)			
1965Br19			750 (110)	17.0 (26)				
1970Pa25			724 (19)	16.6 (5)	3.71 (4)	0.006 6 (7)		0.000 85 (9)
2005Ra29	1010 (1)	4.04 (4)	502 (1)	16.4 (8)	3.98 (4)	0.012 0 (4)	0.009 5 (32)	0.001 1 (4)
Recommended I_{CEK}	1010.0 (16)	5.9 (18)	610 (110)	16.16 (29)	3.84 (13)	0.006 8 (9)	0.009 5 (32)	0.000 86 (9)
χ^2	2.6	6.2	12	0.45	3.9	1.8		0.37
Recommended I_γ	0.046 (11)	0.0161 (9)	5.71 (12)	2.2267 (44)	19.384 (36)	0.020 6 (11)	0.004 7 (2)	0.007 71 (9)
χ^2	4.56	1.13	13.53	0.80	1.5	5.03		0.179

* Not used

Table 4: Determination of α_{K264}.

Energy (keV)	I_{CEK} (%)	I_γ (%)	α_K (by BrIcc)	α_{K264}
121	169.88 (42)	28.7 (6)	0.037 2 (6)	0.006 28 (17)
136	377.95 (41)	97.8 (34)	0.026 3 (4)	0.006 81 (26)
			Adopted	**0.006 44 (24)**

The adopted α_K coefficient for the 264-keV γ transition is 0.006 44, weighted average with an external uncertainty of 0.000 24 and a reduced-χ^2 of 2.87.

Table 5 shows the final results of experimental α_K (deduced using α_{K264} = 0.006 44 (24)), together with mixing ratios δ (deduced from a comparison between experimental (column 2) and theoretical (column 5, calculated with the BrIcc computer code) α_K values.

Table 5: Recommended conversion coefficients and mixing ratios.

E_{γ} (keV)	I_{CEK}/I_{γ}	α_K experimental (= (α_{K264} * I_{CEK}/I_{γ}))	δ (mixing ratio)	α_K theoretical (given by BrIcc)	Multipolarities
24	22 (5) 10^3	141 (34)		165.4 (24)	M2 + (E3)
66	45.2 (45)	0.291 (31)	0.121 (33)	0.29 (3)	M1 + E2
80	370 (110)	2.4 (7)		1.486 (21)	[E2]
96	107 (19)	0.69 (13)		0.772 (11)	E2
198	2.60 (11)	0.016 7 (9)	0315 (39)	0.016 7 (9)	M1 + E2
264	1	0.006 44 (24)	-0.10 (7)	0.006 46 (25)	M1 + E2
279	1.256 (28)	0.008 09 (35)	-0.578 (44)	0.008 1 (4)	M1 + E2
303	7.26 (13)	0.046 7 (19)		0.046 9 (7)	E3
400	0.198 (7)	0.001 28 (6)		0.001 202 (17)	E1
419	0.330 (47)	0.002 13 (31)		0.003 0 (10)	[M1,E2]
556	2.0 (7)	0.013 0 (44)		0.001 628 (25)	[E2]
572	0.162 (21)	0.001 04 (14)	0.19 (1)	0.001 04 (1)	M1 + E2
617	0.112 (12)	0.000 72 (8)		0.001 03 (18)	[M1,E2]

Then, for all γ transitions, the adopted detailed and total internal conversion coefficients (ICC) and associated uncertainties have been obtained using the BrIcc computer program with "the frozen orbital approximation" (2008Ki07).

3 Atomic Data

Atomic values, ω_K, ϖ_L and n_{KL} and X-ray and Auger electron relative probabilities are from Schönfeld and Janβen (1996Sc06).

4 Electron emissions

The conversion electron emission probabilities were deduced from ICC values and γ-ray emission probabilities.

5 Photon Emissions

5.1 X-rays

The X-ray absolute intensities were deduced from the decay data using the EMISSION computer code and are compared in Table 6 with measured values found in the literature. A good agreement has been found between the experimental and our values deduced from decay scheme.

Table 6: Experimental and recommended (calculated) values of X-ray absolute intensities.

	1966Ra09*	1970Pa25*	1974Ca29*	1983Si25*	1992Sc09*	1996Sa22	2000Zhang	Recommended
K x-ray	55.5 (14)	53.1 (15)	53.5 (29)	57.5 (13)	54.7 (11)	58.3 (14)	55.6 (12)	56.0 (13)
Kα x-ray				49.2 (13)	47.6 (11)		48.3 (10)	48.4 (13)
Kβ x-ray				8.25 (24)	7.13 (17)		7.3 (2)	7.58 (25)

*Using normalization factor of 0.5875 (19) (see Table 7, **5.2 Gamma Emissions**)

5.2 Gamma emissions

The energies of the γ-rays given in section 5.2 are from A. F. Farhan (1999Fa05).

The experimental relative γ-ray emission intensities from ^{75}Se have been obtained from all the available relative and absolute values. The normalization factor to convert relative γ-ray emission probabilities to absolute values is from a weighted average of measured absolute values for the 264-keV γ-ray absolute intensity.

Table 7: Experimental 264-keV absolute gamma-ray emission intensities.

References	Experimental values
Y. Yoshizawa (1983Yo03)	0.580 (9)
U. Schötzig (1992Sc09)	0.5950 (54)
H. Miyahara (1994Mi22)	0.5870 (17)
Recommended value	**0.5875 (19)**, χ^2 = 1.35

The experimental γ-ray emission probabilities relative to 100 for the 264-keV γ-ray are given in Table 8.

Our recommended relative and absolute γ-ray emission probabilities are given in Table 9.

The adopted values are the weighted means calculated by the LWEIGHT program (version 3) with the following restrictions:
*: Discrepant data set, omitted from analysis.
@: data set already taken into account in 1987JeZZ, then these references have been omitted from the analysis.
µ: the experimental value has been shown to be an outlier value by the Lweight program.

Table 8: Experimental data sets of the relative γ-ray emission intensities (%) (cont. next page).

Energy (keV) **Reference**	**14**	**24**	**66**	**80**	**96**	**121**	**136**	**198**	**249**	**264**
1955Sc09			1.8 (1)		6.6 (15)	28 (5)	94 (12)			100
1958Va02			2.1 (8)		5.8 (6)	24.5 (30)	76 (5)	3.6 (4)		100
1959Vo30										100
1960De06						28 (5)	86 (15)			100
1960Gr03			1.53 (15)		5.5 (3)	27.9 (13)	96 (5)	2.6 (2)		100
1961Ed02			1.63 (6)		5.57 (18)	28.0 (6)	95.5 (18)	2.4 (1)		100
1965Br19						30 (10)	130 (40)			100
1966Ra09			1.64 (5)		5.53 (16)	27.8 (8)	94.9 (20)	2.28 (5)		100
1969Ra12			1.4 (4)		4.83 (10)	29.2 (29)	96.0 (96)	2.25 (23)		100
1970Pa25		0.044 (6)	1.72 (4)	0.015 (3)	5.12 (10)	27.7 (5)	95.0 (18)	2.38 (7)		100
1970Na14			1.54 (8)		5.43 (16)	28.5 (9)	94.0 (28)	2.78 (14)		100
1971Ge07			1.77 (1)		5.6 (5)	28.2 (14)	98.3 (46)	2.43 (12)		100
1971Pr07		0.032 (10)								
1973Su10*			0.97 (6)		4.7 (2)	25.4 (12)	90.3 (28)	2.5 (1)		100
1973Te06			2.0 (5)		5.0 (5)	25.8 (25)	94.6 (82)	2.2 (2)		100
1973Th07	0.034 (6)	0.063 (8)	1.50 (15)	0.011 (3)	5.4 (4)	26.7 (30)	95.7 (70)	2.59 (20)		100
1974Ca29		0.036 (4)								100
1977Ge12			1.86 (11)		5.90 (35)	29.8 (13)	102.0 (30)	2.53 (11)		100
1978Pr08		0.065 (8)	1.46 (20)	0.012 (4)	5.22 (20)	27.1 (40)	95.5 (60)	2.5 (4)		100
1983Yo03					5.78 (17)	29.24 (32)	99.2 (10)	2.51 (4)		100
1984Si06		0.052 (9)	1.91 (3)	0.014 (4)		29.96 (26)	102.5 (10)	2.52 (6)		100
1987JeZZ - n°1		0.045 (6)	1.850 (31)		5.93 (8)	29.23 (19)	99.9 (5)	2.518 (16)		100
1987JeZZ - n°2		0.127 (12) $^{\mu}$	1.82 (7)		5.68 (19)	29.1 (9)	96.3 (28)	2.52 (9)		100
1987JeZZ - n°3			1.76 (9)		6.13 (22)	27.9 (9)	94.6 (30)	2.25 (9)		100
1987JeZZ - n°4			1.95 (6)		6.47 (19)	29.2 (5)	99.9 (14)	2.568 (35)		100
1987JeZZ - n°5						29.3 (7)	99.9 (13)	2.48 (6)		100
1987JeZZ - n°6			1.78 (7)		5.41 (16)	28.5 (7)	95.9 (27)	2.38 (6)		100
1987JeZZ - n°7			2.00 (18)		5.13 (33)	30.0 (13)	99.5 (40)	2.53 (10)		100
1987JeZZ - n°8			1.860 (22)		5.790 (42)	28.65 (18)	98.2 (6)	2.509 (20)		100
1987JeZZ - n°9			1.960 (41)		5.63 (5)	28.96 (18)	99.9 (6)	2.581 (16)		100
1987JeZZ - n°10		0.0446 (20)	1.910 (25)		5.91 (7)	29.16 (33)	99.7 (11)	2.534 (28)		100
1987JeZZ - n°11			1.940 (34)		5.88 (8)	29.43 (32)	100.4 (11)	2.514 (28)		100
1987JeZZ - n°12			1.88 (1)		5.830 (22)	29.31 (11)	101.2 (3)	2.586 (11)		100
1987JeZZ - n°13			1.950 (24)		5.91 (6)	29.24 (29)	99.4 (12)	2.500 (35)		100
1990An07$^{@}$			1.962 (29)		5.93 (9)	29.24 (41)	100.0 (17)	2.50 (5)		100
1990Me15		0.0460 (46)	1.87 (9)	0.0190 (41)	5.71 (35)	29.8 (15)	100 (6)	2.54 (24)		100
1990Wa09$^{@}$			1.960 (49)		5.91 (12)	29.1 (6)	99.5 (20)	2.50 (6)		100
1992Sc09$^{@}$		0.0446 (20)	1.910 (25)		5.91 (7)	29.16 (33)	99.7 (11)	2.534 (28)		100
1994Bh07*	0.003 (2)	0.056 (6)	1.912 (3)	0.013 (4)		30.1 (9)	102.3 (11)	2.51 (8)		100
1994Mi22					5.779 (45)	29.76 (19)	100.2 (6)	2.555 (20)		100
1997Lo10						28.05 (27)	98.41 (36)	2.58 (7)		100
2005Ra29	0.035 (1)	0.035 (1)	1.79 (1)	0.017 (1)	5.10 (4)	27.40 (22)	94.1 (8)	2.42 (2)	0.0067 (2)	100
Evaluated	0.035 (1)	0.046 (11)	1.792 (34)	0.0161 (9)	5.71 (12)	28.7 (6)	97.8 (34)	2.48 (10)	0.0067 (2)	100
χ^2	0.027	4.56	6.07	1.13	13.53	4.16	5.08	4.43		

Energy (keV) Reference	279	303	373	400 418		468	542 557		572	617 821	
1955Sc09	45.7 (40)	2.0 (5)		24.8 (25)							
1958Va02	52 (5)			28 (2)							
1959Vo30	44.1 (44)	3.2 (12)		22.7 (15)					0.068 (46)		
1960De06	42.5 (20)	2.15 (30)		23 (2)							
1960Gr03	41.0 (25)	2.5 (3)		22.3 (23)					0.18 (6)		
1961Ed02	42.2 (6)	2.29 (14)		19.5 (6)							
1965Br19	53 (15)										
1966Ra09	43.0 (9)	2.39 (5)		22.3 (5)	0.0322 (6)				0.0636 (13)	0.00777 (15)	
1969Ra12	41.3 (41)	2.06 (21)		19.2 (19)	0.020 (3)				0.053 (8)	0.0076 (10)	
1970Pa25	42.0 (8)	2.19 (7)		20.4 (5)	0.023 (2)	0.0010 (5)			0.063 (2)	0.0075 (2)	
1970Na14	41.9 (13)	2.20 (11)		19.5 (6)							
1971Ge07	43.2 (22)	2.31 (12)		19.6 (12)							
1971Pr07						0.00054 (18)					0.000216 (10)
1973Su10*	42.5 (15)	2.20 (8)		19.0 (6)	0.0140 (16)				0.054 (3)	0.0075 (31)	
1973Te06	40.0 (22)			19.6 (7)							
1973Th07	42.1 (8)	2.11 (30)		18.0 (4)	0.017 (3)				0.048 (5)	0.059 (7)	
1974Ca29											
1977Ge12	42.4 (18)	2.21 (7)		19.1 (6)							
1978Pr08	42.6 (8)	2.3 (4)	0.0042 (4)	18.8 (6)	0.018 (4)	0.00062 (10)	0.00022 (4)$^{\mu}$	0.00006 (2)$^{\mu}$	0.050 (4)	0.0062 (8)	0.00028 (2)
1983Yo03	42.43 (29)	2.234 (20)		19.42 (16)	0.0231 (21)				0.0634 (29)	0.0078 (21)	
1984Si06	42.4 (4)										
1987JeZZ - n°1	42.53 (23)	2.248 (13)		19.27 (13)	0.0206 (7)				0.0602 (20)	0.0072 (7)	
1987JeZZ - n°2	43.9 (13)	2.25 (7)		19.7 (6)	0.024 (9)				0.0625 (26)	0.0067 (10)	0.0016 (12)$^{\mu}$
1987JeZZ - n°3	42.2 (13)	2.21 (8)		19.1 (6)							
1987JeZZ - n°4	42.6 (6)	2.091 (27)		19.41 (24)							
1987JeZZ - n°5	42.6 (9)	2.24 (5)		19.50 (42)							
1987JeZZ - n°6	42.4 (9)	2.23 (6)		19.17 (39)	0.0102 (32)				0.0580 (41)	0.0076 (6)	0.00030 (15)
1987JeZZ - n°7	42.6 (16)	2.24 (8)		19.5 (7)	0.0154 (11)				0.0590 (34)	0.0080 (6)	0.0013 (7)$^{\mu}$
1987JeZZ - n°8	42.48 (31)	2.234 (19)		19.60 (14)					0.0610 (18)		
1987JeZZ - n°9	42.36 (22)	2.224 (12)		19.79 (10)					0.0617 (14)	0.0063 (18)	
1987JeZZ - n°10	42.5 (5)	2.242 (25)		19.49 (22)	0.0196 (12)				0.0610 (11)	0.0078 (5)	
1987JeZZ - n°11	42.4 (5)	2.220 (27)		19.08 (23)	0.0217 (5)				0.0603 (9)	0.0077 (3)	
1987JeZZ - n°12	42.25 (7)	2.219 (9)		19.36 (4)	0.0247 (13)				0.067 (2)	0.0108 (12)	
1987JeZZ - n°13	42.69 (37)	2.239 (22)		19.51 (17)					0.064 (3)		
1990An07$^{@}$	42.7 (5)	2.238 (31)		19.51 (24)					0.064 (5)		
1990Me15	42.2 (21)	2.23 (11)		19.5 (10)	0.0180 (31)				0.0600 (42)	0.0077 (6)	0.000220 (23)
1990Wa09$^{@}$	42.4 (9)	2.25 (5)		20.19 (43)	0.0209 (5)				0.0589 (12)	0.0076 (2)	
1992Sc09$^{@}$	42.5 (5)	2.242 (25)		19.49 (22)	0.0196 (12)				0.0610 (11)	0.0078 (5)	
1994Bh07*	42.55 (10)										
1994Mi22	42.78 (25)	2.239 (18)		19.31 (12)							
1997Lo10	43.63 (29)	2.199 (11)		18.84 (16)					0.066 (3)		
2005Ra29	43.07 (34)	2.27 (2)	0.0044 (2)	20.13 (16)	0.035 (1)	0.0036 (2)$^{\mu}$	0.00074 (1)	0.0047 (2)	0.062 (1)	0.0078 (2)	0.0015 (2)$^{\mu}$
Evaluated	42.36 (6)	2.2267 (44)	0.00436 (18)	19.384 (36)	0.0206 (11)	0.00061 (9)	0.00074 (1)	0.0047 (2)	0.06165 (49)	0.00771 (9)	0.00028 (14)
χ^2	0.51	0.80	0.2	1.55	5.03	0.38			1.43	0.179	2.85

Table 9: Recommended relative and absolute γ-ray intensities (%).

Eγ (keV)	**Relative γ-ray intensity (%)**	**Absolute γ-ray intensity (%)**	**Eγ (keV)**	**Relative γ-ray intensity (%)**	**Absolute γ-ray intensity (%)**	**Eγ (keV)**	**Relative γ-ray intensity (%)**	**Absolute γ-ray intensity (%)**
14	0.035 (1)	0.020 6 (6)	**198**	2.48 (10)	1.46 (6)	**418**	0.020 6 (11)	0.012 1 (6)
24	0.046 (11)	0.027 (6)	**249**	0.006 7 (2)	0.003 94 (12)	**468**	0.000 61 (9)	0.000 36 (5)
66	1.792 (34)	1.053 (20)	**264**	100	58.75 (19)	**542**	0.000 74 (1)	0.000 435 (6)
80	0.016 1 (9)	0.009 5 (5)	**279**	42.36 (6)	24.89 (9)	**557**	0.004 7 (2)	0.002 76 (12)
96	5.71 (12)	3.35 (7)	**303**	2.226 7 (44)	1.3082 (50)	**572**	0.061 65 (49)	0.036 22 (31)
121	28.7 (6)	16.86 (36)	**373**	0.004 36 (18)	0.002 56 (11)	**617**	0.007 71 (9)	0.004 53 (5)
136	97.8 (34)	57.7 (20)	**400**	19.384 (36)	11.388 (42)	**821**	0.000 28 (14)	0.000 134 (8)

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^{79}Se - Comments on evaluation of decay data by M. M. Bé and V. Chisté

This evaluation was completed in January 2006.

1. Decay scheme

The J^{π} value and level energy are from **NDS 70,3** (1993).

2. Nuclear Data

- The Q value is from **Audi *et al.*** (2003)
- Published values of the half life are, in years :

Historical values		*a*	
1949	Parker *et al.*	$\leq 6.5 \times 10^4$	Report ORNL- 499, p.45
1951	Glendenin	$\geq 7 \times 10^6$	Radiochimical studies : The fission products, C.D. Coryell, N. Sugarman, New-York, McGraw Hill (1951) 596
Revised value			
1993	B. Singh	$\leq 6.5 \times 10^5$	NDS 70,3 p. 452
Measured Values			
1995	Yu Runlan, Guo Jingru *et al.*	$4.8\ (4) \times 10^5$	J. Radioanalytical and Nuclear Chemistry, Articles, 196,1 p. 165
1997	Jiang Songsheng, Guo Jingru *et al.*	$1.1\ (2) \times 10^6$	Nucl. Instr. Methods B123, p 405
2000	Ming He, Shan Jiang *et al.*	$1.24\ (19) \times 10^5$	Nucl. Instr. Methods B172, p 177
2002	Songsheng Jiang, Ming He *et al.*	$2.95\ (38) \times 10^5$	Nucl. Instr. Methods A489, p 195 or Chin. Phys. Lett. 18 (2001) 746
2002	Ming He, Songshen Jiang *et al.*	$2.80\ (36) \times 10^5$	Nucl. Instr. Methods B194, p 393
2006	Bienvenu, *et al.*	$3.77\ (19) \times 10^5$	To be published
Adopted		$3.56\ (40) \times 10^5$	

Assessments of the Se-79 half-life were done in the years 49-50 (Parker, Glendenin) and a value of 6.5×10^4 *a* was accepted by the various tables and chart of isotopes.

In 1993, due to inconsistencies in the measured and calculated fission yields of ^{79}Se for an irradiated fuel from a reactor, the calculations of Parker were review ed (Singh) and a new value of 6.5×10^5 *a* (i.e. one order of magnitude more) was deduced. Hence, in 1995 a Chinese team carried out the first measurement of this half-life by the means of a radiochemical method, they obtained $4.8\ (4) \times 10^5$ a. However, and since this date, the same team, using the same ^{79}Se source published various results (see table above), the highest being $1.1\ (2) \times 10^6$ *a* (1997), and the last $2.80\ (36) \times 10^5$ *a* (2002).

Only one value (the last) will be used in this evaluation.

In NDS 96,1 (2002) B. Singh adopts the result of 2.96 (38) from the Chinese team.

In 2006, an independent result was published by P. Bienvenu *et al.* confirming the range 10^5 *a* for this half-life. In this study, the concentration of ^{79}Se was measured using ICP-MS coupled with Electro-Thermal Vaporisation to eliminate potential isobaric interferences and, the activity was measured using LSC after gamma ray spectrometry to check the contribution of residual radioactive contaminants.

In this evaluation, the adopted value is the weighted mean of the last Chinese value (NIM B194) and of the Bienvenu *et al.* value. They are in the same range but not consistent so, the adopted uncertainty is the external uncertainty.

2.1 b emission

^{79}Se is a pure beta minus emitter which disintegrates directly to the ground state level of ^{79}Br, no gamma rays are emitted.
The end-point energy is deduced from the Q value. The mean beta energy was calculated for a 1st forbidden unique transition.

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^{85}Kr – Comments on evaluation of decay data
by V. Chisté and M. M. Bé

This evaluation was completed in July 2003 and the half life value has been updated in May 2004.

1) Decay Scheme

^{85}Kr disintegrates by β^- emission to the ^{85}Rb ground state (99.562(10)%) and to the second excited level at 513.998(5) keV (0.438(10)%). The decay scheme is based mainly on the measurements of the 514 keV γ-emission intensity (see § **4. Radiation Emission, 4.2 Gamma Ray Emissions**).

2) Nuclear Data

The Q value is from Audi and Wapstra (1995Au04)

Level energies, spins and parities are from R. A. Meyer (1980Me06).

The measured ^{85}Kr half-life values are, in years:

$T_{1/2}$

Reference	Value (a)	Comments
Thode (1948Th06)	9.4 (4)	
Turner (1953Tu22)	10.57 (14)	
Wanless (1953Wa17)	10.27 (18)	
Lerner (1963Le07)	10.76 (2)	
Anspach (1965An07)	10.75 (3)	
Johnston (1974Jo12)	10.714 (57)	
Walz (1983Wa15)	10.702(8)	Superseded by 2003Sc49
Unterweger (1992Un03)	10.7720(38)	Superseded by 2002Un04
Eberszkorn (1996Er06)	10.757 (49)	
Unterweger (2002Un04)	10.7756(33)	
Schrader (2003Sc49)	10.724(7)	

Evaluators calculated the weighted average of these 9 values using the Lweight program (version 3) as 10.750 years with an external uncertainty of 0.011 and a reduced -χ^2 of 6.34. Evaluators rejected the Thode (1948Th06), Turner (1953Tu22) and Wanless (1953Wa17) values based on the Chauvenet's criterion. For the remaining 6 values, the largest contribution to the weighted average comes from the value of Unterweger (2002Un04), amounting to 79%. The program Lweight 3 increased the uncertainty for the 2002Un04 value from 0.0033 to 0.0064 in order to reduce its relative weight from 79% to 50%.

The adopted value is the weighted mean : *10.752 a*, with an uncertainty of *0.023* (expanded so range includes the most precise value of Unterweger (2002Un04)) and a reduced-χ^2 of 6.

2.1) b$^-$ Transitions

The β^- probabilities and the associated uncertainties have been deduced from γ transition probability balance at each level of the decay scheme, i. e., $P_\beta(0,0)$ = 99.562(10)% and $P_\beta(0,2)$ = 0.438(10)% . The values of log ft have been calculated with the program LOGFT for the Allowed and 1st Unique Forbidden transitions.

2.2) Gamma Transitions

Probabilities

The transition probabilities have been calculated from the gamma emission intensities and the internal conversion coefficients (see § **4.2) Gamma Ray Emissions**).

Mixing ratios and internal conversion coefficients

The adopted δ (= 0.072(4)) for the 151 keV γ-transition and the gamma transition multipolarities of the 362 keV ((E3)) and of the 513 keV (M2, from ^{85}Sr ground state decay) were adopted from Sievers (1991Si01).

The theoretical internal conversion coefficients (table 1) have been interpolated from values in 1978Ro22 using the ICC Computer Code (program Icc99v3a – GETICC dialog).

Table 1:

E_g (keV)	Multipolarity	Value of a$_K$	Value of a$_L$	Value of a$_T$
151.18 (3)	M1 + 0.52(4)% E2	0.0430(13)	0.00485(14)	0.0488(14)
362.81 (3)	(E3)	0.0292(9)	0.0040(1)	0.0340(10)
513.998 (5)	M2	0.00635(19)	0.00072(2)	0.00721(21)

For the 151 keV γ-transition, the α_T is calculated as follows:

α_T(M1) * %(M1) + α_T(E2) * %(E2) = (0.00479(14) * 0.9948(4)) + (0.213(6) * 0.0052(4)) = 0.0488(14)

Calculations of ICC uncertainties for transitions:

* For the all transitions, uncertainties in α_T, α_K and α_L calculated values with ICC Computer Code (program Icc99v3a) are taken to be 3% .

3) Atomic Data

Atomic values (ω_K, $\bar{\omega}_L$ and n_{KL}) are from Schönfeld (1996Sc33).

The X-ray and Auger probabilities are calculated by Emission program.

4) Radiation emissions

4.2) Gamma ray emissions

Gamma ray energies (in keV) are from R. A. Meyer (1980Me06).
Emission probability values are deduced from measured values of the 514 keV absolute γ-emission intensity in Table 2 and using values relative to 514-keV transition for the other gamma-rays (1980Me06) shown in Table 3.

Table 2:

Reference	514 keV γ-emission intensity (%)	Comments
Geiger (1961Ge19)	0.46 (4)	
Eastwood (1964Ea01)	0.431(17)	
Denecke (1967De05)	0.435 (13)	
Weighted Average (Lweight 3)	0.435 (10)	Reduced-χ^2 = 0.22

Table 3:

Energy (keV)	Relative γ-emission intensity measured by R. A. Meyer (1980Me06) (%)	Absolute γ-emission intensity (%)
151	0.0005 (3)	0.0000022(13)
362	0.0005 (1)	0.00000218(44)
514	100	0.435(10)

With theses values shown in table 3, and the values of α_T calculated using the ICC Computer Code (table 1, section 2.2), evaluators deduced the γ-transition probability (table 4).

Table 4:

Energy (keV)	Transition probability (%)
151	0.0000023(14)
362	0.00000225(45)
514	0.438(10)

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^{85}Sr - Comments on evaluation of decay data
by E. Schönfeld, R. Dersch

1 Decay Scheme

The decay scheme is taken from Torti et al. (1972) and Meyer et al. (1980). A level at 951 keV which is depopulated by four gamma transitions (see Section 4.3) was observed by Barnard et al. (1973) in n, γ reactions. An EC transition to this level in the ^{85}Sr disintegration would be second forbidden. An upper limit of 3 10^{-7} was estimated for this transition. The existence of EC transitions to the levels at 281 keV (unique third forbidden) and 151 keV (third forbidden) is also questionable.

Below the Q_{EC} value there are also levels at 919,7 keV (possibly two levels, $1/2^-$ or $3/2^-$ and $5/2^-$, populated in the decay of 68 min ^{85}Sr^{m} and several reactions) and 731,822 keV ($3/2^-$, populated in the decay of 4 h ^{85}Kr^{m} and several reactions). EC transitions from ^{85}Sr ground state to these levels would be both 3rd forbidden, γ rays from these levels have not been observed in the decay of ^{85}Sr.

The main transitions in the EC decay of ^{85}Sr are the EC transition populating the 514 keV level of ^{85}Rb and the γ transition of 514 keV depopulating this level. Besides these transitions there is an EC transition to the 869 keV level which is mainly depopulated by 869 keV γ rays.

The half-lives of the excited levels were taken from Sievers (1991). The half-life of the 514 keV level was determined by Siekman (1956), Löbner (1964). Miller *et al.* (1972) and Walz and Weiß (1976). Sievers took the value of Miller et al. which claims to be the most accurate one.

2 Nuclear Data

The following values of the half-life of ^{85}Sr have been considered ($T_{1/2}$ in d):

1	66	Dubridge and Marshall (1940)
2	65,0(7)	Herrmann and Strassmann (1956)
3	64,0(2)	Wright et al. (1957)
4	63,9(27)	Sattler (1962)
5	65,19(13)	Anspach et al. (1965)
6	66,6(6)	Grotheer et al. (1969)
7	64,93(22)	Emery et al. (1972)
8	64,68(23)	Lagoutine et al. (1972)
9	65,0(49)	Araminowicz and Dressler (1972)
10	65,0(50)	Vatai et al. (1974)
11	64,84(3)	Merritt and Gibson (1976); replaced by value 13
12	64,84(1)	Thomas (1978)
13	64,845(9)	Rutledge et al. (1980)
14	64,856(7)	Houtermans et al. (1980)
15	64,851(6)	Hoppes et al. (1982); replaced by value 17
16	64,85(14)	Walz et al. (1983)
17	64,8530(81)	Unterweger et al. (1992)
18	64,847(3)	unweighted mean of 12, 13, 14, 16, 17
19	64,850(7)	LWM (0,004 (int), 0,003(ext), reduced χ^2 0,46), uncertainty enlarged to the uncertainty of the most accurate single value for the same five values

Values 1 - 11 are only of historical interest. They were not included in the averaging procedure.

The Q_{EC} value was taken from Audi and Wapstra (1995).

2.1 Electron capture Transitions

The main EC transition $\varepsilon_{0,3}$ to the 514 keV level in ^{85}Rb is allowed (lg *ft* = 6,2). A transition leading directly to the ground state ($\varepsilon_{0,0}$) is unique 1st forbidden. The transition probability of this transition was estimated by Yoshizawa and Inoue (1991) by using the average lg *ft* value (according to Gove and Martin (1971)) of 9,47 ± 0,17 for seven neighbouring nuclei with uncertainty of 2 σ. Their result is 0,8(4)%. The probability for the EC transition $\varepsilon_{0,4}$ is deduced from the probabilities of the depopulating γ ray transitions. Concerning EC transitions $\varepsilon_{0,2}$ and $\varepsilon_{0,1}$ see Section 1. The data for the population and depopulation of the 151 keV level are discrepant as $P_{\gamma+ce}(4,1) + P_{\gamma+ce}(3,1) + P_{\gamma+ce}(2,1)$ is larger than $P_{\gamma+ce}(1,0)$. This can be explained (for example) by a too small value for $P_{\gamma+ce}(1,0)$. Moreover, it supports the assumption that an EC transition to the first excited level of ^{85}Rb at 151 keV does not exist.

Double K shell ionization was found by Schupp and Nagy (1984) 6,0(5) 10^{-5} per disintegration.

2.2 Gamma Transitions

The transition probability of 0,8(4)% for the EC transition directly feeding the ground state of ^{85}Rb yields for $P_{\gamma+ce}$(514 keV) = 99,2(4)%. Furthermore, with the total conversion coefficient of the 514 keV transition I_{γ}(514) = 98,5(4)%. The transition probabilities of the other gamma transitions are derived from the measured emission probabilities (Sect. 4.2).
The conversion coefficients are interpolated from the tables of Rösel et al. (1978). The main transition $\gamma_{3,0}$ is assumed to have pure M2 multipolarity. The conversion coefficients of the other transitions have little influence on the balancing procedure because the emission probabilities of the assigned transitions are very small.

3 Atomic data

The atomic data are taken from Schönfeld and Janßen (1996).

3.1 X Radiation

The energies are based on the wavelengths of Bearden (1967). The relative probabilities are taken from Schönfeld and Janßen (1996).

3.2 Auger electrons

The energies are taken mainly from Larkins (1977). The relative probabilities are taken from Schönfeld and Janßen (1996).

4 Radiation Emission

4.1 Electron emission

The energies of the Auger electrons are the same as above. The energies of the conversion electrons are calculated from the transition energy and the binding energies. The number of Auger electrons per disintegration are calculated using the above mentioned atomic shell data and the program EMISSION. The number of conversion electrons related to the 514 keV γ-transition are calculated from the transition probability and the conversion coefficients.

4.1 X-ray emission

For the total K X-ray emission intensity, it was found three measured values :

1	59,59(35)	Grotheer et al. (1969)
2	58,6(3)	Bambynek and Reher (1970)
3	58,66(47)	Thomas (1978)
4	59,04(34)	Weighted mean
5	58,95(32)	Unweighted mean
6	59,2 (6)	calculated from Pe, P_K, ω_K, P_{g+ce} This is the adopted value.

4.2 Photon Emission

The accuracy of the γ ray energy of the main line has improved during the last years, in keV :

1	514,0	Sattler (1962), Vartanov (1966)
2	513,98(3)	Legrand et al. (1968)
3	513,998	Ragaini et al (1972), Meyer et al. (1980)
4	514,009(12)	Helmer et al. (1978)
5	514,0076(22)	Kumahora et al. (1983)
6	514,00492(50)	Chang et al. (1993)
7	514,0048(22)	Helmer and van der Leun (2000), evaluation

The γ ray energies of the other transitions are taken from Sievers (1991).

From the balance of the decay scheme $P_{\gamma+ce}$ (514 keV) is calculated to be 99,2(4)%.

The ratio of the emission probabilities of the 869 keV and the 514 keV transitions were determined to be:

1	$1{,}7 \cdot 10^{-4}$	Sattler (1962)
2	$1{,}0(2) \cdot 10^{-4}$	Vartanov et al. (1966)
3	$1{,}4(2) \cdot 10^{-4}$	Vatai et al. (1974)
4	$1{,}154(63) \cdot 10^{-4}$	Pratt (1977)
5	$1{,}25(5) \cdot 10^{-4}$	Thomas (1978)
6	$1{,}25(5) \cdot 10^{-4}$	Meyer et al. (1980)
7	$1{,}23(3) \cdot 10^{-4}$	LWM of values 2 - 6

With the above-mentioned $I_\gamma(514)$ = 98,5(4) % this yields $I_\gamma(869)$ = 0,0121(4) %.

Barnard *et al.* (1973) have observed in (n,n’ γ) measurements a level at 951,3 keV in ^{85}Rb which is depopulated by the following gamma transitions: 951,3 keV (86 %), 800,2 keV (9 %), 670,3 keV (4 %) and 437,7 keV (1 %). If this level with the populated in the ^{85}Sr decay, the corresponding EC transition is second forbidden (9/2+ → 5/2+; lg *ft* > 11,2; transition energy 114(4) keV). Meyer *et al.* (1980) observed a 951 keV gamma ray in two spectra with high counting statistics and estimated an upper limit of $3\ 10^{-7}$ for the emission probability of these gamma rays.

Levels at 731,9 keV (3/2 -) and 921 keV (1/2 -, 3/2-) in ^{85}Rb have not been found to be populated in the studies of the ^{85}Sr decay carried out by Meyer *et al.* (1980).

A level in ^{85}Rb at 281 keV, found by Barnard *et al.* (1973), is depopulated according to Meyer *et al.* (1980) by 129,8 keV gamma rays with an emission probability of $< 5\ 10^{-3}$. As this is an upper limit the existence of this transition is not sure. Therefore, the population and depopulation of this level is given in the above decay scheme by dashed lines.

The gamma ray emission intensities in Table 5.2 and the corresponding values of the transition probabilities $P_{\gamma+ce}$ given in Table 2.2 are from Meyer *et al.* (1980) (129,8/151,1/355,0/362,8 keV) whereas the value for the 717,8 keV gamma rays is from Jerbic-Zorc (1990). The origin of the values for the 514 keV and 869 keV gamma rays were already explained above.

5 Main Production Modes

The main production modes are taken from Sievers (1991).

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For other references see Chapter “References” in the Table Part.

^{88}Y – Comments on evaluation of decay data
by E. Schönfeld

This evaluation was completed by E. Schönfeld (PTB) in November 1998.
The half-life evaluation was updated by M.-M Bé (LNHB) in February 2003.

1 Decay Scheme

Below the *Q*-value of 3622,6 ke V there are two additional levels at 3486,6 and 3523,6 keV (both probably 2+). They are not shown in the decay scheme because they are not populated in the disintegration of ^{88}Y. Ardisson *et al.* (1974) did not found the 3523,6 keV level but they confirmed the 3584,7 keV level which is populated in the ^{88}Y decay. Up to now these levels were observed only in other disintegration processes, for example in the decay of ^{88}Rb (17,78 min).

An EC or β^+ transition to the ground state of ^{88}Sr was also not observed. This is due to the high forbiddeness of such a transition ($4^- \rightarrow 0^+$). Thus, the decay scheme shown above is almost complete.

The half-lives of the excited levels and the lg *ft* values were taken from Müller (1988).

2 Nuclear Data

The following measured values of the half-life were taken into consideration :

Reference	Value (in days)	Uncertainty	Comments
DuBridge (1940)	105	5	Omitted, too large uncertainty
Peacock (1948); Lazar (1956)	104		Omitted, no uncertainty
Ramaswamy (1960)	105		Omitted, no uncertainty
Wyatt (1961)	108,1	0,3	Omitted, outlier
Anspach (1965)	106,52	0,03	Replaced by Hoppes
Anspach (1965)	106,67	0,03	Replaced by Hoppes
Grotheer (1969)	108,4	0,9	Omitted, outlier
Lagoutine (1975)	106,6	0,4	Superseded by Amiot
Bormann (1976)	107,1	1,4	
Konstantinov (1977)	107,15	0,65	
Houtermans (1980)	106,612	0,032	Original uncertainty = 0,014
Debertin (1982)	106,64	0,08	Superseded by Walz
Hoppes (1982)	106,64	0,05	Superseded by Unterweger
Walz (1983)	106,66	0,06	
Unterweger (1992)	106,626	0,044	
Martin (1997)	106,65	0,13	
Amiot *et al.* (2003)	106,63	0,05	
Recommended value	**106,626**	**0,021**	

An analysis of these values was done using the “Limitation of relative statistical weight” program. The first three values have been omitted from the analysis, the Grother and Wyatt’s (Grother *et* *al.*, 1969) value have been omitted as outliers as suggested by Chauvenet's criterion (Chauvenet, 1976) and the uncertainty on the Houtermans's value (Houtermans *et al.*, 1980) has been increased to 0,032 to ensure that its value has the same "weight" as the most recent values. The reduced χ^2 of this set of data is 0,22. Finally, the recommended value is the weighted mean of the seven remaining values.

The Q-value is taken from Audi and Wapstra (1995).

2.1 Electron Capture Transitions

The fractional capture probabilities P_K, P_L, P_M were calculated on the basis of the paper of Schönfeld (1998). The corresponding values for the transition $\varepsilon_{0,1}$ have been estimated by the evaluator.

2.2 Positron Transitions

A positron transition to the ground state was not observed. However, sufficient energy for a positron transition is available for a transition to the 1836 keV level. The maximum energy of these positrons were determined to be 767,1(10) keV by Barkov *et al.* (1974) while there emission probability were determined to be 0,00203(16) per disintegration by the same authors. The corresponding EC/ β^+ ratio was found to be 26(3) which agrees with the theoretical value of 25,6(8) for an unique first forbidden transition interpolated from the table of Gove and Martin (1971). For the value given for the positron emission probability in Table 2.2, the theoretical value was used. The maximum beta energy of the β^+spectrum was found by Antonewa *et al.* (1974) to be 764,6(15) keV corresponding to a Q value of 3622,6(15) keV.

2.3 Gamma Transitions

The level differences have been calculated from the gamma ray energies (Table 4.2) and the recoil energies. The probabilities $P_{\gamma+ce}$ were calculated from the gamma ray emission proba bilities and the total conversion coefficients. The multipolarities were taken from Müller (1988).

Conversion coefficients were measured as follows:

	a_K	a_t	K/L+M+...
898 keV	0,000301(21) [1]	0,000345(24) [1]	7,0(5) [1]
E1	0,00025(3) [2]	0,00028(3) [2]	8,0(2) [2]
		0,00034(7) [3]	
		0,00027 [4]	
	0,00028(2) [5]	0,00032(3) [5]	
	0,000274 [6]	0,000310 [6]	7,6 [4]
	0,000277(20) [7]	0,000315(23) [7]	7,3 [5]
1836 keV	0,000124(16) [2]	0,000140(16) [2]	7,8(3) [2]
E2		0,00017(4) [3]	
		0,00013 [4]	
	0,000146 [6]		
	0,000135(14) [7]	0,000152(15) [7]	7,9(3) [7]

[1] Hamilton *et al.* 1966
[2] Allan 1971
[3] Metzger and Amacher (1952)

[4] Peacock and Jones cited in [2]
[5] weighted mean of [1] and [2]
[6] theory, interpolated from the tables of Rösel *et al.* (1978)
[7] adopted value

All the other conversion coefficients were interpolated from the tables of Rösel *et al.* (1978).

The mixing ratio parameter for the 898 keV transition has been evaluated in the basis of four publications by Müller (1988) to be $\delta = -0{,}002(9)$, i. e. this transition is an almost pure E1 transition. For the 1382 keV transition, δ was found to be 0,057(18) corresponding to 99,7 % M1 and 0,3 % E2. As the conversion coefficients for these multipolarities are very close together (α_t = 0,000287 for E2 and 0,000292 for M1) the uncertainty of this mixing ratio has a very small influence on the finally adopted value for the conversion coefficient of this transition.

The internal pair creation coefficients were determined experimentally by Allan (1971) as follows:

1836 keV α_π = 0,00023(3) in good agreement with the theoretical value of 0,00023 for E2 multipolarity

2734 keV α_π = 0,00033(5) in fair agreement with the theoretical value of 0,00044 for E3 multipolarity

3 Atomic data

The atomic data are taken from Schönfeld and Janßen (1996).

3.1 X Radiations

The energies are based on the wavelengths of Bearden (1967). The relative probabilities have been taken from Schönfeld and Janßen (1996). The relative probability of the L X rays is calculated from the absolute value setting $P(\mathrm{K}_{\alpha_1}) = 1$.

3.2 Auger Electrons

The energies are taken from the compilation of Larkins (KLL, KLX) or estimated by the evaluator (KXY). The relative probabilities of K Auger electrons are taken from Schönfeld and Janßen (1996). The relative probability of the L Auger electrons is calculated from the absolute value setting *P*(KLL) = 1.

4 Radiation Emissions

4.1 Electron Emissions

The energies of the Auger electrons are the same as above. The energies of the conversion electrons are calculated from the transition energies and the binding energies. The number of Auger electrons per disintegration are calculated using the above-mentioned atomic shell data and the program EMISSION (PTB 1997). The numbers of conversion electrons per disintegration are calculated from the transition probabilities and the conversion coefficients.

4.2 Photon Emissions

The energies of the X rays are the same as above. The number of X rays per disintegration are calculated using the above given atomic shell data and the program EMISSION.

The energy of the gamma radiation was determined to be (in keV)

1	1836,2(3)	898,2(4)	Robinson et al. 1964
2	1836,08(7)	898,01(7)	Black and Heath 1967
3	1836,17(12)	-	White and Groves 1967
4	1836,07(10)	897,90(10)	Ramayya et al. 1967
5	1836,20(8)	898,09(5)	Legrand et al. 1968
6	1836,127	898,020	Gunnink et al. 1968
7	1836,03(11)	897,99(4)	Strauss et al. 1969
8	1836,030(30)	898,010(30)	Kern 1970
9	1836,064(13)	898,042(4)	Helmer et al. 1979
10	1836,052(13)	898,036(4)	Helmer and Van der Leun 1998

Values 10 are adopted and are based on 411,80205(17) keV for the strong line emitted after the decay of ^{198}Au.
The energies of the other gamma rays were taken from Müller (1988) after adjusting to the same scale.

The relative emission probabilities were determined as follows:

E in keV	850	898	1382	1836	2734	3219
1	-	94,0(7)	-	100	0,597(25)	-
2	-	91	3(?)	100	0,97	0,03
3	-	-	-	100	0,63(4)	0,0095(3)
4	-	94,9(5)	-	100	-	-
5	0,066(13)	92,0(7)	0,021(6)	100	0,724(70)	0,0071(20)
6	-	92,1	-	100	0,54(9)	0,007
7	-	95,2(5)	-	100	-	-
8	0,030(4)	93,8(11)	0,014(3)	100	-	-
9	-	94,4(3)	-	100	-	-
10	-	94,9(4)	-	100	-	-
11	-	94,8(9)	-	100	-	-
12	0,048(18)	94,54(22)	0,016(3)	100	0,618(25)	0,007(2)

1 Peelle (1960)
2 Shastry and Bhattacharyya (1964)
3 Sakai et al. (1966)
4 Schötzig et al. (1973), replaced by value 11
5 Ardisson et al. (1974); upper limit for a 3522 keV line: 0,001
6 Heath (1974)
7 Debertin et al. (1977); $P_\gamma = 0,946(5)$ for the 898 keV line from source activity and Ge(Li) measurements, replaced by value 11
8 Antoneva et al. (1979); upper limit for a 484 keV line: $9 \cdot 10^{-4}$
9 Yoshizawa et al. (1980)
10 Hoppes et al. (1982)
11 Schötzig (1989)
12 Adopted value 898 keV: LWM of values 1, 9, 10, 11. Value 5 is classified as outlier, values 2 and 6 are not taken into account because leak of uncertainties ; reduced $\chi^2 = 0,57$; 2734 keV: LWM of values 1, 3, 5, 6, reduced $\chi^2 = 1,2$. LWM has used weighted average and ext. uncertainty.

The normalisation factor is derived from a cut between the ground state and the first excited level of ^{88}Sr:

		$P_\gamma(\mathrm{rel}) \cdot (1 + \alpha_t) \cdot (1 + \alpha_\pi)$	$P_{\gamma+\mathrm{ce}}$ (abs.)
$\gamma_{1,0}$	1836 keV	100,059	0,99379
$\gamma_{2,0}$	2734 keV	0,618	0,00614
$\gamma_{3,0}$	3219 keV	0,007	0,00007

From these figures the absolute emission probability of the 1836 keV gamma ray s is calculated to be 0,9932(3) photons per disintegration and $P_{\gamma+\mathrm{ce}}$ is found to be 0,9938(3).

5 Main production Modes

Taken from the "Table de Radionucléides", LMRI, 1985

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^{89}Sr – Comments on evaluation of decay data
by E. Schönfeld

This evaluation was completed by E. Schönfeld (PTB) in November 1999.
The half-life evaluation was up-dated by M.-M. Bé (LNHB) in November 2002.

1 Decay Scheme

Below the *Q*-value there are no other levels of ^{89}Y. Thus, the decay scheme is complete. Spins and parities of the levels and lg *ft* values are taken from Sievers (1989). The half -life of the isomeric level at 909 keV was determined by Yule (1967) to be 16,06(4) s and by Durrani and Köhler (1966) to be 15,91 (17) s. The weighted mean is 16,05 (4) s. Earlier determinations were carried out by Swann and Metzger (1955) and Sattler (1962). The excited levels of ^{89}Y were studied by Robinson *et al.* (1969).

2 Nuclear Data

For the half-life evaluation the following measurements, carried out since 1954, were considered ($T_{1/2}$ in d):

Reference	**Value (days)**	**Uncertainty**	**Comments**
Herrmann (1954)	50,4	0,5	Superseded by the 2nd value
Herrmann and Strassmann (1955)	50,5	0,2	
Kjelberg and Papas (1956)	51	1	Omitted, outlier
Osmond and Overs (1959)	50,36	0,18	
Sattler (1952)	53,6	0,4	Omitted, outlier
Marsden and Yaffee	50		Omitted, no uncertainty
Flynn *et al.*	52,7	0,5	Omitted, outlier
Anspach *et al.* (1965)	50,70	0,19	
Anspach *et al.* (1965)	50,52	0,04	Original uncertainty = 0,03
Baba *et al.* (1971)	50,55	0,09	
Lagoutine *et al.* (1972)	50,75	0,25	Superseded by Amiot
Amiot *et al.* (2003)	50,65	0,05	
Recommended value	**50,57**	**0,03**	Weighted mean

Four values have been omitted from the analysis, the uncertainty on the second Anspach value (Anspach et al., 1965) has been multiplied by 1,33 in order to reduce its relative weight to 50 % in the calculation of the weighted mean and because it seems optimistic when compared with the other data. The set of six values taken into account in this analysis has a reduced -χ^2 of 1,2. Finally, the adopted value (half -life, uncertainty) is the weighted mean and the external uncertainty.

The *Q*-value is taken from Audi and Wapstra (1995).

2.1 b- Transitions

The shape of the unique 1st forbidden β spectrum of ^{89}Sr was measured by Wohn and Talbert (1970). They found the end-point energy to be 1488(4) keV. The shape corrected lg *ft* was calculated by these authors to be 8,36. Earlier, the maximum beta end-point energy was determined to be 1463(5) keV by Bisi et al. (1955). This value is too small compared with the result of Wohn and Talbert and the larger value taken from the compilation of Audi and Wapstra (1995) which is the here adopted one.

Internal bremsstrahlung accompanying the first forbidden beta decay of ^{89}Sr was measured by Babu et al. (1987), Sayibaba et al. (1987), Basha et al. (1991) and Dhaliwal et al. (1994). Sayibaba et al. carried out their measurements with a HPGe detector and a multichannel analyzer along with a standard geometrical set-up. Their results are satisfactorily accounted for by the KUB theory. Basha et al. compared also their measurements with the theoretical spectra. Dhaliwal et al. measured the spectra using an extrapolation procedure with a beta stopper method. Their results are in agreement with the Lewis and Ford theory in the whole energy region covered by the present measurements and do not favour the KUB and Nilsson theories beyond a photon energy of 400 keV.

2.2 Gamma Transition

The energy of the gamma rays following the ^{89}Sr β^- decay was measured by Merritt et al. (1982) to be 909,12(7) keV whereas Sievers gives 908,96(4) keV as unweighted average from several (n, γ)-reactions and from the decay of ^{89}Zr ($T_{1/2} = 78{,}4$ h). In the present evaluation 909,0(1) keV is adopted. The transition probability of the gamma transition is calculated from the gamma ray emission probability of the 909 keV transition (see section 4.2) and the conversion coefficient of this transition. The conversion coefficients are interpolated from the tables of Rösel et al. (1978).

3 Atomic Data

The atomic data are taken from Schönfeld and Janßen (1996).

3.1 X Radiation

The energies are based on the wavelengths of Bearden (1967). The relative probabilities are taken from Schönfeld and Janßen (1996).

3.2 Auger Electrons

The energies of the Auger electrons are taken mainly from Larkins (1977). The ratios *P*(KLX)/*P*(KLL) and *P*(KXY)/*P*(KLL)are taken from Schönfeld and Janßen (1996).

4 Radiation Emission

4.1 Electron Emission

The energies and emission probabilities of the β particles correspond to the data given already in Section 2.1. The number of conversion electrons per disintegration has been calculated using the gamma ray emission probability P_γ and the conversion coefficient as given in Section 2.2. The emission probabilities of the Auger electrons have been calculated with the PTB program EMISSION using the atomic data as given in Section 3.

4.2 Photon Emissions

The gamma ray emission intensity, per one disintegration, was found to be:

1	$9{,}71(24) \cdot 10^{-5}$	Merritt et al. (AECL)	1980	replaced by value 3
2	$9{,}65(29) \cdot 10^{-5}$	Hoppes et al. (NBS)	1980	
3	$9{,}54(16) \cdot 10^{-5}$	Merritt et al. (AECL)	1982	
4	$9{,}61(13) \cdot 10^{-5}$	Schötzig (PTB)	1990	
5	$9{,}555(34) \cdot 10^{-5}$	Schima (NIST)	1998	
6	$9{,}56(6) \cdot 10^{-5}$	adopted value	1999	

Value 1 is replaced by value 3, value 6 is the LWM of values 2, 3, 4 and 5. The reduced χ^2 of this set is 0,19.

The emission probabilities of K-X rays are very small. This is caused by the small values of $P_{\gamma+\text{ce}}$ and α_K. Lyon and Rickard (1955) were the first who detected these weak gamma rays.

The number of emitted KX rays due to K-shell internal-ionization probabilities in nuclear beta decay were measured in comparison to the absolute beta decay rate by Hansen and Parthasaradhi (1974). Their experimental result is 8,6 (7) 10^{-4} quanta per decay. The contribution of K conversion of the 909 keV γ-transition is only 5,1 10^{-7} per decay.

5 Main Production Modes

The production mode are taken from Sievers (1989).

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[$T_{1/2}$]

^{90}Sr - Comments on evaluation of decay data
by V. Chisté

This evaluation was completed in 2005. The literature available by August 2005 was included.

1 Decay Scheme

^{90}Sr disintegrates by β^- emission to the fundamental level of ^{90}Y ($T_{1/2}$ = 2.6684 (13) d). The decay scheme and level spins and parities are from the evaluation of E. Browne (1997Br34).

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).

The ^{90}Sr half-life has been evaluated from the following data (in days):

1950Po67	7270 (110)
1955Wi15	10117 (146)
1958An40	10702 (584)
1965Fl01	10227 (146)
1965Fl01	10410 (329)
1965An07	10527 (51)
1978La21	10282 (13)
1983Ra09	10589 (92)
1989Ko57	10665 (37)
1992ScZZ	10513 (14)
1994Ma50	10561 (14)
1996Wo06	10495 (4)
2004Sc49	10557 (11)
Adopted	**10522 (27) d or 28.80 (7) y**

The half-life experimental values of 1950Po67 (7270 (110) d), 1955Wi15 (10117 (146) d), 1978La21 (10282 (13) d), 1983Ra09 (10589 (92) d) are rejected by the evaluator following the recommendation given by 1996Wo06.

The half-life weighted average has been calculated by LWEIGHT computer program (version 3).

The evaluator has chosen to take into account the nine values with associated uncertainty for the calculation. One of them (10227 (146) d) from Flynn (1965Fl01) is rejected by the LWEIGHT computer program, based on the Chauvenet's criterion. The largest contribution to the weighted average comes from the value of Woods (1996Wo06) amounting to 76 %. The LWEIGHT program has increased the uncertainty of the 1996Wo06 value from 4.0 to 7.1 in order to reduce its relative weight from 76 % to 50 %.

The recommended value is the weighted average of 10522 d (28.80 (7) y), with an uncertainty of 27 d (expanded so range includes the most precise value of Woods (1996Wo06)). The reduced χ^2 value is 8.

2.1 b- Transitions

The maximum energy of the β^- transition in the decay of ^{90}Sr to ground state in ^{90}Y has been adopted from the Q value of 2003Au03 ($E_{\beta-}$ = Q = 545.9 (14) keV), and is in agreement with the experimental value of 546.0 (16) keV, measured with a magnetic β-ray spectrometer (1983Ha15).

The lg ft value (9.3) for the 546-keV unique first forbidden transition and mean energy value (196 (1) keV) have been calculated with the Logft computer program (version 7.2a).

For measured first forbidden shape factors, see 1964Da16 and 1983Ha35.

3 Atomic Data

Atomic values, ω_K, ϖ_L and n_{KL}, are from Schönfeld and Janβen (1996Sc33).

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^{90}Y - Comments on evaluation of decay data
by V. Chisté

This evaluation was completed in 2005. Updated version in November 2006 and the literature available by this date included.

1 Decay Scheme

^{90}Y disintegrates by β^- emission mainly (99.983 %) to the stable ^{90}Zr ground state level. The decay scheme and level energies, spins and parities are based on the evaluation of E. Browne (1997Br34).
A weak beta branch occurs to the 1760 keV excited level which decays by a E0 gamma transition. This 0+0+ transition undergoes with the emission of two particles materialized by the emission of two gamma, or an electron-positron pair, or internal conversion.

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).

The half-life of the ^{90}Y ground state has been evaluated from the following data (in hours) :

1937Po07	57.6 (24)
1937St08	60.5 (20)
1938Sa01	66 (3)
1940Sa02	66 (2)
1946Bo01	61 (1)
1954Ch29	64.60 (43)
1955Sa27	64.029 (24)
1955Vo03	64.24 (30)
1956He77	64.8 (2)
1957Pe05	63.97 (10)
1961He09	64.10 (8)
1963Vo02	63.74 (10)
1966Ri01	64.06 (11)
1967Bi02	64.6 (8)
1968La10	64.21 (8)
1969Gr38	63.46 (13)
2004Ko18	64.053 (20)
Adopted	**64.041 (31) h** or **2.6684 (13) d**

The weighted average has been calculated with LWEIGHT computer program (version 3).

The evaluator has chosen to take into account the twelve most precise values for the calculation, since the 50's: 1954Ch29, 1955Sa27, 1955Vo03, 1956He77, 1957Pe05, 1961He09, 1963Vo02, 1966Ri01, 1967Bi02, 1968La10, 1969Gr38 and 2004Ko 18. The evaluator's choice is supported by the fact that in preliminary calculation with LWEIGHT program, the 1937P07, 1937St08 and 1946Bo01 values have been rejected based on the Chauvenet's criterion.

With the data set of twelve values, the largest contribution to the weighted average comes from the value of Kossert amounting to 51%. The LWEIGHT program has increased the uncertainty of the 2004Ko18 value from 0.020 to 0.0202 in order to reduce its relative weight from 51 % to 50 % .

The weighted average of 64.041 h and the external uncertainty of 0.031 is the half-life adopted value. The reduced-χ^2 value is 4.7.

2.1 b$^-$ Transitions

The maximum energy of the β^- transitions in the decay of ^{90}Y to excited states in ^{90}Zr has been calculated from the relation of

$E_{\beta-} = Q_{\beta-}$(from 2003Au03) – $E_{\text{level in Zr-90}}$(from 1997Br34)

In the case of the transition $\beta_{0,0}$ (to the ground state), many experimental values of $E_{\beta-}$ have been found in literature (measured with β-ray spectrometer), as shown in the following table (Table 1). It can be noted that the evaluated value, 2279.8 (17) keV, is in agreement with all experimental values.

Table 1: Experimental and adopted energy of the $\beta^-_{0,0}$ transition

Reference	$E_{\beta-}$ (keV)
T. Yuasa and J. Laberrigue-Frolow (1957Yu06)	2265 (5)
O.E. Johnson et al. (1958Jo33)	2261 (3)
R.T. Nichols et al. (1961Ni02)	2271 (2)
S. André and P. Depommier (1964An12)	2268 (2)
L.M. Langer et al. (1964La13)	2273 (5)
H. Daniel et al. (1964Da16)	2284 (5)
P.G. Hansen et al. (1966Ha15)	2275 (5)
P. Riehs (1966Ri01)	2280 (5)
T. Nagarajan et al. (1971Na09)	2288 (3)
H. Hansen (1983Ha35)	2279.5 (29)
C. Greenwood and M.H. Putnam (1993Gr17)	2274.8 (30)
Adopted value	2279.8 (17)

For the probabilities of the β^- transitions, the available published data are given in Table 2:

Table 2: Measured and adopted probabilities of β^- transitions in %.

Populated level (keV)	**1961La07**	**1970Va09**	**1976Gr16**	**Adopted values**
ground state	99.9885 (15)	99.977 (9)		99.983 (6)
1760.72	0.0115(15)	0.023(9)		0.017 (6)
2186.282			0.0000014 (3)	0.0000014 (3)

For the ground state and 1760.72-keV β transitions, the adopted values are the weighted averages of the two values given with uncertainties.
The lg ft values have been calculated with the LOGFT program (version 7.2a).

2.2 g Transitions

The 1760- and 2186-keV γ-ray transition probabilities are 0.017 (6) % and 0.0000014 (3) %, respectively. These values come directly from the evaluated β^- transition probabilities and adopted decay scheme.

Multipolarities of these γ-ray transitions are from 1997Br34.

The internal conversion coefficients (α_T, α_K and α_L) for 2186-keV γ-ray transition has been calculated using the ICC Computer Code (program Icc99v3a – GETICC dialog). The adopted values have been interpolated from the new tables of Band et al.(2002Ba85). The uncertainties in α_T, α_K and α_L have been estimated as 3 %.

The intensity of the conversion electrons was measured by Legrand (1972) being 1,3 (7) × 10^{-2} %.

3 Atomic Data

Atomic values, ω_K, ϖ_L and n_K, are from Schönfeld and Janβen (1996Sc33).

5 Photon emissions

5.1 g-ray Emissions

The 2186-keV γ-ray absolute emission probability has been deduced from the total (γ+ce) transition probability of 0.0000014 (3) % (§ 2.2) and the theoretical α_T (2002Ba85) for a E2 transition.

The ratio of two photon decay $P_{\gamma\gamma}$, occurring during the 0+ - 0+ gamma transition, to the sum of internal-pair decay P_{e+e-} and internal-conversion decay P_{ic} : $P_{\gamma\gamma} / (P_{e+e-} + P_{ic})$ is 0,040 (5) (1997Br34).

The number of positrons (leading to the emission of the 511 keV annihilation peak) is : 31,9 (5) × 10^{-4} per 100 beta decays (R.G.Selwyn). Other values : 36 (5) × 10^{-4} (1956Gr21) and 34 (4) (1961La07).

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^{90}Y^{m} - Comments on evaluation of decay data
by V. Chisté

This evaluation was completed in 2005. The literature available by August 2005 was included.

1 Decay Scheme

^{90}Y^{m} disintegrates 99.9981 (2) % through isomeric transition to the ^{90}Y ground state and 0.0019 (2) % by β^- emission to the 2318 keV excited state in ^{90}Zr. The decay scheme, level energies, spins and parities and half-lives of excited states are based on the evaluation of E. Browne (1997Br34).

2 Nuclear Data

The Q value in the decay of ^{90}Y^{m} → ^{90}Zr (2961.8 (17) keV) has been calculated from the following relation:

$Q(^{90}Y^{m} \rightarrow {}^{90}Zr) = Q(^{90}Y \rightarrow {}^{90}Zr) + Q(^{90}Y^{m} \rightarrow {}^{90}Y)$

Both latter values are from the atomic mass evaluation of Audi *et al.* (2003Au03).

The experimental ^{90}Y^{m} half-life values (in hours) are given in Table 1:

Table 1: Experimental values of ^{90}Y^{m} half-life

Reference	Value (h)
Carter-Waschek and Linder (1961Ca12)	3.2 (1)
Heath et al.(1961He09)	3.14 (10)
Haskin and Vandenbosch (1961Ha17)	3.19 (6)
Abecasis et al.(1962Ab03)	3.15 (5)
Grench et al.(1967Gr02)	3.19 (1)
Anthony et al.(1992An19)	3.244 (5)
Adopted	3.19 (6)

The weighted average has been calculated with the LWEIGHT computer program (version 3).

The evaluator has chosen to take into account the seven values with associated uncertainties for the statistical processing. The largest contribution to the weighted average comes from the value of Anthony (1992An19) amounting to 79 %. The LWEIGHT program has increased the uncertainty for the 1992An19 value from 0.005 to 0.010 in order to reduce its relative weight from 79 % to 50 %.

The recommended value is the weighted average of 3.19 h with a final uncertainty of 0.06, expanded to include the most precise value of Anthony (1992An19, 3.244 (5) h). The reduced-χ^2 value is 3.5.

2.1 b- Transitions

The maximum energy of the β^- transition in the decay of ^{90}Y^{m} → ^{90}Zr has been calculated from the relation:

$E_{\beta-} = Q(^{90}Y^{m} \rightarrow {}^{90}Zr$, from 2003Au03) – $E_{\text{level in Zr-90}}$(from 1997Br34) = 642.9 (17) keV.

The *lg ft* of 9.6 and mean energy of 231.7 (7) keV have been calculated with the LOGFT computer program for the 642-keV unique first forbidden transition.

The 642-keV β^- transition probability is deduced from the ratio I_γ(2319 keV)/ I_γ(479 keV) given by H. C. Griffin (1976Fr16). The value of this ratio has been recalculated by the evaluator with the adopted photon branching ratio (see **5.2** g**-ray Emission**).

2.2 g Transitions

For the $^{90}Y^m \rightarrow {}^{90}Y$ and $^{90}Y^m \rightarrow {}^{90}Zr$ branching, the transition probabilities have been calculated using gamma ray intensities and the internal conversion coefficients (see **5.2** g**-ray emissions**).

Multipolarities of γ-ray transitions in both decays of $^{90}Y^m$ are from 1997Br34:
202-keV γ-ray : M1 + E2, δ = -0.04 (4)
479-keV γ-ray : M4 (+ E5)
682-keV γ-ray : E5
2319-keV γ-ray (from $^{90}Y^m \rightarrow {}^{90}Zr$): E5

The internal conversion coefficients (ICC's) have been calculated using the Icc99v3a computer program (GETICC dialog). The adopted values have been interpolated from new tables of Band et al.(2002Ba85). The uncertainties of internal conversion coefficients have been estimated as 3 %.

3 Atomic Data

Atomic values are from 1996Sc33.

4 Electron Emissions

The Auger electrons emission probabilities have been calculated from γ-ray and conversion electron data by using the EMISSION computer program. The Auger electrons emission probabilities of ^{90}Zr aren't given in the table file, because they are negligible (of the order of 10^{-7}).

5 Photon Emissions

5.1 X-ray Emissions

The X-ray emission probabilities have been calculated from γ-ray and conversion electron data by using the EMISSION computer program. The X-ray emission probabilities of ^{90}Zr aren't given in the table file, because they are negligible (of the order of 10^{-7}).

5.2 g-ray Emissions

The relative emission probabilities measured in the isomeric decay of $^{90}Y^m$ are given in Table 2. The 479-keV line as been taken as 100 %.

Table 2: Relative γ-ray emission probabilities measured in the isomeric decay of $^{90}Y^m$, in %.

Energy (keV)	Heath (1961He09)	Hanser (1973Ha18)	Raman (1973Ra10)	Kluge (1974Kl06)	Griffin (1976Gr17)	Rao (1978Ra05)	Evaluated Values
202.53	104.99 (44)	107.2 (4)	103.7 (33)	none	none	none	106.1 (11)
682.04	< 0.01	none	none	0.40 (8)	0.34 (5)	0.35 (3)	0.352 (24)

For each γ-ray, the evaluated relative γ-ray emission probabilities are weighted averages (calculated with the LWEIGHT computer program, version 3) of the three values measured with uncertainties.

The normalization factor to convert the relative emission probabilities to the absolute emission probabilities has been calculated from the intensity balance at the ^{90}Y ground state. As β^- branching in the ^{90}Y^m is negligible (1976Gr16), the normalization factor is:

$$\text{Normalization factor} = \frac{100\%}{[(1 + a_T(202))P_{rel}(202)] + [(1 + a_T(682))P_{rel}(682)]}$$

From the theoretical α_T and the evaluated relative emission probabilities of the 202 and 682-keV γ-rays (Table 2), the normalization factor becomes **0.915 (9) %**. The uncertainty was calculated through the propagation on the formula given above.

The 479-keV transition probability is given by:
$P_{(\gamma+ce)}$(682 keV) + $P_{(\gamma+ce)}$ (479 keV) = 100 %.
Taking into account the evaluated normalization factor, the theoretical α_T and the evaluated relative emission probability of the 682-keV γ-rays (Table 2), then $P_{(\gamma+ce)}$(682 keV) = 0.329 (23) % and, therefore, $P_{(\gamma+ce)}$ (479 keV) = 99.671 (23) %.

The evaluated relative and absolute emission intensities for the 202-, 479- and 682-keV γ-rays are given in Table 3:

Table 3: Evaluated relative and absolute γ-ray emission intensities.

Energy (keV)	Relative emission intensity (%)	Absolute emission intensity (%)
202.53	106.1 (11)	97.1 (14)
479.53	99.4 (10)	90.97 (24)
682.04	0.352 (24)	0.322 (22)

From the 479-keV γ-ray absolute emission intensity value (Table 3) and the value of I_γ(2319 keV)/ I_γ(479 keV) = 2.1 (2) 10^{-5}, as given by Griffin (1976Gr16), then I_γ(2319 keV) = 0.0019 (2) %.

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2003Au03 – G. Audi, A.H. Wapstra, C. Thibault, Nucl. Phys. A729(2003)129 [Q].

^{93}Nb^{m} – Comments on evaluation of decay data by V. P. Chechev and N. K. Kuzmenko

1 Decay scheme

The ^{93}Nb^{m} decay scheme is very simple. It includes the single 30,77 keV gamma transition with the well-established multipolarity of M4 (1972Ko59, 1997Ba13).

2 Nuclear Data

Q(IT) value is the energy of the isomeric transition to the ground state of ^{93}Nb (1977Mo07).

There are available the seven measurements of the ^{93}Nb^{m} half-life, in years:

~ 4	1954Sc74
13,6(3)	1965Fl02
11,4(9)	1976Hegedues
16,4(4)	1977Ll01
15,3(13)	1980Vaninbroukx
16,11(19)	1981Ll01
16,16(15)	1983Va25

The measurement result of 1954Sc74 was omitted as crude. The 1977Ll01 and 1980Vaninbroukx values measured by Lloret and by Vaninbroukx, respectively, were only preliminary results. They were obtained from observations over relatively short periods. In both cases the measurements have been continued over about four more years. Consequently only the final values of 1981Ll01 and 1983Va25 have been used by the evaluator for statistical processing. Then, the low values of 1965Fl02 and 1976Hegedues were omitted as less precise and disagreed with the two best measurements of 1981Ll01 and 1983Va25.

Averaging of these latter values gives the unweighted mean of 16,12(1) and the weighted mean of 16,12 with an internal uncertainty of 0,12 and an external uncertainty of 0,01. As the measurement method was the same in both cases, the minimum input uncertainty of 0,15 has chosen for the final uncertainty of the weighted mean . Thus, the evaluated ^{93}Nb^{m} half-life is 16,12 (15) years.

2.1 Gamma Transition and Internal Conversion Coefficients.

The energy of the gamma transition, 30,77(2) keV, has been taken from the 1977Mo07 measurement. The 1972FlZM measurement value of 30,4(3) keV is significantly less accurate.

The multipolarity of the gamma transition, M4, is determined confidently from measured subshell ratios :

K/(L+M) = 0,18(2) (1964Ho08),

K/L = 0,21(2) (1964Ho08),

K/(L+M+…) = 0,19(2) (1982Re09)

L/(M+N+…) = 3,8(4) (1982Re09).

The internal conversion coefficient (α_K) is obtained by the interpolation from the ICC tables of 1978Ro22 using database IC4 of 2000Co05. The relative uncertainty of α_K has been adopted as 3% in accordance with the available estimations of the reliability of the calculations of the theoretical ICC with a pure multipolarity (see 2000Co05). The adopted value of α_K conforms well to α_K(experimental) = 2,58 (15) 10^4 (1976Ju04) and disagrees with α_K(experimental) = 1,7 (3) 10^4 calculated in (1977Mo07) from the measured ratio P_γ/Px_K= 8(1) 10^{-5}. See also 1987Table : α_K = 2,63 (6) 10^4

The adopted value of α_K is supported by the recent measurement result of 2,4(9) $\cdot 10^4$ obtained by the quite different method –investigation of "electron bridge" in ^{93}Nb^{m} decay (1999ZhZY).

The evaluated α_L, α_M, α_T are also theoretical values for M4 multipolarity.

3 Atomic Data.

3.1. Fluorescence yields

The fluorescence yields are taken from 1996Sc06 (Schönfeld and Janβen).

3.2. X Radiations

The X-ray energies are based on the wave lengths in the compilation of 1967Be65 (Bearden). The relative K X-ray emission probabilities are taken from 1999Schönfeld.

3.3. Auger Electrons

The energies of Auger electrons are from 1977La19 (Larkins) and 1987Table (Table de Radionucléides).

The ratios P(KLX)/P(KLL) and P(KXY)/P(KLL) are taken from 1996Sc06.

4 Photon Emissions.

4.1 X-Ray Emissions

The total K X-ray absolute emission probability computed with use of the ICC α_T, α_K and the K-fluorescence yield ω_K=0,751(4) is 10,99(40) per 100 disintegrations. It coincides with the averaged value [10,99(22)] of three measurement results of 10,7(3) (1982Alberts), 11,04(28) (1985Gehrke), 11,12(22) (1990Co17). The other measurements have given slightly higher values: 11,6(4) (1978Bambynek, 1980Vaninbroukx) and 11,5(3) (1983Va25). (See these references also in 1991BaZS).

The adopted value of the total K X-ray absolute emission probability is 10,99(22).

The absolute emission probabilities of the K X-ray components have been computed from P_{XK} using the relative probabilities from 1996Sc06.

The total L X-ray absolute emission probability has been computed with use of the ICC α_L and the atomic data of ϖ_L=0.0347(9), n_{KL}=1.045(4) from 1996Sc06.

4.2 Gamma Emissions

The energy of the gamma ray, 30,77(2) keV, is from the 1977Mo07.

The absolute emission probability of the gamma ray is computed from the decay scheme using the ICC α_T.

5. Electron Emissions

The energies of the conversion electrons have been calculated from the gamma-transition energies given in 2.1 and the electron binding energies.

The total emission probability of the conversion electrons has been obtained as $P(_{ec1,0\ T}) = 100 - P_\gamma$ (per 100 disintegrations). The emission probabilities of the K-, L-, M-, NO-conversion electrons have been calculated using the conversion coefficients given in 2.1.

The values of the emission probabilities of K-Auger electrons have been calculated using the gamma transition probability given in 2.1, the atomic data given in 3, and the conversion coefficients given in 2.1.

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^{99}Mo - Comments on evaluation of decay data

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This evaluation was completed in December 2000 with minor editing in September 2001. Updated half-life value in 2004.

1- DECAY SCHEME

Molybdenum 99 disintegrates to the technetium 99 excited levels by beta minus transitions. The 1205 keV (3/2-) and 1321 keV (1/2-) levels could be fed by non-unique 1st forbidden β^- decays. From lg ft systematic and with lg $ft \geq 8$, the β^- branches to 1205 keV and 1321 keV levels, if they exist, would be expected $\leq$ 0,010% and $\leq$ 0,00014%, respectively. Forbiddeness of other possible β^--transitions is still greater. Therefore, all of these unobserved branches can be considered negligible.

Unlike the decay scheme of Peker based mainly on Goswamy (1992Go22), we have not found any justification for placing β^-- transition to the 534 keV level. The $P_{\gamma+ce}$ balance for this level has led to the evaluated probability of β^-- transition of the order of 0,0010(10) %. Also because of the significant lg *ft*, the attribution of 3/2+ to the 534 keV level seems to be unlikely.

Apart from that, in comparison with 1994Pe15 we have shown a β^--transition feeding the 1072 keV level. The spin and parity of this level are not defined exactly. Other J^{π} values are from Peker.

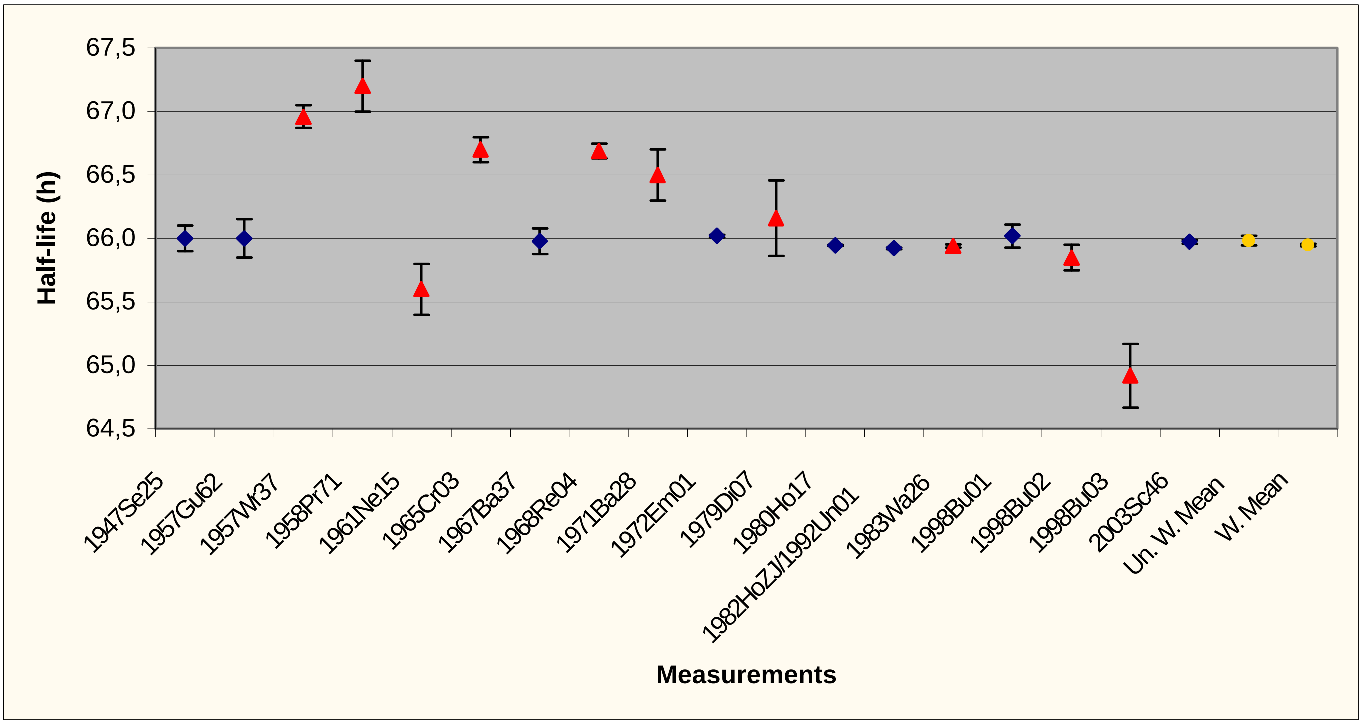
For this evaluation Mo-99 and Tc-99m are considered being in equilibrium. Therefore, the ratio of their activities is 1,1.

2- NUCLEAR DATA

Q^- is from Audi and Wapstra 1995 (95Au04).

- The measured **half-life** values are, in hours :

66,0(1)	Seiler (1947Se25)	^{235}U(n,f) ic
66,00(15)	Gunn *et al.*(1957Gu62)	^{235}U(n,f),Mo(n,γ) pc
66,96(9)	Wright *et al.*(1957Wr37)	^{98}Mo(n,γ)
67,2(2)	Protopopov *et al.* (1958Pr71)	^{235}U(n,f) GM
65,6(2)	Newman (1961Ne15)	^{235}U(n,f) pc
66,7(1)	Crowther and Eldridge (1965 Cr03)	^{98}Mo(n,γ) well scin
65,98(10)	Baldwin (1967Ba37)	Mo(n,γ) from 2 meas. pc + scin
66,69(6)	Reynolds *et al.*(1968Re04)	^{235}U(n,f) ic
66,5(2)	Baba *et al.* (1971Ba28)	^{238}U(p,f)
66,02(1)	Emery *et al.* (1972Em01)	^{235}U(n,f)
66,16(30)	Dickens (1979Di07)	
65,945(3)	Houtermans *et al.* (1980Ho17)	ic
65,924(6)	Hoppes *et al.* (1982HoZJ) Unterweger *et al.* (1992Un01)	ic
65,942(12)	Walz *et al.* (1983Wa26)	Superseded by 2003Sc49
66,02(9)	Butsev *et al.* (1998)	^{98}Mo(n,γ)
65,85(10)	Butsev *et al.* (1998)	235U(n,f)
64,92(25)	Butsev *et al.* (1998)	181Ta(12C,x) 99Mo
65,974(14)	Schrader *et al.* (2003Sc49)	ic



Looking at the graphical representation given above, it appears that 5 values are ≥ 66,5 h and 12 are in the range > 65,5 and < 66,5. The five high values are rejected of the statistical treatment (Chauvenet's criterion). The last value given by V .S. Butsev (1998) has also been rejected : ^{181}Ta(^{12}C,x)^{99}Mo is an exotic reaction, and the result is clearly outlier.

When processing the 17 values, the LWEIGHT program has detected 1957Wr37, 1958Pr71, 1961Ne15, 1965Cr03, 1968Re04, 1971Ba28, 1979Di07 and 2 values of 1998Bu (65,85(10) and 64,92(25)) to be outliers, based on Chauvenet's criterion. The Limited Relative Statistical Weight method increases the uncertainty for the 1980Ho17 value from 0,003 to 0,00481 and used the unweighted mean of 65,983(38) with the large uncertainty that does not correspond to the most accurate measured values (1980Ho17, 1982HoZJ or 1992Un01 and 2003Sc49).

With the set of the 5 most recent values (1972Em01, 1980Ho17, 1982HoZJ or 1992Un01, 1998Bu01 and 2003Sc49), the Limited Relative Statistical Weight method increases the uncertainty for the 1980Ho17 value from 0,003 to 0,00482 and used the weighted mean of 65,949 (14), where 0,014 is the external uncertainty, the reduced-χ^2 is 10,4.

The adopted value is 65,949(14) h or 2,7479(6) d.

- The measured half-life values of the 140,5 keV level of Tc-99 are in ns:

0,277	(14)	STEINER *et al.* (1969St04)
0,160	(20)	MCDONALD (1971Do02)
0,205	(4)	ALFTER *et al.*(1993Al23)
0,237	(14)	SHENOY *et al.* (1973Sh21)

The value of Steiner (1 969) given here, is from the original article ; the NDS value (1994Pe15) from the same reference is very different : 0,192 ns.
The value of 0,160(20) ns from J.McDonald (1971) is very far from the others and is not taken into account.
The values from Alfter and Shenoy were determined by using the Moessbauer effect.
The uncertainty on the Alfter *et al.* (1993) value was increased 2,47 times by LRSW.
Reduced-χ^2 = 8,94

LWEIGHT has used the weighted average and the external uncertainty.
The adopted value from the LWEIGHT program is : **0,221(20) ns**

- The measured half-life value of the 181 keV level is **3,61(7) ns** (McDonald (1971))

- The values of the level energies are from NDS 73,1.

2.1 BETA-MINUS TRANSITIONS

The energies of β-transitions have been computed from the Q value and the adopted level energies. The probabilities of β^--transitions have been obtained from the $P_{\gamma+ce}$ balance for each level based on the P_γ normalization factor of 0,1212(15) (see section 4.2.3).

The sum of all the beta transition probabilities leaving the molybdenum must be equal to 100 %; this leads to a probability of 82,1(15)% for the beta transition feeding the 142 keV level, taking into account the gamma transitions feeding this level.

The measured energies and probabilities of some β-transitions are given below for comparison with calculated data:

	Measured[a]		Calculated	
	Energy, keV	Probability (%)	Energy, keV	Probability (%)
$\beta^-_{0,12}$	245	0,2	228,1(10)	0,011 (1)
$\beta^-_{0,9}$	450(10)	14	436,6(10)	16,45 (30)
$\beta^-_{0,4}$	840(5)	2	848,1(10)	1,18 (3)
$\beta^-_{0,2}$	1214(1)	80(2)	1214,5(10)	82,1 (15)

[a] Nagarajan (1971Na01) except P($\beta^-_{0,2}$) for which unweighted mean of six experimental results quoted in Kholnov (1982KhZW) is given.

2.2 - GAMMA TRANSITIONS and INTERNAL CONVERSION COEFFICIENTS

The evaluated energies of the gamma transitions are the sums of the energies of gamma rays and the recoil energy.

2.2.1- INTERNAL CONVERSION COEFFICIENTS

The ICC have been evaluated using experimental information for the multipolarity admixture coefficients and the theoretical values from 1978Ro22 (Rösel *et al.*) and 1976Ba63 (Band *et al.*) (for $\gamma_{2,1}$).

The relative uncertainties of ICC were adopted to be 2%, for pure multipolarities. The ICC uncertainties for mixed multipolarities were evaluated by taking into account the uncertainties of the respective multipolarity admixture coefficients given in the referenced papers.

The internal conversion coefficients adopted in this evaluation are the theoretical values deduced from the Rösel et al. (1978Ro22) tables. They have been compared with experimental values.

Transition 3-1 : 40,584 keV

Internal Conversion Coefficients a_T
Some authors measured the mixing ratio δ :

δ	First author and NSR code	Transition	α_T (Rösel *et al.*)
-0,008 (8)	GARDULSKI (1974Ga01)	M1 + 0,0064%E2	3,80
0,03 (3)	SINGH (1982Si16)	M1 + 0,09%E2	3,87
-0,119 (8)	ALFTER (1993Al23)	M1 + 1,4%E2	4,18
	MCDONALD (1971Mc02)	M1 + 1,4(2)%E2	4,18(13) (adopted)

The E2 admixture of 1,4(2) % for $\gamma_{3,1}$(40,6 keV) has been adopted from 1971Mc02. The $\gamma\gamma(\theta)$ precise measurement of 1993Al23 confirmed this value (δ=–0,119(8)) and rejected the 0,0064 % value of 1974Ga01 which was adopted in Peker's evaluation (1994Pe15). This increases the total ICC for $\gamma_{3,1}$ from 3,76 to 4,18 and improves the intensity balance for the 140,5 keV and 181,1 keV levels.

Internal Conversion Coefficients a_K

a_K	Transition	First author and year
3,2 (2)	M1 transition	Ranakumar (1969)
3,7 (5)	M1 transition	Bashandy (1969Ba03)
3,27 (19)	Weighted average, external uncertainty	LWEIGHT (χ^2= 0,86)
Adopted: 3,50 (8)	M1+1,4(2)%E2	Rösel *et al.* (with the adopted admixture)

Internal Conversion Coefficients a_L

From the measurement of the K/L ratio of the conversion electron emission probabilities and, with α_K= 3,50(8), the α_L value is deduced :

K/L	a_L	First author and year
9,3 (20)	0,38(8)	RAVIER (1961)
8,3 (9)	0,42(5)	BASHANDY (1969Ba03)
	0,41(4)	LWEIGHT (χ^2= 0,18)
Adopted:	**0,560 (13)**	Rösel *et al.* for M1+1,4(2)%E2

Transition 1-0 : 140,511 keV

Internal Conversion Coefficients a_T

Experimental measurements :

0,118 (8)	AMTEY *et al.* (1966)
0,113 (6)	DICKENS and LOVE (1980)
0,122 (5)	VUORINEN (1969)
0,118 (3)	LEGRAND *et al.* (1973)
0,1181(23)	LWEIGHT (reduced-χ^2= 0,44 weighted average and internal uncertainty)
Adopted: 0,119(3)	**Rösel *et al.* (1978) for M1+3,2(3)%E2**

Dickens and Love (1980) have determined α_T from the α_K value given by Gardulski and Wiedenbeck (1974) and the K/L/MN values reported by Hager and Selzer and by Medsker (NDS - 12-4 - 1974).
α_T was evaluated by Vuorinen (1969) from measurements of conversion electrons in coincidence with fluorescence X-rays.

Multipolarity
There are a significant number of measurements. However most authors gave different values with and without large uncertainties: these multipolarities make it possible to calculate the total internal conversion coefficients. We have assigned a 5% uncertainty to α_T:

/d/	**Transition**	**a$_{T}$ (Rösel)**	
0,31 (2)	M1 + 8,25% E2	0,132(7)	SINGH and SAHOTA (1982Si16)
0,178 (12)	M1 + 3,1% E2	0,119(6)	ALFTER *et al.*(1993Al23)
	M1 + 4%(2) E2	0,121(6)	MCDONALD *et al.*(1971Mc02)
	M1+<3%E2		VOINOVA *et al.*(1971Vo06)
0,194(30)	M1+E2		VUORINEN (1969Vu03)
	M1+<8%E2		VAN EIJK *et al.* (1968Va14),calculated from ICCk
	M1+9%(5)E2	0,134(7)	VAN EIJK *et al.*(1968), calculated from K/L ratio
	M1+2,8%E2	0,118(6)	COOK *et al.*(1969 Co18)
	M1+7(3)%E2	0,129(7)	MEYER (1974)
	M1+1,4%E2	0,114(6)	DICKENS and LOVE (1980Di16)
	M1+6,5(40)E2	0,128(7)	AGEEV *et al.*(1969Ag04)
0,118(6)	M1+1,4(2)%E2	0,114(6)	GARDULSKI and WIEDENBECK (1974Ga01)
	M1+2,8(3)%E2	0,118(6)	GEIGER (1968GeZW)
	M1+9%E2		SIMONITS *et al.* (1982Si15)
	M1+E2		AMTEY *et al.* (1966Am04)
	M1		BASHANDY (1969Ba54)
		0,120(2)	LWEIGHT (reduced-χ^2= 1,16), weighted average and external uncertainty= 0,0015
0,186 (8)	**M1 + 3,2(3)%E2**	**0,119 (3)**	**Adopted (Rösel *et al.*)**

From each determination of the multipolarity of the transition, the Rösel theoretical internal coefficient was calculated. From the set of the 10 deduced ICC values the LWEIGHT program recommends a weighted mean of 0,120(2). The value obtained is very close to that obtained by considering the 4 experimental values for α_T (see table above).

Internal Conversion Coefficients a$_{K}$

Experimental values:

0,096 (6)	VOINOVA *et al.* (1971Vo06)
0,093 (6)	VOINOVA *et al.* (1971Vo06)
0,102 (7)	VAN EIJK *et al.* (1968Va14)
0,094 (8)	VUORINEN (1969Vu03)
0,102 (5)	DICKENS and LOVE (1980Di16)
0,096 (3)	LWEIGHT (χ^2=0,35; weighted average and internal uncertainty)
0,104 (3)	**Rösel *et al.* (1978) (adopted)**

- α_K was measured by Voinova *et al.* (1971) with a spectrometer which provided simultaneous measurement of conversion electrons and γ-ray spectra..
- Van Eijk *et al.*(1968) calculated ICCk from measurements of the 140,5 keV gamma-ray emission probability (P_γ) relative to the gamma-ray emission probability of the 661,6 keV gamma transition in decay of Cs-137 and from measurements of the conversion electron emission probability P_{ce} of the 140,5 keV K-conversion line relative to the conversion electron emission probability of the 661,6 keV K-conversion line in decay of Cs-137. With P_{ceK} = 6,84(19); P_γ = 6,00(35); α_K(661,6 keV) = 0,0896 (15) (Helmer in BÉ 1999 (1999BeZQ)), the value becomes 0,102(7).
- Vuorinen (1969) evaluated the internal conversion coefficient α_K by measuring the electron conversion emissions following the conversion of the 140 keV gamma ray in coincidence with fluorescence X-rays.

- α_K given by Dickens and Love (1980) was computed from the tables of Hager and Seltzer for a M1 transition and a 1,4% E2 admixture. An 5% uncertainty assigned to α_K reflects the added uncertainty to the usual 3% assignment due to the rapid change of α_k with admixture. This value is not taken into account in our calculations.

Internal Conversion Coefficients a_L

From each measurement of the K/L ratios of the conversion electron emission probabilities, and with α_k = 0,104(3), a value for α_L is deduced :

K/L	α_L	
8,1 (5)	0,0125(8)	BASHANDY(1969Ba03)
7,70 (30)	0,0132(7)	VAN EIJK *et al.* (1968Va14)
8,3 (3)	0,0122(6)	RAVIER *et al.* (1961Ra04)
7,63 (32)	0,0133(7)	BRAHMAVAR (1968)
7,8 (3)	0,0130(6)	GEIGER (1968GeZW)
	0,0128(3)	LWEIGHT has used the weighted average and the internal uncertainty. Reduced-χ^2 =0,52
Adopted	**0,0129 (4)**	Rösel *et al.* (1978)

Transition 2-0: 142,683 keV

Internal Conversion Coefficients a_T

For a M4 transition the theoretical value from Rösel is : **40,9(8).**

Internal Conversion Coefficients a_K

- The 2 following values were calculated from experimental data and given by the authors :

23 (6)	Van Eijk *et al.* (1968)
30 (3)	Bashandy (1969Ba54)

Van Eijk *et al.* (1968) calculated the K ICC value from the ratios of K(142,7)/K(140,5) = 0,072(32) and $I_\gamma(142,7)/I_\gamma(140,5)$ = 0,00030(6) after correction for α_K(661,6 keV, Cs-137) = 0,0896(15)
Bashandy (1969) calculated the K ICC from internal conversion spectra and photon emission probabilities $I_\gamma(142)/I_\gamma(140)$ = 0,00030(6)

- The following α_K coefficients are calculated from the K(142,7)/K(140,5) ratio given by the authors and based on the ratio $I_\gamma(142,7)/I_\gamma(140,5)$ = 0,00030(6) given by Van Eijk *et al.* (1968) and on α_K (140,5) = 0,104 (3).

K(142,7)/K(140,5)	α_K (142,7)	
0,072(4)	24 (6)	AMTEY *et al.* (1966Am04)
0,0746(12)	25 (6)	GEIGER (1968GeZW)
0,075 (8)	26 (6)	AGEEV *et al.* (1969Ag04)

If we take into account the ratio $I_\gamma(142,7)/I_\gamma(140,5)$ = 0,00021(3) given by Dickens and Love (1980Di16), with α_K(140,5) = 0,104(3), the same calculations give higher results for α_K(142,7) :

K(142,7)/K(140,5)	α_K (142,7)	
0,072(4)	34 (6)	AMTEY *et al.* (1968)
0,0746 (12)	36 (5)	GEIGER (1968)
0,075 (8)	36 (7)	AGEEV *et al.* (1969)

If we have taken into account all the six possible data, the weighted average, with the external uncertainty, calculated by LWEIGHT is 29,5(18) (reduced-χ^2= 0,87)

The **adopted** theoretical K conversion coefficient, for a M4 transition, is **: 29,3(6)** (Rösel *et al.* (1978)).

Internal Conversion Coefficients a_L

From the measurement of the ratio of the conversion electron intensities (BASHANDY and IBRAHIEM), with α_K = 29,3(6), α_L can be deduced. This value is close to the adopted theoretical value:

K/L	α_L		
2,9 (5)	10,1 (18)	M4 transition	BASHANDY and IBRAHIEM
Adopted:	**9,35 (20)**	M4 transition	Rösel *et al.* (1978)

Transition 3-0 : 181,094 keV

Internal Conversion Coefficients a_T

0,140(5) DICKENS and LOVE (1980Di16)

GARDULSKI and WIENBECK (1974Ga01) measured a low multipole mixing ratio of 0,002(7) for a M3/E2 transition.

For a E2 transition, the theoretical value is : **0,149(3) (Rösel *et al.* (1978))**

Internal Conversion Coefficients a_K

0,13(3)		RAVIER *et al.* (1961)
0,127(11)*	E2 ≤ 12%M1	VAN EIJK *et al.* (1968)
0,133(20)	E2 transition	BASHANDY (1969Ba54)
0,12(1)		VOINOVA *et al.* (1972)
0,125(7)		LWEIGHT (reduced-χ^2 = 0,16, weighted average and the internal uncertainty)
0,125 (3)	E2 transition	**Rösel *et al.* (adopted)**

(*) value corrected for α_K(661keV Cs-137)= 0,0896(15) (Helmer in Bé 1999)

Internal Conversion Coefficients a_L

From the measurement of ratio K/L of conversion electron intensities, with α_K = 0,125(3), α_L can be deduced:

K/L	α_L	Transition	
4,9 (1)	0,025(6)		RAVIER *et al.* (1961)
6,8 (7)	0,0184(20)		BASHANDY (1969Ba03)
Adopted:	**0,0191 (4)**	E2	**Rösel *et al.* (1978)**

Transition 4-2 : 366,422 keV

Internal Conversion Coefficients a_T

0,0081 (2)		DICKENS and LOVE (1980)
0,00915 (18)	M1 transition	**Rösel *et al.* (1978) (adopted)**

Internal Conversion Coefficients a_K

0,0072 (10)		BASHANDY (1969Ba54)
0,00802(16)	M1 transition	**Rösel *et al.* (1978) (adopted)**

Transition 13-7 : 380,13 keV

Internal Conversion Coefficients a_K

0,009 (1)	M1+E2	BASHANDY (1969Ba54)
0,0091 (7)	M1+63(22)%E2	**Rösel *et al.* (1978) (adopted)**

- From the value of Bashandy (1969Ba54), it can be deduced a M1+63%E2 transition and multipole mixing ratio $\delta = 1,3(6)$.

Transition 14-7 : 410,27 keV

Internal Conversion Coefficients a_K

0,0060 (8)		BASHANDY (1969Ba54)
0,0065 (2)	M1+20(3)%E2	**Rösel *et al.* (1978) (adopted)**

Transition 9-4 : 411,492 keV

Internal Conversion Coefficients a_K

0,0030 (5)	E1 transition	BASHANDY (1969Ba54)
0,00226(5)	E1 transition	**Rösel *et al.* (1978) (adopted)**

Transition 12-6 : 457,60 keV

The E2 admixture of 72(55) % has been adopted from the evaluation of Kholnov (1982KhZW).

Internal Conversion Coefficients a_K

0,0054 (6)		BASHANDY (1969Ba54)
0,0054 (4)	M1+72(55)%E2	**Rösel *et al.* (1978) (adopted)**

Transition 6-2 : 528,790 keV

Internal Conversion Coefficients a_K

0,0050 (6)	E2 transition	BASHANDY (1969Ba54)
0,00375(8)	E2 transition	**Rösel**
0,00331(7)	M1 transition	**Rösel *et al.* (1978) (adopted)**

Transition 8-1: 621,771 keV

Internal Conversion Coefficients a$_K$

0,0020 (4)		BASHANDY (1969Ba54)
0,00227 (5)	M1 transition	**Rösel *et al.* (1978) (adopted)**

Transition 9-3 :739,503 keV

Internal Conversion Coefficient a$_K$

0,0016 (4)	M1 or E2	BASHANDY(1969Ba54)
0,00154 (40) *		VAN EIJK et a.l. (1968)
0,00151 (3)	E2+7,6%M1	**Rösel *et al.* (1978) (adopted)**

*value corrected for α_K(661keV Cs-137) = 0,0896(15) (Helmer in BÉ 1999)

The multipole mixing ratio : δ = 3,58(20) measured by Gardulski and Wiedenbeck (1974), leads to an E2 + 7,2% M1 transition.
Singh and Sahota (1982) indicated an E2 + 8,0(1)%M1 multipolarity.

Transition 9-2 : 777,924 keV

Internal Conversion Coefficient a$_K$

0,0005 (1)		BASHANDY (1969Ba54)
0,000518 (10)	E1 transition	**Rösel *et al.* (1978) (adopted)**

Transition 10-3 : 822,976 keV

Internal Conversion Coefficient a$_K$

0,0004 (1)		BASHANDY(1969Ba54)
0,0004 (1)	E1+1%M2 transition	SINGH (1982)
0,000461(9)	E1 transition	**Rösel *et al.* (1978) (adopted)**

For an E1+1%M2 transition, the theoretical value would be higher than the experimental values and we do not accept this type of transition.

Transition 13-3 : 960,759 keV

Internal Conversion Coefficient

Based on α_K = 0,0024(5) Bashandy deduced a M2 multipolarity. From the decay scheme Singh gave a M2 + E3 multipolarity. This is not consistent with the adopted spins and parities which lead to a M1+E2 transition. For a M1 transition, α_T = 0,00097 from the Rösel tables.

Transition 13-1 : 1001,348 keV

Internal Conversion Coefficient

Based on α_K = 0,0018(3) Bashandy deduced a M2+E3 multipolarity. This is not consistent with the adopted spins and parities which lead to a E2+M3 transition. For a E2 transition, α_T = 0,00083 from the Rösel tables.

2.2.2 GAMMA TRANSITION PROBABILITIES

The gamma transition probabilities have been calculated from the gamma emission probabilities and the internal conversion coefficients for the transitions occurring above the 142 keV level.

The total gamma and beta transition probabilities populating the 142 keV level is : 87,65(19)%.
Within the Tc-99m decay, the 2,17 keV gamma transition probability (from the level 2 to the level 1) is deduced to be : 99,0(4)%; the 142 keV gamma transition probability is evaluated to be : 1,0(1) % and the 140 keV gamma transition probability is 99,0(4)%.

So, the transition probabilities are deduced to be : 86,8(19)% and 0,88(6)% for the 2,17 keV and the 142 keV, respectively. Taking into account the level balance, the 140 keV transition probability is deduced to be 92,1(19) %.

3. Atomic Data

3.1. Fluorescence yields

- ω_k is from Bambynek (1984)
- ϖ_L , η_{KL} , η_{LM} are from Schönfeld and al.(1996)
- ϖ_M is from Hubbell and al. (1994)

3.2. X Radiations

The X-ray energies are based on the wave lengths in the compilation of 1967Be65 (Bearden). The relative K X-ray emission Kβ/Kα and Kα_2/Kα_1 probabilities are taken from 1996Sc06.

3.3. Auger Electrons

The energies of Auger electrons are from 1977La** (Larkins).
The ratios P(KLX)/P(KLL) and P(KLY)/P(KLL) are taken from 1996Sc06.

4. Photon Emissions

4.1. X-Ray Emissions

The total absolute emission probability of K X-rays (P_{XK}) has been computed using the adopted value of ω_K and the evaluated total absolute emission probability of K conversion electrons (P_{ceK}). The absolute emission probabilities of the K X-ray components have been computed from P_{XK} using the relative probabilities from 1996Sc06.

The measured values of the total absolute emission probability of K X-rays ($P_{XK}\times100$) are given below in comparison with the calculated (adopted) value:

Dickens and Love	Goswamy	Calculated (adopted)
11,3(5)	11,5(4)	11,2(2)

Above agreement of the measured and calculated values shows concord between the evaluated data for ^{99}Mo including the gamma-ray emission probabilities, gamma-multipolarity admixtures, ICC α_K and the fluorescence yield ω_K.

The total absolute emission probability of L X-rays has been computed using total absolute sums P_{ceL}, P_{ceK}, and atomic data of section 3 (ω_K, ϖ_L, η_{KL}).

M X-ray and Auger spectra have been investigated in Gerasimov. The influence of the chemical state on the K X-ray intensity has been studied in Yoshihara (1981Yo08).

4.2. GAMMA RAY EMISSIONS

4.2.1 GAMMA RAY ENERGIES

The γ-ray energies of $\gamma_{2,1}$(2,17 keV), $\gamma_{3,1}$(40,6 keV) and $\gamma_{1,0}$(140,5 keV) are taken from Gerasimov (1981Ge05), Gardulski (1972Ga37) and Helmer (2000He14), respectively. These values are based on the most accurate measurements with the electrostatic spectrometer (E $\gamma_{2,1}$, see also Lacasse (1971La12)) and curved-cristal spectrometer (E$\gamma_{3,1}$ and E$\gamma_{1,0}$, see also Helmer (1981He15)). The energies of $\gamma_{2,0}$(142,7 keV), $\gamma_{3,0}$(181,1 keV), $\gamma_{7,0}$(761,7 keV) and $\gamma_{11,0}$(1072,2 keV) have been computed from the Q value and the adopted energies of other gamma transitions using gamma cascades in the decay scheme. The energy of $\gamma_{15,4}$(689,6 keV) is taken from 1969Co18 (this γ-ray was seen also by Goswamy *et al.* (1992Go22) but was defined as some contamination in the source). All other gamma-ray energies have been adopted from the recent measurements with large volume Ge(Li) and high-purity Ge detectors by R.A. Meyer (1990Me15).

4.2.2 GAMMA RAY RELATIVE EMISSION PROBABILITIES

Several authors measured the relative emission probabilities to the emission probability of 739 keV line, and others to the emission probability of the 140,5 keV line.

In this evaluation the 739 keV line is taken as the reference line rather than the 140 keV line because the 739 line is not a part of the Tc-99m decay scheme, and the measurements carried out relative to this line, are more recent.

Measurements relative to the 140,5 keV line have been taken into account by converting the data so that they are relative to the 739 keV line.

The available experimental values for the γ-ray relative emission probabilities are given in Table 1. Where necessary, these data (including uncertainties) have been converted by the evaluators to values relative to the $\gamma_{9,3}$(739,5 keV) taken as 100. Some old references differ widely far from more recent studies and are not included in the statistical processing.

The adopted (evaluated) values are displayed in last column of Table 1. Reasons for adopting specific data are given in Table 2 which includes the following designations :

R indicates that the value was rejected due to Chauvenet criteria.

n is the number of values taken into account, WM is the weighted mean, *s* and *S* are the internal and external uncertainties of WM, respectively;

”c^2-table” is $(c^2)^{0,05}_{n-1}$,”*reduced* c^2-set” is $c^2/(n-1)$ for the given data set; s_{min} is the minimum experimental uncertainty for the given data set, *tS* is the external uncertainty multiplied by the Student’s factor *t* ,”MBAYS” is the uncertainty from a modified Bayesian analysis.

The doublet $\gamma_{14,7}$+$\gamma_{9,4}$(410-411 keV) has been calculated as two different lines because several authors were able to distinguish separated values.

For the doublet $\gamma_{7,3}$+$\gamma_{8,3}$(580-581 keV) several authors measured only one line, except Meyer (see Table 1).

For the doublet $\gamma_{12,4}$+ $\gamma_{8,1}$(620-622 keV) the emission intensity was computed for the two combined lines in order to take into account most of the measurements, and then these lines were separated by using the intensity ratio for components deduced from the measurements of Meyer of 0,09(3).

Table 1. Experimental and evaluated values for γ-ray relative emission probabilities

	keV	Van Eijk	Cook	Gehrke Heath	Morel	Dickens 1980	Yang 1980	Singh	Chen Da	Meyer 1990	Goswamy 1992	Evaluated
$\gamma_{3,1}$	**40,58**		6,9(8)	4,6(18) *R*	5,9(15)	8,68(27)		7,7(6)		8,6(5)	8,49(25)	8,43(20)
$\gamma_{1,0}$	**140,5**	649(25)	704(45)	730(49)	743(19)	747(12)	759(20)	686(49)	752(28)	755(26)	739(11)	739(11)
$\gamma_{2,0}$	**142,6**	0,195(40)				0,149(25)				0,189(11)		0,174(14)
$\gamma_{9,7}$	**158,8**		0,10(3)	0,095(30)	0,112(15)			0,11(4)		0,139(8)	0,156(6)	0,12(4)
$\gamma_{6,4}$	**162,4**			0,073(22)	0,067(15)			0,078(13)		0,097(5)	0,098(5)	0,094(5)
$\gamma_{3,0}$	**181**	48,7(23)	49,9(34)	49,6(42)	49,1(16)	50,1(7)		49,8(33)	48,7(13)	50,3(17)	49,4(8)	49,6(7)
$\gamma_{10,7}$	**242,3**		0,0070(25)					0,0118(44)		0,0117(17)	0,021(4)	0,0114(28)
$\gamma_{9,6}$	**249**	0,039(20)	0,05(2)					0,04(3)		0,024(3)	0,032(4)	0,0285(30)
$\gamma_{4,2}$	**366,4**	10,6(8)	10,7(6)	10,0(9)	9,8(3)	9,52(32)		9,8(8)		9, 92(25)	9,82(15)	9,85(15)
$\gamma_{13,7}$	**380,1**	0,071(20)	0,07(2)	0,058(15)	0,045(15)			0,07(2)		0, 075(3)	0,086(7)	0,075(4)
$\gamma_{5,2}$	**391,7**	0,016(4)									0,026(5)	0,021(5)
$\gamma_{14,7}$	**410,3**	0,010(5)						0,009(9)		0,016(4)		0,013(3)
$\gamma_{9,4}$	**411,5**	0,18(2)	0,13(2)	0,36(4) *R*	0,134(23)			0,14(2)		0,120(6)		0,133(10)
$\gamma_{12,6}$	**457,6**	0,039(20)	0,08(2)					0,04(2)		0,056(5)	0,067(5)	0,061(5)
$\gamma_{10,5}$	**469,6**		0,0060(15)*R*							0,022(4)	0,022(4)	0,022(4)
$\gamma_{6,2}$	**528,8**	0,39(5)	0,49(5)	0,36(4)	0,43(6)			0,44(4)		0,447(15)	0,47(2)	0,446(15)
$\gamma_{11,5}$	**537,8**		0,0100(25)					0,009(3)		0,013(5)	0,027(5)	0,012(4)
$\gamma_{7,3}$	**580,5**	0,026(7)						0,021(8)		0,036(4)	0,026(4)	0,0294(31)
$\gamma_{8,3}$	**581,3**									0,008(4)		0,008(4)
$\gamma_{12,4}$+ $\gamma_{8,1}$	**620** **621,7**	0,21(3)	0,217(22)	0,19(6)	0,30(4)			0,26(2)		0, 232(11)	0,24(4)	0,236(11)

	keV	Van Eijk	Cook	Gehrke Heath	Morel	Dickens 1980	Yang 1980	Singh	Chen Da	Meyer 1990	Goswamy 1992	Evaluated
$\gamma_{15,4}$	**689,6**		0,0035(15)									0,0035(15)
$\gamma_{9,3}$	**739,5**	100	100	100	100	100	100	100	100	100	100	100
$\gamma_{7,0}$	**761,8**		0,019(5)							0,0092(8)	0,033(3)	0,019(11)
$\gamma_{9,2}$	**777,9**	35,1(24)	34,9(20)	35,8(30)	35,5(10)	35,8(9)		34,8(19)		35,3(12)	35,1(5)	35,3(5)
$\gamma_{10,3}$	**822,9**	1,04(8)	1,11(8)	1,09(10)	1,09(5)	1,09(5)		1,10(7)		1, 06(4)	1,10(2)	1,09(2)
$\gamma_{10,2}$	**861,2**		0,006(2)	0,015(6)				0,005(3)			0,006(3)	0,006(2)
$\gamma_{13,3}$	**960,722**	0,78(7)	0,78(6)	0,80(8)	0,76(4)	0,84(4)		0,79(6)		0, 76(4)	0,78(2)	0,78(2)
$\gamma_{12,2}$	**986,4**	0,013(5)	0,014(4)	0,016(4)						0,0108(9)	0,012(4)	0,0112(8)
$\gamma_{13,1}$	**1001**	0,045(13)	0,036(16)	0,027(4)	0,052(15)			0,045(12)		0,033(1)	0,045(4)	0,035(3)
$\gamma_{15,3}$	**1017**	0,006(3)									0,005(2)	0,0055(21)
$\gamma_{15,2}$	**1056,2**		0,008(2)					0,007(3)		0,0083(9)	0,0089(7)	0,0085(7)
$\gamma_{11,0}$	**1072,2**							0,010(4)				0,010(4)

Table 2. Results of data statistical processing on relative γ-ray emission probabilities

	n	WM	*s*	*S*	c^2		Final uncertainty
					table	set	and type
$\gamma_{3,1}$	6	8,43	0,16	0,20	14,07	1,82	0,20 *(S)*
$\gamma_{1,0}$	10	739	5,7	7,6	18,31	2	11 (s_{min})
$\gamma_{2,0}$	3	0,174	0,014	0,014		1	0,014 (S)*
$\gamma_{9,7}$	6	0,12 [d]	0,0047	0,0078	11,07	3	0,04 *(S)*
$\gamma_{6,4}$	5	0,094	0,0033	0,0042	9,49	1,6	0,005 (s_{min})
$\gamma_{3,0}$	10	49,6	0,42	0,20	16,92	0,13	0,7 (s_{min})
$\gamma_{10,7}$	4	0,0114	0,0014	0,0024	7,82	2,96	0,0028 *(tS)*
$\gamma_{9,6}$	5	0,0285	0027	0,0026	9,49	0,9	0,0030 (s_{min})*
$\gamma_{4,2}$	9	9,85	0,11	0,08	15,51	0,58	0,15 (s_{min})
$\gamma_{13,7}$	7	0,075	0,0037	0,0042	12,59	1,3	0,004 *(S)**
$\gamma_{5,2}$	2	0,021	0,0035	0,005		2	0,005 (S)*
$\gamma_{14,7}$	3	0,013	0,003	0,002		0,56	0,003 *(s)*
$\gamma_{9,4}$	5	0,133	0,007	0,01		1,81	0,01 *(s)**
$\gamma_{12,6}$	5	0,061	0,0034	0,0040	9,49	1,4	0,005 (s_{min})
$\gamma_{10,5}$	3	0,022 [b]					0,004 [b]
$\gamma_{6,2}$	7	0,446	0,010	0,012	12,59	1,1	0,015 (s_{min})
$\gamma_{11,5}$	4	0,012	0,0017	0,0032	7,82	3,6	0,0038 *(tS)*
$\gamma_{7,3}$	4	0,0294	0,0025	0,0031		1,6	0,0031 *(s)*
$\gamma_{8,3}$	1	0,008					0,004
$\gamma_{12,4}+\gamma_{8,1}$	7	0,236	0,0083	0,0085	12,59	1	0,011 (s_{min})*
$\gamma_{15,4}$		0,0035 [c]					0,0015 [c]
$\gamma_{9,3}$		100					
$\gamma_{7,0}$	3	0,019	0,0018	0,0077	5,99	18	0,011 (MBAYS)*
$\gamma_{9,2}$	9	35,3	0,34	0,17	15,51	0,2	0,5 (s_{min})
$\gamma_{10,3}$	8	1,09	0,015	0,0063	14,07	0,1	0,02 (s_{min})*
$\gamma_{10,2}$	4	0,006	0,0014	0,0012	7,82	0,6	0,002 (s_{min})
$\gamma_{13,3}$	9	0,78	0,014	0,0083	15,51	0,08	0,02 (s_{min})
$\gamma_{12,2}$	5	0,0112	0,0015	0,0008	9,49	0,44	0,0008 *(s)*
$\gamma_{13,1}$	7	0,035	0,0017	0,0026	12,59	1,9	0,0028 *(tS)**
$\gamma_{15,3}$		0,0055 [d]					0,0021 [d]
$\gamma_{15,2}$	4	0,0085	0,00056	0,00025	7,82	0,22	0,0007 (s_{min})*
$\gamma_{11,0}$		0,010 [e]					0,004 [e]

[a] Adopted from Goswamy (1992Go22)
[b] Adopted from Meyer (1990Me15) and 1992Go22 (the same values)
[c] Adopted from Cook (1969Co18)
[d] Unweighted average
[e] Adopted from Singh (1982Si16)
* LRSW increased an uncertainty for one of the values(1992Go22 or 1990Me15).

All values for relative γ-ray emission probabilities are given for the equilibrium mixture ^{99}Mo + ^{99}Tc^{m}.

For $\gamma_{2,0}$(142,7 keV) the following measured intensity ratios of $\gamma_{2,0}/\gamma_{1,0}$(140,5 keV) have been used: $3,0(6)\cdot 10^{-4}$ (Van Eijk), $2,0(2)\cdot 10^{-4}$ (Ageev), $2,0(3)\cdot 10^{-4}$ (Dickens, 1980Di16), $2,50(9)\cdot 10^{-4}$ (Meyer, 1990Me15). The weighted average of these values is $2,29(16)\cdot 10^{-4}$ with an external uncertainty; in terms of the $\gamma_{9,3}$(739,5 keV) a relative intensity of 0,169(12) is obtained.

For $\gamma_{11,0}$ (1072,2 keV) the relative γ-ray emission probability is taken from Singh (1982Si16).

4.2.3 GAMMA RAY ABSOLUTE EMISSION PROBABILITIES

Several absolute measurements of the emission intensity of the 739 keV line are available to give a consistent set of data.

Emission 9 - 3 : 739,500(17) keV

Absolute measurement : photon emission per 100 decays

11,9 (3)	Chen Da - 1985 (Ge(Li) gamma spectrometer) (measured)
12,3 (3)	Simonits (1981)
12,14 (22)	Dickens and Love(1980) (calculated)
12,00 (33)	Meyer (Fizika - 22 - p153 (1990))

Lweight has used the weighted average and the internal uncertainty. Reduced-χ^2=0,45
Adopted absolute g **emission probability: 12,12(15)%**

This absolute γ-ray emission probability can be compared with the value obtained by considering the balance of the decay scheme. The γ-ray absolute emission probabilities P_γ have been computed using relative (γ+ce)-probabilities (relatively to the 739,5 keV gamma ray) and the ^{99}Tc ground state intensity balance, which assumes no β-feeding to the g.s. and the 140,5 keV level as confirmed by the high degree of forbiddenness. The P_γ intensity of the 739 keV line has been deduced to be 12,18(17)% taking into account the correlation ΣP_β=1 and the factor of 1,100 for the gamma transitions in Tc-99m.

All the absolute gamma ray emission probabilities are given per 100 disintegrations of Mo-99 (in equilibrium with Tc-99m) taking into account the correction factor of 1,100 for $\gamma_{2,1}$(2,17 keV), $\gamma_{2,0}$(142,7 keV) and $\gamma_{1,0}$(140,5 keV) intensities.

It should be noted that Singh and Sahota (1982Si16) have reported nine controversial γ-rays at energies of 38,4; 163,4; 319,8; 321,0; 352,9; 599,6; 721,7; 940 and 1082,0 keV. These γ-rays have not been confirmed by Goswamy *et al.* (1992Go22) and are not placed in the decay scheme; neither are the 344,6 keV γ-ray observed by Cook *et al.* (1969Co18) and the 89,4; 455,84; 490,53 keV γ-rays observed by Meyer (1990Me15).

5. Electron Emissions

The energies of the conversion electrons have been calculated from the gamma-transition energies given in 2.2 and the electron binding energies. The emission probabilities have been calculated using the conversion coefficients given in 2.2. and the gamma emission probabilities.

Many measurements of conversion electron spectra for ^{99}Mo in equilibrium with ^{99}Tc^{m} have been made (1968Va14, 1969Ag04, 1969Ba03, 1969Ba54, 1969Ra01, 1971La12, 1971Vo06, 1973Le29, 1981Ge05). However the computed values of the conversion electron energies and emission probabilities are more accurate.

The values of the emission probabilities of K-Auger electrons have been calculated using the gamma transition probabilities given in 2.1 and 2.2, the atomic data given in 3. and the conversion coefficients given in 2.2.

Experimental Auger spectra can be found in 1981Ge05.

BETA-MINUS EMISSIONS

The β^- transition energies are derived from the level energies.
T. NAGARAJAN (1971Na01) analysed the β spectrum of Mo-99. This study revealed four β groups with end points :

	Energy keV	Transition probability
$\beta_{0,2}$	1214(1)	84
$\beta_{0,4}$	840(5)	2
$\beta_{0,9}$	450(10)	14
$\beta_{0,12}$	245	<0,2

No evidence was found for a β group with endpoint higher than 1214 keV.

These values are in a rough agreement with those established by considering the balance of the decay scheme (paragraph 2.1).

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^{99}Tc - Comments on evaluation of decay data

by X. Mougeot

This evaluation was done in 2010, taking into account the available literature by March 2010.

1 Decay Scheme

The decay scheme is complete since all of the levels in ^{99}Ru below the decay energies are populated. The J^{π} of the ground and excited levels are from the evaluation of Muller et al. (1986Mu09).

2 Nuclear Data

The Q value is from 2003AU03: $Q(\beta^-) = 293{,}8$ (14) keV. Measurements of the end-point of the main β transition are given in Table 1.

Table 1: Measured end-points of the main β transition.

Reference	E_{max} (keV)	Uncertainty (keV)
1947MO15	320	-
1950KE02	300	10
1951TA05	290	4
1952FE16	290	4
1960BO08	290	10
1966SN02	294	4
1974RE11	293	2

The evaluation of the ^{99}Tc half-life is described in the next section. Table 2 summarizes the measurements and their methodology.

Although the β-decay of ^{99}Tc is practically 100 % from its $9/2^+$ ground state to the $5/2^+$ ground state of ^{99}Ru, 1973LE10 and 1974EN02 observed a β-decay with a very small intensity to the $3/2^+$ first excited state of ^{99}Ru. Thus, its energy, half-life and the multipolarity of the de-exciting γ-ray are evaluated. The β^- branching ratio is evaluated next.

An analysis of the published form factors of the main β^- transition is presented here. With the described limitations, an evaluation was carried out and the mean energy of the spectrum was calculated.

2.1 ^{99}Tc half-life

The measured half-life values of ^{99}Tc are given in Table 2 together with the experimental methods that were used. The value from 1947MO15 was not used in the evaluation because an experimental uncertainty was not reported. The value from 1960BO08 is a more recent one from the same authors.

Table 2: ^{99}Tc half-life measurements.

Reference	$T_{1/2}$ (x10^5 a)	Uncertainty (x10^5 a)	Method	Observations
1947MO15	9,4	-	Aluminium absorption	Not used: no uncertainty
1951FR05	2,12	0,04	Aluminium absorption	
1960BO08	2,15	0,05	Aluminium absorption	Same authors as 1947MO15
1966GO10	2,14	0,05	Liquid Scintillation Counting	
1984CO30	2,111	0,012	Liquid Scintillation Counting	

The statistical processing was done using the LWEIGHT program. A weighted average was adopted here from the resulting consistent data set, with a reduced-χ^2 value of 0,29. The statistical weight is 82 % for 1984CO30, the most recent and precise measurement. Finally, the adopted value, with its internal uncertainty, is:

$$T_{1/2} = 2{,}115\ (11) \times 10^5\ \text{a}.$$

2.2 γ transition : first excited state of ^{99}Ru

2.2.1 Energy

The measured energies of the first excited state of ^{99}Ru are given in Table 3 with the experimental methods used.

Table 3: Measurements of the energy of the first excited state of ^{99}Ru.

Reference	Energy (keV)	Uncertainty (keV)	Method
1967MO20	89,36	0,40	^{99}Rh decay, γ Ge(Li)
1970AN12	89,6	0,5	^{99}Rh, γ Ge(Li)
1971LE20	89,4	1,0	^{98}Mo(α,3n)^{99}Ru, γ Ge(Li)
1973LE10	89,7	0,4	^{99}Tc decay, β Si(Li)
1974EN02	89,5	0,2	^{99}Tc decay, γ Si(Li)

The statistical processing was done using the LWEIGHT program. A weighted average was adopted from the resulting consistent data set, with a reduced-χ^2 value of 0,10. The statistical weight is 59 % for 1974EN02, the most precise measurement. Finally, this evaluation gives:

$E_\gamma(^{99}Ru)$ = 89,52 (15) keV.

2.2.2 $T_{1/2}(^{99}$Ru, 89 keV)

The measured half-life values of the first excited state of ^{99}Ru are given in Table 4 together with the experimental methods used. The original uncertainty of 1972GU01, not explained in detail in the article, seems to be underestimated. 1973BE72 used the same method, with nearly the same statistics, and reported an uncertainty of 0,6. The uncertainty of 0,1 given by 1972GU01 seems to be only that from the data fitting. Thus, the evaluator decided to increase the uncertainty of 1972GU01 from 0,1 to 0,6.

Table 4: Measurements of the half-life of the first excited state of ^{99}Ru.

Reference	$T_{1/2}$ (ns)	Uncertainty (ns)	Method	Observation
1964BO28	19,7	0,4	^{99}Rh, γ spectro.	
1965KI01	20,0	1,0	^{99}Rh, γ spectro.	
1965MA27	20,7	0,3	^{99}Rh, γ spectro.	
1972GU01	20,5	0,6	^{99}Rh, γ Ge(Li)	Uncertainty increased from 0,1 to 0,6
1973BE72	21,04	0,6	^{99}Rh, γ Ge(Li)	
1974EN02	18,9	1,0	^{99}Tc decay, γ Si(Li)	

The statistical processing was done using the LWEIGHT program. A weighted average was adopted here from the resulting consistent data set, with a reduced-χ^2 value of 1,52. The statistical weight is 45 % for 1965MA27. These authors gave some details on their estimation of the uncertainty, and there is no reason to believe it was underestimated. Finally, this evaluation gives:

$T_{1/2}(^{99}$Ru, 89 keV) = 20,36 (25) ns.

2.2.3 Multipolarity

The γ transition from the $3/2^+$ first excited state to the $5/2^+$ ground state of ^{99}Ru is M1+E2. Measurements were carried out to obtain the mixing ratio δ^2 = E2/M1. They are summarized in Table 5 with the experimental methods used. Only two measurements were used for the evaluation because most of the publications are from the same author. Only the most recent one, which is also the most precise, was included. The value from 1973BE72 was not used because the experimental uncertainty was not reported.

The statistical processing was done using the LWEIGHT program. A weighted average was adopted here from the resulting consistent data set, with a reduced-χ^2 value of 2,69. The statistical weight is 94 % for 1976KI02, the most precise measurement. Finally, this evaluation gives:

$\delta^2(^{99}$Ru, 89 keV) = 2,45 (6).

Then δ = -1,56 (2), and the multipolarity is:

M1 + 71,0 (5) % E2.

Table 5: Measurements of the multipolarity mixing ratio of the first excited state of ^{99}Ru. The values from 1973Gibb and 1976KI02 were the only ones that were used for the evaluation.

Reference	δ^2 = E2/M1	Uncertainty	Method	Observation
1964KI01	~ 2	-	Ru-99 Mössbauer γ transition	Not used: no uncertainty
1965KI01	2,4	0,9	Ru-99 Mössbauer γ transition	Same author as 1964KI01
1966KI02	2,7	0,6	Ru-99 Mössbauer γ transition	$\delta<0$, same author as 1964KI01
1972Wagner	2,7	0,6	Ru-99 Mössbauer γ transition	Coming from 1966KI02
1973BE72	2,57	-	^{99}Rh, γ Ge(Li)	Not used: no uncertainty
1973Gibb	2,72	0,17	Ru-99 Mössbauer γ transition	
1976KI02	2,43	0,04	Ru-99 Mössbauer γ transition	δ = -1,56 (2), same author as 1964KI01

2.2.4 Branching ratio

1973LE10 and 1974EN02 inferred a small β^- transition from the $9/2^+$ ground state of ^{99}Tc to the $3/2^+$ 89 keV level of ^{99}Ru, by detecting a de-exciting γ-ray. Thus, this β transition is second unique forbidden, whereas the main transition is second non-unique forbidden.

The authors reported the number of photons detected per decay: 6,5 (1,5) × 10^{-6} for 1973LE10 and 4,9 (1,7) × 10^{-6} for 1974EN02. Next, they used a total internal conversion coefficient α_T = 1,5 calculated from 1968HA52 to determine the corresponding total γ-ray transition probability, and thus the β^- branching.

The absolute γ-ray intensity was evaluated. The statistical processing was done using the LWEIGHT program. A weighted average was adopted from the resulting consistent data set, with a reduced-χ^2 value of 0,50. The statistical weight is 56 % for 1973LE10. Finally, this evaluation gives:

$$I_{abs}(^{99}\mathrm{Ru},\ 89\ \mathrm{keV}) = 5{,}8\ (11) \times 10^{-4}\ \%.$$

The total conversion coefficient α_T was calculated using the BrIcc program (2008KI07): α_T = 1,495 (25). Thus the β^- branching is equal to $I_{abs}(1+\alpha_T)$. Finally, this evaluation gives:

$$P_{\beta 0,1} = 1{,}45\ (30) \times 10^{-3}\ \%.$$

2.3 β^- transition

The branching of the main β^- transition is practically 100 %. A small contribution to the first excited state of ^{99}Ru exists, with a branching of 1,45 (30) × 10^{-3} %, as deduced in Section 2.2.4.

The main β^- transition is from the $9/2^+$ ground state of ^{99}Tc to the $5/2^+$ ground state of ^{99}Ru. This is a second forbidden non-unique transition, thus one can expect a form factor as given below (1976Behrens):

$$C(W) = A(W)q^2 + B(W)\lambda_2 p^2 + D(q^4 + 10/3\lambda_2 q^2 p^2 + \lambda_3 p^4),$$

where q is the linear momentum of the neutrino, p the linear momentum of the electron, and W is the normalised energy of the electron. Measurements show that the following form factor for a first unique forbidden transition gives a good description of the measured energy spectrum:

$$C(W) = q^2 + \lambda p^2.$$

The determination of the form factor is highly dependent on the calculated spectrum used for the comparison with experimental data. Consequently, the form factor depends on the hypothesis made and the data used for the calculation: Coulomb corrections, screening correction due to electron cloud, finite nuclear size correction, radiative corrections, end-point energy, and nature of the transition. The form factor is generally determined by a comparison with a calculated allowed spectrum.

Table 6: Measurements of the form factor of the main β transition.

Reference	λ	Uncertainty	E_{max} (keV)	Energy range (keV)	Method	Observation
1951TA05	~ 1	-	290 (4)	150 - end-point	Mag. spectro.	Not used: no uncertainty
1952FE16	0,50	0,13	292 (3)	60 - end-point	Mag. spectro	Recalculated by 1966Lipnik
1966SN02	0,49	0,04	294 (4)	50 - 280	Plastic scint.	Recalculated by 1976Behrens
1974RE11	0,54	0,02	293 (2)	55 - 250	Si(Li)	

Experimental data are summarized in Table 6 with the energy range of their validity, and the experimental methods used. The value from 1951TA05 was not used because no experimental uncertainty was reported. The value from 1952FE16 was calculated by 1966Lipnik in the correct form. The value from 1966SN02 was recalculated by 1976Behrens using more recent tables for the Fermi function, leading to an increase of the uncertainty from 0,011 to 0,04. The statistical processing was done using the LWEIGHT program. A weighted average was adopted from the resulting consistent data set, with a reduced-χ^2 value of 0,65. The statistical weight is 78 % for 1974RE11, the most recent and precise measurement. Finally, this evaluation gives:

$$C(W) = q^2 + 0{,}529\ (18)\ p^2.$$

It should be underline the main difficulty of the evaluation of form factors: the authors of the published data did not describe in detail all the possible sources of distortion of the measured spectra and their contributions. Obviously, this is a difficult task. In some articles, it is clear that all these problems were not taken into account. The temptation could be great to adjust some known parameters within the uncertainty range to obtain a result close to the previous published ones.

Resulting from the violation parity, electrons emitted in nuclear β-decay are longitudinally spin-polarized. If the decaying neutron is influenced by the nuclear structure in which it is embedded, the value of the polarization may be altered. The authors of 1990GA13 measured the longitudinal electron polarization, and they suggested that the decaying neutron is not influenced more than 3,3 % by the nuclear structure. This could explain why a form factor of a first unique forbidden transition is sufficient to describe a second non-unique forbidden transition. One can note the usual approximation in the theoretical calculation of β spectra: a non-unique forbidden transition is treated as a unique forbidden transition with the same variation of the total angular momentum. It means that a second non-unique forbidden transition is treated as a first unique forbidden transition.

The mean energy of the β spectrum was calculated with the Q value and the form factor given previously. The calculation is based on the analytical approach developed by N.B. Gove and M.J. Martin (1971GO40) and it includes the following correction terms: Coulomb corrections (1961RO33), screening correction due to electron cloud (1954GO69), finite nuclear size correction (1980Dillman), and radiative corrections (1982Behrens). The uncertainty is estimated by the product of E_{mean} with the uncertainty on λ. The result is:

$$E_{mean} = 94{,}6\ (17)\ \text{keV}.$$

The log *ft* value for the main transition (second non-unique forbidden) has been calculated with the LOGFT program: log *ft* (^{99}Tc→^{99}Ru^{gs}) = 12,323 (7). In the same way, for the second unique forbidden transition to the first excited state of ^{99}Ru: log *ft* (^{99}Tc→^{99}Ru*) = 15,82 (9).

For the sake of completeness, we mention some publications on K-shell auto-ionization probabilities accompanying the β decay of ^{99}Tc: 1967ST36, 1972WA32, 1974HA12, and 1980LA02, for experimental studies, and 1977IS05, for theoretical studies. The emitted β particle can ionize the electron cloud of the daughter nucleus, ^{99}Ru, distorting the β spectrum. This phenomenon is negligible in almost all applications, since its probability is about 0,05 % per emitted β.

3 Atomic Data (Ru, Z=44)

3.1 X Radiations and Auger electrons

The X-ray and Auger electron data were computed using the EMISSION program with the atomic data of Schönfeld and Janßen (1996SC06).

4 Radiation Emissions

4.1 Electron Emission

The β^- intensities were evaluated as described above in Section 2.

4.2 Photon Emission

The details of the photon emission evaluation are in Section 2. ^{99}Ru decays from its first excited state at 89,52 (15) keV, with a half-life of 20,36 (25) ns, and a γ-ray multipolarity of M1 + 71,0 (5) % E2. The absolute γ-ray emission intensity is evaluated as 5,8 (11) x10^{-4} %, leading to a β^- branching to ^{99}Ru*(89 keV) of 1,45 (30) × 10^{-3} %.

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^{99}Tc^{m} - Comments on evaluation of decay data
by C. Morillon*, M. M. Bé*, V. Chechev**, A. Egorov**

This evaluation was completed in December 2000. The half-life has been updated in January 2004.

1. DECAY SCHEME

Tc-99m mainly decays to the ground level of Tc-99.
Very weak beta minus transitions to the ground and two excited levels of Ru-99 have been observed.
The J^{π} values and the level energies are from Peker(1994Pe15).

2. NUCLEAR DATA

Q_{IT} (^{99}Tc^{m}) from the 142,7 keV level energy
Q^{-}(^{99}Tc^{m}) from Audi and Wapstra (1995)

2.1 HALF-LIFE

- The measured half-life values are, in hours:

1	6,13(5)	CROWTHER and ELDRIDG	(1965)	1965Cr03	rejected
2	6,006(7)	GOODIER and WILLIAMS	(1966)	1966Go22	
3	6,014 (4)	VUORINEN	(1969)	1969Vu03	
4	6,031 (12)	LEGRAND et al.	(1970)	1970Le07	
5	6,007 (2)	SANTRY and BOWES	(1989)	1989Sa**	
6	6,03 (13)	DECOMBAZ et al.	(1972)	1972De76	
7	6,02 (1)	EMERY et al.	(1972)	1972Em01	
8	6,049 (35)	EMERY et al.	(1972)	1972Em01	rejected
9	6,02 (3)	MEYER	(1974)	1974Me**	
10	6,008 (4)	RUTLEDGE et al.	(1980)	1980RuZY	TcO_4Na
11	6,006 (2)	HOUTERMANS et al.	(1980)	1980Ho17	No precision
12	6,0072 (10)	AYRES and HIRSHFELD	(1982)	1982Ay**	Normal saline solution
13	6,0170(19)	AYRES and HIRSHFELD	(1982)	1982Ay**	Acid solution
	6,0062 (7)	WALZ et al.	(1983)	1983Wa26	Superseded by 2003Sc49
14	6,020(2)	KOLTSOV et al.	(1998)	1998Ko**	TcO_4Na
15	6,0058(12)	SCHRADER	(2004)	2004Sc49	TcO_4Na
16	6,0071(21)	Da SILVA et al.	(2004)	2004Si04	TcO_4Na

The chemical medium probably has an influence on the half-life. Changes in the half-life values have been observed with the modification of external environment or chemical composition (influence on internal conversion of electrons of 2,17 keV transition in external shells : Mazaki (1980Ma03) , Koltsov, and others).

Comparisons of the decay constant of Tc-99m in different chemical environments were made. In the following table λ_0 is the decay constant for Tc-99m in the form of pertechnetate (TcO_4).

Author	Type of source	Source pair	Relative variation of decay constant, %
Koltsov	Sulfide	$[\lambda_0 - \lambda\ (Tc_2S_7)] / \lambda_0$	0,14 (8)
Koltsov	Silver	$[\lambda_0 - \lambda\ (Ag)] / \lambda_0$	0,35 (7)
Koltsov	Gold	$[\lambda_0 - \lambda\ (Au)] / \lambda_0$	0,25 (7)
Mazaki	Sulfide	$[\lambda_0 - \lambda\ (Tc_2S_7)] / \lambda_0$	0,32 (7)
Mazaki	Sulfide - metal	$[\lambda\ (Tc_2S_7) - \lambda\ (Metal)] / \lambda\ (Metal)$	0,056 (3)
Ayres		Acid solution – Normal saline	0,16

If we consider the set of 16 measured values given in the table above, where :
- Emery *et al.*(1972) and Ayres and Hirshfeld (1982) measured the half-life of Tc-99m by 2 different methods or 2 media: both values were taken into account. (NB : the experiment and results described by Ayres and Hirshfeld are the same as those described by Hoppes *et al.* in NBS-SP-626 (1982) 85 and by Unterweger *et al.* in NIM A312 (1992) 349) ;
- the value of Crowther and Eldridge (1965) and the second value of Emery et al. (1972) are rejected due to the Chauvenet criterion.

With the set of 14 remaining values, LWEIGHT recommended the unweighted average (Reduced-χ^2 = 5,3) and expanded the uncertainty to include the most precise value of 6,0072 (Ayres *et al.* 1983). This leads to 6,014 (7) h.

With the 7 most recent values (from 10 to 16) (>1980), the LWEIGHT program derived the weighted mean and expanded the uncertainty: the recommended value is 6,0089 (19) h. (Reduced-χ^2 = 10,2).

Nevertheless, the most commonly used chemical composition is sodium pertechnetate (TcO_4Na) in a physiological saline solution, this solution is chemically stable. This is the result of the way of production of ^{99}Tc^{m} for medical purposes. The metallic matrix have been made for very specific studies and do not correspond to a general use.

Then, taking into consideration the most recent values obtained from a (TcO_4Na) solution, i.e. values 10 – 12 – 14 – 15 – 16 ; the value 14 (Koltsov) is outlier, omitting it the weighted mean is 6,006 7 (7) with the internal uncertainty, the reduced χ^2 is 0,32.

Conclusions :

- Due to the fact that the pertechnetate solution is a stable solution and the most commonly used, *the adopted half-life is : 6,006 7 (10) h*, uncertainty of the most precise measurement value.

- Uncertainty should be enlarged to 0,009, to take into account a possible chemical effect of 0,15% for other solutions, then the half life would be : 6,007 (9) h.

DECAY Tc-99m to Tc-99

- Measured half-life of the 140,5 keV level in ns:

0,277 (14)	STEINER *et al.*	(1969St04)
0,160 (20)	MCDONALD *et al.*	(1971Mc02)
0,205 (4)	ALFTER *et al.*	(1993Al23)
0,237 (14)	SHENOY *et al.*	(1973Sh21)

The value of Steiner *et al.*(1969) is from the original article; the NDS value from the same reference has been adjusted to 0,192 ns.
The value of 0,160(20) ns from McDonald *et al.* (1971) deviates far from the others and is not taken into account.
The Steiner *et al.*(1969) and Shenoy *et al.*(1973) values were determined using the Mössbauer effect.
The uncertainty in the Alfter *et al.* (1993) value was increased 2,47 times by LWEIGHT.
Reduced-χ^2 = 8,94
LWEIGHT has used the weighted average and the external uncertainty.

The adopted value is : **0,221(20) ns**

- **Level energy of technetium 99**

The values of the level energies are from NDS 73,1

Level 2	142,6833 (11)
Level 1	140,5108 (10)

2.2 GAMMA TRANSITIONS and INTERNAL CONVERSION COEFFICIENTS

The energies of the gamma transitions are derived from the energies of the gamma rays, taking recoil into account. The probabilities of gamma transitions $P_{\gamma+ce}$ have been computed using the evaluated absolute gamma-ray emission probabilities and the total internal conversion coefficients (ICC).

INTERNAL CONVERSION COEFFICIENTS

The ICC have been evaluated using the experimental information of the multipolarity admixture coefficients and the theoretical values from Rösel *et al.* and Band *et al.* (for $\gamma_{2,1}$ 2,17 keV).
For pure multipolarities the uncertainties on the ICC values are adopted to be 2%. For mixed multipolarities the uncertainties of ICC were evaluated taking into account the uncertainties of respective multipolarity admixture coefficients.
The ICC adopted values are compared with the measured values, and are, generally, in good agreement.

Transition 2-1: 2,17 keV

No experimental value has been found. Band theoretical values (1976Ba63):
$\alpha_{T=}$ 1,35 (4) 10^{10} and $\alpha_{M=}$ 1,19 (3) 10^{10}

Transition 1-0: 140,511 keV

Total Internal Conversion Coefficient a_T

Experimental measurements :

0,118 (8)	AMTEY *et al.* (1966)
0,113 (6)	DICKENS and LOVE (1980)
0,122 (5)	VUORINEN (1969)
0,118 (3)	LEGRAND *et al.* (1973Le29)
0,1181(23)	LWEIGHT (reduced χ^2= 0,44; weighted average and internal uncertainty)
Adopted: 0,119(3)	**Rosel *et al.* for M1+3,3(3)%E2**

Dickens and Love (1980) determined α_T from the α_k value given by Gardulski and Wiedenbeck (1974) and the K/L/MN values reported by Hager and Selzer and by Medsker (NDS 12-4 - 1974)

α_T was evaluated by Vuorinen (1969) from measurements of conversion electrons in coincidence with fluorescence X-rays.

Multipolarity

Large number of measurements have been made. However, most of the authors gave different values without, or with a large uncertainty. These multipolarities permit the calculation of the total internal conversion coefficients, to which we have assigned a 5% uncertainty:

/d/	**Transition**	a_T **(Rösel)**	
0,31 (2)	M1 + 8,25% E2	0,132(7)	SINGH and SAHOTA (1982Si16)
0,178 (12)	M1 + 3,1% E2	0,119(6)	ALFTER (1993Al23)
	M1 + 4%(2) E2	0,121(6)	MCDONALD *et al.*(1971Mc02)
	M1+<3%E2		VOINOVA *et al.*(1972Vo06)
0,194(30)	M1+3,8%E2		VUORINEN (1969Vu03)
	M1+<8%E2		VAN EIJK *et al.*(1968Va14) calculated from ICCk
	M1+9%(5)E2	0,134(7)	VAN EIJK *et al.*(1968) calculated from K/L ratio
	M1+2,8%E2	0,118(6)	COOK *et al.*(1969Co18)
	M1+7(3)%E2	0,129(7)	MEYER (1974)
	M1+1,4%E2	0,114(6)	DICKENS and LOVE (1980Di16)
	M1+6,5(40)E2	0,128(7)	AGEEV *et al.*(1969Ag04)
0,118(6)	M1+1,4(2)%E2	0,114(6)	GARDULSKI and WIEDENBECK (1974Ga01)
	M1+2,8(3)%E2	0,118(6)	GEIGER (1968GeZW)
	M1+9%E2		SIMONITS *et al.* (1981Si15)
	M1+E2		AMTEY *et al.* (1966Am04)
	M1		BASHANDY (1969Ba54)
		0,120(2)	LWEIGHT (reduced-χ^2= 1,16), weighted average and external uncertainty= 0,002
0,186 (8)	**M1+ 3,2(3)%E2**	**0,119(3)**	**Adopted (Rösel *et al.*)**

From each determination of the multipolarity of the transition, the Rösel theoretical internal coefficient was calculated. From the set of the 10 deduced ICC values the LWEIGHT program recommends a weighted mean of 0,120(2). The value is very closed to that obtained by considering the 4 experimental values for α_T (see table above).

Internal Conversion Coefficients a_K

Experimental values:

0,096(6)	VOINOVA *et al.* (1971Vo06)
0,093 (6)	VOINOVA *et al.* (1971Vo06)
0,102 (7)	VAN EIJK *et al.* (1968Va14)
0,094 (8)	VUORINEN (1969Vu03)
0,102 (5)	DICKENS and LOVE (1980Di16)
0,096 (3)	LWEIGHT (χ^2=0,35; weighted average and internal uncertainty)
0,104 (3)	**Rösel *et al.* (1978) (adopted)**

- α_K was measured by Voinova *et al.* (1971) with a spectrometer which provided simultaneous measurement of conversion electrons and γ-ray spectra.

- Van Eijk *et al.*(1968) calculated α_K from measurements of the 140,5 keV gamma -ray emission probability (P_γ) relative to the gamma-ray emission probability of the 661,6 keV gamma transition in the decay of Cs-137, and from measurements of the conversion electron emission probability P_{ce} of the 140,5 keV K-conversion line relative to the conversion electron emission probability of the 661,6 keV K-conversion line in the decay of Cs-137: P_{ceK} =6,84(19); P_γ =6,00(35); α_K(661,6 keV) = 0,0896 (15) (Helmer in 1999BeZQ).
- Vuorinen (1969) evaluated the internal conversion coefficient α_K by measuring the electron conversion emissions following the conversion of the 140 keV gamma -ray in coincidence with fluorescence X-rays.
- α_K given by Dickens and Love (1980) was computed from the tables of Hager and Seltzer for a M1 transition and a 1,4% E2 admixture. An 5% uncertainty assigned to α_K reflects the added uncertainty to the usual 3% due to the rapid change of α_k with admixture. This value is not taken into account in our calculations.

Internal Conversion Coefficients a$_L$

α_L can be deduced from measurements of the K/L ratio of the conversion electron emission probabilities, and with α_k = 0,104(3) :

K/L	α_L	
8,1 (5)	0,0125(8)	BASHANDY(1969Ba03)
7,70 (30)	0,0132(7)	VAN EIJK *et al.* (1968Va14)
8,3 (3)	0,0122(6)	RAVIER *et al.* (1961Ra04)
7,63 (32)	0,0133(7)	BRAHMAVAR (1968)
7,8 (3)	0,0130(6)	GEIGER (1968 GeZW)
	0,0128(3)	LWEIGHT has used the weighted average and the internal uncertainty. Reduced-χ^2 =0,52
Adopted	**0,0129(4)**	Rösel *et al.* (1978)

Transition 2-0: 142,683 keV

Internal Conversion Coefficients a$_T$

For a M4 transition the theoretical value from Rösel is : **40,9(8).**

Internal Conversion Coefficients a$_K$

- The two following values were calculated from experimental data, and listed by the authors:

23 (6)	VAN EIJK *et al.* (1968)
30 (3)	BASHANDY (1969Ba54)

Van Eijk *et al.* (1968) calculated the K ICC from the ratios of K(142,7)/K(140,5) = 0,072(32) and $I_\gamma(142,7)/I_\gamma(140,5)$ = 0,00030(6), after correction for α_K (661,6 keV, Cs-137) = 0,0896(15)
Bashandy (1969) calculated the K ICC from internal conversion spectra and photon emission probabilities $I_\gamma(142)/I_\gamma(140)$ = 0,00030(6)

- The following α_K coefficients are calculated from the K(142,7)/K(140,5) ratio given by the authors, based on the ratio $I_\gamma(142,7)/I_\gamma(140,5)$ = 0,00030(6) [Van Eijk (1968)] and α_K (140,5) = 0,104(3).

K(142,7)/K(140,5)	α_K(142,7)	
0,072(4)	24 (6)	AMTEY (1966Am04)
0,0746(12)	25 (6)	GEIGER (1968GeZW)
0,075 (8)	26 (6)	AGEEV *et al.* (1969Ag04)

If we take into account the ratio $I_\gamma(142,7)/I_\gamma(140,5)$ = 0,00021(3) given by Dickens and Love (1980Di16), with $\alpha_K(140,5)$ = 0,104(3) the same calculations give higher results for $\alpha_K(142,7)$:

K(142,7)/K(140,5)	$\alpha_K(142,7)$	
0,072(4)	34 (6)	AMTEY (1966)
0,0746 (12)	36 (5)	GEIGER (1968)
0,075 (8)	36 (7)	AGEEV *et al.* (1969)

If we take into account all the six possible data, the weighted average, with the external uncertainty, calculated by LWEIGHT is 29,5(18) (reduced-χ^2 = 0,87)

The **adopted** theoretical K conversion coefficient, for a M4 transition, is **: 29,3(6)** (Rösel *et al.* (1978)).

Internal Conversion Coefficients a_L

From the measurement of the ratio of the conversion electron intensities, with α_K = 29,3(6), it can be deduced that α_L (BASHANDY and IBRAHIEM) is closed to the adopted theoretical value:

K/L	α_L		
2,9 (5)	10,1 (18)	M4 transition	BASHANDY and IBRAHIEM (1969Ba03)
Adopted:	**9,35 (20)**	M4 transition	RÖSEL *et al.* (1978)

3. ATOMIC DATA

3.1. FLUORESCENCE YIELDS

The fluorescence yields are taken from Schönfeld and Janβen (96Sc06).

3.2. X RADIATIONS

The X-ray energies are based on the wavelengths given by Bearden and were converted into energy with 1Å =1,00001481(92) 10^{-10}m
The emission intensities are calculated with the EMISSION program from PTB. No experimental data have been found.

3.3. AUGER ELECTRONS

The energies of Auger electrons are from 1977La** (Larkins).
The ratios P(KLX)/P(KLL) and P(KLY)/P(KLL) are taken from 1996Sc06.

4. PHOTON EMISSIONS

4.1. X-RAY EMISSIONS

The absolute emission probabilities of K X-rays (P_{XK}) have been computed using the adopted value of ω_K , the evaluated internal conversion coefficients and the emission probabilities.

4.2. GAMMA RAY EMISSIONS

4.2.1 GAMMA RAY ENERGIES

The γ-ray energies of $\gamma_{2,1}$(2,17 keV) and $\gamma_{1,0}$(140,5 keV) are taken from Gerasimov *et al.* (1981Ge05) and Helmer (2000He14), respectively. These values are based on the most accurate measurements with an electrostatic spectrometer (E $\gamma_{2,1}$, see also 1971La12 – Lacasse and Hamilton) and curved-crystal spectrometer (E$\gamma_{1,0}$, see also 1981He15 – Helmer *et al.*). The energy of $\gamma_{2,0}$ (142,7 keV) has been computed as the sum of the adopted energies of $\gamma_{2,1}$(2,17 keV) and $\gamma_{1,0}$(140,5 keV) .

4.2.2 GAMMA RAY EMISSION INTENSITIES

140,511 keV (1,0)

Absolute values (per 100 decays)

88,20 (26)	Chen Da (1985)
87,30(21)	Simonits *et al.* (1981Si15)
88,75 (14)	Rutledge *et al.* (1980Ru20)
87,2 (5)	Dickens and Love (1980Di16) (calculated)
88,0 (24)	Legrand *et al.* (1973Le29)

LWEIGHT has been used to derive the weighted average and expand the uncertainty so that the range includes the most precise value of 88,75(14). This leads to the average of 88,4(4) % (reduced-χ^2 = 2,24). Omitting the calculated value of Dickens and Love (1980) and the value of Simonits (1981) from statistical considerations, we have a weighted average of 88,5 % with an external uncertainty of 0,2. LWEIGHT has increased the uncertainty of Rutledge *et al.* (1980) to 0,258. Reduced-χ^2 = 1,14.
The **adopted** value is **: 88,5(2)%**

142,675 keV (2,0)

Relative measurements of the $\gamma_{1,0}$(140,5 keV) line are not precise: from 0,00020(3) of Dickens *et al.*(1980) to 0,00030(6) of Van Eijk *et al.* (1969).
The ratio of $I_{\gamma+ce}(142,7)/I_{\gamma+ce}(140,5)$ from the ^{99}Mo+^{99}Tc^{m} evaluation for the "slow" component of the 140,5 keV transition is 0,0097(7), corresponding to $I_{\gamma}(142,7)/ I_{\gamma}(140,5)$ = 0,00026(2) and $P_{\gamma}(142,7)$ = **0,023(2)%** (**adopted value**).

5. ELECTRON EMISSIONS

The energies of the conversion electrons have been calculated from the gamma-transition energies given in 2.2 and the electron binding energies. Emission probabilities have been calculated using the conversion coefficients given in 2.2. and the adopted gamma emission probabilities.

Measurements of conversion electron spectra for ^{99}Tc^{m} (in equilibrium with ^{99}Mo) have been made in many studies (Van Eijk -1968Va14, Ageev-1969Ag04, Bashandy-1969Ba03, Bashandy-1969Ba54, Ravier-1961Ra01, Lacasse-1971La12, Voinova-1971Vo06, Legrand-1973Le29, Gerasimov-1981Ge05). However, the computed values of the conversion electron energies and emission probabilities are more accurate.

The values of the emission probabilities of K-Auger electrons have been calculated using the transition probabilities given in 2.1 and 2.2, the atomic data given in 3. and the conversion coefficients given in 2.2.

Experimental Auger spectra can be found in 1981Ge05 (Gerasimov *et al.*).

Tc-99m to Ru-99 b- DECAY

From Alburger *et al.* (1980Al02) the total transition probability of the β-transition is: 0,0037(6)%

2- NUCLEAR DATA

Level energy of Ru-99

The values of the level energies are from Peker (NDS 73,1)

Level 2	322,38 (6)
Level 1	89,68 (5)

2.1- b-TRANSITIONS

Only Alburger *et al.* (1980) have totally studied the beta decay of Tc-99m.
The lg ft values were calculated by Singh *et al.* (1998) and derived from measurements by Alburger *et al.* (1980):

Transition	Energy	lg ft **Singh** *et al.*	lg ft **Alburger** *et al.*	Nature
0-0	434,8 (26)	9,4	9,39(11)	unique first-forbidden
0-1	346,7(20)	8,7	8,66(8)	first-forbidden
0-2	113,8 (20)	8,50	7,79(3)	first-forbidden

The adopted values of lg ft and average beta energies have been calculated using the LOGFT program and the level energies from ENSDF.

2.2 GAMMA TRANSITIONS and INTERNAL CONVERSION COEFFICIENTS

Multipolarity

Transition 322 keV	M1+(E2)
Transition 233 keV	(M1+E2)
Transition 89 keV	29%M1+E2 ($\delta = -1,56(2)$ measured by Kistner (1976Ki02))

Internal Conversion Coefficients

No experimental data have been found in the known literature.
The Rösel tables were used to deduce theoretical coefficients :

keV	a_T	a_K	a_L	a_M
322,4	0,01747	0,01519		
232,8	0,0478	0,0412		
89,6	1,492	1,171	0,270	0,0512

3. ATOMIC DATA

The fluorescence yields taken from 96Sc06 (Schönfeld and Janβen) are:
ω_K = 0,796(4) , ϖ_L = 0,0453(11), n_{KL} = 1,000(4)

4. PHOTON EMISSIONS

4.1 X-RAY EMISSIONS

The emission intensities are very low and have not been calculated.

4.2 GAMMA EMISSIONS

Energy, keV	Relative emission probability	Absolute emission intensity	Author(s)
322	$0,97 \cdot 10^{-6}$ (15)		Jones and Griffin (1970Jo24)
	$1,10 \cdot 10^{-6}$ (10)		Decombaz *et al.* (1972De76)
	$1,13 \cdot 10^{-6}$ (9)		Alburger *et al.*.(1980Al02)
	$1,09 \cdot 10^{-6}$ (6)	$0,96 \cdot 10^{-4}$(6)	LWEIGHT reduced-χ^2 = 0,42 weighted mean and internal uncertainty
232	$0,95 \cdot 10^{-7}$ (17)	$0,84 \cdot 10^{-5}$ (15)	Alburger *et al.*. (1980)
89		$1,04 \cdot 10^{-3}$ (20)	deduced from the level balance

For the 322 keV and the 232 keV gamma -rays, the measured emission probabilities are relative to the 140,5 keV emission probability. The absolute emission probabilities are deduced from the adopted absolute emission probability of the 140,5 keV gamma-ray: 88,5(2) %.

For the 89 keV line, no experimental value is available.
The 89 keV level is mainly fed by the beta transition from Tc-99m. With a beta transition probability of $2,6(5)*10^{-3}$ and $a_T = 1,49(5)$, the absolute emission probability is : $1,04(20)*10^{-3}$.

5. ELECTRON EMISSIONS

For the 434,8 and 346,7 keV β^- transitions, the energies and transition probabilities were measured by Alburger (1980).
For the third β^- transition of 113,8 keV, no direct experimental data was found.
The energy is estimated by Alburger *et al.* (1980), and the absolute transition probability is derived from 3 experimental and relative values :

$P_\gamma(322)/P_\gamma(140,5) = 1,10(6) \times 10^{-6}$	Decombaz *et al.*(1972)
$P_\gamma(322)/P_\gamma(140,5) = 0,97(15) \times 10^{-6}$	Jones and Griffin (1970Jo24)
$P_\gamma(322)/P_\gamma(140,5) = 1,113(9) \times 10^{-6}$	Alburger *et al.*(1980)

The weighted mean of γ emission probability relative to the 140 keV -line calculated by Alburger *et al.* (1980) is: $1,10(6) \times 10^{-6}$.

The gamma transitions probabilities are calculated from the gamma emission probabilities and the internal conversion coefficients :

$$P_\gamma(322) = P_\gamma(322) \times (1+ \alpha_T(322))$$
$$P_\gamma(322) = 1,10 \times 10^{-6} \times P_\gamma(140,5)$$
$$P_\gamma(322) = 1,10 \times 10^{-6} \times 88,5 \times 1,0175 = 0,99 \times 10^{-4}$$

As the level 0 is feeding by 93% of the transitions starting from the 322 keV-level, the probability of the 322-keV β transition can be deduced : $0,99 \times 10^{-6}/0,93 =$ **1,06(6) ´ 10^{-4}.**

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^{108}Ag – Comments on evaluation of decay data
by V. Chisté and M. M. Bé

The full decay data evaluation was completed in 2005. The literature available by January 2005 was included.

1. Decay Scheme

^{108}Ag disintegrates by electron capture (2,19 (14) %) and β^+ emission (0,283 (20) %) to excited states of ^{108}Pd and by β^- emission (97,53 (14) %) to excited states of ^{108}Cd .

2. Nuclear Data

The Q values are from the 2003Au03 evaluation.

Level energies, spin, parities and half -life of excited states are from J. Blachot (2000Bl04, see also 1982Ha37).

The half-life of the ^{108}Ag ground state has been determined from the following data (in minutes):

1958Gu31	2,43 (5)
1960Wa10	2,42 (2)
1965Eb38	2,41 (2)
1971Jo07	2,38 (3)
1974HeYW	2,41 (1)
1974Ry01	2,37 (1)
1991Yamamoto	2,353 (9)
Adopted	2,382 (11)

The half-life weighted average has been calculated by Lweight program (version 3).

The evaluator has chosen to take into account the seven values with associated uncertainty for the calculation. The largest contributions to the weighted average come from values of Head (1974HeYW), Ryves (1974Ry01) and Yamamoto (1991Yamamoto) (25 %, 25 % and 31 %, respectively).

The weighted average value is *2,382 min* with a reduced -χ^2 value of 4,35. The ext ernal uncertainty is 0,011 min. Then, the adopted value is 2,382 (11) min.

2.1 b$^-$ transition

The maximum energy of the β^- transitions in the decay of ^{108}Ag to excited states in ^{108}Cd is calculated from:

$E_{\beta-}$ = Q(from 2003Au03) – $E_{\text{level in Cd-108}}$(from 2000Bl04)

For the probabilities of the β^- transitions, the published data are (table 1):

Table 1: β^- transition measured intensity values in %.

Populated Level	1953Pe16	1960Wa10	1962Fr02	1965Fr01
β^- ^{108}Cd ground state	97,3	93,8	95,0 (3)	95,9 (3)
β^- ^{108}Cd 632 keV	0,8	1,9	1,73 (10)	1,75 (10)

For the β^- ^{108}Cd ground state transition , the values given by 1953Pe16 and 1960Wa10 have no uncertainties and the other two values are from the same author; the evaluators have chosen the most recent value published by L. Frevert (1965Fr01). This value, 95,9 (3) %, is important to determine the decay-scheme normalization factor (see **Gamma Ray Transition and Emission**).

For the β^- transition to the ^{108}Cd 632 keV level, the adopted value (1,63 (26) %), consistent with the Frevert value (1,75 (10) %) (table 1) has been deduced from the decay scheme balance .

The total β^- branching ratio was deduced taking into account that gamma -ray adopted relative emission intensities (see **4.1 Gamma Emissions**), the normalization facto r (see **4.1 Gamma Emissions)** and the $I_{\beta+,\varepsilon}$ (g.s.) = 2,01 (12) % (see **2.3 Electron capture transition**):

$I_{\beta+-,\varepsilon}$ = $I_{\beta+,\varepsilon}$ (g.s.) + N * [I_γ (433 keV) + I_γ (931 keV) + I_γ (1441 keV) + I_γ (1539 keV)]
$I_{\beta+-,\varepsilon}$ = 2,01(12) % + 0,0046(7) ∗ [100 + 0,105(8) + 0,585(28) + 0,205(14)] = 2,47 (14)%

And $I_{\beta-}$ = 100 – 2.47(14) % = 97,53 (14) %

The lg ft values have been calculated by Logft program (version 7.2a).

2.2 b$^+$ transition

The maximum energy of the β^+ transitions in the decay of ^{108}Ag is calculated by the same way as for the β^- transition.

For the probability of β^+ transition to the ground state, the published data are (table 2):

Table 2: β^+ transition probability measured values in %.

Level Populated	1953Pe16	1960Wa10	1962Fr02	1965Fr01
β^+ ^{108}Pd ground state	0,14	0,36	0,28 (2)	0,28 (2)

From the total of 0,283 (20) % (2 transitions: to the 433 -keV level and to the ground state) β^+ transition decaying by this mode, 0,28 (2)%, measured by Frevert (1965Fr01) go directly to the ground state. Most of the remaining 0,0026 (3) % (2000Bl04 and 1982Ha37) populate the 433 -keV level (from theoretical ratio ε/β^+) (this electron -capture transition to the 433 -keV level hasn't been measured by Frevert (1965Fr01)).

2.3 Electron capture transition

Some values for the electron capture branching ratio (in %) have been found in the literature, as shown in the following table:

Populated Level	1953Pe16	1960Wa10	1962Fr02	1965Fr01
EC ^{108}Pd ground state	1,5	3,35	2,49 (25)	1,73 (12)
EC ^{108}Pd 433 keV level	0,06	0,18	0,19 (3)	0,19 (3)
EC ^{108}Pd 1052 keV level	0,22	0,42	0,26 (3)	0,27 (3)

For the ground state, the adopted value is the most recent measurement of Frevert (1965Fr01). For the other levels, the electron-capture probabilities have been deduced from the imbalance at each level of the decay scheme. It can be noted that for the levels at 433 keV and 1052 keV the adopted electron capture branchings of 0,19 (8) % and 0,243 (39) %, respectively, are consistent with the Frevert measured values.

P_K, P_L, P_M values have been ca lculated for allowed electron -capture transitions in the decay of ^{108}Ag to the excited states in Pd-108 using the EC-Capture computer program.

2.4 Gamma transitions

Probabilities

The transitions probabilities have been calculated from the gamma -ray emission intensities and the internal conversion coefficients (see **Gamma ray emission**).

Multipolarity and internal conversion coefficients

For the 433 - ([E2]), 633 -(E2) and 1441 -keV ([E2]) gamma -ray transitions, multipolarities are from J. Blachot (2000Bl04, see also 1982Ha37)

The internal conversion coefficients (α_T, α_K and α_L) for these transitions have been calculated using the ICC Computer Code (program Icc99v3a – GETICC dialog). The adopted values have been interpolated from the new tables of Band (2002Ba85).

Their uncertainties are taken as 3% of the calculated values with the ICC computer code.

3. Atomic data

Atomic values, ω_K, ϖ_L and η_{KL}, are from Schönfeld (1996Sc33).
The X-ray and Auger electrons emission probabilities are calculated from the data set values by using the program EMISSION.

4. Photon Emissions
4.1 Gamma Emissions

The measured relative emission intensities are given in table 3, they are relative to the 433 -keV gamma ray taken as 100. Energy values are in keV.

Table 3: Measured relative gamma emission intensities in %.

Energy (keV)	Okano et al. (1971Ok01)	Singhal (1973Si02)	Adopted values
383,13 (16)	none	0,18 (6)	0,18 (6)
388,36 (7)	none	0,37 (12)	0,37 (12)
433,938 (5)	100	100	100
497,13 (12)	0,25 (9)	0,45 (11)	0,33 (7)
618,86 (5)	54,1 (24)	52,4 (26)	53,3 (18)
632,98 (5)	355,1 (14,9)	349,6 (175)	353 (11)
880,26 (10)	0,65 (3)	0,64 (5)	0,647 (26)
931,07 (12)	0,091(16)	0,11 (1)	0,105 (8)
1007,22 (5)	2,71 (11)	2,79 (14)	2,74 (9)
1106,01 (7)	0,26 (2)	0,33 (3)	0,282 (17)
1441,15 (5)	0,56 (4)	0,61 (4)	0,585 (28)
1539,94 (7)	0,20 (2)	0,21 (2)	0,205 (14)

The adopted values are the weighted averages of the two values given with uncertainties. One set of values, N. D. Johnson (1971Jo07) , was not taken into account by the evaluator because the measured relative emission probabilities were relative to that of the 633 keV gamma ray and not to that of the 433 keV gamma ray as done by the other authors (normalization could introduce an overestimation of uncertainties).

The normalization factor to convert the relative emission intensities to absolute emission intensities is calculated with the formula:

Normalization = $\dfrac{100 - I_{b-}(g.s.) - I_{b+,e}(g.s)}{(\Sigma(1 + a_T)P_{rel})}$

where the sum is to be done over all the gamma transitions to the ground state, and:
$I_{\beta-}$ (g.s.)= 95,9 (3) % and $I_{\beta+,\varepsilon}$ (g.s.) = 2,01 (12) %. (see explanations above)

From the theoretical α_T and the evaluated relative emission intensities (table 3), the calculated normalization factor is 0,0046 (7). The uncertainties were propagated on the above formula. Absolute emission intensities are given in table 4.

Table 4: Absolute emission intensities for the γ-rays in the decay of the ^{108}Ag (in %).

Energy (keV)	Relative Emission intensity	Absolute emission intensity
383,13 (16)	0,18 (6)	0,00083 (30)
388,36 (7)	0,37 (12)	0,0017 (6)
433,938 (5)	100	0,46 (7)
497,13 (12)	0,33 (7)	0,00152 (40)
618,86 (5)	53,3 (18)	0,245 (39)
632,98 (5)	353 (11)	1,62 (26)
880,26 (10)	0,647 (26)	0,00298 (48)
931,07 (12)	0,105 (8)	0,00048 (8)
1007,22 (5)	2,74 (9)	0,0126 (20)
1106,01 (7)	0,282 (17)	0,00130 (22)
1441,15 (5)	0,585 (28)	0,00269 (44)
1539,94 (7)	0,205 (14)	0,00094 (16)

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^{108}Ag^{m} – Comments on evaluation of decay data

by V. Chisté and M. M. Bé

The full decay data evaluation was completed in 2005. The literature available by January 2005 was included.

1. Decay Scheme

^{108}Ag^{m} disintegrates 90.9 (6) % by electron capture to the 1771 keV excited state in Pd-108, and by 9.1(6)% through isomeric transitions (two gamma-rays in cascade) in ^{108}Ag.

2. Nuclear Data

The Q value (= 2031 (6) keV) is from the 2003Au03.

Level energies, spin and parities are from J. Blachot (2000Bl04).

The measured ^{108}Ag^{m} half-life values are, in years :

1969Ha07	127 ± 7
1969Vo06	310 ± 132
1992Sc25	418 ± 15
2004Sc49	438 ± 9

The evaluators have chosen as their recommended value the most recent result from Schrader (2004Sc49) who followed the decay by using a ionisation chamber for about 20 years.

2.1 Electron capture transition

For the 260 keV electron capture transition, the adopted value has been deduced from the decay-scheme balance at the 1771-keV level.

P_K, P_L, P_M have been calculated for allowed electron capture transition in the decay of ^{108}Ag^{m} to the 1771-keV excited state in Pd-108 using the EC Capture computer program.

2.4 Gamma transitions

Probabilities

The transition probabilities have been calculated using the gamma-ray emission intensities and the relevant internal conversion coefficients (see **Gamma ray Emission**)

Multipolarity and internal conversion coefficients

The multipolarities for the 30- (M4) and 79-keV gamma-ray transitions (E1) in ^{108}Ag, and the 433-([E2]), 614- (E2) and 722-keV (E2) gamma-ray transitions in ^{108}Pd have been taken from J. Blachot (2000Ba04, see also 1982Ha37).

The internal conversion coefficients (α_T, α_K and α_L) for theses gamma -ray transitions have been interpolated from the tables of Band (2002Ba85) using the ICC Computer Code (program Icc99v3a – GETICC dialog). Their uncertainties are taken to be 3%.

3. Atomic data

Atomic values for ω_K, ϖ_L and η_{KL}, are from Schönfeld (1996Sc33).

The X-ray and Auger electron emission probabilities have been calculated from the data set values by using the program EMISSION.

4. Photon Emissions

4.1 Gamma-ray Emissions

The energy of the 433-, 614- and 722-keV gamma-ray lines are from Helmer et al. (2000He14).

The measured relative emission intensities are given in table 1, they are relative to the 433 -keV gamma ray taken as 100. Energy values are in keV.

Table 1: Measured relative emission intensities, in %.

Energy (keV)	Kistner (1966Ki03)	Kracíková (1968Kr23)	Hamilton (1971Ha31)	Heath (1974HeYW)	Weighted Average values
γ in ^{108}Ag					
30.309 (8)	none	none	none	none	none
79.131 (3)	7.3 (8)	8.3 (9)	none	none	7.7 (6)
γ in ^{108}Pd					
433.938 (4)	100	100	100	100 (5)	100
614.276 (4)	103 (3)	105 (10)	99.3 (20)	100 (5)	100.5 (16)
722.907 (10)	102 (2)	102 (10)	100.4 (20)	100 (5)	100.8 (16)

Adopted values are weighted averages (calculated by the Lweight program, version 3) of the four values measured with uncertainties. The normalization factor to convert the relative emission intensities to absolute emission intensities is calculated with the formula:

$$\text{Normalization} = \frac{100}{[(1 + a_T(433))P_{rel}(433)] + [(1 + a_T(79))P_{rel}(79)]}$$

where the 79- and 433-keV gamma-ray transitions populate the ground state level of ^{108}Ag and ^{108}Pd, respectively.

From the theoretical α_T and the relative evaluated emission intensities of the 79 - and 433-keV gamma-rays (table 1), the normalization factor becomes 0.901 (6). The uncertainty was calculated through the propagation on the formula given above. Absolute emission intensities are given in table 2.

Table 2: Absolute emission intensities for the γ-rays, in %.

Energy (keV)	Relative Emission intensity	Absolute emission intensity
79.131 (3)	7.7 (6)	6.9 (5)
433.938 (4)	100	90.1 (6)
614.276 (4)	100.5 (16)	90.5 (16)
722.907 (10)	100.8 (16)	90.8 (16)

The 30-keV transition probability in the decay of ^{108}Ag^{m}→^{108}Ag is equal to 9.1 (6) % (from decay scheme transition probability balance).

Energy (keV)	Transition probability (%)	Absolute emission intensity (%)
30.309 (8)	9.1 (6)	0.0000215 (18)

The 30-keV absolute emission intensity has been deduced the from total transition probability and the theoretical α_T (Band *et al.* , 2002) for a M4 transition.

5. References

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^{109}Pd - Comments on evaluation of decay data
by A. L. Nichols

Evaluated: January 2007/March 2009

A.1. Evaluation Procedure

Limitation of Relative Statistical Weight Method (LWM) was applied to average the measured decay data when appropriate (see below).

Decay Scheme

A reasonably comprehensive decay scheme was constructed from the gamma-ray studies of 1968Gr02, 1968Be22, 1969Sc12, 1970Bo37, 1975El10 and 1978Pr08. Other earlier studies involved the use of low-resolution NaI(Tl) detectors, and these data have been set aside from consideration in this particular evaluation [1962Br15, 1962Ec02]. The gamma-ray emission probabilities were expressed in terms of the emission probability of the 647.3-keV gamma ray (100 %), and weighted mean data were derived as appropriate.

Most of the beta decay goes directly to the 88.034-keV metastable state of ^{109}Ag (half-life of 39.7 s). Hence, the resulting 88.03360-keV gamma ray dominates the decay scheme.

A.2. Nuclear Data

^{109}Pd undergoes beta decay to ^{109}Ag, including population of the 88.034-keV nuclear level (^{109}Ag^{m}, half-life of 39.7 s) that undergoes 100 % gamma decay to the stable ground state of ^{109}Ag.

Half-life (^{109}Pd)

The recommended half-life has been determined from the measurements of Gueben and Govaerts (1958Gu09), Starner (1959St28), Brandhorst and Cobble (1962Br15), Bormann *et al.* (1970Bo22), Gindler and Glendenin (1977Gi11), Chatterjee and Baliga (1983Ch42) and Abzouzi *et al.* (1990Ab06). A value of 13.58 (12) hours was derived in terms of LWM, with the uncertainty extended to include the most precise measurement of 13.7012 hours.

Half-life measurements (^{109}Pd)

Reference	Half-life (*h*)
1958Gu09	13.99 ± 0.16 13.20 ± 1.66
1959St28	13.45 ± 0.01
1962Br15	13.47 ± 0.01
1970Bo22	13.67 ± 0.07
1977Gi11	13.427 ± 0.014
1983Ch42	13.85 ± 0.17
1990Ab06	13.7012 ± 0.0024
Recommended value	13.58 ± 0.12

Half-life (^{109}Ag^{m})

The recommended half-life has been determined from the measurements of Helmholz (1941He03), Wiedenbeck (1945Wi11), Bradt *et al.* (1945Br06, 1946Bro7, 1947Br05), Wolicki *et al.* (1951Wo15), Middelboe (1967Mi11), Abrams and Pelekis (1967Ab07), and Cottrell (1973Co10). A value of 39.7 (2) seconds was derived in terms of LWM.

Half-life measurements (^{109}Ag^{m})

Reference	Half-life (*s*)
1941He03	40 ± 3
1945Wi11	40.4 ± 0.2
1947Br05	39.2 ± 0.2
1951Wo15	40 ± 1
1967Mi11	39.80 ± 0.18
1967Ab07	39.3 ± 0.3
1973Co10	35 ± 5
Recommended value	39.7 ± 0.2

Gamma Rays

Energies

Gamma-ray transition energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 2006Bl02 were adopted, and used to determine the energies of the gamma-ray transitions between the populated-depopulated levels, apart from the 88.03360-keV gamma ray which was adopted from 2000He14.

Emission Probabilities

Specific features of the earlier decay data studies of ^{109}Pd were considered and adopted to varying degrees during the course of assembling a reasonably consistent decay scheme (1953Av25, 1953Nu04, 1954Mo38, 1957Ma16, 1957Wa05, 1962Ec02, 1967Bl08, 1968BaZY and 1970Fo01). Relative emission probabilities and their uncertainties were determined from the measurements of 1968Gr02, 1968Be22, 1969Sc12, 1970Bo37, 1975El10, 1978Pr08 and 1983Ch42 normalized to the 647.3-keV gamma ray (100 %). These seven data sets were in reasonably good agreement with each other, although some difficulties occurred as noted below.

The 44.7-keV gamma ray has only been observed and quantified by 1968Gr02, 1968Be22 and 1970Bo37. Equivalent relative emission probabilities for the high-intensity 88.0336-keV gamma ray varied by as much as 25 %, and all of these measurements possess rather large uncertainties of ± 9 % to 10 % - not a particularly satisfactory situation for such an important gamma transition. A few gamma-ray emissions of questionable origin were noted by 1975El10 (in particular), 1978Pr08 and 1983Ch42. Thus, the 114.2-, 400.7-, 500.6-, 565.1- and 787.1-keV gamma rays have only been observed by 1975El10. The 327.2-, 395.6-, 609.8- and 869.5-keV gamma rays are also of doubtful origin.

Gamma-ray emission probabilities as measured and reported.

transition	E_γ (keV)	P_γ^{rel}								
		1962Ec02$^{\#}$	1968BaZY	1968Be22	1968Gr02	1969Sc12	1970Bo37	1975El10	1978Pr08	1983Ch42
$\gamma_{2,1}$ (Ag)	44.7 (1)	-	-	4.5 (14)	3.6 (11)	-	4.8 (5)	-	-	-
$\gamma_{1,0}$ (Ag)	88.03360 (103)	4.35 (90)	-	11600 (1160)	8900 (800)	3850 (350)	11700 (1150)	11568 (995)	14600 (1300)	16252 (2194)
$\gamma_{4,3}$ (Ag)	103.8 (2)	-	-	1.0 (3)	2.2 (7)	1.0 (2)	1.9 (2)	2.2 (4)	2.8 (5)	1.59
$\gamma_{14,6}$ (Ag)	114.2 (9) ?	-	-	-	-	-	-	0.20 (6)	-	-
$\gamma_{16,11}$ (Ag)	134.2 (2)	-	3.2	3.7 (11)	3.2 (10)	1.4 (3)	4.0 (4)	3.8 (4)	6.1 (9)	8.0 (13)
$\gamma_{16,10}$ (Ag)	145.1 (2)	-	2.5	2.5 (8)	2.7 (8)	1.2 (2)	3.1 (3)	2.8 (3)	3.8 (8)	4.3 (18)
$\gamma_{7,4}$ (Ag)	286.7 (3)	-	-	-	-	0.15 (4)	-	0.660 (72)	0.5 (1)	0.84 (11)
$\gamma_{10,4}$ (Ag)	309.1 (3)	-	-	9 (1)	-	5.0 (15)	11.0 (9)	13.30 (14)	20 (6)	29.8 (36)
$\gamma_{3,0}$ (Ag)	311.4 (1)	0.046 (9)	100	85 (9)	100	34 (3)	91 (8)	100	124 (6)	140.4 (152)
$\gamma_{4,1}$ (Ag)	327.2 (2) ?	-	-	-	-	-	-	-	-	0.52 (5)
$\gamma_{7,3}$ (Ag)	390.5 (2)	0.010 ?	2.3	3.0 (9)	2.5 (5)	1.0 (2)	3.2 (3)	3.2 (4)	3.6 (3)	3.6 (4)
$\gamma_{9,3}$ (Ag)	395.6 (3)	-	-	-	-	0.07 (3)	-	0.60 (19)	0.27 (5)	0.46 (13)
$\gamma_{23,6}$ (Ag)	400.7 (6) ?	-	-	-	-	-	-	0.20 (7)	-	-
$\gamma_{10,3}$ (Ag)	413.0 (2)	0.016 (3)	47 (complex)	22 (2)	26 (8)	7 (1)	23 (2)	23.50 (23)	29 (2)	32.9 (37)
$\gamma_{4,0}$ (Ag)	415.2 (2)	-		45 (5)	23 (7)	11.3 (10)	45.0 (42)	35.2 (3)	42 (3)	46.0 (50)
$\gamma_{11,3}$ (Ag)	423.9 (2)	-	1.7	3.8 (11)	1.8 (4)	1.0 (2)	3.9 (3)	3.1 (3)	3.5 (3)	3.8 (4)
$\gamma_{15,4}$ (Ag)	447.6 (4)	0.005	1.8	3.3 (10)	2.6 (6)	0.88 (20)	3.3 (3)	2.46 (30)	3.5 (3)	3.6 (4)
$\gamma_{16,4}$ (Ag)	454.3 (3)	-	0.9	2.5 (8)	-	0.56 (25)	2.3 (2)	1.80 (23)	1.7 (2)	1.7 (2)
$\gamma_{20,4}$ (Ag)	496.9 (10)	-	-	0.2 (1)	-	-	0.15 (3)	-	0.31 (6)	0.33 (9)
$\gamma_{14,3}$ (Ag)	500.6 (6) ?	-	-	-	-	-	-	0.15 (3)	-	-
$\gamma_{15,3}$ (Ag)	551.4 (3)	0.006 (1) ?	1.9	2.6 (8)	1.5 (5)	0.65 (15)	2.5 (3)	2.1 (3)	2.7 (2)	2.6 (3)
$\gamma_{16,3}$ (Ag)	558.1 (2)	-	6.4	9.8 (10)	6.2 (8)	2.6 (3)	9.6 (9)	8.70 (95)	9.9 (7)	9.7 (10)
$\gamma_{6,2}$ (Ag)	565.1 (5) ?	-	-	-	-	-	-	0.35 (4)	-	-
$\gamma_{11,2}$ (Ag)	602.6 (2)	0.003	21	34 (3)	21.5 (20)	8.5 (5)	34 (3)	28.1 (20)	35 (2)	33.2 (37)
$\gamma_{6,1}$ (Ag)	609.8 (4) ?	-	-	-	-	0.15 (7)	-	0.60 (15)	-	-
$\gamma_{10,1}$ (Ag)	636.3 (1)	-	31	41 (4)	27 (3)	10.6 (5)	41.0 (38)	32.5 (3)	42 (3)	41.5 (45)
$\gamma_{11,1}$ (Ag)	647.3 (1)	0.031 (6)	64	100	65 (5)	26 (2)	100	81.2 (80)	100	100
$\gamma_{7,0}$ (Ag)	701.9 (2)	0.004 (1)	9.2	15 (2)	9.2 (10)	3.3 (3)	14.7 (12)	11.20 (12)	13.5 (18)	12.6 (14)

transition	E_γ (keV)	P_γ^{rel}								
		1962Ec02[#]	1968BaZY	1968Be22	1968Gr02	1969Sc12	1970Bo37	1975El10	1978Pr08	1983Ch42
$\gamma_{9,0}$ (Ag)	707.0 (2)	-	3.8	6.9 (7)	4.5 (5)	1.7 (2)	7.1 (7)	5.8 (6)	6.3 (9)	5.6 (7)
$\gamma_{10,0}$ (Ag)	724.4 (1)	-	-	1.2 (4)	-	0.20 (5)	1.1 (1)	0.8 (2)	0.4 (1)	0.27 (7)
$\gamma_{16,2}$ (Ag)	736.7 (2)	-	4.4	7.8 (8)	5.0 (6)	1.8 (2)	7.7 (7)	6.1 (7)	6.8 (9)	6.4 (7)
$\gamma_{19,2}$ (Ag)	778.3 (5)	-	-	4 (1)	-	1.6 (5)	4.0 (4)	4.7 (6)	7.3 (25)	9.6 (13)
$\gamma_{16,1}$ (Ag)	781.4 (1)	0.010 (2)	34	49 (5)	33 (3)	11.7 (12)	50 (4)	40.0 (35)	48 (3)	50.5 (56)
$\gamma_{23,3}$ (Ag)	787.1 (3) ?	-	-	-	-	-	-	0.070 (4)	-	-
$\gamma_{19,1}$ (Ag)	823.0 (4)	-	0.5	0.8 (2)	-	0.20 (3)	0.5 (1)	1.2 (3)	0.77 (11)	0.66 (8)
$\gamma_{15,0}$ (Ag)	862.8 (2)	-	0.4	0.6 (2)	< 0.5	0.14 (3)	0.3 (1)	0.40 (15)	0.66 (11)	0.68
$\gamma_{16,0}$ (Ag)	869.5 (1) ?	-	-	-	-	-	-	-	0.21 (6) ?	-
$\gamma_{23,2}$ (Ag)	965.8 (3)	-	-	0.10 (3)	-	-	< 0.1	0.3 (1)	0.25 (4)	0.28
$\gamma_{23,1}$ (Ag)	1010.5 (2)	-	-	0.10 (3)	-	-	< 0.1	0.200 (66)	0.11 (4)	0.12 (4)

[#] NaI(Tl) detectors were used with a lack of spectral resolution – this data set was discarded.

Relative gamma-ray emission probabilities – re-normalised for weighted mean analysis.

E_γ (keV)	P_γ^{rel}								
	1968BaZY[§]	1968Gr02	1968Be22	1969Sc12	1970Bo37	1975El10	1978Pr08	1983Ch42	Recommended
44.7 (1)	-	5.5 (17)	4.5 (14)	-	4.8 (5)	-	-	-	4.8 (5)
88.03360 (103)	-	13690 (1230)[*]	11600 (1160)[*]	14810 (1350)	11700 (1150)[*]	14250 (1230)	14600 (1300)	16252 (2194)[*]	14540 (750)
103.8 (2)	-	3.4 (11)[*]	1.0 (3)[*]	3.8 (8)[*]	1.9 (2)[*]	2.7 (5)	2.8 (5)	1.5[*]	2.8 (4)
114.2 (9) ?	-	-	-	-	-	0.25 (8)	-	-	0.25 (8)
134.2 (2)	5	4.9 (15)	3.7 (11)[*]	5.4 (12)	4.0 (4)	4.7 (5)	6.1 (9)[*]	8.0 (13)[*]	4.4 (3)
145.1 (2)	3.9	4.2 (12)	2.5 (8)	4.6 (8)	3.1 (3)	3.4 (4)	3.8 (8)	4.3 (18)	3.3 (2)
286.7 (3)	-	-	-	0.58 (15)	-	0.81 (9)	0.5 (1)	0.84 (11)	0.70 (5)
309.1 (3)	-	-	9 (1)[*]	19 (6)	11.0 (9)[*]	16.4 (2)	20 (6)	29.8 (36)[*]	16.4 (2)
311.4 (1)	156	154 (12)[*]	85 (9)[*]	131 (12)	91 (8)[*]	123 (12)	124 (6)	140.4 (152)[*]	125 (5)
327.2 (2) ?	-	-	-	-	-	-	-	0.52 (5)	0.52 (5)
390.5 (2)	3.6	3.8 (8)	3.0 (9)[*]	3.8 (8)	3.2 (3)[*]	3.9 (5)	3.6 (3)	3.6 (4)	3.7 (2)
395.6 (3)	-	-	-	0.27 (12)	-	0.74 (23)[*]	0.27 (5)	0.46 (13)[*]	0.27 (5)

E_γ (keV)	P_γ^{rel}								
	1968BaZY§	1968Gr02	1968Be22	1969Sc12	1970Bo37	1975El10	1978Pr08	1983Ch42	Recommended
400.7 (6) ?	-	-	-	-	-	0.25 (9)	-	-	0.25 (9)
413.0 (2)	73(complex)	40 (12)*	22 (2)	27 (4)	23 (2)	28.94 (28)	29 (2)	32.9 (37)	27 (2)
415.2 (2)		35 (11)	45 (5)	43 (4)	45.0 (42)	43.3 (4)	42 (3)	46.0 (50)	43.3 (4)
423.9 (2)	2.7	2.8 (6)*	3.8 (11)	3.8 (8)	3.9 (3)	3.8 (4)	3.5 (3)	3.8 (4)	3.7 (2)
447.6 (4)	2.8	4.0 (9)	3.3 (10)	3.4 (8)	3.3 (3)	3.03 (37)	3.5 (3)	3.6 (4)	3.4 (2)
454.3 (3)	1.4	-	2.5 (8)	2.2 (10)	2.3 (2)	2.22 (28)	1.7 (2)	1.7 (2)	2.0 (1)
496.9 (10)	-	-	0.2 (1)	-	0.15 (3)*	-	0.31 (6)	0.33 (9)	0.29 (5)
500.6 (6) ?	-	-	-	-	-	0.18 (4)	-	-	0.18 (4)
551.4 (3)	3.0	2.3 (8)	2.6 (8)	2.5 (6)	2.5 (3)	2.6 (4)	2.7 (2)	2.6 (3)	2.6 (2)
558.1 (2)	10	9.5 (12)	9.8 (10)	10 (1)	9.6 (9)	10.7 (12)	9.9 (7)	9.7 (10)	9.9 (4)
565.1 (1) ?	-	-	-	-	-	0.43 (5)	-	-	0.43 (5)
602.6 (2)	33	33.0 (31)	34 (3)	33 (2)	34 (3)	34.6 (25)	35 (2)	33.2 (37)	34 (1)
609.8 (4) ?	-	-	-	0.6 (3)	-	0.74 (19)	-	-	0.7 (2)
636.3 (1)	48	42 (5)	41 (4)	41 (2)	41.0 (38)	40.0 (4)	42 (3)	41.5 (45)	40.1 (4)
647.3 (1)	100	100	100	100	100	100	100	100	100
701.9 (2)	14.4	14.2 (15)	15 (2)	12.7 (12)	14.7 (12)	13.79 (14)	13.5 (18)	12.6 (14)	13.8 (2)
707.0 (2)	5.9	6.9 (8)	6.9 (7)	6.5 (8)	7.1 (7)	7.1 (7)	6.3 (9)	5.6 (7)*	6.8 (3)
724.4 (1)	-	-	1.2 (4)	0.8 (2)	1.1 (1)	1.0 (3)	0.4 (1)*	0.27 (7)*	1.0 (1)
736.7 (2)	6.9	7.7 (9)	7.8 (8)	6.9 (8)	7.7 (7)	7.5 (9)	6.8 (9)	6.4 (7)	7.2 (3)
778.3 (5)	-	-	4 (1)*	6.2 (19)	4.0 (4)*	5.8 (7)	7.3 (25)	9.6 (13)*	5.9 (6)
781.4 (1)	53	51 (5)	49 (5)	45 (5)	50 (4)	49 (4)	48 (3)	50.5 (56)	49 (2)
787.1 (3) ?	-	-	-	-	-	0.086 (5)	-	-	0.086 (5)
823.0 (4)	0.8	-	0.8 (2)	0.77 (12)	0.5 (1)*	1.5 (4)*	0.77 (11)	0.66 (8)	0.72 (6)
862.8 (2)	0.6	< 0.8	0.6 (2)	0.54 (12)	0.3 (1)*	0.49 (18)	0.66 (11)	0.68*	0.59 (7)
869.5 (1) ?	-	-	-	-	-	-	0.21 (6) ?	-	0.21 (6)
965.8 (3)	-	-	0.10 (3)*	-	< 0.1	0.4 (1)	0.25 (4)	0.28*	0.27 (4)
1010.5 (2)	-	-	0.10 (3)	-	< 0.1	0.25 (8)	0.11 (4)	0.12 (4)	0.12 (2)

§ Uncertainties were not assigned to the intensity measurements – this data set was discarded.

* Data were not used in the weighted mean analysis process (LWM) – some of these data lack quantified uncertainties, while other data deviate considerably from the majority of equivalent data from other sources.

Gamma-ray emissions: recommended energies, relative emission probabilities, multipolarities and theoretical internal conversion coefficients (frozen orbital approximation).

E_γ (keV)	P_{γ}^{rel}	Multipolarity	α_K	α_L	α_{M+}	α_{tot}
44.7 (1)	4.8 (5)	M1 + E2 δ = 0.533	5.69 (9)	2.69 (5)	0.62 (2)	9.00 (15)
88.033 60 (103)	14 540 (750)	E3	11.41 (16)	12.06 (17)	2.86 (4)	26.33 (40)
103.8 (2)	2.8 (4)	M1 + E2 δ = – 0.045	0.329 (6)	0.041 (1)	0.009	0.379 (7)
114.2 (9) ?	0.25 (8)	(M1 + E2)	-	-	-	-
134.2 (2)	4.4 (3)	M1 + E2 (δ = 0.15)	0.165 8 (25)	0.021 2 (4)	0.005 (1)	0.192 (3)
145.1 (2)	3.3 (2)	(M1 + E2) δ = 0.132	0.132 6 (20)	0.016 70 (25)	0.003 7	0.153 (2)
286.7 (3)	0.70 (5)	M1 + E2 (δ = 0.199)	0.021 6 (3)	0.002 64 (4)	0.000 56	0.024 8 (4)
309.1 (3)	16.4 (2)	(E1)	0.005 91 (9)	0.000 697 (10)	0.000 163	0.006 77 (10)
311.4 (1)	125 (5)	M1 + E2 δ = – 0.22	0.017 49 (25)	0.002 13 (3)	0.000 48	0.020 1 (3)
327.2 (2) ?	0.52 (5)	E1	0.005 09 (8)	0.000 599 (9)	0.000 131	0.005 82 (9)
390.5 (2)	3.7 (2)	M1 + E2 δ = 0.19	0.009 80 (14)	0.001 178 (17)	0.000 262	0.011 24 (16)
395.6 (3)	0.27 (5)	(E1)	0.003 12 (5)	0.000 366 (6)	0.000 084	0.003 57 (5)
400.7 (6) ?	0.25 (9)	(M1 + E2)	-	-	-	-
413.0 (2)	27 (2)	(E1 (+ M2)) δ = 0.18	0.003 66 (7)	0.000 442 (8)	0.000 098	0.004 20 (8)
415.2 (2)	43.3 (4)	E2	0.009 44 (14)	0.001 257 (18)	0.000 283	0.010 98 (16)
423.9 (2)	3.7 (2)	E1 (+ M2) δ = – 0.27	0.004 36 (7)	0.000 536 (9)	0.000 124	0.005 02 (8)
447.6 (4)	3.4 (2)	M1 + E2 δ = – 0.16	0.006 98 (10)	0.000 833 (12)	0.000 187	0.008 00 (12)
454.3 (3)	2.0 (1)	E1	0.002 22 (4)	0.000 259 (4)	0.000 051	0.002 53 (4)
496.9 (10)	0.29 (5)	M1 + E2 (δ = 0.20)	0.005 41 (8)	0.000 644 (10)	0.000 146	0.006 2 (1)
500.6 (6) ?	0.18 (4)	(E1)	0.001 756 (25)	0.000 205 (3)	0.000 049	0.002 01 (3)
551.4 (3)	2.6 (2)	M1 + E2 δ = – 0.28	0.004 20 (6)	0.000 500 (7)	0.000 12	0.004 82 (7)
558.1 (2)	9.9 (4)	E1 (+ M2) δ = – 0.26	0.002 07 (4)	0.000 249 (4)	0.000 061	0.002 38 (4)
565.1 (5) ?	0.43 (5)	(E2)	0.003 86 (6)	0.000 489 (7)	0.000 111	0.004 46 (7)
602.6 (2)	34 (1)	E2	0.003 24 (5)	0.000 407 (6)	0.000 093	0.003 74 (6)
609.8 (4) ?	0.7 (2)	(M1 + E2)	-	-	-	-
636.3 (1)	40.1 (4)	(E2)	0.002 81 (4)	0.000 350 (5)	0.000 07	0.003 23 (5)
647.3 (1)	100	M1 + E2	-	-	-	-
701.9 (2)	13.8 (2)	M1 + E2 δ = 0.029	0.002 39 (4)	0.000 280 (4)	0.000 06	0.002 73 (4)
707.0 (2)	6.8 (3)	(E1)	0.000 807 (12)	0.000 093 3 (13)	0.000 020 7	0.000 921 (13)
724.4 (1)	1.0 (1)	(E1)	0.000 766 (11)	0.000 088 5 (13)	0.000 019 5	0.000 874 (13)
736.7 (2)	7.2 (3)	E2	0.001 93 (3)	0.000 236 (4)	0.000 044	0.002 21 (4)
778.3 (5)	5.9 (6)	M1 + E2	-	-	-	-
781.4 (1)	49 (2)	M1 + E2	-	-	-	-
787.1 (3) ?	0.086 (5)	(E1)	0.000 644 (9)	0.000 074 3 (11)	0.000 016 7	0.000 735 (11)
823.0 (4)	0.72 (6)	M1 + E2	-	-	-	-
862.8 (2)	0.59 (7)	E2	0.001 313 (19)	0.000 158 3 (23)	0.000 038 7	0.001 51 (2)
869.5 (1) ?	0.21 (6)	M2 (+ E3)	0.003 72 (6)	0.000 453 (7)	0.000 097	0.004 27 (6)
965.8 (3)	0.27 (4)	-	-	-	-	-
1010.5 (2)	0.12 (2)	-	-	-	-	-

Much of the lower-energy gamma-ray data of 1968Gr02, 1968Be22, 1970Bo37 and 1983Ch42 deviated significantly from the studies of 1969Sc12, 1975El10 and 1978Pr08 (particularly below 400 keV) and after careful consideration of the individual data sets, some of these measurements were set aside and not included in the eventual weighted mean analyses. Despite these problems, every effort has been made to incorporate all of the gamma-ray data within a reasonably comprehensive decay scheme. One result of this effort is the introduction of two relatively poorly defined nuclear levels at 697.8 (5/2+) and 812.0 (3/2+) keV, primarily to accommodate the 114.2-, 500.6-, 565.1- and 609.8-keV gamma rays. Additional low-intensity gamma transitions were also incorporated into the proposed decay scheme, including the 327.2-, 400.7-, 787.1- and 869.5-keV gamma rays.

Multipolarities and Internal Conversion Coefficients

The nuclear level scheme specified by Blachot (2006Bl02) has been used to define the multipolarities of the gamma transitions on the basis of known spins and parities. Somewhat disparate mixing ratios were obtained by 1970Ro14, 1975El10, 1977Bo04 and 1978Pro8 based on angular correlation measurements, and these data were used to determine the assignments and internal conversion coefficients of the 103.8-, 145.1-, 311.4-, 390.5-, 413.0-, 423.9-, 447.6-, 551.4-, 558.1- and 701.9-keV-keV gamma rays. Recommended internal conversion coefficients were determined from the theoretical tabulations of Band *et al.* (2002Ba85, 2002Ra45) by means of the methodology of Kibedi *et al.* (2008Ki07) in which the frozen orbital approximation was adopted. Finally, the theoretical internal conversion coefficients and mixing ratio of the 44.7-keV (M1 + E2) gamma transition were derived from the population-depopulation balance of the 132.74-keV nuclear level (with no populating beta transition).

A normalization factor of 0.000 252 (14) was calculated from the internal conversion coefficients and relative emission probabilities of the gamma-ray transitions populating the ^{109}Ag ground state directly, assuming that there is no direct beta feeding as implied from the spins and parities derived for the ^{109}Pd ($5/2^+$) and ^{109}Ag ($1/2^-$) ground states:

$$\sum P_{\gamma+ce}^{rel} = 100\%$$

$$397\,572\ (21\,307)\ F = 100$$

$$F = 0.000\,251\,53 \pm 0.000\,013\,51 \quad [= 0.000\,252 \pm 0.000\,014]$$

Beta-particle Emissions

Energies and emission probabilities

The beta-particle energies were calculated from the structural detail of the proposed decay scheme. Nuclear level energies adopted from Blachot (2006Bl02) and a Q_{β^-} value of 1116.1 ± 2.0 keV from Audi *et al.* (2003Au03) were used to determine the energies and uncertainties of the beta-particle transitions. Beta-particle emission probabilities were calculated from the relative gamma-ray emission probabilities, the associated normalization factor and the theoretical internal conversion coefficients derived from Kibedi *et al.* (2008Ki07). Direct beta population of the 132.74-keV nuclear level and ground state of ^{109}Ag were assumed to be zero on the basis of spin and parity considerations ($5/2^+$ to $9/2^+$ (2nd forbidden non-unique), and $5/2^+$ to $1/2^-$ (1st forbidden unique), respectively).

Beta-particle Emission Probability per 100 Disintegrations of ^{109}Pd.

Transition	E_β (keV)	P_β	Transition type	log*ft*
$\beta^-_{0,23}$	17.6 ± 2.0	0.000 18 ± 0.000 03	(allowed)	6.22
$\beta^-_{0,20}$	204.0 ± 2.2	0.000 074 ± 0.000 014	1st forbidden non-unique	9.87
$\beta^-_{0,19}$	205.1 ± 2.0	0.001 66 ± 0.000 17	allowed	8.53
$\beta^-_{0,16}$	246.6 ± 2.0	0.019 4 ± 0.000 9	allowed	7.72
$\beta^-_{0,15}$	253.3 ± 2.0	0.001 67 ± 0.000 10	1st forbidden non-unique	8.82
$\beta^-_{0,14}$	304.1 ± 2.1	0.000 108 ± 0.000 024	(allowed)	10.3
$\beta^-_{0,11}$	380.8 ± 2.0	0.033 4 ± 0.001 5	allowed	8.096
$\beta^-_{0,10}$	391.8 ± 2.0	0.020 4 ± 0.000 9	(allowed)	8.351
$\beta^-_{0,9}$	409.1 ± 2.0	0.001 78 ± 0.000 12	(allowed)	9.47
$\beta^-_{0,7}$	414.2 ± 2.0	0.004 60 ± 0.000 21	1st forbidden non-unique	9.08
$\beta^-_{0,6}$	418.3 ± 2.0	0.000 16 ± 0.000 07	(allowed)	10.55
$\beta^-_{0,4}$	700.9 ± 2.0	0.006 3 ± 0.000 2	1st forbidden non-unique	9.73
$\beta^-_{0,3}$	804.7 ± 2.0	0.019 1 ± 0.002 2	1st forbidden non-unique	9.46
$\beta^-_{0,1}$	1028.1 ± 2.0	99.891 ± 0.003	allowed	6.134 (5)
		Σ 99.999 832		

A.3. Atomic Data

The X-ray and Auger electron data have been calculated using the evaluated gamma-ray data, and the atomic data from 1996Sc06, 1998ScZM and 1999ScZX.

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^{109}Cd - Comments on evaluation of decay data
by E. Schönfeld, R. Dersch

1 Decay Scheme

The main transition in the decay of ^{109}Cd is the allowed EC transition $\varepsilon_{0,1}$ to the 88 keV level in ^{109}Ag. If there is a EC branch to the ground state of ^{109}Ag, it would have $\Delta J = 2$ with no change of parity, so it would be 2nd forbidden. From the paper of S. Raman et al. (1973) it is then expected to have a lg *ft* greater than 11,0, and this corresponds to an EC branch of less than 0,005 %.

Below the decay energy of ^{109}Cd there is beside the 88 keV level in ^{109}Ag a level at 132.74(11), 9/2+ or 7/2+, 2.60(12) ns. This level has been observed in the decay of ^{109}Pd but not in the decay of ^{109}Cd. This level is much more of a problem. If it has J^{π} = 7/2+, the decay to it would be allowed; then if the lg *ft* were the same as that to the 88-keV level, the branch to it would be about 30 % or smaller. Since the total conversion coefficient of the resulting 44-keV gamma would be much less than that of the 88-keV gamma, the 44-keV photons should be observed along with the conversion electrons. If the 132-keV level has J^{π} = 9/2+, the EC branch is 2nd forbidden with an expected lg *ft* greater than 11,0 and an emission probability of less than 0,0003 %. This assignment is more probable than the first assumption as up to now no 44-keV photons have been observed. The J^{π} data and $T_{1/2}$ = 39,6(2) s (88 keV) are taken from Blachot (1984).

2 Nuclear Data

The following values of the half-life have been considered ($T_{1/2}$ in d):

1	470(8)	Gum and Pool (1950)
2	453(2)	Leutz et al. (1965)
3	459(6)	East and Murphy (1968)
4	450(5)	Reynolds et al. (1968)
5	461,9(3)	Vaninbroukx et al. (1981)
6	463,1(8)	Lagoutine and Legrand (1982); uncertainty 3 σ
7	463,2(6)	Hoppes et al. (1982)
8	460,2(2)	Martin and Taylor (1996)
9	462,6(7)	IAEA-TECDOC-619 (1991) derived from values 4 - 7
10	461,4(12)	adopted value, present evaluation

The uncertainty of the value No. 6 is related to 3 σ. For the calculation of the weighted mean it has been reduced to 0,3 d. For the weighted mean only the values 5 - 8 have been used. No. 8 contributes just 50 % to the mean. The internal uncertainty for the average of the values 5 - 8 is 0,14 days with the reduced-χ^2 is 26,6. It should be noted that the adopted value does not fall within the 1-σ range of any of the four values. Also, the values 8 and 6 differ by 2,9(4) d or about 7 σ. From the reduced-χ^2 and these statements it must be concluded that the 4 values are very discrepant although they are all from metrology laboratories. There is need to clarify this situation by new measurements. According to the agreed rules LWM has used the weighted average and expanded the uncertainty so that the uncertainty of the adopted value 10 includes the most precise value 8.

Makaryunas and Makaryunene (1984) searched for a chemical alteration of the probability of EC by the ^{109}Cd nucleus. Metallic Cd, CdS and CdTe have been used. No significant change ($\Delta\lambda/\lambda < 1 \cdot 10^{-4}$) could be found from a 1000 d measurement with NaI(Tl) detector equipped with Be window and collimation.

The Q_{EC} value 213,8(27) is taken from Audi and Wapstra (1995). There are some discrepancies in the Q_{EC} value: 183,9 keV is derived from internal bremsstrahlung measurements (Gopinathan et al. (1968)); 201(3) keV from $P(L)/P(K)$ = 0,193(3) (Goedbloed (1968), Goedbloed et al. (1970)) exp. measured;

220(3) keV from P(L, M, N)/P(K) = 0,227(2) (average from Leutz et al. (1965), Goedbloed (1968), Goedbloed et al. (1970) exp. measured). Kozub and Hindi (1994) have attempted (but so far failed) to resolve this discrepancy by remeasuring the internal bremsstrahlung endpoint. The most probable value extracted from the measurements is 201,8(1,3) keV. This situation is not satisfying.

In the present evaluation P(L)/P(K) = 0,184(3) and P(L, M, N)/P(K) = 0,232(4) was derived starting from the Audi and Wapstra Q-value whereas in the Table de Radionucléides (1982) for this ratio 0,218 and
Q_{EC} = 182(3) keV is given.

2.1 Electron Capture Transitions

The transition energy of the allowed transition to the 88 keV level in ^{109}Ag is calculated from the Q_{EC} value (Audi and Wapstra, 1995) and the level energy. P_{K}, P_{L}, P_{M} are calculated using this transition energy and the report of Schönfeld (1995).
For comparison:

	P_{K}	P_{L}	$P_{\mathrm{M+}}$	$P_{\mathrm{L}}/P_{\mathrm{K}}$	$P_{\mathrm{LMN}}/P_{\mathrm{K}}$	
1	-	-	-	0,28(3)		Der Mateosian (1953)
2	-	-	-	0,32(4)		Bertolini et al. (1954)
3	0,805(27)	-	-	-	0,24(4)	Wapstra and van der Eijk (1957)
4	0,814(2)	0,159	0,027	0,195(5)	0,228(3)	Leutz et al. (1965)
5	0,778(25)	0,184	0,038	0,237(15)	0,332(15)	Moler and Fink (1965)
6	0,794(25)	-	-	-	0,26(4)	Durosinmi-Etti (1966)
7	0,816(2)	0,157(5)	0,027	0,193(3)	0,226(3)	Goedbloed et al.(1970) Goedbloed (1968)
8	0,780(15)	-	-	-	0,282	Plch et al. (1979)
9	0,815(2)					weighted mean 3-8 reduced-χ^2 = 1,8
10	0,788(10)	0,172(5)	0,040(4)	0,218	0,269	Table de Radionucléides (1982)
11	0,812(3)	0,150(3)	0,038(1)	0,185(3)	0,232	Present evaluation (Theory)

Theoretical values other than value 11 are not given because they depend critically on the transition energy
$Q_{\mathrm{EC}} - E_{\gamma}$ and are based on very different values for Q_{EC}. The present value for P_{K} is in good agreement with the values 4 and 7, i. e. the most confident values, and also with the weighted mean which is dominated by these two values. The values of item 10 are significantly different from those of 11 because they are based on a much lower Q_{EC} value of 184 keV.

Vatai (1970) discussed the measurements of Moler and Fink (1965) and pointed out that the values for $P_{\mathrm{L}}/P_{\mathrm{M}}$ measured with multi-wire proportional counter (MWPC) are not so reliable, as was thought. Fink (1969) revised the original value measured by Moler and Fink (1965), $P_{\mathrm{M}}/P_{\mathrm{L}}$ = 0,232(20) using gaseous sources in a MWPC to give the new value $P_{\mathrm{L}}/P_{\mathrm{M}}$ = 0,202(20).

2.2 Gamma Transitions

The level difference is calculated from the gamma ray energy (4.2) and the recoil energy. The total conversion coefficient is calculated from the experimental determined gamma-ray emission probability (4.2). a_{K} and a_{L} are calculated from the ratios $a_{\mathrm{K}}/a_{\mathrm{L}}/a_{\mathrm{t}}$ = 11,35 / 12,43 / 26,78 as given by the theory (Rösel et al., 1978), interpolated by cubic spline method.
The value of a_{t} = 26,58(20) of the present evaluation is between the theoretical value 26,78 and the experimental value 26,4(4) of Dragoun et al. (1976). The evaluated value is by 0,8 % lower than the

theoretical value. This tendency is qualitatively in agreement with that found by Nemeth and Veres (1990) for E3 and M3 transitions.

3 Atomic data

The atomic data are taken from Schönfeld and Janßen (1996).

3.1 X Radiation

The energy values are calculated from the wavelengths in Å* as given by Bearden (1967). The relative emission probabilities $P(K_\beta)/P(K_\alpha)$ and $P(K_{\alpha_2})/P(K_{\alpha_1})$ are taken from Schönfeld and Janßen. The ratio for $P(K_{\beta_2'})/P(K_{\beta_1'})$ is taken from the calculation of Scofield (1974). The ratio $P(X_L)/P(K_{\alpha_1})$ is calculated from the absolute emission probabilities (Section 4.2). The total K -X ray emission probability is (assumed that there is no EC transition to the ground state)

$$P(KX) = \omega_K \{P_K + [\alpha_K/(1 + \alpha_t)]\}$$

$P(KX)$ is calculated from $P(KX)/P_\gamma$ with the here adopted value of P_γ.

	$P(KX)$	$P(KX)/P_\gamma$	
1	1,225(25)	33,8(7)	Wapstra and van der Eijk (1957)
2	0,950(22)	26,2(6)	Leutz et al. (1965)
3	0,805(22)	22,2(6)	Jansen and Wapstra (1966)
4	1,055(36)	29,1(10)	Freedman et al. (1966)
5	1,088(145)	30(4)	Foin (1968)
6	0,928(33)	25,6(9)	Campbell and Mc Nelles (1972)
7	0,979(11)	27,0(3)	Dragoun et al. (1976)
8	0,990(22)	27,3(6)	Plch et al. (1979)
9	0,991(10)	27,34(27)	Hoppes and Schima (1982)
10	1,026(30)	28,3(9)	Geidelman et al. (1988)
11	1,012(14)	27,9(4)	Yegorov et al. (1989)
12	1,002(17)		Unweighted mean without values 1 and 3
13	0,990(8)		Weighted mean without values 1 and 3; reduced-χ^2 = 1,9
14	0,994(10)		Rec. by Bambynek in IAEA-TECDOC-619 (1991)
15	1,014(7)	29,0(2)	Present evaluation using the above equation together with the adopted values of ω_K, P_K, α_K, α_t

Value 15 is larger than values 12 to 14. Values 1 and 3 have been rejected from statistical considerations. These values differ by a factor 1,52, both claiming an uncertainty of less than 3 %. The unweighted mean (value 12) avoids an unjustified influence of single values with possibly overestimated accuracies. The more up-to-date values 7 to 11 are in reasonable agreement with the adopted value 15.

3.2 Auger Electrons

The energy values are taken from Larkins (1977) (KLL) and the Table de Radionucléides (1982; LMRI).

The ratios $P(KLX)/P(KLL)$ and $P(KXY)/P(KLL)$ are taken from Schönfeld and Janßen (1996).
The ratio $P(e_{AL})/P(KLL)$ is calculated from the absolute emission probabilities (Section 4.1).
A precise measurement of the Ag KLL Auger spectrum has been carried out by Kawakami et al. (1986).

4 Radiation Emission

4.1 Electron Emission

The Auger electron energies are the same as above. The conversion electron energies are calculated from the transition energy and the binding energies of the electrons of the corresponding shells. The number of electrons per disintegration are based on P_{K}, P_{L}, P_{M} as given in Section 2.1, a_{K}, a_{L} as given in Section 2.2 and the atomic data as given in Section 3.

4.2 Photon Emission

	E_γ in keV	
1	88,008(42)	Freedman et al. (1966)
2	88,041(87)	Schima and Hutchinson (1967)
3	88,05(5)	Libert (1967)
4	88,033(42)	Pierson and Marsh (1967)
5	88,09(3)	Foin et al. (1968)
6	88,21(3)	Furuta and Rhodes (1968)
7	88,036(8)	Heath (1969)
8	88,036(8)	Greenwood et al. (1970)
9	88,035(6)	Raeside (1970)
10	88,035(4)	Morii (1978)
11	88,0341(11)	Helmer et al. (1978)
12	88,0336(1)	R. G. Helmer and C. van der Leun (2000), here adopted

The X-ray energies are the same as above. The γ ray energy is taken from Helmer and van der Leun (1996). The number of X ray photons per disintegration are based on P_{K}, P_{L}, P_{M} as given in Section 2.1, a_{K}, a_{L} as given in Section 2.2 and the atomic data as given in Section 3.
The following values for the number of γ ray photons per disintegration have been taken into account:

	P_γ	correspond. a_{t}	
1	0,0365(4)	26,4(3)	Plch et al. (1979)
2	0,03594(19)	26,82(14)	Plch and Suran (1988)
3	0,0367(7)	26,2(6)	Martin (AECL, 1988)
4	0,0365(3)	26,40(23)	Gostely (IER, 1988)
5	0,0370(6)	26,0(5)	Park et al. (KSRI, 1988)
6	0,03600(10)	26,78(8)	Chauvenet (LMRI, 1988)
7	0,0357(10)	27,0(8)	Woods and Smith (NPL, 1988)
8	0,0365(8)	26,4(6)	Szörenyi et al. (OMH, 1988)
9	0,03675(18)	26,21(15)	Ballaux et al. (1988)
10	0,0366(5)	26,3(4)	Hino and Kawada (1989)
11	0,0368(7)	26,2(5)	Funck and Schötzig (1989), Schötzig et al. (1991)
12	0,0365(5)	26,4(4)	Chechev (1989)
13	0,03614(12)	26,67(12)	Ratel (1994) based on measurements in the framework of a BIPM intercomparison including the results measured b by the others of values 2 to 8
14	0,0389(7)	24,7(5)	Leutz et al. (1965); from a_{t}
15	0,0397(21)	24,2(14)	Sen and Durosinmi-Etti (1965); from a_{t}
16	0,0329(25)	29,4(25)	Foin et al. (1968); from a_{t}
17	0,0379(7)	25,4(5)	Legrand et al. (1973) ; from a_{t}
18	0,0360	26,8	Rysavy (1976); from theoretical a_{t}
19	0,0365(5)	26,4(4)	Dragoun et al. (1976); from a_{t}
20	0,03600	26,78	Rösel et al. (1978); from theoretical a_{t}
21	0,0365(3)	26,4(5)	Table de Radionucléides (1982); evaluation
22	0,0365(7)	26,0(3)	Hansen (1985); evaluation
23	0,03632(12)	26,53(9)	IAEA-TECDOC-619 (1991)
24	0,03626(26)	26,58(20)	present evaluation, weighted mean direct exp. values 1 - 12 and 14 - 17, 19

The weighted mean is calculated from all experimentally determined valus. Value 2 does not supersede value 1; it is an independent measurement. Value 2 through 8 were determined in the frame of an BIPM intercomparison, summarized by Ratel (value 13). When calculating the weighted mean (value 24) the largest weights come from values 2, 6 and 9. Whereas 2, 6 and also 13 are in excellent agreement, the value 9 is somewhat larger than these. [Values 21 to 23 are given only for comparison. In contrast to the above, for the calculation of value 23 the uncertainties of the values 9 and 6 has been increased by a factor of 2 on the basis of statistical considerations.] Value 6 agrees well with values 2 and 13 and value 9 is to be considered as a result of a careful work. For the present purpose the originally given uncertainties have not been changed. The weighted mean is 0,03626(7), but LWM has expanded the uncertainty so as to include the most precise value 6. The adopted value (line 24) is in agreement with values 13 (BIPM intercomparison), 18, 20 (from theoretical conversion coefficient) and the results of other evaluations (21 - 23).

Davidonis et al. (1988), compared measured ratios (88 keV) $L_1 : L_2$, $L_1 : L_3$, $L_2 : L_3$, $M_{4+5} : M_{1+2+3}$, N : M with the corresponding theoretical values, interpolated from the Tables of Hager-Seltzer, Rösel et al. and Band and Trzhazkovskaya (Dirac-Fock-Slater and Dirac-Fock approximation). Generally there is agreement within the uncertainties.

Experimentally and theoretically determined conversion coefficients are compiled in the following table:

	a_K	a_t	a_K/a_L	$a_K/(a_L+a_M+a_N)$	
1	12,4(10)	-	-	0,85(2)	Brunner et al. (1953)
2	10,3(5)	-	-	-	Wapstra and van der Eijk (1957)
3	-	-	0,95(3)	-	Boyd et al. (1964)
4	11,0(3)	24,7(5)	-	-	Leutz et al. (1965)
5	11,3(4)	24,2(14)	-	-	Sen and Durosinmi-Etti (1965)
6	12,7(9)	29,4(25)	0,94	0,76(2)	Foin et al. (1968)
7	-	-	-	0,76(2)	Planskoy (1969)
8	10,6(5)	-	-	-	Bashandy (1970)
9	-	25,4(5)	-	-	Legrand et al. (1973)
10	11,4(3)	26,4(4)	0,933	0,760	Dragoun et al. (1976)
11	9,6(2)	-	-	-	Prochazka et al. (1978)
12	11,4(3)	26,4(3)	-	-	Plch et al. (1979)
13	-	26,21(14)	-	-	Ballaux et al. (1988)
14	-	26,67(9)	-	-	Ratel (1994)
15	11,28(12)	26,62(9)	0,913	0,736	weighted mean of experimental values
16	11,4	26,8	0,91	0,740	Rysavy (1976), theory
17	11,35	26,78	0,913	0,736	Rösel et al. (1978), theory
18	11,1(2)	26,0(3)	-	-	Hansen (1985), evaluation
19	11,3(2)	26,4(5)	0,904	0,748	Table de Radionucléides (1982)
20	11,28(12)	26,58(20)	0,913(9)	0,736(7)	present evaluation; the value for α_t corresponds to the evaluated value of P_γ

As a_t and P_γ are closely connected, further experimental values can be found in papers which are dealing with the determination of P_γ (above table). The most confident experimental values of conversion coefficients have been measured by Dragoun et al. (1976) (Entry 10). They have measured also a_{L_1} = 0,63(13), a_{L_2} = 5,48(18), a_{L_3} = 6,11(20), a_M = 2,40(8), and a_{NO} = 0,405(21). In order to obtain finally adopted values of the conversion coefficients, we follow here the procedure of Hansen (1985), who took into consideration only the values 4, 5, 9, 10 and 12 where the first two have been recalculated. The recommended values derived from this set are given under line 18.Values 16 and 17 are from theory, the latter is taken as cited in the IAEA -TECDOC-619 (1991). Shevelev et al. (1978) have measured the following ratios for the conversion coefficients of the 88 keV transition in ^{109}Ag: K / L / M / N = 0,98(5) / 1 / 0,20(1) / 0,050(5) and L_1 / L_2 / L_3 = 0,185(15) / 1 / 1,163(27). The ratios found by Shevelev et al. are in poor agreement with those of Dragoun. Davidonis et al. (1980) determined the ratios L_1 / L_2 / L_3 in sources containing Cd, CdTe and CdSe to be 0,148(7) / 0,86(2) / 1 and (N+O):M = 0,178(3) in good agreement with the corresponding theoretical values of Dragoun et al. (1976) and Rösel et al. (1978). A former measurement of Brenner and Perlman (1972) gave L_1 / L_2 / L_3 = 0,132(8) / 0,830(20) / 1. Martin et al. (1975) measured also the L_1 / L_2 / L_3-ratio for the 88 keV E3 transition in ^{109}Ag^{m} and found no significant departures from theory.

Nemeth and Veres (1973) pointed out that the internal conversion coefficients calculated by Hager and Seltzer are considered to be systematically 2 - 3 % higher for high multipol electromagnetic transitions than the experimental value. This was found already by Raman et al. (1973). Again, Nemeth and Veres (1990) compare theoretical conversion coefficient interpolated from the tables of Rösel et al. (1978) and came to the conclusion that for third and fourth order the theoretical values give better agreement with experimental values when they are multiplied by 0,975. For the 88 keV transition in ^{109}Ag the ratio between the adopted value and the Rösel value is 0,993. Band and Trzhaskovskaya (1993) have calculated ICCs for some high-multipole-order transitions using Dirac-Fock electron wave functions in different approximations. For the 88 keV E3 transition they found a_K values between 11,1 and 11,6 in reasonable agreement with value 18.

Double K-shell vacancy creation in the decay of ^{109}Cd has been measured by van Eijk and Wijnhorst (1977): P_{KK} (IC) = 2,8(7) $\cdot 10^{-5}$ per K internal conversion. In a later paper van Eijk et al. (1979) determined the probability P_{KK}(IC) of double K-shell vacancy creation per K internal conversion of the 88 keV E 3 transition in the decay of ^{109} Ag^{m} by means of a K_α-X-ray-K-X-ray coincidence experiment on ^{109}Pd to be
(13,0 $\pm$ 1,1) $\cdot 10^{-5}$. From a similar experiment on ^{109}Cd the probability P_{KK}(EC) of double K-shell vacancy production per K-electron capture decay of ^{109}Cd has been determined to be (1,02 $\pm$ 0,36) $\cdot 10^{-5}$. The energy shift of the hypersatellite Ag $K_{\alpha 1}{}^{H}$-X-ray line was found to be (532 $\pm$ 6) eV. Martin et al. (1975) measured ratios of L subshell conversion electrons. By Nagy et al. (1975) the probability that a double K-shell vacancy is formed per K-shell internal conversion was found to be 1,53(24) $\cdot 10^{-4}$. Horvath and Ilakovac (1985) measured the decay of the double-K-shell vacancy state in ^{109}Ag^{m} the probability of creation of double K-shell vacancies per ^{109}Cd decay was determined to be 6,07(12) $\cdot 10^{-5}$. Probability ratios of several hypersatellite peakes of K_α and K_β are determined. Inteman (1985) calculated the total probability per K-capture event for the ionization of the remaining K electron for a dozen nuclides of interest using a semirelativistic theory and compared them with experimental values. Ilakovac et al. (1988) searched for Double Photon Decay of the ^{109}Ag metastable state at 88 keV and found an experimental upper limit of the relative transition probability $P_{\gamma\gamma}/P_\gamma < 6 \cdot 10^{-7}$ using a pair of Ge detectors and a fast-slow coincidence system.

5 Main Production Modes

Taken from the „Table de Radionucléides“, LMRI, 1982.

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^{110}Ag – Comments on evaluation of decay data
by R. G. Helmer

1) Decay Scheme

The β^- emission to ^{110}Cd from the ^{110}Ag ground state occurs in 99,70% (6) of the decays and the remaining 0,30% (6) is by electron capture to ^{110}Pd.

2) Q values and half-lives

The Q values from the 1995Au04 evaluation for the decay of the ^{110}Ag ground state are 2892,2 (16) keV for the β^- decay and 892 (11) keV for the electron-capture decay.

The half-life of the ^{110}Ag ground state has been determined from the following data (in seconds):

1935Am01	22	omitted, no uncertainty
1938Po03	22	omitted, no uncertainty
1938Re04	23	omitted, no uncertainty
1944Fl01	24	omitted, no uncertainty
1946Hi06	24,5 (3)	
1954Bo39	24 (2)	
1957Se19	24,2 (12)	
1962Ma38	24,42 (14)	
1967Yu01	24,93 (22)	
1970Va08	24,7 (7)	
Adopted	24,56 (11)	

The adopted value is the weighted average of the six values with uncertainties, and the reduced-χ^2 value is 0,82, so the values are consistent.

3) g-ray data

The energies for the γ-rays from the decay of ^{110}Ag (24 s) were determined as shown in Table 1. The precise energies from the ^{110}Ag^m (249 d) isomer decay are adopted where appropriate.

Table 1. γ-ray energies from the β^- decay of ^{110}Ag (24 s).

1970Va08	1972Ka34 [a]	Adopted [b]
	295,3 (1)	295,3 (2)
657,8 (2)	657,6 (1)	657,7600 (11) [c]
815,5 (3)	815,5 (1)	815,5 (2)
817,8 (12)	818,2 (1)	818,0244 (18) [c]
	1074,0 (1)	1074,0 (2)
1125,9 (3)	1125,8 (1)	1125,699 (20) [d]
1186,4 (7)	1186,3 (1)	1186,3 (2)

1421,8 (13)	1421,4 (1)	1421,5 (2)
1475,8 (13)	1475,8 (1)	1475,7792 (23) [c]
1630,0 (12)	1629,9 (1)	1629,9 (2)
1674,2 (9)	1674,3 (1)	1674,3 (2)
1783,3 (13)	1783,6 (7)	1783,46 (3) [d]
	2004,4 (2)	2004,4 (2)

[a] The author's uncertainties are quoted to 0,01 keV, but the energies are only given to 0,1 keV, so the last digit in the uncertainty is of no use.

[b] For energies from 1972Ka34 and 1970Va08, a minimum uncertainty of 0,2 keV has been used for the adopted value.

[c] From evaluation of 2000He14,

[d] From adopted value from ^{110}Ag^{m} decay.

The relative emission probabilities of the γ-rays from the decay of ^{110}Ag (24 s) were determined from the measurements in Table 2 :

Table 2: Relative emission probabilities of the γ-rays from the decay of ^{110}Ag (24 s)

E_γ (keV)	1970Va08	1972Ka34	Adopted
295		0,17 (3)	0,17 (3)
657	100,	100,	100,
815	0,79 (12)	0,85 (2)	0,85 (2)
818	0,10 (9)	0,20 (1)	0,20 (1)
1074		0,02 (1)	0,02 (1)
1125	0,36 (3)	0,34 (1)	0,34 (1)
1186	0,056 (2)	0,06 (1)	0,06 (1)
1421	0,044 (30)	0,05 (1)	0,05 (1)
1475	0,11 (5)	0,08 (1)	0,08 (1)
1629	0,048 (30)	0,05 (1)	0,05 (1)
1674	0,15 (6)	0,16 (1)	0,16 (1)
1783	0,17 (9)	0,10 (1)	0,10 (1)
2004		0,08 (1)	0,08 (1)

The normalization of the relative emission probabilities for the γ-rays from the decay of ^{110}Ag (24 s) depends on the probability of the β branch to the ground state of ^{110}Cd and the fact that 0,30(6)% ofthe decays are by electron capture to ^{110}Pd (1961Fr01). The intensity of the β branch to the ^{110}Cd ground state can be obtained from the ratio of the emission probabilities for the branches to the 657 -keV level and the ground state, $I_{\beta-}(657)/I_{\beta-}(0)$, as deduced from the decomposition of the β^- spectrum. However, the following results for this ratio are very inconsistent.

	$I_{\beta^-}(657)/I_{\beta^-}(0)$
1962Ka07	0,14 (5)
1963Da03	0,21
1963Fr07	0,0465 (25)
1967Mo12	0,070 (22)
Adopted	0,047 (4)

The adopted value is the weighted average of the three values with uncertainties. For this average the internal uncertainty is 0,0025 and the external uncertainty is 0,0038. Although the reduced-χ^2 value is 2,30, this does not necessarily imply an inconsistent set since one has only three values. If one does consider it an inconsistent set and applies the Limitation of Relative Statistical Weight rule (1985ZiZY, 1992Ra08) of reducing the relative weight of the 1963Fr07 value from 98% to 50%, the weighted average becomes 0,064 with an internal uncertainty of 0,014, a reduced-χ^2 value of 1,6, and an external uncertainty of 0,018.

From this β^- branching ratio, the 0,30 (6)% electron-capture, and 0,1% β^- branching to higher energy levels, the branch to the ground state is 95,1(4) % and that to the 657-keV level is 4,5(4) %. The emission probability of the 657-keV γ-ray is then 4,6 (4) % of the decays of the ground state including both the direct and indirect feeding.

Table 3: Absolute emission probabilities for the γ-rays from the decay of the ^{110}Ag ground state.

E_γ	P_γ (%)
295	0,0078 (16)
657	4,6 (4)
815	0,039 (4)
818	0,0092 (9)
1074	0,0009 (5)
1125	0,0156 (14)
1186	0,0028 (5)
1421	0,0023 (5)
1475	0,0037 (6)
1629	0,0023 (5)
1674	0,007 (1)
1783	0,0046 (8)
2004	0,0037 (6)

The γ-ray multipolarities and mixing ratios were taken from the 2000De11 evaluation and are as follows:

E1: 1421 -keV
E2: 657, 815, 1074, 1186,1475, 1783, 2004 -keV
M1+E2: 818 [d = − 1,36 (7)] ; 1125 [d = + 0,33 (8)]
E2(+M1): 1629 [d = + 0,06 (3)]
(E1): 295 -keV

4) Atomic data

From the EMISSION code and the decay data, the following information was obtained.

Quantity	Pd (Z=46)	Cd (Z=48)
ω_k	0,820(4)	0,842(4)
ω_L average	0,0536 (13)	0,0632 (16)
n_{KL}	0,975 (4)	0,953 (4)
$K_{\alpha2}/K_{\alpha1}$	0,5293 (25)	0,5317 (25)
K_β/K_α	0,2099 (17)	0,2151 (18)

Due to the high energy of the strong transitions, the Auger electrons are negligible and no related data are included here.

The K X-ray emission probabilities are calculated as follows:

From the decay of ^{110}Ag (24 s), the Pd X-rays per 100 decays of parent:

$K_{\alpha2}$	0,060 (12)
$K_{\alpha1}$	0,114 (23)
K_β	0,037 (8)

and the Cd X-rays per 100 decays of parent:

$K_{\alpha2}$	0,00322 (28)
$K_{\alpha1}$	0,0061 (6)
K_β	0,00200 (18)

5) b$^-$ decay intensities

The β^- decay intensities for the decay of the ^{110}Ag ground state are simply deduced from the above data and the γ-ray probability balances.

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^{110}Ag^{m} – Comments on evaluation of decay data
by R. G. Helmer

1) Decay Scheme

The β$^-$ decay of the ^{110}Ag^{m} (249 d) isomer to levels in ^{110}Cd occurs in 98,64(8) % of the decays and the remaining 1,36(8) % is by an isomeric transition to the ^{110}Ag ground state (24 s). The β$^-$ emission to ^{110}Cd from the ground state occurs in 99,70(6) % of the decays and the remaining 0,30(6) % is by electron capture to ^{110}Pd. The comments on the decay ^{110}Ag (24 s) ground state are provided under that decay.

2) Q values and half-lives

The Q values from the 1995Au04 evaluation for the decay of the ^{110}Ag ground state are 2892,2 (16) keV for the β$^-$ decay so the decay energy for the β$^-$ decay of the ^{110}Ag^{m} (249 d) isomer is then 3009,8 (16) keV.

The half-life of the ^{110}Ag^{m} isomeric state has been determined from the following data (in days):

1938Li07	225 (20)	omitted, large uncertainty
1950Gu54	270	omitted, no uncertainty
1976WaZH	249,78 (4)	superseded by 1983Wa26
1980Ho17	249,74 (5)	
1983Wa26	249,79 (2)	
Adopted	249,78 (2)	

The adopted value is the weighted average of the last two values, and the reduced-χ^2 value is 0,86.

3) g-ray data

Several of the γ-rays from the decay of the isomer ^{110}Ag^{m} (249 d) have precisely measured energies; these values were taken from the evaluation 2000He14 and are on a scale for which the energy of the strong line from the decay of ^{198}Au is 411,80205(17) keV. The other energies were determined as shown in Table 1 from the data of 1979Ve03, 1981Ma09, 1990Me15, and 1993Ki18. In order to provide a set of energies consistent with those of 2000He14, the values 1990Me15 were adjusted by additive amounts of 0 to 15 eV as shown in the table. No additional uncertainty was assigned for these adjustments. The values of the remaining references were not adjusted.

Table 1. γ-ray energies (keV)

1979Ve03	1981Ma09 [a]	1993Ki18	1990Me15	1990Me15 adjusted & rounded	2000He14	Adopted
			116,485 (46)	116,48 (5)		116,48 (5)
120,4 (2)	120,3 (1)	120,2 (2)	120,226 (26)	120,23 (3)		120,23 (3)
133,3 (2)	133,4 (1)	133,2 (1)	133,333 (7)			133,333 (7)
219,2 (2)	219,4 (1)	219,4 (1)	219,348 (8)			219,348 (8)

1979Ve03	1981Ma09 [a]	1993Ki18	1990Me15	1990Me15 adjusted & rounded	2000He14	Adopted
221,0 (1)	221,0 (1)	221,1 (2)	221,079 (10)			221,079 (10)
229,3 (2)	229,4 (1)	229,4 (3)	229,423 (23)			229,423 (23)
	264,4 (1)	264,1 (3)	264,254 (58)	264,25 (6)		264,25 (6)
266,9 (2)	267,0 (1)	267,0 (3)	266,913 (12)			266,913 (12)
	341,4 (1)	340,9 (5)	341,2 (2)			341,3 (2)
	356,4 (1)	356,5 (2)	356,43 (10)			356,43 (10)
360,7 (2)	360,0 (1)	360,2 (5)	360,228 (75)	360,23 (8)		360,23 (8)
365,54 (10)	365,4 (1)	365,3 (1)	365,450 (10)	365,448 (10)		365,448 (10)
387,2 (2)	387,1 (1)	387,1 (6)	387,075 (9)	387,073 (9)		387,073 (9)
397,1 (2)	396,8 (1)	396,5 (6)	396,897 (23)	396,895 (23)		396,895 (23)
	409,6 (1) [d]	409,6 (4)	409,330 (45)	409,33 (5)		409,4 (5)
446,87 (5)		446,8 (2)	446,808 (8)		446,812 (3)	446,812 (3)
466,9 (2)	466,9 (1)	465,8 (7)	467,029 (36)	467,03 (4)		467,03 (4)
493,8 (2)	493,0 (1)	493,6 (1)	493,432 (91)	493,43 (9)		493,43 (10)
554,8 (2)	544,5 (1)	544,9 (5)	544,555 (45)	544,55 (5)		544,55 (5)
	572,7 (1)	573,1 (7)	573,0 (4)			572,8 (2)
	603,1 (1)	603,1 (4)	603,065 (90)	603,06 (9)		603,08 (10)
620,45 (5)		620,4 (1)	620,362 (1)		620,3553 (17)	620,3553 (17)
626,24 (5)	626,1 (1)	626,4 (2)	626,262 (10)	626,258 (10)		626,258 (10)
	630,6 (1)	630,7 (4)	630,626 (55)	630,62 (6)		630,62 (6)
	648,2 (10)	647,8 (4)				647,8 (4)
657,75 (5)		657,7 (2)	657,766 (5)		657,7600 (11)	657,7600 (11)
	666,1 (2)	667,1 (1)				666,6 (5)
	676,6 (1)		676,58 (10)			676,58 (10)
677,72 (5)		677,6 (1)	677,623 (7)		677,6217 (12)	677,6217 (12)
687,10 (5)			687,005 (11)		687,0091 (18)	687,0091 (18)
706,74 (5)			706,688 (8)		706,6760 (15)	706,6760 (15)
	708,3 (1)	708,6 (5)	708,133 (20)	708,128 (20)		708,128 (20)
	714,9 (1)	715,0 (3)				714,9 (1)
744,35 (5)			744,279 (8)		744,2755 (19)	744,2755 (18)
763,98 (5)			763,947 (8)		763,9424 (17)	763,9424 (17)
	774,8 (1)	774,6 (1)	774,8 (2)			774,70 (10)
818,00 (5)			818,037 (8)		818,0244 (18)	818,0244 (18)
884,65 (5)			884,037 (8)		884,6781 (13)	884,6781 (13)

1979Ve03	1981Ma09 [a]	1993Ki18	1990Me15	1990Me15 adjusted & rounded	2000He14	Adopted
937,55 (5)			937,505 (13)		937,485 (3)	937,485 (3)
957,3 (2)	957,4 (1)	957,6 (7)	957,368 (85)	957,35 (9)		957,35 (10)
997,12 (5)	997,2 (1)	997,2 (4)	997,258 (15)	997,243 (15)		997,243 (15)
1019,0 (2)	1019,1 (1)	1018,8 (5)	1018,893 (50)	1018,88 (5)		1018,95 (8)
	1050,1 (3)	1051,8 (6)				1050,5 (5)
1085,7 (1)	1085,5 (1)	1085,3 (4)	1085,462 (14)	1085,447 (14)		1085,447 (14)
1117,7 (2)	1117,5 (1)	1117,2 (3)	1117,474 (28)	1117,46 (3)		1117,46 (3)
1125,7 (2)	1125,6 (1)	1125,6 (4)	1125,714 (20)	1125,699 (20)		1125,699 (20)
1163,5 (2)	1163,1 (2)	1163,1 (3)	1163,159 (75)	1163,14 (8)		1163,14 (8)
1165,6 (2)	1164,5 (2)	1165,2 (8)	1164,959 (85)	1164,94 (9)		1164,94 (9)
	1186,7 (1)	1186,5 (2)	1186,7 (2)			1186,7 (1)
1251,2 (2)	1251,0 (1)	1251,2 (3)	1251,057 (42)	1251,04 (4)		1251,04 (4)
1300,0 (2)	1300,1 (1)	1300,3 (4)	1300,03 (12)	1300,02 (12)		1300,05 (10)
1334,53 (10)	1334,4 (1)	1334,3 (3)	1334,341 (17)	1334,326 (17)		1334,326 (17)
1384,47 (5)			1384,305 (8)		1384,2931 (20)	1384,2931 (20)
	1421,1 (1)	1420,9 (5)	1420,081 (50)	1420,07 (5)		1420,07 (5)
	1465,6 (1)	1465,6 (1)				1465,6 (1)
1475,80 (5)			1475,305 (12)		1475,7792 (23)	1475,7792 (23)
1505,05 (5)			1505,039 (8)		1505,0280 (20)	1505,0280 (20)
1562,37 (5)			1562, 305 (9)		1562,2940 (18)	1562,2940 (18)
	1572,3 (2)		1572,4 (2)			1572,4 (2)
1592,8 (1)	1593,0 (2)	1593,1 (4)	1592,672 (95)	1592,66 (10)		1592,80 (15)
	1630,0 (2)	1630,0 (1)	1629,692 (63)	1629,68 (6)		1629,75 (15)
	1698,5 (2)	1698,9 (1)				1698,8 (2)
1775,6 (2)	1775,4 (1)	1775,4 (2)	1775,422 (39)	1775,41 (4)		1775,41 (4)
1783,4 (2)	1783,6 (1)	1783,4 (2)	1783,480 (30)	1783,46 (3)		1783,46 (3)
1903,9 (2)	1903,4 (1)	1904,1 (8)	1903,530 (35)	1903,52 (4)		1903,52 (4)
	2004,6 (1)	2003,8 (8)	2004,74 (10)	2004,72 (10)		2004,65 (10)

[a] The uncertainties of 0,1 keV are from a general statement and not specific to each γ-ray.

[d] Reported to be a doublet.

The relative γ-ray intensities for the decay of ^{110}Ag^{m} (249 d) are given in Table 2. The adopted values are the weighted averages computed by the Limitation of Relative Statistical Weight method (1985ZiZY, 1992Ra09) and take into account the measurements from 1976De, 1977Ge12, 1979Ve03, 1980Ro22, 1980Yo05, 1981Ma09, 1990Me15, and 1993Ki18.

The γ-ray energies in Table 2 that are flagged with a "c" are from the evaluation 2000He14 and are considered especially suitable for energy calibration.

Table 2. Relative γ-ray intensities for ^{110}Ag^{m} decay

Energy (keV)	1969Br03 1972Ph04[a]	1976De	1977Ge12	1979Ve03	1980Ro22	1980Yo05	1981Ma09	1990Me15	1993Ki18	LRSW average	χ_R^2 if > 1,0	σ_{int}	σ^{ext}	σ_{LWM}
116,48 (5)	isomeric decay							0,085 (3)						
120,23 (3)	<0,15			0,17 (3)			0,18 (1)	0,19 (1)	0,66(1) [e]	0,179 (9)				
133,333(7)	0,9 (2)			0,86 (13)			0,80 (5)	0,77 (3)	0,78 (2)	0,780 (16)				
219,348(8)	1,3 (3)			0,80 (6)			0,77 (5)	0,70 (2)	0,81 (1) [i]	0,76 (5)	5,8	0,013	0,030	0,046
221,079 (10)	1,1 (3)			0,80 (11)			0,74 (5)	0,72 (1)	0,67 (3)	0,716 (10)	1,1	0,009	0,010	
229,423 (23)	0,32 (15)			0,19 (5)			0,11 (1)	0,128 (8) [i]	0,22 (3)	0,126 (14)	4,7	0,007	0,014	
264,25 (6)							0,070 (7)	0,059 (5)	0,11 (3)	0,064(6)	2,0	0,004	0,006	
266,913 (12)	0,5 (1)			0,65 (6)			0,37 (2)	0,43 (1) [i]	0,53 (4)	0,43 (4)	9,5	0,012	0,037	
341,3 (2)							0,06 (3)	0,022 (4)	0,13 (9)	0,023 (5)	1,5	0,004	0,005	
356,43(10)							0,06 (3)	0,045 (3)	0,04 (2)	0,045 (3)				
360,23 (8)				0,14 (2)			0,11 (5)	0,035(7) [i]	0,09 (5)	0,08 (5)	5,4	0,012	0,028	0,048
365,448 (10)	1,1 (2)			1,27(14)		0,91 (19)	0,92 (5)	1,02 (8)	1,10 (12)	0,98 (5)	1,8	0,038	0,050	
387,073(9)	0,43 (9)			0,54 (13)		0,8 (4)	0,54 (3)	0,55 (1)	0,61 (24)	0,549 (9)				
396,895 (23)	0,36 (8)			0,68 (12)		0,6 (3)	0,35 (2)	0,43 (1) [i]	0,30 (10)	0,39 (4)	3,8	0,014	0,027	0,036
409,4 (5)							0,08 (4)	0,068 (7)	0,01 (4)	0,067 (7)	1,1	0,007	0,007	
446,812 (3) [c]	35 (2)		38,6 (4)	41,8 (6) [e]	39,0 (12)	39,55 (28)	39 (2)	38,9 (6)	38,22 (12) [i]	38,7 (5)	2,9	0,15	0,25	0,48
467,03 (4)				0,35 (5)			0,26 (2)	0,26 (5)	0,21 (5)	0,264 (19)	1,4	0,016	0,019	
493,43(10)				0,06 (2)			0,10 (2)	0,11 (1)	0,13 (4)	0,101 (11)	1,8	0,008	0,011	
544,55 (5)				0,10 (2)			0,19 (1)	0,22 (1)	0,15 (6)	0,19 (3)	9,8	0,007	0,021	0,027
572,8 (2)							0,19 (1)	0,13 (3)	0,14 (6)	0,183 (13)	2,1	0,009	0,013	

Energy (keV)	1969Br03 1972Ph04[a]	1976De	1977Ge12	1979Ve03	1980Ro22	1980Yo05	1981Ma09	1990Me15	1993Ki18	LRSW average	χ_R^2 if > 1,0	σ_{int}	σ^{ext}	σ_{LWM}
603,08(10)							0,20 (3)	0,042 (9) [i]	0,30 (12)	0,12 (8)	8,2	0,021	0,059	0,081
620,3553 (17) [c]	29 (2)		29,3 (3)	29,5 (4)	31,4 (13)	29,65 (19)	28,0 (14)	29,4 (5)	28,00 (15) [i]	28,8 (8)	10,1	0,10	0,32	0,8
626,258 (10)	1,85 (20)			2,2 (2)		2,28 (14)	2,3 (1)	2,48 (4)	2,10 (3) [i]	2,27 (17)	12,7	0,025	0,09	0,17
630,62 (6)							0,30 (2)	0,40 (1) [i]	0,30 (8)	0,35 (5)	6,6	0,014	0,035	0,050
647,8 (4)							0,19 (4)		0,186 (4)	0,185 (5)	1,6	0,004	0,005	
657,7600 (11) [c]	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000				
666,6 (5)							0,16 (2) [i]		0,43 (5)	0,30 (14)	14,6	0,035	0,14	
676,58(10)								1,5 (1)						
677,6217 (12) [c]	122 (7)		113,1(11	111 (2)	112,6 (29)	110,9 (8)	112 (6)	112 (2)	112,6 (11)	111,9 (5)				
687,0091 (18) [c]	74 (6)		68,5 (7)	75,8 (14) [e]	69,0 (27)	68,0 (6)	67 (3)	68,5 (5) [i]	69,2 (21)	68,3 (3)				
706,6760 (15) [c]	172 (7)	175 (10)	176,7 (18)	175,4 (20)	176,2 (22)	176,6 (10)	174 (7)	172,8 (5) [i]	176,9 (26)	174,6 (7)	1,9	0,5	0,6	
708,128 (20)							2,0 (2)	2,9 (2)	2,4 (3)	2,4 (5)	5,1	0,11	0,29	0,46
714,9 (1)							0,09 (2)		0,17 (6)	0,098 (24)	1,6	0,019	0,024	
744,2755 (18) [c]	44 (4)		49,2 (5)	52,3 (8)	49,5 (16)	50,00 (27)	48,0 (25)	49,3 (8)	50,2 (14)	49,9 (3)	2,0	0,21	0,31	
763,9424 (17) [c]	240 (8)	237 (2)	236,0 (24)	243,7 (30)	237,4 (31)	235,5 (9)	243 (12)	236 (3)	239,1 (53)	236,4 (7)	1,1	0,70	0,74	
774,70 (10)							0,03 (2)	0,02 (1)	0,092 (4) [i]	0,06 (3)	15,4	0,006	0,025	0,035
818,0244 (18) [c]	78 (3)		77,3 (8)	80,5 (10)	77,4 (17)	77,6 (4)	79 (4)	77,1 (5)	78,8 (18)	77,7 (4)	1,7	0,27	0,35	
845,8 (1)							0,10 (3)		0,10 (2)	0,10 (2)				
884,6781 (13) [c]	796 (20)	775 (5)	769 (8)	811 (10)	780 (10)	767,6 (26)	800 (40)	771 (10)	706,6 (12) [i]	784 (12)	13,3	1,5	5,3	12,5
927,6 (1)							0,065 (10)		0,067 (8)	0,063 (6)				
937,483 (3) [c]	365 (11)	366 (3)	362,2 (36)	380 (4)	369 (4)	363,1 (12) [i]	374 (18)	363 (6)	376 (8)	365,7 (26)	2,7	1,2	1,9	2,6

Energy (keV)	1969Br03 1972Ph04[a]	1976De	1977Ge12	1979Ve03	1980Ro22	1980Yo05	1981Ma09	1990Me15	1993Ki18	LRSW average	χ_R^2 if > 1,0	σ_{int}	σ^{ext}	σ_{LWM}
957,35(10)				0,28 (5)			0,11 (1)	0,08 (1)	0,14 (5)	0,099 (19)	6,2	0,007	0,017	0,019
997,243 (15)	1,4 (2)			1,6 (1)		1,42 (5)	1,4 (1)	1,32 (4)	1,33 (10)	1,36 (4)	1,8	0,033	0,043	
1018,95(8)	0,3 (1)			0,17 (5)			0,15 (1)	0,15 (1)	0,08 (5)	0,149 (7)				
1050,5 (5)							0,08 (1)		0,08 (6)	0,08 (1)				
1085,447 (14)	0,58 (8)			0,95 (10)		0,66 (12)	0,74 (4)	0,71 (2)	0,81 (24)	0,76 (4)	1,2	0,035	0,0371	
1117,46(3)	0,39 (7)			0,55 (20)		0,41 (6)	0,52 (3)	0,52 (1)	0,38 (20)	0,517 (9)				
1125,699 (20)	0,26 (6)			0,35 (10)		0,38 (8)	0,34 (2)	0,30 (2)	0,22 (21)	0,322 (14)				
1163,14(8)				1,5 (1)			0,54 (5) [i]	0,79 (7)	1,0 (4)	0,78 (24)	23,4	0,04	0,19	0,24
1164,94(9)				0,96 (10) [e]			0,42 (5)	0,50(5)	0,47 (4)	0,46 (3)				
1186,7 (1)								0,015 (5)	0,0170 (5)	0,0170 (5)				
1251,04(4)	0,58 (19)			0,52 (5)		0,24 (7)	0,31 (2)	0,26 (1) [i]	0,25 (2)	0,28 (3)	7,5	0,0090	0,0260	
1300,05 (10)				0,20 (2)		0,25 (8)	0,19 (1)	0,21 (1)	0,22 (11)	0,200 (7)				
1334,326 (17)	1,55 (20)			1,8 (1)		1,49 (6)	1,40 (7)	1,49 (5) [i]	1,55 (33)	1,50 (5)	2,8	0,03	0,05	
1384,2931 (20) [c]	277 (8)	261 (2)	257,0 (26)	277,9 (30)	271 (5)	256,6 (8) [i]	278 (14)	261 (5)	276,6 (26)	262 (5)	12,8	0,8	2,9	5,0
1420,07(5)						0,39 (3)	0,27 (2)	0,24 (2)	0,37 (9)	0,28 (4)	6,2	0,013	0,032	0,041
1465,6 (1)							0,019 (2)							
1475,7792 (23) [c]	45,0 (20)		42,1 (4)	44,8 (6)	44,9 (12)	42,22 (17) [i]	45 (2)	42,4 (8)	45,7 (13)	42,7 (5)	4,6	0,20	0,43	0,5
1505,0280 (20) [c]	148 (4)	139 (1)	138,4 (14)	145,2 (16)	147,0 (29)	137,8 (5) [i]	151 (7)	140,1 (19)	149,2 (28)	139,4 (16)	6,1	0,45	1,1	1,6
1562,2940 (18) [c]	13,3 (6)		12,50(13) [i]	13,2 (2)	14,0 (8)	10,87 (7)	13,0 (7)	12,6 (6)	13,5 (4)	12,8 (3)	3,4	0,11	0,21	0,30
1572,4 (2)								0,012 (3)						
1592,80 (15)				0,4 (1)		0,221 (13)	0,20 (2)	0,22 (1)	0,34 (18)	0,219 (8)	1,2	0,007	0,0081	

Energy (keV)	1969Br03 1972Ph04[a]	1976De	1977Ge12	1979Ve03	1980Ro22	1980Yo05	1981Ma09	1990Me15	1993Ki18	LRSW average	χ_R^2 if > 1,0	σ_{int}	σ^{ext}	σ_{LWM}
1629,75 (15)						0,061 (11)	0,036 (4)	0,046 (5)	0,11 (5)	0,042 (5)	2,6	0,003	0,005	
1698,8 (2)							0,019 (2)		0,012 (4)	0,018 (3)	2,4	0,002	0,003	
1775,41(4)				0,067(10		0,067 (11)	0,076 (4)	0,063 (4)	0,07 (6)	0,069 (3)	1,4	0,0026	0,0031	
1783,46(3)				0,085 (30)		0,103 (11)	0,110 (6)	0,092 (3)	0,07 (4)	0,107 (5)				
1903,52(4)				0,20 (2)		0,158 (15)	0,18 (1)	0,16 (1)	0,15 (2)	0,169 (7)	1,5	0,006	0,007	
2004,65 (10)							0,012(1)[i]	0,011 (2)	0,028 (4)	0,013 (4)	7,7	0,0013	0,0035	

a The values from these two articles, by the same authors, are for comparison and were not used in the calculated averages.
c γ-ray energy is from the 2000He14 evaluation and is useful for energy calibrations.
e Value was not used in the calculation of the average.
i The published uncertainty, which is given, was increased in the LRSW analysis to reduce the relative weight to 50 %.

The mixing ratios for the M1+E2 γ-rays have been evaluated in this work (from references 1962Ka07, 1963Su07, 1964Ne05, 1970Kr03, 1973Jo08, 1978Wa07, 1979Ve03, 1980Ru03, 1990Ke02, and 1993Ki18). The results are very similar to those in the most recent ENSDF evaluation (2000De11), so those from ENSDF have been used. From the measurements of 1979Ve03, mixing ratios for M3 contributions to predominantly E2 transitions are quoted in ENSDF. The δ(M3/E2) values that do not include 0,0 in their uncertainties are those of 763 and 1562 -keV γ-rays; both are δ = -0,10 (+2-3). Although the conversion coefficients are small, the high precision of the relative γ-ray intensities makes them significant; for example, $\alpha_{(657)}$ = 0,00318.

The normalization of the relative emission probabilities for the γ-rays from the decay of ^{110}Ag^{m} (249 d) is determined by requiring that the sum of the γ-ray transition intensities to the ground states of ^{110}Cd and ^{110}Ag be 100 % of the decays of the isomeric state. However, the 657 keV γ-ray occurs in both the direct β^- decay and that which follows the isomeric decay. Since 4,6(4) % the ground -state decays lead to the 657-keV γ ray, the intensity of the isomeric decay is reduced by this fraction in computing the intensity feeding the ground states.

Then, in the units of Table 2, one has $I_{\gamma(116)}[1+\alpha_{(116)}][0,954] + I_{\gamma(657)}[1+\alpha_{(657)}] + I_{\gamma(1475)} + I_{\gamma(1783)}$ = 0,085[169][0,954] + 1000[1,003] + 42,7 + 0,107. If an uncertainty of 5 % is assigned to $\alpha_{(116)}$, this sum is 1059,5 (9), so the normalization factor for the γ-ray intensities in Table 2 is 0,09438 (8).

The resulting intensity of the isomeric decay branch is then 0,085[0,09438][169] = 1,36 with an uncertainty of 0,08 and that of the β^- decay is 98,64 (8) %. This gives the 657 -keV photon intensity of 94,38 (8) per 100 decays of the isomeric state.

The isomeric decay of ^{110}Ag^{m} (249 d) occurs via an M4 γ-ray of 116,48 (5) keV with α = 168 [i.e., P_γ = 0,0080 (4)] followed by an E1 γ-ray of 1,113 keV energy. The γ-rays following the β^- decay of the ground state are all very weak due to the small isomeric decay branch (1,36 %) and the large β^- branch to the ground state (95,1 %). Also, the 4,6 % branch to the 657 level is already included in Table 2. Therefore, the remaining γ-rays following the β^- decay of the ground state are neglected.

The γ-ray multipolarities and mixing ratios were taken from the 2000De11 evaluation and are as follows:

E1: 603, 1421-keV

E1(+M2): 409 [δ = -0,029(23)]; 997 [δ = -0,30(46)]; 1117 [δ = +0,021(44); 1300 [δ = +0,0(1)]

E2: 626, 657, 884, 1085, 1334, 1475, 1592, 1783, 2004

(E2): 467; 774

M1(+E2): 120 [δ = -0,13(33)]

M1+E2: 446 [δ = -0,38(2)]; 544; 620 [δ = -0,50(4)]; 677 [δ = 0,36(2)]; 687 [δ = -1,76(6)]; 706 [δ = -1,42 (7)]; 708 [δ = -0,15(9)]; 818 [δ = -1,36(7)]; 957 [δ = -0,9(7)]; 1018 [δ = -0,56(35)]; 1125 [δ = +0,33(8)]; 1163 [δ = -0,03(+6-9)]; 1164 [δ = +0,0(3)]; 1384 [δ = -0,44(2)]; 1505 [δ = -1,21(4)]; 1629 [δ = +0,06(3)]; 1697; 1775

E2(+M3): 744 [δ = -0(+16-10)]; 937 [δ = -0,07(+7-3)]; 1562 [δ = -0,10(+2-3)]

M3+E2: 763 [δ = -0,10 (+2-3)]

4) Atomic data

From the EMISSION code and the decay data, the following information was obtained.

Quantity	Ag (Z=47)	Cd (Z=48)
ω_K	0,831 (4)	0,842 (4)
ω_L average	0,0583 (14)	0,0632 (16)
n_{KL}	0,964 (4)	0,953 (4)
$K_{\alpha 2}/K_{\alpha 1}$	0,5305 (25)	0,5317 (25)
K_β/K_α	0,2125 (17)	0,2151 (18)

Due the high energy of the strong transitions, the Auger electrons are negligible and no related data are included here.

The K X-ray emission probabilities are calculated as follows:

For the decay of ^{110}Ag^{m} (249 d), Ag KX-rays per 100 decays of parent

$K_{\alpha 2}$	0,198 (12)
$K_{\alpha 1}$	0,372 (22)
K_β	0,121 (7)

Cd KX-rays per 100 decays of the parent

$K_{\alpha 2}$	0,153 (9)
$K_{\alpha 1}$	0,288 (16)
K_β	0,095 (6)

5) b$^-$ decay intensities

The β^- decay intensities for the decay of the ^{110}Ag ground state are simply deduced from the above data and the γ-ray intensity balances. Since the spin of the isomeric state is large, namely 6, there are several β^- decay branches for which the log *ft* systematics (1998Si17) given lower limits on the intensities than can be derived from the intensity balances. These data are given in Table 3

Table 3. Data used to deduce β^- decay intensities and log*ft* values.

Level(keV)	J^π	$\Delta J,\Delta\pi$	log*ft* limit	I_β from log*ft* limit	I_β from intensity balance	I_β adopted	log*ft*
0	0^+	6,no			1,3 (4)	0	
657	2^+	4,no	>22	$<10^{-10}$	-1,2 (12)	0	
1475	2^+	4,no	>22	$<10^{-10}$	0,08 (8)	0	
1522	4^+	2,no	>10,6	<6	0,8 (13)	<2	>11
1783	2^+	4,no	>22	$<10^{-11}$	0,0156 (23)	0	
2078	3^-	3,yes	>16,5	$<10^{-6}$	0,002 (8)	$<10^{-6}$	>16,5
2162	3^+	3,no	>13,9	<0,0004	-0,01 (19)	<0,0004	>13,9
2220	4^+	2,no	>10,6	<0,6	0,06 (9)	<0,15	>11,2

Level(keV)	J^{π}	$\Delta J,\Delta\pi$	log*ft* limit	I_β from log*ft* limit	I_β from intensity balance	I_β adopted	log*ft*
2250	4^+	2,no	>10,6	<0,6	0,06 (5)	0,06 (5)	11,5
2287	2^+	4,no	>22	<2x10^{-12}	0,0040 (5)	0	
2356	(1^+,2^+)	4 or 5, no	>22	<10^{-12}	0	0	
2433	3^+	3,no	>13,9	<0,0001	-0,008 (6)	0	
2479	6^+	0,no			30,8 (3)	30,8 (3)	8,282
2539	5^-	1,yes			0,060 (4)	0,060 (4)	10,82
2561	4^+	2,no	>10,6	<0,1	-0,003 (7)	<0,005	>11,8
2659	5^-	1,yes			0,031 (4)	0,031 (4)	10,67
2662					0	0	
2705	4^+	2,no	>10,6	<0,03	0,006 (23)	<0,029	>10,5
2707	4^+	2,no	>10,6	<0,03	-0,010 (7)	0	
2793	4^+	2,no	>10,6	<0,03	-0,013 (7)	0	
2842	5^-	1,yes			0,0252 (10)	0,0252 (10)	9,73
2876	6^+	0,no			0,392 (18)	0,392 (18)	8,23
2926	5^+	1,no			67,5 (6)	67,5 (6)	5,36

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^{111}In - Comments on evaluation of decay data
by V.P. Chechev.

The initial ^{111}In decay data evaluation was done by V.P. Chechev in 1998 (1999Be). This current (revised) evaluation has been carried out in March 2006. The literature available by March 2006 has been included.

1 Decay Scheme

Transitions to the ground state and the exited level of 245 keV of ^{111}Cd have not been observed. Limits on the electron capture branches to these levels can be deduced from the log ft systematics of 1998Si17. The transitions to the levels at 0 and 245 keV are 4 th and 2nd forbidden with expected log ft's of > 22 and > 10.6, respectively. The corresponding electron capture branch limits are < 1.0×10^{-14} % and < 5×10^{-4} %, respectively (2003Bl10).

The upper limit of 0.01 % hasbeen found for the electron capture branch to the excited level of 396 keV by Meyer and Landrum (1972MeZD).

2 Nuclear Data

Q_{EC} value is from 2003Au03.

The evaluated ^{111}In half-life is based on the experimental data given in Table 1.

Table 1. Experimental values of the ^{111}In half-life (in days)

Reference	Author(s)	Value	Comments
1949He06	Helmholz *et al.*	2.84 (3)	
1957Ma26	Maier	2.81 (1)	
1968Li08	Liskien	2.84 (11)	
1968Sm08	Smend *et al.*	2.96 (8)	
1972Em01	Emery *et al.*	2.83 (1)	
1972Gu19	Gureev *et al.*	2.84	Uncertainty is not quoted
1978La21	Lagoutine *et al.*	2.802 (1)	Quoted uncertainty, corresponding to 99.7 % confidence level, has been reduced by a factor 3
1980Ho17	Houtermans *et al.*	2.8071 (15)	
1982HoZY	Hoppes *et al.*	2.8048 (5)	Replaced by 1992Un01
1983Wa26	Walz *et al.*	2.8049 (5)	
1986Ru09	Rutledge *et al.*	2.8048 (1)	
1992Un01	Unterweger *et al.*	2.80477 (53)	Cited also in 2002Un02
2004Sc04	Schrader	2.8063 (7)	

The value of 1972Gu19 has been omitted because of the absence of an estimated uncertainty. The value of 1982HoZY has been omitted as it is replaced in 1992Un01. The value of 1968Sm08 has been omitted as outlier using the Chauvenet's criterion. Hence the eleven values have been used for the statistical data processing.

The uncertainty of 1986Ru09 was increased to 0.00030 to adjust weights according to the LRSW method. A weighted average for the final data set is 2.8049 with an internal uncertainty of 0.00021 and an external uncertainty of 0.00034 and a reduced χ^2/ν = 2.5. An unweighted average is 2.815 (5).

Different statistical procedures (1994Ka08) give the following results: UINF, PINF and NORM – 2.8049 (3), LWM – 2.815 (10), IEXW – 2.805 (13), RAJ – 2.8049 (2), BAYS and MBAYS – 2.8049 (4).

The adopted value of the ^{111}In half-life is 2.8049 (4) days.

The evaluated half-life of the metastable level of 396 keV (^{111m}Cd) is based on the experimental results given in Table 2.

Table 2.Experimental values of the ^{111m}Cd half-life (in minutes)

Reference	Author(s)	Value
1945Wi11	Wiedenbeck	48.7 (3)
1948Ho37	Hole	50 (2)
1949He06	Helmholz et al.	48.6 (3)
1968Bo28	Bornemisza-Pauspertl et al.	49.4 (7)
1987Ne01	Nemeth et al.	48.54 (5)
1997We13	Wen et al.	48.30 (15)

The uncertainty of 1987Neo1 was increased to 0.12 to adjust weights according to the Limitation of Relative Statistical Weight (LRSW) method. A weighted average for the final data set is 48.50 with an internal uncertainty of 0.085 and an external uncertainty of 0.082 and a reduced $\chi^2/\nu = 0.93$. An unweighted average is 48.9 (3).

Different statistical procedures (1994Ka08) give the following results: IEXW, LWM, MBAYS, NORM and UINF – 48.50 (9), PINF – 48.50 (8), RAJ – 48.51(9), BAYS – 48.50 (11).

The adopted value of the ^{111}In half-life is 48.50 (9) minutes.

2.1 Electron Capture Transitions

The electron capture transition energies have been calculated from Q_{EC} value and the ^{111}Cd level energies given in Table 3 from 2003Bl10. The electron capture transition probability $P_{\varepsilon 0,2} = 5\ (5) 10^{-3}$ has been evaluated taking into account the observed upper limit of 1×10^{-2} (1972MeZD). The fractional electron capture probabilities P_K, P_L, P_M have been calculated using the LOGFT computer program.

Table 3. ^{111}Cd levels populated in the ^{111}In ε-decay

Level number	Energy, keV	Spin and parity	Half-life	Probability of EC-transition (x100)
0	0.0	$1/2^+$	Stable	$< 1.0 \times 10^{-14}$
1	245.35 (4)	$5/2^+$	84.5 ns	$< 5 \times 10^{-4}$
2	396.16 (5)	$11/2^-$	48.50 min	0.005 (5)
3	416.63 (5)	$7/2^+$	0.12 ns	99.995 (5)

2.2 g Transitions

The energies of γ-ray transitions are virtually the same as the γ-ray energies because nuclear recoil is negligible. The γ-ray transition probabilities have been calculated from the γ-ray emission probabilities and the evaluated total internal conversion coefficients (α_T).

The evaluated α_T values for $\gamma_{1,0}$ (245 keV) and $\gamma_{3,1}$ (171 keV) gamma-ray transitions have been obtained from the sets of 5 data including theoretical values (Table 4). The values of α_K, α_L, α_M have been calculated from the evaluated α_T using the theoretical ratios $\alpha_K/\alpha_L/\alpha_M/\alpha_{NO}$. The relative uncertainties of α_K, α_L, α_M have been taken as 2 %.

The theoretical α_T has been used for the E3 $\gamma_{2,1}$ (151 keV) gamma-ray transition (see also 1973Pathak).

Table 4. Experimental, theoretical and evaluated values of the total internal conversion coefficients (α_T)

	1956St64	1966Sp04	1975Sh29	1985Ka29	Theory (2006Ra03)	Evaluated
$\gamma_{1,0}$ (245 keV)	0.0621 (15)	0.0618 (15)	0.0634 (30)	0.0620 (7)	0.0637 (9)	0.0625 (7)
$\gamma_{3,1}$ (171 keV)	0.099 (3)	0.100 (3)	0.124 (6)	0.1018 (13)	0.1068 (15)	0.1036 (24)

The theoretical α_T values have been calculated using the BRICC computer program (2006Ra03).

The gamma-ray transition multipolarities have been adopted from measurements of 1956St54 and 1974Kr03. The gamma-ray multipolarity mixing ratio δ(E2/M1) of the $\gamma_{3,1}$ (171 keV)-transition has been evaluated using the following data:

0.146(3)	Steffen (1956St64)
0.141(3)	Budz-Jorgensen (1973)
0.145	Kreische and Lampert (1974Kr03)
0.144(3)	Weighted average of 1956St04 and 1973Budz-Jorgensen

The adopted value of 0.144 (3) corresponds to an E2 admixture of 2.07 (9) %.

3 Atomic Data

3.1. Fluorescence yields

The fluorescence yield data ω_K, ϖ_L, n_{KL} are from 1996Sc06 (Schönfeld and Janßen).

3.2. X Radiations

The energy values for X-rays have been calculated from the wavelengths given by Bearden (1967Be65). The relative emission probabilities of KX ray components have been taken from 1996Sc06.

3.3. Auger Electrons

The energies of Auger electrons are from 1977La19 (Larkins) and Table of Isotopes. The ratios P(KLX)/P(KLL), P(KXY)/P(KLL) are taken from 1996Sc06.

4 Electron Emissions

The energies of the conversion electrons have been calculated from the gamma transition energies and the electron binding energies. The emission probabilities of conversion electrons have been deduced from the evaluated P(γ) and ICC values.

The total absolute emission probability of K Auger electrons has been calculated with the EMISSION computer program using the adopted $\omega_K = 0.842$ (4).

The absolute total emission probability of L Auger electrons has been calculated with the EMISSION computer program using the adopted $\varpi_L = 0.0632$ (16).

Experimental data on conversion electrons (1951Mc61, 1966Sp04, 1975Sh29) and Auger electrons (2005Ya03) are concordant with the adopted values

5 Photon Emissions

5.1 X-ray Emissions

The absolute emission probabilities of Cd KX-rays have been calculated with the EMISSION computer program using the adopted values of P_K and ω_K (Cd).

The absolute emission probabilities of Cd LX-rays have been calculated with the EMISSION computer program using the adopted values of P_L, ϖ_L (Cd), P_K, ω_K (Cd), n_{KL} (Cd).

5.2 g-ray Emissions

The energy of $\gamma_{2,1}$-ray (151 keV) has been taken from 1975Sh29.

The energy of the $\gamma_{3,1}$-ray (171 keV) has been evaluated using the experimental results given below:

172.1 (5)	McGinnis (1951Mc11) - Omitted from data processing
171.29 (3)	Sparrman et al. (1966Sp04)
171.20 (10)	Heath (1974HeYW)
171.28 (3)	Shevelev et al. (1975Sh29)
171.28 (3)	Weighted average (adopted value)

The energy of the $\gamma_{1,0}$-ray (245 keV) has been evaluated using the experimental results given below:

246.6 (7)	McGinnis (1951Mc11) - Omitted from data processing
245.35 (4)	Sparrman et al.(1966Sp04)
245.27 (10)	Heath(1974HeYW)
245.35 (4)	Shevelev et al. (1975Sh29)
245.35 (4)	Weighted average (adopted value)

The absolute emission probabilities of $\gamma_{2,1}$ (151 keV), $\gamma_{3,1}$ (171 keV) and $\gamma_{1,0}$(245 keV) gamma rays have been calculated using the below relations:

$$P\gamma_{2,1}\ (\times 100) = 99.995\ (5)/(1 + \alpha_T\,(\gamma_{2,1}))$$

$$P\gamma_{3,1}\ (\times 100) = 0.005\ (5)/(1 + \alpha_T\,(\gamma_{3,1}))$$

$$P\gamma_{1,0}\ (\times 100) = 100/(1 + \alpha_T(\gamma_{1,0})).$$

In 1975Sh29 the latter value has been estimated as ~ 0.003.

The relative intensity of $\gamma_{1,0}$ / $\gamma_{3,1}$ from 0.90 to 0.97 has been measured with an accuracy not better than 3 % in the above works. This accuracy is considerably worse in comparison with the calculation from the decay scheme using α_T values.

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^{123}Te^{m} - Comments on evaluation of decay data
by M. M. Bé and V. Chisté

This evaluation was completed in October 1993 and has been updated in September 2002.
Several measurements of the gamma emission intensity and of the total internal conversion coefficient of the 159-keV line were carried out. The decay scheme has been constructed mainly from these measurements.

Nuclear Data

- Spins and parities are from the LPRI “Table de Radionucléides” [1]-

- The half-life value is the weighted average of : 119,7(3) (Emery 1970 – 1970EmZY) and 119,2(1) (Coursey 1992 – 1992Co11) ; its uncertainty is the internal uncertainty.

Gamma Transitions

- <u>88-keV gamma transition</u>

For this M4 transition, the various theoretical conversion coefficients differ by about 5%. They are compared with measured values in the following table :

	Th. value Band 2002 – (2002Ba85)	Th. Value Rösel 1978 – (1978Ro22)	Exp. Value Kalinausskas 1969 – (1968Ka20)	Exp. Value Raman 1973 – (1973Ra32)	Exp. value Chu 1964 – (1964Ch18)
α_T	1099	1151	1000 (70)	1080 (40)	
α_K	463	483			455 (9)
α_L	493	517			482 (14)
α_M	118	124			

Values interpolated from the new Band *et al.* tables (2002Ba85), have been adopted following the recommendations of Gorozhankin (2002) [3].
The transition probability has been deduced from the decay scheme balance at the 159-keV level.

- <u>247-keV gamma transition</u>

The conversion coefficients, for this E5 transition, were calculated using the new tables of Band *et al.* (2002Ba85) as suggested by Gorozhankin [2, 3]. The theoretical α_T (7,75 (30)) agrees with the measured value (8,1(4)) given by Raman (1973Ra32).
The transition probability has been deduced using this theoretical value for α_T and the gamma emission intensity (see below).

<u>- 159-keV gamma transition</u>

For the 159-keV gamma transition, the following values of the mixing ratio squared δ^2 have been found in the literature :

Reference	d^2	a_T
Goldberg *et al.* – (1955Go25)	0,013(1)	$1,919\ 10^{-1}$
Fagg *et al.* – (1955Fa40)	0,0034(20)	$1,905\ 10^{-1}$
Chu *et al.* – (1964Ch08)	0,0067(11)	$1,909\ 10^{-1}$
Gupta *et al.* – (1966Gu02	0,011(8)	$1,916\ 10^{-1}$
Alkhazov *et al.* – (1964Al28)	0,004(5)	$1,906\ 10^{-1}$
Törnkvist *et al.* – (1969To02)	0,0119(9)	$1,917\ 10^{-1}$
Krane – (1977Kr13)	0,01232 (47) (adopted value)	$1,918\ 10^{-1}$

The internal conversion coefficients were calculated by ICC Computer Code [2] by interpolation of the Rösel tables (1978Ro22).

Elsewhere, the following measurements of the α_T coefficients were carried out :

Chu1964 (1964ch08)	0,1964 (74)
Hatch1966 (1966Ha03)	0,1979 (54)
Janssen1992 (1999Ja15)	0,1932 (46)
Janssen1992 (1999Ja15)	0,1895 (13)

The weighted mean of the above values is 0,1904 with a reduced -χ^2 of 1,14 ; the internal uncertainty is 0,0012; the external uncertainty 0,0013. This value is in good agreement with the theoretical adopted α_T (0,1918(19)).
The transition probability was deduced from the evaluated value (see below) of the emission intensity, using the adopted α_T .

Gamma Ray Emissions

- 159-keV gamma ray emission intensity is the weighted mean of :

83,65	0,50	(Chu – 1964Ch08)
83,48	0,38	(Hatch – 1966Ha03)
83,2	0,5	(Schötzig 1991 – [5])
83,9	0,6	(Coursey – 1992Co11)
83,81	0,32	(Janssen – 1992Ja15)
84,07	0,09	(Janssen – 1992Ja15)

The adopted value 83,99 is the weighted mean with an internal uncertainty of 0,08, and a reduced -χ^2 of 1,18.

[From the decay scheme and the α_T = 0,1918(19), the expected value is 83,90(14).]

- From α_T = 1099(33) and the decay scheme, the 88-keV gamma ray emission intensity is 0,0909(27). This value agrees with $I_\gamma(88)$ = 0,0927(34), deduced from the ratio $I_\gamma(159)/I_\gamma(88)$ = 906(33) measured by Raman (1972Ra07), using $I_\gamma(159)$ = 83,99(8).

- The 247-keV gamma ray emission intensity of 0,000344(34) has been deduced from the ratio $I_\gamma(247)/I_\gamma(159) = 4{,}1(4)\ 10^{-6}$ measured by Raman (1973Ra32).

Conversion electrons

The conversion electron emission intensities have been calculated using conversion coefficients and gamma-ray emission intensities.

Atomic Data

The ω_K value is from Bambynek (1984) [6].
The ϖ_L value is from Schönfeld (1996Sc06).
The X-ray and Auger electron emission intensities have been calculated by using the program EMISSION (version 3.01) [4]

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^{123}I – Comments on evaluation of decay data
by V. Chisté and M.M. Bé

1) Decay Scheme

There are 2 excited levels at 247 keV and 532 keV in ^{123}Te that have not been reported here. The 247 keV isomer ($T_{1/2}$ = 119,7 d) is not populated in the electron capture decay of ^{123}I, and the expected electron capture population to the level 532 keV, if any, is very small.

2) Nuclear Data

The Q value is from Audi and Wapstra (1995Au04)

Level energies, spin and parities are from S. Ohya and T. Tamura (1993Oh07).

For level E= 687 keV, there are two possible spin values : 3/2+ and 5/2+. The 5/2+ value was suggested by Schoeters (1979Sc23) not after a measurement but by considering a proposal from Walters (1976Wa13). On the other hand, the $3/2^+$ value was measured by Sergolle ($\gamma\gamma$ coincidence (1969Se09) and Coulomb excitation (1970Se03)), Lien ((d,p) reaction (1975Li22)) and Andreev (Coulomb excitation (1975An16)). Then, the adopted value is 3/2+.

The half-life value, calculated by the Lweight program (version 3), is the weighted mean of :

$T_{1/2}$

Reference	Value (h)	Comments
Anderson (1964An03)	13,30 (5)	
Hupf (1968Hu01)	13,02 (4)	
Jonsson (1968Jo02)	13,4 (5)	
Karim (1973Ka01)	13,50 (11)	
Lagoutine (1982La13)	13,21 (2)	
Hoppes (1982Ho26)	13,219 (7)	Superseded 1992Un03
Unterweger (1992Un03)	13,2235 (19)	
Silva (2003Si04)	13,2228 (29)	
Schrader (2003Sc49)	13,232 (6)	

The original uncertainty given by Hupf (1968Hu01) (= 0,02) seems under estimated and has been multiplied by 2 by the evaluator. The uncertainty adopted by Lagoutine (1982La13) is the sum of the statistical uncertainty assessed at 3σ and the systematic uncertainty at 1σ; consequently, the standard deviation cannot be obtained dividing the original uncertainty by 3 and we adopted the value 0,02. With this set of data, the reduced χ^2 is 4,7. The largest contribution comes from the value of Unterweger (1992Un03), amounting to 62%. The program Lweight 3 increases the uncertainty for the 1992Un03 value from 0,0019 to 0,00242 in order to reduce its relative weight from 62% to 50%.

The adopted value is the weighted mean : *13,2234 h*, with the external uncertainty of *0,0037 h*.

2.1) Electron Capture Transitions

The partial sub-shell capture probabilities are calculated with the program EC -Capture for the Allowed and 1st Forbidden transitions.
The electron capture probabilities and the related uncertainties have been deduced from the imbalance on each level of the decay scheme, assuming no EC transition to the ground state and to the 599 keV level. If this transition exists its intensity is of the order of a few per thousands.

2.3) Gamma Transitions

For the 159, 280, 346, 440 and 624 keV gamma transitions, the adopted δ (mixing of different multipolarities) are from the Krane evaluation (1977Kr06) of experimental measurements in which angular distribution and correlation data have been analyzed. For other transitions, the values of δ are from S. Ohya and T. Tamura (1993Oh07).
The internal conversion coefficients are calculated by ICC Computer Code (program Icc99v3a – GETICC dialog). The adopted values are interpolated from Rösel tables.

For the 159 keV gamma transition, many values of δ^2 have been found in the literature, as shown in the following table:

Reference	**Value of** d^2	**Value of** a_T
Goldberg et al – Phys. Rev. 100(1955)1350	0,013(1)	1,919 10^{-1}
Fagg et al – Phys. Rev. 100(1955)1299	0,0034(20)	1,905 10^{-1}
Chu et al – Phys. Rev. 133(1964)B1361	0,0067(11)	1,909 10^{-1}
Gupta et al – Nucl. Phys. 80(1966)471	0,011(8)	1,916 10^{-1}
Alkhazov et al – Phys. Serv. 28(1964)1575	0,004(5)	1,906 10^{-1}
Törnkvist et al – Nucl. Phys. A130(1969)604	0,0119(9)	1,917 10^{-1}
Krane et al - Atomic Data and Nuclear Data Tables 19(1977)19	0,01232 (47) (adopted value)	1,918 10^{-1}

It can be noted that even with values of δ^2 quite different the resulting α_T values are close with differences smaller than 1%; thus the adopted uncertainty is 1%.

For the 440 keV gamma transition, the following values of δ^2 have been found in the literature:

Reference	**Value of** d^2	**Value of** a_T
Sergolle et al – Nucl. Phys. A139(1969)554	0,149	0,0129912
Sergolle et al – Nucl. Phys. A145(1970)351	0,16	0,0129803
Roney et al – Nucl. Phys. A236(1974)165	4,41	0,0120886
Schoeters et al – Nucl. Phys. A323(1979)1	10,11	0,0119637
Krane - et al - Atomic Data and Nuclear Data Tables 19(1977)19	4,41 (adopted value)	0,0120886

In his articles (1969 and 1970), Sergolle deduced two values of δ for the 440 keV transition from 2 values of δ^2 for the 159 keV transition. The one reported here (δ^2(440)=0,149) was calculated with δ^2(159) = 0,0119 (Tornkvist). Nevertheless, this value is not close to the adopted one.

The 1% mixture of the 505 transition is from Sergolle (1969).

For the other transitions, measurements aren't precise, and only ranges of values are given for δ^2.
Uncertainties calculations:

* For the 257 and 330 keV transitions (E2 pure), the α_T, α_K and α_L uncertainties are taken to be 3% from the calculated values with ICC Computer Code (program Icc99v3a).

* For the other transitions, the uncertainties calculations were made as follow : α_T was calculated for a pure M1(or M3) transition and for a pure E2 transition. The difference between these values, normalized by α_T, is the uncertainty (%) of α_T. The same method is used for α_K and α_L uncertainties.

3) Atomic Data

Atomic values (ω_K, ϖ_L and n_{KL}) are from Schönfeld (1996Sc33).
The X-ray and Auger electron emission probabilities are calculated from the data set values by using the program EMISSION.

4) Radiation emissions

4.2) Gamma ray emissions

Gamma ray emission energies are from S. Ohya and T. Tamura (1993Oh07) and W. B. Walters (1976Wa13).

The measured emission intensities are given in table 1, they are relative to a value of 100 for the 159 keV gamma ray. Energy values are in keV.

Remarks to table 1 :
The original uncertainties given by Jacquemin (1987Ja10) for the 440, 528 and 538 lines have been multiplied by 2 by the evaluator to take into account some important factors:

1) During the measurement, there was a contamination that was not taken into account (Te-123m) by the author ;
2) As the value given is an absolute value, the uncertainty on the relative intensity given in table 1, has been estimated using the normalization factor and its uncertainty taking from the reference quoted by Jacquemin.

Two sets of values (R. C. Ragaine (1968Ra11) and E. H. Spejewski(1970Sp03)) were omitted in several cases from the analysis due to discrepancy with the other data.

For the 528 keV gamma line, the value given by R. K. Gupta (1960Gu14) was also omitted because it did not agree with the other values.

The normalization factor to convert the relative emission intensities to absolute intensities is calculated with the formula:

$$\text{Normalization} = \frac{100}{(\Sigma(1 + a_T)P_{rel})}$$

where the sum is to be done over all the gamma transitions to the ground state.
From the calculated α_T and the evaluated relative emission intensities (Table 1), the deduced normalization factor is ***83,25 (21)***. The uncertainties were calculated through their propagation on the above formula.
Absolute emission intensities are given on the last line in table 1.

4.2) Conversion electrons

The conversion electron emission intensities were deduced from the ICC values and from the gamma -ray emission probabilities. To our knowledge, there are no measured values for the conversion electron emission intensities.

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Table 1.I-123, gamma emission intensities, relative values to the 158 keV and, absolute values 04/12/01

Ref	174,2	182,61	192,17	197,26	198,25	206,82	207,82	242,32	247,96	257,51	278,36
60Gu14											
68Ra11		0,03(2)	0,03(2)						0,08(1)		
70Sp03		0,03(1)	0,03(2)						0,07(2)		
73So04		0,028(4)	0,025(4)		0,005(2)		0,0022(16)		0,068(6)		
76Wa13	0,0010(3)	0,0155(5)¤	0,0238(8)	0,0004(2)	0,004(1)	0,004(1)	0,0013(4)	0,0004	0,0854(15)**	0,0018(5)	0,0027(5)
86Ag01									0,0864(31)	0,0026(12)	
87Ja10											
Adopted	0,0010(3)	0,022(6)	0,0239(8)	0,0004(2)	0,0042(9)	0,004(1)	0,00135(4)	0,0004	0,0838(27)	0,0019(5)	0,0027(5)
N	1	4	4	1	2	1	2	1	5	2	1
chi2/N-1**	0	2,07	0,09	0	0,2	0	0,3	0	2,16	0,38	0
Method		LWM, exp.unc	LWM, int. unc.		LWM, int. unc.		LWM, int. unc.		LWM, ext. unc.	LWM, int. unc.	
Abs. Value	0,00083(25)	0,0183(50)	0,0199(7)	0,00033(17)	0,0035(7)	0,0033(8)	0,00112(32)	0,0003330(8)	0,0698(23)	0,00160(22)	0,00225(42)

** = Input uncertainty multiplied by 1,75 in the program LWEIGHT

¤ = Input uncertainty multiplied by 7,30 in the program LWEIGHT

exp.unc. = LWM expanded the uncertainty so range includes the most precise value.

int.unc. = internal uncertainty

ext.unc. = external uncertainty

Normalization factor = 83,25 (21)

Table 1.I-123, gamma emission intensities, relative values to the 158 keV and, absolute values 04/12/01

Ref	281,03	295,09	329,38	330,7	343,73	346,35	405,02	437,5	440,02	454,76	505,33
60Gu14	0,14(3) £			0,012(3)		0,16(3)			0,44(9)		0,280(6)
68Ra11	0,08(1)					0,12(2) (O)			0,42(2) (O)		0,31(5)
70Sp03	0,08(3)					0,11(3) (O)			0,42(8) (O)		0,32(8)
73So04	0,09(1)			0,017(6)		0,12(1)			0,46(2)	0,004(1)	0,27(3)
76Wa13	0,095(1)	0,0019	0,0031(7)	0,0139(5)	0,0051(5)	0,151(1)	0,0035(7)	0,0009(9)	0,514(6)	0,0047(6)	0,379(3)
86Ag01	0,095(44)			0,0142(7)	0,0055(5)	0,152(6)	0,0036(3)		0,524(21)	0,0051(3)	0,376(2)
87Ja10									0,450(29) ®		
Adopted	0,0948(1)	0,0019	0,0031(7)	0,01398(40)	0,00530(35)	0,151(1)	0,00358(28)	0,0009(9)	0,508(5)	0,00495(26)	0,32(5)
N	5	1	1	4	2	4	2	1	5	3	6
chi2/N-1**	0,68	0	0	0,27	0,32	3,22	0,02	0	2,98	0,66	3,8
Method	LWM, int. unc.			LWM, int. unc.	LWM, int. unc.	LWM, int. unc.	LWM, int. unc.		LWM, int. unc.	LWM, int. unc.	LWM, int. unc.
Abs. Value	0,0789(9)	0,0015818(40)	0,0026(6)	0,01164(33)	0,00441(29)	0,1257(9)	0,00298(23)	0,0007(7)	0,4229(43)	0,00412(22)	0,266(42)

® = Initial uncertainty multiplied by 2 by the evaluator

int.unc. = internal uncertainty

£ = Data rejection parameters for deviation from weighted average
(Chauvenet's criteria)

(O) = omitted value

Normalization factor = 83,25 (21)

Table 1.I-123, gamma emission intensities, relative values to the 158 keV and, absolute values 04/12/01

Ref	528,96	538,54	556,05	562,79	578,26	599,69	610,05	624,57	628,26	687,95	735,78
60Gu14	2,0(3) (O)										
68Ra11	1,27(11) (O)	0,32(2) (O)						0,08(1)		0,03(1)	0,04(1) (O)
70Sp03	1,26(24) (O)	0,31(6) (O)						0,07(2) (O)		0,04(2) £	0,05(2) (O)
73So04	1,40(5)	0,38(4)	0,0033(4)	0,0012(3)				0,085(5)		0,030(2)	0,06(3)
76Wa13	1,670(5)	0,458(5)	0,0037(5)	0,0013(5)	0,0018(5)	0,0031(11)	0,0013(4)	0,100(1)*	0,0019(3)	0,0321(15)	0,0739(14)
86Ag01	1,66(5)	0,460(21)		0,0014(1)	0,0015(1)	0,0032(2)		0,101(5)	0,0020(2)	0,0329(9)	0,0742(35)
87Ja10	1,41(6)®	0,379(31)®									
Adopted	1,58(10)	0,455(5)	0,00346(31)	0,00138(9)	0,00151(1)	0,0032(2)	0,0013(4)	0,0958(24)	0,00197(17)	0,0323(7)	0,074(1)
N	4	4	2	3	2	2	1	4	2	4	3
chi2/N-1**	8,34	3,3	0,39	0,21	0,35	0,01	0	3,28	0,08	0,5	0,11
Method	LWM, exp.unc.	LWM, int. unc.	LWM, int. unc.	LWM, int.unc.	LWM, int.unc.	LWM, int. unc.		LWM, ext. unc.	LWM, int. unc.	LWM, int. unc.	LWM, int. unc.
Abs. Value	1,32(8)	0,3788(43)	0,00288(26)	0,00115(7)	0,00126(8)	0,00266(17)	0,00108(33)	0,0798(20)	0,00164(14)	0,0269(6)	0,0616(8)

* = Input uncertainty multiplied by 3,33 in the program LWEIGHT

® = Initial uncertainty multiplied by 2 by the evaluator

£ = Data rejection parameters for deviation from weighted average (Chauvenet's criteria)

(O) = omitted value

exp.unc. = LWM expanded the uncertainty so range includes the most precise value

int.unc. = internal uncertainty
ext.unc. = external uncertainty

Normalization factor = 83,25 (21)

Ref	783,59	837,1	877,52	894,8	909,12	1036,63	1068,12
60Gu14							
68Ra11	0,05(1) (O)						
70Sp03	0,05(2) (O)						
73So04	0,068(5)	0,0008(2)	0,0010(2)	0,0017(5)	0,0017(4)	0,0010(2)	0,0014(2)
76Wa13	0,0713(14)	0,0006(1)	0,0013(8)	0,0011(3)	0,0016(3)	0,0012(3)	0,0017(1)
86Ag01	0,0718(35)	0,00070(1)	0,0010(1)	0,0012(1)	0,0017(1)	0,0012(1)	0,0018(1)
87Ja10							
Adopted	0,0712(13)	0,000699(10)	0,00100(9)	0,00121(9)	0,00169(9)	0,00116(9)	0,00171(8)
N	3	3	3	3	3	3	3
chi2/N-1**	0,22	0,62	0,07	0,55	0,05	0,41	1,61
Method	LWM, int. unc.	LWM, int. unc.	LWM, int. unc.	LWM, int. unc.	LWM, int.unc.	LWM, int. unc.	LWM, ext.unc.
Abs. Value	0,0591(11)	0,000582(8)	0,00083(7)	0,00101(7)	0,00141(8)	0,00097(7)	0,00142(7)

(O) = omitted value

int.unc. = internal uncertainty

ext.unc. = external uncertainty

Normalization factor = 83,25 (21)

^{124}Sb - Comments on evaluation of decay data
by M.M. Bé and V. Chisté

This evaluation was completed in December 2008. The literature available by this date was included as well as the results obtained as a part of a specific exercise dedicated to the ^{124}Sb activity and γ-ray emission intensity measurements organized by the Euramet organisation (Project 907, full report to be published).
In the following, the participants in the Euramet 907 project will be referred as E907- *n*, where *n* is a serial number.

1. Decay Scheme

This decay scheme is complete and is based on those proposed by Goswamy (1993Go10), Patil (2006Pa16) and the results obtained in the Euramet-907 project.
A good agreement was found between the effective Q value of 2906 (8) keV computed from the decay scheme data and the adopted Q value of 2904,3 (15) keV from the mass adjustment of Audi *et al.*

2. Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).

Experimental half-life values (in days) are listed below:

Reference	**$T_{1/2}$**	**Uc**	**Comments**
Macklin (1957Ma50)	60,4	0,2	
C.H.Johnson (1958Jo01)	59,9	0,5	
J.P.Cali (1959Ca12)	60,1	0,3	
S.A.Reynolds (1968Re04)	60,3	0,2	
D.M.Fleming (1966Fl01)	60,20	0,03	calorimetry
I.A.Kharitonov (2000Kh04)	60,11	0,07	4πβ–γ coincidence method
* E907- 8	60,212	0,011	Ionization chamber
Adopted	**60,208**	**0,011**	Reduced χ^2 =1 ; critical χ^2 =4,6

*Euramet 907 participant number 8

The adopted value is the weighted mean of the three most precise values with the external uncertainty.

2.1 Beta transitions

β^- transition energies have been energies are calculated from the Q value and the level energies.

The β^- transition probabilities were deduced from the γ transition probability balance at each level of the decay scheme. The adopted values are compared with the measured values in the following table:

	(0, 1) 2301 keV %	(0, 3) 1579 keV %	(0, 5) 946 keV %	(0, 10) 610 keV %	(0, 20) 210 keV %
Langer (1953La35)	21	7	9	49	14
Moreau (1954Mo83)	22	7	9	53	9
Azuma (1955Az29)	22	6	4	56	12
Hsue (1965Hs02)	23	5			
Zolotavin (1956Zo06)	28	10	4	49	9
Adopted	23,44 (28)	4,815 (29)	2,295 (7)	51,21 (19)	8,663 (27)
Nature	1st S=q2+(1p2+16(2) (Hsue) S=k(1-0,25W-0,06/W+0,041W2)(Hsue) S=q2+(1p2+7(2) (Canty) S=0,9q2+p2 (Johnson)				

The weak beta transition probabilities are based on the γ transition probability balance at each level of the decay scheme, especially in the upper part of the decay scheme (from level 2886-keV to level 2483-keV) where there are only gamma transitions depopulating these levels. In this evaluation, only the gamma rays observed in several independent experiments have been retained (see § 4.2) so the corresponding levels can be considered definitely established.

2.2 Gamma transitions and internal conversion coefficients

γ-ray measurements carried out by Doll *et al.* (2000Do11) confirmed the doublet structure of the 2039 level ; one with J^{π} assignment 2^{+} and the second with 3^{+} ; with a spacing of 129 eV.
The γ transitions with energy : 2039,4- ; 790,8- ; 1436,7- ; 713,9-keV start from level with $J^{\pi} = 2^{+}$ and, those with energy : 790,7- ; 1436,6- ; 713,8-keV from level with $J^{\pi} = 3^{+}$. They are shown as doublets in the following table.

Internal conversion coefficients

Multipolarity and multipole mixing ratio (δ) for some transitions were determined using the techniques of directional correlation and nuclear orientation measurements, these are summarized in Table 1 :

Table 1 :

Transition energy (keV)	multipole mixing ratio (d)	Multipolarity	Reference
444	0,57 (17) or 0,06 (8)		Robinson *et al.* 1983
646	0,013 (9) 0,000 (1)	E2, M3	Goswamy *et al.* 1993 Baker *et al.* 1972
709	- 0,8 (+3, -4) - 1 (+6, -8) - 0,18 (5) 0,04 (3, -5)	M1, E2	Goswamy *et al.* 1993 Goswamy *et al.* 1993 Robinson *et al.* 1983 Grabowski *et al.* 1971
714	- 0,65 (+38, -0,54) 1,15 (16, - 25) 1,5 (7)	M1, E2	Goswamy *et al.* 1993 Subrahmanyeswara *et al.* 1990 Robinson *et al.* 1983

Transition energy (keV)	**multipole mixing ratio (d)**	**Multipolarity**	**Reference**
	1,5 (6) 0,98 (19)		Baker *et al.* 1972 Grabowski *et al.* 1971
723	3,74 (12) - 3,8 (2) - 3,4 (3) - 3,3 (2) - 3,4 (1) - 7,5 (20) - 3,4 (6)	M1, E2	Goswamy *et al.* 1993 Subrahmanyeswara *et al.* 1990 Robinson *et al.* 1983 Baker *et al.* 1972 Grabowski *et al.* 1971 Sites *et al.* 1970 Stelson, 1967
791	- 0,15 (+5, -2) - 0,3 (+52, -14)	E2, M3	Goswamy *et al.* 1993 Goswamy *et al.* 1993
968	0,038 (3) - 0,35 (8) - 0,02 (2) - 0,03 (6, -5) - 0,02 (8)	E1, M2	Goswamy *et al.* 1993 Subrahmanyeswara *et al.* 1990 Robinson *et al.* 1983 Baker *et al.* 1972 Sites *et al.* 1970
1045	- 0,14 (+3, -4) - 0,03 (2) 0,041 (47, -41) - 0,1 (1)	E1, M2	Goswamy *et al.* 1993 Robinson *et al.* 1983 Baker *et al.* 1972 Sites *et al.* 1970
1356	- 0,32 (+25, -18)	E2, M1	Goswamy *et al.* 1993
1368	- 0,28 (6) - 0,02 (1) - 0,045 (90) - 0,01 (8)		Subrahmanyeswara *et al.* 1990 Robinson *et al.* 1983 Baker *et al.* 1972 Sites *et al.* 1970
1376	0,26 (11) < 0,29 - 0,01 (3)	E1, M2	Goswamy *et al.* 1993 Goswamy *et al.* 1993 Robinson *et al.* 1983
1437	0,51 (+13, -11) 1,5 (8) 3,7 (27, -20)	M1, E2	Goswamy *et al.* 1993 Robinson *et al.* 1983 Baker *et al.* 1972
1445	0,015 (80) 0,10 (9)	E1, M2	Goswamy *et al.* 1993 Robinson *et al.* 1983
1489	0,10 (23) - 3,4 (9, -15)		Robinson *et al.* 1983 Baker *et al.* 1972
1691	- 0,009 (22) - 0,06 (3) - 0,02 (1) 0,00 (3)	E1, M2	Goswamy *et al.* 1993 Subrahmanyeswara *et al.* 1990 Baker *et al.* 1972 Sites *et al.* 1970
2091	0,031 (6) 0,032 (32) 0,00 (2, -3) 0,07 (3)	E1, M2	Goswamy *et al.* 1993 Subrahmanyeswara *et al.* 1990 Baker *et al.* 1972 Sites *et al.* 1970

Moreover, two sets of measured values of the conversion electron intensities (Ice$_i$) are also available: by Grigor'eev *et al.* (1968), and by Johnson (1974Jo03). These values as well as their weighted means are summarized in where α_{K602} is the theoretical K conversion coefficient interpolated from Band's tables using the program BrIcc with the "frozen orbital approximation" (Kibédi *et al.* 2008Ki07) for an E2 transition ; Ice$_i$ are the conversion electron intensities, and Iγ_i, the relative gamma-ray emission probabilities as summarized in Table 3.

The experimental α_{Ki} conversion coefficients have been compared with the theoretical ICC, the deduced mixing ratios δ are in good agreement with those determined by directional correlation and nuclear orientation measurements summarized in Table 1.

Table 2. Then, the experimental K conversion coefficients α_{Ki} were deduced from the relation:
$\alpha_{Ki} = \alpha_{K602} \times Ice_i / I\gamma i$
where α_{K602} is the theoretical K conversion coefficient interpolated from Band's tables using the program BrIcc with the "frozen orbital approximation" (Kibédi *et al.* 2008Ki07) for an E2 transition ; Ice_i are the conversion electron intensities, and $I\gamma_i$, the relative gamma-ray emission probabilities as summarized in Table 3.

The experimental α_{Ki} conversion coefficients have been compared with the theoretical ICC, the deduced mixing ratios δ are in good agreement with those determined by directional correlation and nuclear orientation measurements summarized in Table 1.

Table 2 :

α_k (602)= 0,00420 0,00006

	Johnson		Grigor'eev						α_k =						
Energy	Iec	Uc	Ice	Uc	Ice WM	Uc dopt.	Ig rel.	Uc Ig	Ice/Ig * ak602	uc α_k	Multipolarity	delta	%	α_k theo	α_T theo.
159	2,3	0,2			2,3	0,2	0,0050	0,0006	1,93	0,29					
254	0,10	0,08			0,1	0,08	0,0145	0,0009	0,0290	0,0232	E1 ?			0,01269 (18)	0,01465 (21)
336	0,12	0,08			0,12	0,08	0,0741	0,0009	0,0068	0,0045	E1			0,00611 (9)	0,00704 (10)
371	0,1	0,08			0,1	0,08	0,0292	0,0011	0,0144	0,0115					
400	0,45	0,08			0,45	0,08	0,128	0,0027	0,0148	0,0027	E2			0,01323 (2)	0,01566 (2)
444	0,35	0,15			0,35	0,15	0,192	0,009	0,0077	0,0033	M1+E2	0,06	26,5	0,01092 (16)	0,01261 (18)
469	< 0,14				< 0,14		0,0469	0,0027			E1			0,00268 (4)	0,00309 (5)
481	< 0,07				< 0,07		0,0237	0,0032							
525	0,14	0,08			0,14	0,08	0,1484	0,0036	0,0040	0,0023	M1+E2	1	50	0,0066 (3)	0,0077 (3)
602	100		100		100		100		0,00420	0,00006	E2			0,00420 (6)	0,00490 (7)
646	5,4	0,5	6,6	0,3	6,28	0,53	7,591	0,015	0,0035	0,0003	E2+M3	0,006	0,0036	0,00351 (5)	0,00409 (6)
709	1,4	0,5	1,2	0,1	1,21	0,10	1,3941	0,0046	0,0036	0,0003	M1+E2	-0,18	3,1	0,00349 (5)	0,00402 (6)
713	1,6	0,5	1,6	0,2	1,60	0,19	2,325	0,007	0,0029	0,0003	M1+E2	1	50	0,0031 (4)	0,0036 (4)
722	5,7	0,5	7,5	0,3	7,02	0,79	10,952	0,022	0,0027	0,0003	M1+E2	-3,4	92	0,00271 (4)	0,00314 (5)
735	0,04	0,02			0,04	0,02	0,1342	0,0016	0,0013	0,0006					
766	0,035	0,02	0,06	0,02	0,048	0,014	0,0105	0,0009	0,0190	0,0059	E0, M1			0,019 (6)	0,021 (7)
790	0,44	0,08	0,44	0,03	0,440	0,028	0,7584	0,0025	0,0024	0,0002	E2			0,00214 (6)	0,00248 (8)
968	0,24	0,08	0,33	0,03	0,319	0,030	1,93	0,01	0,0007	0,0001	E1(+M2)	-0,2	3,8	0,000569 (9)	0,000653 (11)
1045	0,18	0,08	0,25	0,03	0,241	0,028	1,894	0,014	0,0005	0,0001	E1(+M2)	-0,03	0,09	0,000494 (9)	0,000567 (10)
1325	0,35	0,1	0,30	0,03	0,304	0,029	1,623	0,007	0,0008	0,0001	E2			0,000693 (10)	0,000827 (12)
1355	0,17	0,1	0,20	0,02	0,199	0,020	1,0649	0,0039	0,0008	0,0001	E2(+M3)	-0,32	9,3	0,0009 (5)	0,0011 (5)
1368	0,14	0,05	0,22	0,03	0,199	0,035	2,680	0,008	0,0003	0,0001	E1(+M2)	-0,02	0,04	0,000303 (5)	0,000478 (7)
1376	0,035	0,03			0,035	0,03	0,5113	0,0044	0,0003	0,0002	E1(+M2)	-0,01	0,01	0,000300 (5)	0,000479 (7)
1418	0,25	0,1			0,25	0,1	0	0							
1436	0,28	0,1	0,17	0,03	0,18	0,03	1,262	0,008	0,0006	0,0001	M1+E2	1,5	69,23	0,00063 (5)	0,00078 (5)
1489	0,14	0,1	0,13	0,02	0,13	0,02	0,6924	0,0038	0,0008	0,0001	M1+E2	0,1	0,9901	0,000659 (14)	0,000829 (16)
1526	0,035	0,03	< 0,04		0,035	0,03	0,4232	0,0048	0,0003	0,0003	E1			0,000252 (6)	0,000535 (8)
1657	0,2	0,1			0,2	0,1	0,00	0,00							
1691	2,7	0,4	2,5	0,2	2,54	0,18	48,54	0,19	0,00022	0,00002	E1+M2	0,01	0,01	0,000213 (4)	0,000615 (9)
2090,9	0,24	0,06	0,20	0,04	0,212	0,033	5,618	0,025	0,00016	0,00002	E1(+M2)	0,03	0,1	0,0001522 (23)	0,000838 (12)

3. Atomic Data

The fluorescence yield data are from 1996Sc06 (Schönfeld and Janssen).

3.1 X Radiations

The relative K x-ray emission probabilities are from 1996Sc06.

3.2 Auger Electrons

The ratios P(KLX)/P(KLL) and P(KXY)/P(KLL) are from 1996Sc06.

4. Radiation Emissions

4.1 Electron Emissions

The β- emission energies and intensities were deduced from γ transition probabilities (§ 2.1).
The conversion electron emission intensities have been calculated from the γ-ray emission intensities in sect. 4.2, and the internal-conversion coefficients in sect. 2.2.
The Auger electron emission intensities were calculated by the EMISSION program from PTB using the γ-ray emission probabilities, the atomic data of sect. 3, and the internal-conversion coefficients of sect. 2.2.

4.2 Photon Emissions

The X-ray absolute emission intensities were calculated using the EMISSION program and the γ-ray emission intensities, the atomic data given in sect. 3, and the internal-conversion coefficients in sect. 2.2. They are compared with the three sets of absolute values measured by participants in the Euramet exercise. They are, in general, in good agreement.

	E907- 2		**E907- 3**		**E907- 8**		**Calculated**	
Energy (keV)	**I %**	**Uc**	**I %**	**Uc**	**I %**	**Uc**	**I %**	**Uc**
27,2 (Kα2)			0,128	0,002	0,130	0,003	0,1252	0,0018
27,5 (Kα1)			0,264	0,004	0,230	0,006	0,233	0,003
30,9 (Kβ’2)			0,068	0001	0,063	0,002	0,0667	0,0012
31,7 (Kβ’1)			0,0170	0,0005	0,0136	0,0006	0,0145	0,0005
Kα	0,35	0,07	0,392	0,0045	0,359	0,007	0,358	0,0035
Kβ	0,087	0,018	0,085	0,0011	0,076	0,0018	0,081	0,0013
K X Total	0,437	0,072	0,476	0,005	0,436	0,007	0,439	0,004

The X-ray relative emission intensities given by Euramet participants 2 and 3 are compared, in the following table, with the published values of Patil (2006) and Goswamy (1993).

	E907- 2		**E907- 3**		**Patil (2006)**		**Goswamy (1993)**	
Energy (keV)	Rel. Int.	Uc	Rel. Int.	Uc	Rel. Int.	Uc	Rel. Int.	Uc
Kα : 27,3	0,361	0,076	0,4000	0,0046	0,3681	0,0066	0,366	0,017
Kβ : 30,9 – 31,8	0,089	0,018	0,0864	0,0014	0,0852	0,0017	0,084	0,050

g-ray energies

The γ-ray energies in the following table are from Helmer (2000He14). The other energies were deduced from the level energy differences.

E (keV)	Uc (keV)	E (keV)	Uc (keV)
602,7260	0,0023	1045,125	0,004
645,8520	0,0019	1325,504	0,004
713,776	0,004	1368,157	0,005
722,782	0,003	1436,554	0,007
790,706	0,007	1690,971	0,004
968,195	0,004	2090,930	0,007

g-ray emission intensities

The 6 participants in the Euramet project sent their γ-ray emission intensities in both relative and absolute scales, since they also carried out activity measurements of the solution.
Moreover, eight sets of measured values published in the literature are available. All of them are relative to the most intense 602-keV γ-ray line (Table 3).
Among the 111 γ rays mentioned before or in this exercise, some weak lines were observed once and not confirmed by other measurements, these are summarized below:

- Weak gamma rays of weak intensities observed by one Euramet participant often described being “barely visible” and then not adopted in the decay scheme:
2871-keV ; 2274-keV ; 2253-keV ; 2151-keV ; 1970-keV (just detection limits) ; 1950-keV ; 1657-keV ; 1557-keV ; 1428-keV ; 1269-keV ; 1202-keV ; 1198-keV; 1180-keV ; 1163-keV ; 669-keV ;

- Weak gamma rays of weak intensities observed by Patil but by none of the Euramet participant and not adopted in the decay scheme:
2814-keV ; 2746-keV ; 2515-keV ; 2490-keV ; 2386-keV (just detection limits) ; 2373-keV ; 2256-keV ; 2232-keV ; 2145-keV ; 1418-keV ; 795-keV ; 743-keV ; 592-keV ; 186-keV.

A number of weak gamma rays were observed by some Euramet participants or by others:
- 2224-keV, 2204-keV the reported intensities are quite discrepant so they were omitted;
- 1453-keV could be between levels 2701,6 and 1248,5-keV, but the reported intensities are quite discrepant so this γ-ray was omitted ;
- 476-keV could be between levels 2701,6 and 2224,8-keV, but the reported intensities are quite discrepant so this ray has not been retained ;
- 1757-keV ; 1509-keV ; 1253-keV ; 1097-keV ; 1014-keV ; 937-keV ; 553-keV ; 498,4-keV; 385-keV ; 346-keV ; do not correspond to levels differences, they have not been retained.

- 1235-keV ; 997-keV ; 159,8-keV were accepted but not placed in the decay scheme.

602-keV absolute g-ray emission intensity

1) A first attempt was made to determine the 602-keV line absolute emission intensity using the results of the absolute measurements carried out in the framework of the Euramet project:

Participant	Ig_{602} in %	Uc
E907- 2	97,5	0,7
E907- 3	97,8	0,9
E907- 5	97,6	0,7
E907- 6	91	1
E907- 7	97,84	0,34
E907- 8	98,1	1,5

Chi2	0,1		χ^2 / (n-1)
Chi2 crit:	3,3		
UWM:	97,787		Unweighted mean
WM:	97,769		Weighted mean
Uc (int):	0,26		Internal uncertainty
Uc (ext) :	0,07		External uncertainty
LWM :	97,77	0,26	Limited WM

The value of participant 6 was found to be an outlier based on Chauvenet's criterion. Value of participant 7 contributes to 58 % to the weighted mean (WM). The set of the five remaining values is consistent, then the evaluated value (LWM) is the weighted mean with the internal uncertainty.

All absolute γ-ray emission intensities measured by the Euramet participants are summarized in Table 4.

2) A second attempt using all the available measurements was done. Since the Euramet participating laboratories sent their results as relative values also, these six sets of results were used as well as the previous measurements published in the literature. So, 14 sets of data were included in the evaluation (Table 3).

In the Euramet project, the participants sent their results as values relative to the reference line $I\gamma_{602} = 100$; with its uncertainty included in the uncertainties of the other γ-ray lines.
In the other publications, when an author gave an uncertainty on this $I\gamma_{602}$ reference line, then this uncertainty was included into each individual value using the relation : Uc = sqrt ($Uc_{rel}*Uc_{rel} + Uc_{I\gamma602}*Uc_{I\gamma602}$). So, all gamma rays have been treated with emission intensities relative to $I\gamma_{602} = 100$ (with no uncertainty).

Since no beta transition populating the ground state level in Tellurium 124 is expected, the sum of the gamma transition probabilities with energy 2807-, 2693-, 2681-, 2455-, 2323-, 2294-, 2182-, 2039-, 1657-, 1325-, 602-keV which populate the ground state must be equal to 100. That is:

$$\sum_i I_{g_i}\left[1+a_{Ti}\right]=\frac{100}{N}$$

Where: $I_{\gamma i}$ is the relative emission probability of the gamma-ray, α_{Ti} is its total conversion coefficient, and N is a normalisation factor between the relative and absolute scales.

N, the normalization factor, is then deduced from the measured relative $I_{\gamma i}$ values:

$$N=\frac{100}{\sum_i I_{g_i}\left[1+a_{Ti}\right]} \quad \text{and} \quad dN^2=\sum_i\left(\frac{\partial N}{\partial I_{g_i}}dI_{g_i}\right)^2+\sum_i\left(\frac{\partial N}{\partial a_{T_i}}da_{T_i}\right)^2$$

The α_T coefficients are theoretical values interpolated from Band's tables (2002Ba85) using the program BrIcc with the "frozen orbital approximation" (Kibédi *et al.* 2008Ki07). All transitions with a measured multipolarity are E2.

This leads to N = 0,977 75 (20).

The absolute emission intensity of the 602-keV g-ray is then deduced to be: 97,775 (20) %.

This value is in full agreement with the above value of 97,77 (26) %. However, because of the normalization procedure used, its uncertainty is ten times smaller.
Having in mind that the energies of the involved transitions are relatively high and their respective multipolarities are E2, the conversion coefficient values deduced from theoretical calculations can be considered very reliable. Hence, this second absolute intensity value and its associated uncertainty were adopted here.

All the measured relative gamma emission intensities are summarized in Table 3, with the unweighted mean for each set of values given, as well as the weighted mean, the reduced χ^2 and the internal and external uncertainties, the adopted relative emission intensity value and its uncertainty and the deduced and adopted absolute values.

All the absolute gamma-ray emission intensities measured by the participants in the Euramet 907 project are summarized in Table 4. The most intense lines are compared to those obtained from relative values and conversion coefficients (Table 3) in the following table. The agreement is very good.

g-ray energy keV	From absolute measurements (Table 4)	From relative measurements and ICC (Table 3)
602	97,77 (26)	97,775 (20)
645	7,414 (21)	7,422 (15)
709	1,3635 (43)	1,363 (5)
713	2,269 (11)	2,273 (7)
722	10,712 (31)	10,708 (22)
968	1,880 (6)	1,887 (10)
1045	1,835 (6)	1,852 (14)
1325	1,583 (6)	1,587 (7)
1368	2,615 (9)	2,620 (8)
1690	47,39 (22)	47,46 (19)
2090	5,491 (26)	5,493 (24)

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Table 3 : Relative gamma ray intensities and absolute values calculated with (*)Ig602 = 97,775 (20) %.
(i , j) refers to initial and final levels, (-1, n) transition not placed in the decay scheme. DL = Detection Limit

	(14, 12)	148keV	(-1, 1)	159keV	(16, 12)	186keV	(14, 10)	189 keV	(20, 14)	209keV	(10, 6)	254keV	(23, 14)	291keV
	Value	Uc	Value	Uc	Value	Uc	Value	Uc	Value	Uc	Value	Uc	Value	Uc
E907- 2	0,012	0,005	0,005	0,001			0,002	0,001	(o) 0,0088	0,0012	0,009	0,001	0,0046	0,0008
E907- 3	DL=0,0031		DL=0,0032		DL=0,0041		DL=0,0042		DL=0,0043		0,014	0,002	DL=0,0053	
E907- 5														
E907- 6														
E907- 7	0,0053	0,0012	0,0070	0,0014			0,010	0,006	0,0047	0,0024	0,0159	0,0015	0,0092	0,0010
E907- 8	0,0028	0,0008	0,0045	0,0007			0,0049	0,0005	0,0054	0,0010	0,0165	0,0014	0,0059	0,0012
Patil (2006Pa16)					0,0020	0,0036			(o) 0,0147	0,0005	0,0137	0,0006	0,0070	0,0006
Goswamy (1993Go10)	0,0037	0,0007					0,0037	0,0007	0,0055	0,0010	0,0163	0,0008	0,0088	0,0008
Jianming (1988Yo05)	0,006	0,002					0,006	0,002	0,0062	0,0028	0,0214	0,0041	0,012	0,006
Mardirosian (1984Ma13)											(o) 0,030	0,007		
Iwata (1984Iw03)														
Johnson (1974Jo03)														
Meyer (1990Me15)														
Sharma (1979Sh08)														
Chi2	1,4		1,2				1,6		0,1		4,3		4,0	
Chi2 crit:	3,8		4,6				3,3		3,8		2,8		3,0	
UWM:	0,00449		0,00552				0,00530		0,00546		0,01520		0,00795	
WM:	0,00382		0,00504				0,00441		0,00543		0,01447		0,00713	
Uc (int):	0,00047		0,00054				0,00039		0,00066		0,00041		0,00036	
Uc (ext) :	0,00057		0,00060				0,00049		0,00015		0,00086		0,00073	
LWM :	0,0038	0,0006	0,0050	0,0006			0,00441	0,00049	0,0054	0,0007	0,0145	0,0009	0,0071	0,0007
I Abs.*	0,0037	0,0006	0,0049	0,0006	omitted		0,0043	0,0005	0,0053	0,0007	0,0142	0,0009	0,0069	0,0007

(o) Outlier

Table 3 (Cont'd) : Relative gamma ray intensities and absolute Values calculated with $^{(*)}$Ig602 = 97,775 (20) %.
(i , j) refer to initial and final levels, (-1, n) transition not placed in the decay scheme. DL = Detection Limit

	(10, 5)	336 keV		346,5 keV	(20, 11)	371 keV		385 keV	(20, 10)	400 keV	(14, 6)	444 keV	(20, 9)	469 keV
	Value	Uc	Value	Uc	Value	Uc	Value	Uc	Value	Uc	Value	Uc	Value	Uc
E907- 2	0,079	0,008	0,0034	0,0016	0,034	0,011	0,038	0,026	0,128	0,008	0,190	0,004	0,053	0,009
E907- 3	0,073	0,004	DL=0,0064		0,033	0,006	DL=0,0078		0,120	0,006	0,198	0,006	0,038	0,003
E907- 5	0,072	0,021			>0,0217	<0,0338			0,146	0,011	0,198	0,011	0,045	0,006
E907- 6									0,175	0,066	0,211	0,076		
E907- 7	0,0733	0,0016	0,0018	0,0018	0,0295	0,0027	DL=0,0024		0,130	0,007	0,1981	0,0024	0,0518	0,0028
E907- 8	0,0708	0,0026	0,0036	0,0025	0,0333	0,0022			0,1246	0,0037	0,1901	0,0047	0,0449	0,0021
Patil (2006Pa16)	0,076	0,002			0,0257	0,0015			0,125	0,007	0,1830	0,0021	0,0364	0,0023
Goswamy (1993Go10)	0,0750	0,0021	0,0060	0,0013	0,034	0,008			0,124	0,013	0,1920	0,0028	0,047	0,003
Jianming (1988Yo05)	$^{(o)}$ 0,086	0,006	0,013	0,005	0,036	0,006			0,155	0,013	0,204	0,010	0,053	0,003
Mardirosian (1984Ma13)	0,078	0,007			0,024	0,006			0,168	0,012	0,226	0,015	$^{(o)}$ 0,079	0,005
Iwata (1984Iw03)					$^{(o)}$ 0,051	0,009			0,129	0,016	0,205	0,010	0,058	0,008
Johnson (1974Jo03)					0,03	0,01			0,132	0,015	0,173	0,015	0,031	0,010
Meyer (1990Me15)									0,15	0,01	0,20	0,01		
Sharma (1979Sh08)					0,0315	0,0025			$^{(o)}$ 0,215	0,006	0,221	0,006	0,064	0,003
Chi2	0,5		1,3		1,4				2,2		4,7		7,4	
Chi2 crit:	2,6		3,8		2,4				2,2		2,1		2,3	
UWM:	0,07459		0,00369		0,03103				0,13890		0,19929		0,04749	
WM:	0,07407		0,00414		0,02925				0,12934		0,19237		0,04685	
Uc (int):	0,00094		0,00083		0,00097				0,00219		0,00116		0,00098	
Uc (ext) :	0,00069		0,00096		0,00115				0,00323		0,00252		0,00267	
LWM :	0,0741	0,0009	0,0041	0,0010	0,0292	0,0011			0,1293	0,0032	0,199	$^{(e)}$0,016	0,0469	0,0027
I Abs.*	0,0725	0,0009	omitted		0,0286	0,0011	omitted		0,1264	0,0031	0,195	0,016	0,0459	0,0026

$^{(o)}$ Outlier
$^{(e)}$ expanded uncertainty so range to include the most precise Value

Table 3 (Cont'd) : Relative gamma ray intensities and absolute Values calculated with (*)Ig602 = 97,775 (20) %.
(i , j) refer to initial and final levels, (-1, n) transition not placed in the decay scheme. DL = Detection Limit

	?(21, 9)	**476 keV**	**(23, 10)**	**481 keV**		**498 keV**	**(14, 5)**	**525 keV**	**(26, 12)**	**530 keV**		**553 keV**	**(26, 10)**	**572 keV**
	Value	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**
E907- 2	0,046	0,017	0,024	0,007	0,038	0,014	0,1428	0,005	0,043	0,006	0,019	0,005	0,020	0,004
E907- 3	DL=0,0069		(o) 0,015	0,006			0,140	0,005	0,022	0,003			0,013	0,004
E907- 5			>0,0197	<0,0298			0,182	0,009						
E907- 6			(o) 0,163	0,055			(o) 0,055	0,046						
E907- 7	DL=0,0018		0,0253	0,0014	DL=0,0018		0,140	0,005	0,0281	0,0012	0,0019	0,0008	0,0153	0,0017
E907- 8	0,0020	0,0009	0,0269	0,0014	0,0007	0,0005	0,1451	0,0034	0,0431	0,0015				
Patil (2006Pa16)			0,0205	0,0010			0,1429	0,0076	0,0421	0,0013			0,0184	0,0010
Goswamy (1993Go10)			0,024	0,0020			0,14	0,02	0,043	0,002			0,0193	0,0013
Jianming (1988Yo05)			0,029	0,0080			0,165	0,010	0,047	0,011			0,025	0,010
Mardirosian (1984Ma13)			0,030	0,005			0,178	0,012						
Iwata (1984Iw03)							0,117	0,012						
Johnson (1974Jo03)							0,132	0,010						
Meyer (1990Me15)							0,16	0,01						
Sharma (1979Sh08)							0,162	0,004						
Chi2	3,5		3,1				4,5		20,6				1,3	
Chi2 crit:	6,6		2,8				2,2		2,8				3,0	
UWM:	0,02402		0,02567				0,14975		0,03828				0,01843	
WM:	0,02402		0,02367				0,14837		0,03675				0,01799	
Uc (int):	0,01171		0,00065				0,00168		0,00068				0,00070	
Uc (ext) :	0,02198		0,00115				0,00357		0,00310				0,00080	
LWM :	0,024	0,022	0,0237	0,0032			0,1484	0,0036	0,037	(e) 0,009			0,018	0,0008
I Abs.*	omitted		0,0232	0,0031	omitted		0,1451	0,0035	0,036	0,009	omitted		0,0176	0,0008

(o) Outlier
(e) expanded uncertainty so range to include the most precise Value

Table 3 (Cont'd) : Relative gamma ray intensities and absolute Values calculated with $^{(*)}$Ig602 = 97,775 (20) %.
(i , j) refer to initial and final levels, (-1, n) transition not placed in the decay scheme. DL = Detection Limit

		592 keV	(1, 0)	602 keV	(5, 3)	632 keV	(2, 1)	646 keV	(21, 6)	662 keV		669 keV	(5, 2)	709 keV
	Value	Uc	Value	Uc	Value	Uc	Value	Uc	Value	Uc	Value	Uc	Value	Uc
E907- 2			100		0,100	0,008	7,57	0,07	0,041	0,004			1,358	0,019
E907- 3			100		0,098	0,004	7,59	0,10	DL=0,0063				1,388	0,016
E907- 5			100		0,109	0,007	7,603	0,027	<0,0157				1,396	0,007
E907- 6			100				7,69	0,14					1,484	0,072
E907- 7			100		0,1073	0,0010	7,58	0,03	0,0139	0,0009			1,397	0,006
E907- 8			100		0,1053	0,0028	$^{(o)}$ 7,35	0,16	0,0227	0,0012	0,180	0,004	1,36	0,03
Patil (2006Pa16)	0,014	0,002	100		0,0990	0,0013	7,69	0,09	0,0148	0,0010			1,39	0,02
Goswamy (1993Go10)			100		0,1070	0,0015	7,55	0,11	0,032	0,002			1,34	0,02
Jianming (1988Yo05)			100		0,101	0,006	7,55	0,13	0,035	0,011			1,38	0,04
Mardirosian (1984Ma13)			100		0,118	0,007	$^{(o)}$ 7,82	0,22	0,043	0,005			1,49	0,07
Iwata (1984Iw03)			100		0,114	0,006	7,61	0,04	0,016	0,005			1,399	0,012
Johnson (1974Jo03)			100		0,12	0,03	7,53	0,16	0,015	0,003			1,38	0,09
Meyer (1990Me15)			100		0,10	0,01	7,55	0,05					1,38	0,02
Sharma (1979Sh08)			100		0,111	0,003	7,52	0,15	0,0148	0,0015			1,465	0,029
Chi2					3,4		0,3		18,7				1,6	
Chi2 crit:					2,2		2,2		2,4				2,1	
UWM:					0,10692		7,5861		0,02480				1,4008	
WM:					0,10524		7,5911		0,01790				1,3941	
Uc (int):					0,00064		0,0152		0,00050				0,0036	
Uc (ext) :					0,00118		0,0084		0,00217				0,0046	
LWM :					0,1052	$^{(e)}$ 0,0021	7,591	0,015	$^{(u)}$ 0,025	$^{(e)}$ 0,011			1,394	0,005
I Abs.*	Omitted		97,775	0,020	0,1029	0,0021	7,422	0,015	0,024	0,011	omitted		1,363	0,005

$^{(o)}$ Outlier
$^{(e)}$ expanded uncertainty so range to include the most precise Value
$^{(u)}$ unweighted mean

Table 3 (Cont'd) : Relative gamma ray intensities and absolute Values calculated with $^{(*)}$Ig602 = 97,775 (20) %.
(i , j) refer to initial and final levels, (-1, n) transition not placed in the decay scheme. DL = Detection Limit

	(6, 3)	713 keV	(3, 1)	722 keV	(23, 6)	735 keV		743 keV	(7, 3)	766 keV	(25, 6)	775 keV	(6, 2)	790 keV
	Value	Uc	Value	Uc	Value	Uc	Value	Uc	Value	Uc	Value	Uc	Value	Uc
E907- 2	2,26	0,03	10,81	0,10	0,137	0,005			0,012	0,003	0,0104	0,0017	0,756	0,008
E907- 3	2,324	0,026	10,95	0,13	0,132	0,006			DL=0,0072		0,000		0,753	0,012
E907- 5	2,327	0,012	10,950	0,037	0,125	0,013			>0,0177	<0,0268			0,756	0,008
E907- 6	2,33	0,09	10,95	0,20	$^{(o)}$ 0,22	0,06							$^{(o)}$ 0,824	0,073
E907- 7	2,33	0,01	10,96	0,04	0,1338	0,0016			0,0080	0,0012	0,0097	0,0005	0,758	0,004
E907- 8	2,26	0,05	10,73	0,24	0,1245	0,0030			0,0089	0,0014	0,0100	0,0014	$^{(o)}$ 0,733	0,016
Patil (2006Pa16)	2,29	0,03	10,88	0,16	0,1399	0,0024	0,0058	0,0011	$^{(o)}$ 0,0039	0,0003	0,0119	0,0012	0,766	0,012
Goswamy (1993Go10)	2,27	0,04	10,77	0,18	0,129	0,002			0,0124	$^{(i)}$ 0,0002	0,0093	0,0018	0,752	0,012
Jianming (1988Yo05)	2,29	0,05	10,99	0,19	0,145	0,021			0,0092	0,0041	0,0112	0,0041	0,753	0,013
Mardirosian (1984Ma13)	2,46	0,09	$^{(o)}$ 11,46	0,16	0,142	0,005			0,009	0,005	0,0112	0,0041	0,766	0,008
Iwata (1984Iw03)	2,338	0,015	11,02	0,06	0,133	0,009							0,758	0,009
Johnson (1974Jo03)	2,43	0,10	11,16	0,20	0,14	0,03							0,763	0,015
Meyer (1990Me15)	2,32	0,03	11,0	0,2	0,14	0,01							0,76	0,01
Sharma (1979Sh08)	2,42	0,05	$^{(o)}$ 11,31	0,22	0,146	0,004							0,734	0,016
Chi2	1,4		0,6		2,8				2,2		0,5		0,2	
Chi2 crit:	2,1		2,2		2,2				3,0		2,8		2,3	
UWM:	2,3317		10,9300		0,1359				0,00986		0,01052		0,75832	
WM:	2,3250		10,9525		0,1342				0,01053		0,01002		0,75842	
Uc (int):	0,0061		0,0224		0,0010				0,00059		0,00041		0,00247	
Uc (ext) :	0,0072		0,0176		0,0016				0,00089		0,00030		0,00120	
LWM :	2,325	0,007	10,952	0,022	0,1342	0,0016			0,0105	0,0009	0,01002	0,00041	0,7584	0,0025
I Abs.*	2,273	0,007	10,708	0,022	0,1312	0,0016	omitted		0,0103	0,0009	0,0098	0,0004	0,7415	0,0024

$^{(o)}$ Outlier
$^{(i)}$ This original uncertainty was increased in order to limit the relative weight to 50 %

Table 3 (Cont'd) : Relative gamma ray intensities and absolute Values calculated with (*)Ig602 = 97,775 (20) %
(i , j) refer to initial and final levels, (-1, n) transition not placed in the decay scheme. DL = Detection Limit

		795 keV	(23, 5)	817 keV	(8, 3)	856 keV	(9, 3)	899 keV		937 keV	(10, 3)	968 keV	(9, 2)	976 keV
	Value	Uc	Value	Uc	Value	Uc	Value	Uc	Value	Uc	Value	Uc	Value	Uc
E907- 2			0,081	0,007	0,0203	0,006	0,023	0,009	0,0206	0,005	1,907	0,055	0,084	0,005
E907- 3			0,074	0,007	0,017	0,006	0,026	0,016	DL=0,0085		1,921	0,024	(o) 0,095	0,011
E907- 5			0,076	0,013	>0,0187	<0,0288	<0,0187				1,909	0,013	0,088	0,013
E907- 6											(o) 2,857	0,118		
E907- 7			0,0735	0,0037	0,0228	0,0007	0,0175	0,0010	DL=0,0012		1,926	0,008	0,0862	0,0011
E907- 8			0,0745	0,0021	0,0243	0,0017	0,0176	0,0015	0,0032	0,0012	1,873	0,042	0,0833	0,0023
Patil (2006Pa16)	0,0368	0,0012			0,0216	0,0011	0,020	0,001			(o) 2,105	0,031	0,0841	0,0013
Goswamy (1993Go10)			0,074	0,002	0,024	0,001	0,0175	0,0014			1,92	0,028	0,0845	0,0019
Jianming (1988Yo05)			0,074	0,007	0,032	0,006	0,020	0,006			1,945	0,030	0,088	0,005
Mardirosian (1984Ma13)			0,086	0,008	0,027	0,006					2,038	0,024	0,088	0,012
Iwata (1984Iw03)			0,079	0,006	0,029	0,007	0,016	0,009			1,919	0,015	0,088	0,008
Johnson (1974Jo03)			(o) 0,065	0,006	0,022	0,006	0,011	0,004			2,03	0,04	(o) 0,102	0,020
Meyer (1990Me15)											1,93	0,03	0,09	0,01
Sharma (1979Sh08)			0,083	0,003	0,029	0,003	0,028	0,004			2,03	0,04	(o) 0,097	0,004
Chi2			1,1		1,2		1,4		5,3		3,5		0,4	
Chi2 crit:			2,4		2,3		2,4		6,6		2,2		2,4	
UWM:			0,0775		0,02447		0,01962		0,0119		1,9457		0,08639	
WM:			0,0761		0,02315		0,01825		0,0119		1,9304		0,08512	
Uc (int):			0,0012		0,00048		0,00059		0,0038		0,0053		0,00070	
Uc (ext) :			0,0012		0,00052		0,00071		0,0087		0,0099		0,00042	
LWM :			0,0761	0,0012	0,0232	0,0005	0,0183	0,0007	0,012	0,009	1,93	0,01	0,0851	0,0007
I Abs.*	omitted		0,0744	0,0012	0,0227	0,0005	0,0179	0,0007	omitted		1,887	0,010	0,0832	0,0007

(o) Outlier

Table 3 (Cont'd) : Relative gamma ray intensities and absolute Values calculated with (*)Ig602 = 97,775 (20) %
(i , j) refer to initial and final levels, (-1, n) transition not placed in the decay scheme. DL = Detection Limit

	(-1, 2)	997 keV		1014 keV	(10, 2)	1045 keV	(4, 1)	1053 keV	(12, 2)	1086 keV	1097 keV			1163 keV
	Value	Uc	Value	Uc	Value	Uc	Value	Uc	Value	Uc	Value	Uc	Value	Uc
E907- 2	0,025	0,007			1,884	0,036			0,041	0,004	0,034	0,008		
E907- 3	DL=0,0091		DL=0,0093		1,867	0,024	DL=0,0097		0,042	0,009			DL=0,0108	
E907- 5					1,861	0,017			0,050	0,008				
E907- 6					2,00	0,11								
E907- 7	0,0014	0,0014 (i)	0,0025	0,0025	1,880	0,008	0,0026	0,0026	0,0369	0,0012	DL=0,0019		DL=0,0019	
E907- 8	0,0046	0,0009	0,0046	0,0014	1,841	0,041	0,0036	0,0012	0,0368	0,0018	0,0026	0,0012	0,0033	
Patil (2006Pa16)					2,026	0,022			0,0358	0,0016				
Goswamy (1993Go10)					1,87	0,03	0,005	0,002	0,038	0,002				
Jianming (1988Yo05)					1,90	0,03			0,043	0,005				
Mardirosian (1984Ma13)					2,01	0,02	0,007	0,001	(o) 0,058	0,005				
Iwata (1984Iw03)					1,86	0,02			0,038	0,009				
Johnson (1974Jo03)					1,92	0,04			0,031	0,005				
Meyer (1990Me15)					1,88	0,04								
Sharma (1979Sh08)					1,97	0,04			0,046	0,004				
Chi2	5,8		0,5		6,2		1,9		1,2					
Chi2 crit:	4,6		6,6		2,1		3,8		2,3					
UWM:	0,01033		0,00354		1,9123		0,00457		0,03985					
WM:	0,00343		0,00408		1,8936		0,00538		0,03739					
Uc (int):	0,00099		0,00124		0,0053		0,00070		0,00074					
Uc (ext) :	0,00238		0,00088		0,0133		0,00097		0,00081					
LWM :	0,0034	0,0024	0,0041	0,0012	1,894	0,014	0,0054	0,0010	0,0374	0,0008				
I Abs.*	0,0033	0,0023	Omitted		1,852	0,014	0,0053	0,0010	0,0366	0,0008	omitted		omitted	

(o) Outlier
(i) This original uncertainty was increased in order to limit the relative weight to 50 %

Table 3 (Cont'd) : Relative gamma ray intensities and absolute Values calculated with (*)Ig602 = 97,775 (20) %
(i , j) refer to initial and final levels, (-1, n) transition not placed in the decay scheme. DL = Detection Limit

		1180 keV		**1198 keV**		**1205 keV**	**(-1, 3)**	**1235 keV**		**1253 keV**	**(15, 2)**	**1263 keV**		**1269 keV**
	Value	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**
E907- 2							0,028	0,006	0,042	0,009	0,043	0,004		
E907- 3			DL=0,0112		DL=0,012				DL=0,0117		0,030	0,010	DL=0,0118	
E907- 5											0,031	0,008		
E907- 6														
E907- 7			DL=0,002		DL=0,016		0,0047	(i) 0,0010	DL=0,0019		0,0413	0,0015	DL=0,0019	
E907- 8	0,630	0,014	0,0031	0,0009	0,0314	0,0012	0,0094	0,0012			0,0382	0,0018	0,0037	0,0013
Patil (2006Pa16)											0,0482	0,0015		
Goswamy (1993Go10)											0,042	0,002		
Jianming (1988Yo05)											0,043	0,005		
Mardirosian (1984Ma13)											0,054	0,010		
Iwata (1984Iw03)											0,046	0,015		
Johnson (1974Jo03)											0,045	0,010		
Meyer (1990Me15)														
Sharma (1979Sh08)											0,057	0,005		
Chi2							9,8				3,1			
Chi2 crit:							4,6				2,2			
UWM:							0,0141				0,0432			
WM:							0,0075				0,0432			
Uc (int):							0,00086				0,0008			
Uc (ext) :							0,00269				0,0014			
LWM :							0,0075	0,0027			0,0432	(e) 0,0019		
I Abs.*	Omitted		omitted		omitted		0,0073	0,0026	omitted		0,0422	0,0019	omitted	

(e) expanded uncertainty so range to include the most precise Value
(i) This original uncertainty was increased in order to limit the relative weight to 50 %

Table 3 (Cont'd) : Relative gamma ray intensities and absolute Values calculated with (*)Ig602 = 97,775 (20) %.
(i , j) refer to initial and final levels, (-1, n) transition not placed in the decay scheme. DL = Detection Limit

	(17, 2)	**1301 keV**	**(3, 0)**	**1325 keV**	**(5, 1)**	**1355 keV**	**(20, 3)**	**1368 keV**	**(21, 3)**	**1376 keV**	**(22, 3)**	**1385 keV**		**1418 keV**
	Value	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**
E907- 2	0,032	0,004	1,637	0,033	1,066	0,031	2,650	0,045	0,521	0,021	0,072	0,006		
E907- 3	0,047	0,010	1,599	0,027	1,059	0,022	2,628	0,034	0,481	0,016	0,051	0,012		
E907- 5	0,037	0,009	1,603	0,016	1,055	0,022	2,686	0,017	0,505	0,009	0,064	0,008		
E907- 6			1,582	0,137	1,011	0,114	2,65	0,13	0,516	0,099	(o) 0,20	0,08		
E907- 7	0,0339	0,0021	1,621	0,007	1,062	0,004	2,682	0,011	0,5130	(i) 0,0034	0,070	0,002		
E907- 8	0,037	0,003	(o) 1,768	0,040	1,070	0,024	2,633	0,061	0,493	0,011	0,060	0,002		
Patil (2006Pa16)	0,0256	0,0013	1,707	0,026	1,093	0,017	2,7	0,034	0,543	0,007	0,064	0,002	0,005	0,002
Goswamy (1993Go10)	0,035	0,001	1,61	0,03	1,05	0,015	2,64	0,04	0,493	0,008	0,062	0,003		
Jianming (1988Yo05)	0,039	0,005	1,645	0,028	1,103	0,021	2,696	0,041	0,496	0,011	0,071	0,006		
Mardirosian (1984Ma13)	(o) 0,061	0,008	1,69	0,29	1,108	0,022	2,758	0,069	0,531	0,046	0,079	0,025		
Iwata (1984Iw03)	0,041	0,015	1,584	0,023	1,042	0,027	2,67	0,03	0,50	0,02	0,061	0,026		
Johnson (1974Jo03)			1,67	0,04	(o) 1,14	0,04	2,76	0,06	0,54	0,03	(o) 0,03	0,01		
Meyer (1990Me15)			1,66	0,04	1,06	0,04	2,68	0,05	0,51	0,04				
Sharma (1979Sh08)	0,045	0,004	1,71	0,04	1,17	0,02	(o) 2,82	0,06	(o) 0,572	0,012	0,053	0,003		
Chi2	5,5		2,0		1,1		0,7		2,9		3,5			
Chi2 crit:	2,4		2,2		2,2		2,2		2,2		2,3			
UWM:	0,0372		1,6399		1,06493		2,6794		0,51101		0,06434			
WM:	0,0327		1,6233		1,06491		2,6796		0,51128		0,06337			
Uc (int):	0,0007		0,0051		0,00363		0,0076		0,00258		0,00096			
Uc (ext) :	0,0017		0,0073		0,00387		0,0063		0,00438		0,00180			
LWM :	(u) 0,0372	(e) 0,0022	1,623	0,007	1,0649	0,0039	2,680	0,008	0,5113	0,0044	0,063	(e) 0,006		
I Abs.*	0,0364	0,0022	1,587	0,007	1,0412	0,0038	2,620	0,008	0,4999	0,0043	0,062	0,006	omitted	

(o) Outlier
(e) expanded uncertainty so range to include the most precise Value
(u) unweighted mean

Table 3 (Cont'd) : Relative gamma ray intensities and absolute Values calculated with (*)Ig602 = 97,775 (20) %.
(i , j) refer to initial and final levels, (-1, n) transition not placed in the decay scheme. DL = Detection Limit

	1428 keV		**(6, 1)**	**1436 keV**	**(20, 2)**	**1445 keV**	**(21, 2) ?**	**1453 keV**	**(7, 1)**	**1489 keV**		**1509 keV**	**(23, 2)**	**1526 keV**
	Value	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**
E907- 2	0,049	0,007	1,253	0,026	0,336	0,008	0,032	0,007	0,686	0,018	0,052	0,016	0,421	0,019
E907- 3			1,266	0,022	0,309	0,014	DL=0,0163		0,684	0,016			0,404	0,012
E907- 5			1,244	0,031	0,350	0,012			0,693	0,015			0,443	0,016
E907- 6			1,19	0,10	0,38	0,09			0,71	0,09			0,43	0,08
E907- 7	DL=0,0026		1,257	(i) 0,005	0,336	(i) 0,002	DL=0,0027		0,700	0,007			0,4184	(i) 0,0026
E907- 8	0,0276	(i) 0,0017	1,313	0,030	0,384	0,009	0,080	0,002	0,667	0,015	0,0074	0,0025	0,398	0,010
Patil (2006Pa16)			1,27	0,017	0,335	0,032			0,692	0,009	0,008	0,001	0,451	0,006
Goswamy (1993Go10)			1,25	0,016	0,334	0,005			0,687	0,009			0,414	0,006
Jianming (1988Yo05)			1,236	0,021	0,346	0,011			0,71	0,05			0,434	0,010
Mardirosian (1984Ma13)			1,34	0,27	0,329	0,014			0,72	0,02			0,433	0,008
Iwata (1984Iw03)			1,225	0,024	0,358	0,017			0,68	0,02			0,41	0,02
Johnson (1974Jo03)			1,38	0,04	0,30	0,03			0,70	0,03			0,45	0,02
Meyer (1990Me15)			1,26	0,05	0,34	0,04			0,71	0,03			0,41	0,03
Sharma (1979Sh08)			1,37	0,03	0,41	0,01			(o) 0,80	0,02			(o) 0,49	0,01
Chi2	4,9		2,5		7,2		21,4		0,7		3,7		3,4	
Chi2 crit:	6,6		2,1		2,1		6,6		2,2		4,6		2,2	
UWM:	0,0383		1,2748		0,3460		0,0561		0,6959		0,0225		0,4241	
WM:	0,0383		1,2619		0,3423		0,0561		0,6924		0,0081		0,4232	
Uc (int):	0,0049		0,0051		0,0021		0,0052		0,0038		0,0009		0,0022	
Uc (ext) :	0,0107		0,0080		0,0057		0,0241		0,0031		0,0018		0,0040	
LWM :	0,038	0,011	1,262	0,008	0,342	(e) 0,007	0,056	0,024	0,6924	0,0038	0,0081	0,0018	0,423	0,005
I Abs.*	omitted		1,234	0,008	0,334	0,007	omitted		0,677	0,0037	omitted		0,414	0,005

(o) Outlier
(e) expanded uncertainty so range to include the most precise Value
(i) This original uncertainty was increased in order to limit the relative weight to 50 %

Table 3 (Cont'd) : Relative gamma ray intensities and absolute Values calculated with (*)Ig602 = 97,775 (20) %.
(i , j) refer to initial and final levels, (-1, n) transition not placed in the decay scheme. DL = Detection Limit

	1557 keV		**(25, 2)**	**1565 keV**	**(8, 1)**	**1580 keV**	**(9, 1)**	**1622 keV**	**(4, 0)**	**1657 keV**	**(10, 1)**	**1691 keV**	**(11, 1)**	**1720 keV**
	Value	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**
E907- 2					0,441	0,018	0,041	0,003			46,72	1,16	0,098	0,005
E907- 3			DL=0,0105		0,422	0,015	0,043	0,008	DL=0,0089		48,08	0,57	(o) 0,090	0,004
E907- 5			>0,0197	<0,0298	0,414	0,008					48,28	0,21	0,100	0,007
E907- 6							(o) 0,22	0,05			49,12	0,94	(o) 0,135	0,044
E907- 7	DL=0,0017		0,012	0,001	(r) 0,145	0,001	0,041	0,001	DL=0,0012		48,70	0,18	0,0967	0,0007
E907- 8	0,014	0,007	0,006	(i) 0,001	0,354	0,009	0,042	0,001	0,0086	0,0034	46,35	1,13	0,0963	0,0025
Patil (2006Pa16)					0,460	0,006	0,0477	0,0013			46,63	0,65	0,097	0,0180
Goswamy (1993Go10)			0,015	0,004	0,427	0,007	0,042	0,001			49,32	0,74	0,096	0,0022
Jianming (1988Yo05)			0,013	0,004	0,42	0,04	0,040	0,004			48,73	0,78	0,102	0,0041
Mardirosian (1984Ma13)					(r) 0,238	0,007	0,047	0,004			50,88	0,88	0,101	0,005
Iwata (1984Iw03)					(r) 0,155	0,012	0,035	0,012			48,58	0,25	0,097	0,0070
Johnson (1974Jo03)					(r) 0,15	0,05	(o) 0,03	0,01			51,3	1,0	0,096	0,007
Meyer (1990Me15)					0,42	0,03					48,4	0,8		
Sharma (1979Sh08)					0,49	0,01	0,047	0,003			50,6	1,0	(o) 0,104	0,003
Chi2			2,9		0,4		3,0				3,0		0,3	
Chi2 crit:			3,8		3,3		2,4				2,1		2,4	
UWM:			0,0114		0,4203		0,0425				48,692		0,09794	
WM:			0,0111		0,4217		0,0425				48,545		0,09684	
Uc (int):			0,0007		0,0047		0,0005				0,108		0,00063	
Uc (ext) :			0,0012		0,030		0,0009				0,186		0,00035	
LWM :			0,0111	0,0012	0,422	0,005	0,0425	(e) 0,0019			48,54	0,19	0,0968	0,0006
I Abs.*	omitted		0,0109	0,0012	0,412	0,005	0,0416	0,0019			47,46	0,19	0,0946	0,0006

(i) This original uncertainty was increased in order to limit the relative weight to 50 %
(r) Removed from analysis
(o) Outlier
(e) expanded uncertainty so range to include the most precise Value

Table 3 (Cont'd) : Relative gamma ray intensities and absolute Values calculated with $^{(*)}$Ig602 = 97,775 (20) %.
(i , j) refer to initial and final levels, (-1, n) transition not placed in the decay scheme. DL = Detection Limit

		1757 keV	**(13, 1)**	**1852 keV**	**(16, 1)**	**1918 keV**		**1950 keV**		**1970 keV**	**(18, 1)**	**2016 keV**	**(6, 0)**	**2039 keV**
	Value	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**
E907- 2					0,056	0,005					0,013	0,002	0,0633	0,004
E907- 3			DL=0,0077		0,051	0,003			DL=0,016		0,008	0,002	0,064	0,003
E907- 5					0,054	0,008							0,064	0,006
E907- 6	0,007	0,021	$^{(o)}$0,341	0,061	$^{(o)}$0,077	0,038								
E907- 7	DL=0,0009		0,0054	0,0006	0,0537	0,0005	DL=0,0006				0,0092	$^{(i)}$0,0003	0,0636	0,0006
E907- 8			0,0008	$^{(i)}$0,0001	0,0529	0,0019	0,053	0,011			0,0098	0,0011	$^{(o)}$0,0753	0,0020
Patil (2006Pa16)			0,0026	0,0001	0,058	0,016					0,0090	0,0009	0,0661	0,0020
Goswamy (1993Go10)	0,0049	0,0023	0,0062	0,0009	0,055	0,002					0,0112	0,0010	0,066	0,0021
Jianming (1988Yo05)			$^{(o)}$0,0112	0,0031	0,06	0,03					0,0124	0,0007	0,068	0,0021
Mardirosian (1984Ma13)	0,0188	0,0035	0,0025	0,0025	0,055	0,003					0,0112	0,0025	0,068	0,003
Iwata (1984Iw03)					0,052	0,004					0,0093	0,0026	$^{(o)}$0,0589	0,0029
Johnson (1974Jo03)					0,058	0,004					0,007	0,002	0,067	0,004
Meyer (1990Me15)					0,05	0,01							0,07	0,01
Sharma (1979Sh08)					0,059	0,002					0,012	0,001	0,067	0,003
Chi2	4,0		10,5		0,8						2,9		0,9	
Chi2 crit:	4,6		3,3		2,2						2,3		2,3	
UWM:	0,01032		0,00350		0,05494						0,01017		0,06611	
WM:	0,01170		0,00314		0,05405						0,00999		0,06446	
Uc (int):	0,0024		0,0003		0,00046						0,00026		0,00051	
Uc (ext) :	0,0049		0,0009		0,00042						0,00044		0,00049	
LWM :	0,0117	0,0049	0,0031	0,0009	0,0541	0,0005					0,0100	$^{(e)}$0,0008	0,0645	0,0005
I Abs.*	omitted		0,0030	0,0009	0,0529	0,0005	omitted		omitted		0,0098	0,0008	0,0631	0,0005

$^{(o)}$ Outlier
$^{(e)}$ expanded uncertainty so range to include the most precise Value
$^{(i)}$ This original uncertainty was increased in order to limit the relative weight to 50%

Table 3 (Cont'd) : Relative gamma ray intensities and absolute Values calculated with (*)Ig602 = 97,775 (20) %.
(i , j) refer to initial and final levels, (-1, n) transition not placed in the decay scheme. DL = Detection Limit

	(19, 1)	**2079 keV**	**(20, 1)**	**2090,9 keV**	**(21, 1)**	**2099 keV**	**(22, 1)**	**2108 keV**		**2145 keV**		**2151 keV**	**(23, 1)**	**2172 keV**
	Value	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**
E907- 2	0,0289	0,003	5,28	0,20	0,046	0,003	0,052	0,003						
E907- 3	0,024	0,001	5,56	0,08	0,058	0,001	0,048	0,001					0,0030	0,0003
E907- 5	0,018	0,002	5,59	0,05	0,054	0,003	0,057	0,004						
E907- 6														
E907- 7	0,0206	0,0006	5,63	0,02	0,0448	(i) 0,0004	0,0430	(i) 0,0003			DL=0,0002		0,0014	(i) 0,0001
E907- 8	0,0213	0,0008	5,34	0,14	0,0532	0,0016	0,0457	0,0013			0,0010	0,0005	0,0057	0,0002
Patil (2006Pa16)	(o) 0,0741	0,0019	5,40	0,07	0,0572	0,0013	0,0501	0,0009	0,00068	0,0000				
Goswamy (1993Go10)	0,0268	0,0014	5,74	0,09	0,047	0,001	0,045	0,002					0,0021	0,0005
Jianming (1988Yo05)	0,0163	0,0025	5,69	0,11	0,046	0,002	0,044	0,002						
Mardirosian (1984Ma13)	0,037	0,009	5,92	0,1	0,037	0,005	0,035	0,005					0,0046	0,0010
Iwata (1984Iw03)	0,0163	0,0025	5,59	0,03	0,045	0,006	0,0438	0,0027						
Johnson (1974Jo03)	(r) 0,081		5,86	0,14	0,051	0,020	0,056	0,010						
Meyer (1990Me15)			5,7	0,1	0,04	0,01	0,04	0,01						
Sharma (1979Sh08)	0,0305	0,0010	5,75	0,12	0,04	0,01	0,047	0,002						
Chi2	12,2		2,8		12,0		6,1						74,3	
Chi2 crit:	2,4		2,2		2,2		2,2						3,3	
UWM:	0,02393		5,6195		0,04762		0,04667						0,00337	
WM:	0,02286		5,6176		0,04824		0,04540						0,00301	
Uc (int):	0,00036		0,0150		0,00042		0,00037						0,00011	
Uc (ext) :	0,0012		0,025		0,00146		0,00092						0,00094	
LWM :	0,0229	(e) 0,0023	5,618	0,025	0,0482	(e) 0,0034	0,0454	(e) 0,0024					0,0030	(e) 0,0016
I Abs.*	0,0224	0,0022	5,493	0,024	0,0471	0,0033	0,0444	0,0023	omitted		omitted		0,0029	0,0016

(i) This original uncertainty was increased in order to limit the relative weight to 50 %
(o) Outlier
(e) expanded uncertainty so range to include the most precise Value

Table 3 (Cont'd) : Relative gamma ray intensities and absolute Values calculated with $^{(*)}$Ig602 = 97,775 (20) %.
(i , j) refer to initial and final levels, (-1, n) transition not placed in the decay scheme. DL = Detection Limit

	(8, 0)	2182 keV	? (24, 1)	2204 keV	? (9, 0)	2224 keV		2232 keV		2253 keV		2256 keV		2274 keV
	Value	Uc	Value	Uc	Value	Uc	Value	Uc	Value	Uc	Value	Uc	Value	Uc
E907- 2	0,043	0,003	0,030	0,002	0,021	0,013								
E907- 3	0,041	0,001												
E907- 5	0,042	0,008												
E907- 6														
E907- 7	0,0422	0,0004	0,0004	0,0002	0,0002	0,0001			DL=0,00014		DL=0,00015			
E907- 8	0,0424	0,0011	0,0051	0,0002	0,0020	0,0003			0,0006	0,0001			0,0008	0,0003
Patil (2006Pa16)	$^{(o)}$ 0,036	0,007	0,0310	0,0007			0,001	0,003			0,0006	0,0002		
Goswamy (1993Go10)	0,044	0,001												
Jianming (1988Yo05)	0,045	0,002												
Mardirosian (1984Ma13)	$^{(o)}$ 0,048	0,002												
Iwata (1984Iw03)	0,0398	0,0019												
Johnson (1974Jo03)	0,041	0,003												
Meyer (1990Me15)	0,04	0,01												
Sharma (1979Sh08)	0,044	0,001												
Chi2	1,0		706,4		11,9									
Chi2 crit:	2,3		3,8		4,6									
UWM:	0,04217		0,01671		0,00773									
WM:	0,04241		0,00415		0,00109									
Uc (int):	0,00032		0,00015		0,00020									
Uc (ext) :	0,00031		0,00392		0,00068									
LWM :	0,04241	0,00032	0,017	0,016	0,0011	0,0009								
I Abs.*	0,04147	0,00031	Omitted		omitted		omitted		omitted		omitted		omitted	

$^{(o)}$ Outlier

Table 3 (Cont'd) : Relative gamma ray intensities and absolute Values calculated with (*)Ig602 = 97,775 (20) %.
(i , j) refer to initial and final levels, (-1, n) transition not placed in the decay scheme. DL = Detection Limit

	(27, 1)	2283 keV	(10, 0)	2294 keV	(11, 0)	2323 keV		2373 keV		2386 keV	(13, 0)	2455 keV		2490 keV
	Value	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**	**Value**	**Uc**
E907- 2	(o) 0,024	0,015	(r) 0,082	0,007	(o) 0,0098	0,0044					0,0093	0,0034		
E907- 3	0,0051	0,0004	0,029	(i) 0,001	DL=0,005		DL=0,0049		DL=0,004					
E907- 5			0,032	0,002										
E907- 6														
E907- 7	0,0046	0,0006	0,0342	0,0010	0,0020	(i) 0,0001					0,0015	0,0002		
E907- 8	0,0064	0,0004	(o) 0,413	0,011	0,0037	0,0003					0,0019	0,0003		
Patil (2006Pa16)	(o) 0,0422	0,0010	0,056	0,023	(o) 0,0060	0,0003	0,0009	0,0003	0,00024	0,00002	(r) 0,0092	0,0001	0,0020	0,0010
Goswamy (1993Go10)	0,0101	0,0008	(r) 0,076	0,005	0,0027	0,0003					0,0018	0,0002		
Jianming (1988Yo05)	0,0076	0,0014	0,031	0,005	0,0025	0,0007					0,0016	0,0006		
Mardirosian (1984Ma13)	0,010	0,002	0,045	0,002	0,004	0,001					0,0010	0,0005		
Iwata (1984Iw03)	0,0041	0,0013	0,031	0,010										
Johnson (1974Jo03)	0,007	0,002	0,025	0,005										
Meyer (1990Me15)	0,008	0,001	0,031	0,001										
Sharma (1979Sh08)	0,0051	0,0006	0,059	0,002										
Chi2	5,8		43,2		5,7						0,8			
Chi2 crit:	2,4		2,4		3,3						3,3			
UWM:	0,00677		0,0374		0,00298						0,00156			
WM:	0,00596		0,03335		0,00260						0,00164			
Uc (int):	0,00020		0,00042		0,00014						0,00012			
Uc (ext) :	0,00048		0,0027		0,00034						0,00011			
LWM :	0,0060	0,0005	0,0334	(e) 0,0042	0,0026	(e) 0,0006					0,00164	0,00012		
I Abs.*	0,0059	0,0005	0,0327	0,0041	0,0025	0,0006	omitted		omitted		0,00160	0,00012	omitted	

(o) Outlier
(e) expanded uncertainty so range to include the most precise Value
(r) removed from analysis
(i) This original uncertainty was increased in order to limit the relative weight to 50 %

Table 3 (Cont'd) : Relative gamma ray intensities and absolute Values calculated with (*)Ig602 = 97,775 (20) %.
(i , j) refer to initial and final levels, (-1, n) transition not placed in the decay scheme. DL = Detection Limit

		2515 keV	(19, 0)	2682 keV	(20, 0)	2693 keV		2746 keV	(24, 0)	2807 keV		2814 keV		2871 keV
	Value	Uc	Value	Uc	Value	Uc	Value	Uc	Value	Uc	Value	Uc	Value	Uc
E907- 2			(o) 0,007	0,003	0,0048	0,0021			(o) 0,0069	0,003				
E907- 3					0,0019	0,0001								
E907- 5					0,0025	0,0003								
E907- 6														
E907- 7			0,0017	0,0001	0,0033	0,0001			0,0007	0,0002			0,0002	0,0001
E907- 8			0,0019	0,0001	(o) 0,0433	0,0012			0,0016	0,0002				
Patil (2006Pa16)	0,00049	0,00001			0,0003	0,0001	0,0010	0,0001			0,0035	0,0002		
Goswamy (1993Go10)			0,0020	0,0004	0,0047	0,0005			0,0015	0,0002				
Jianming (1988Yo05)			0,0018	0,0006	0,0026	0,0016			0,0020	0,0008				
Mardirosian (1984Ma13)			(o) 0,0025	0,0010	0,0056	0,0010								
Iwata (1984Iw03)					0,0027	0,0019								
Johnson (1974Jo03)					0,0024	0,0005								
Meyer (1990Me15)					0,0026	0,0003								
Sharma (1979Sh08)					0,0066	0,0005								
Chi2			0,7		48,2				4,5					
Chi2 crit:			3,8		2,2				3,8					
UWM:			0,00187		0,00334				0,00145					
WM:			0,00180		0,00186				0,00121					
Uc (int):			0,00006		0,00005				0,00011					
Uc (ext) :			0,00005		0,00038				0,00024					
LWM :			0,00180	0,00006	(u) 0,0033	(e) 0,0014			0,0012	(e) 0,0005				
I Abs.*	omitted		0,00176	0,00006	0,0032	0,0014	omitted		0,0012	0,0005	omitted		omitted	

(o) Outlier
(e) expanded uncertainty so range to include the most precise Value
(u) unweighted mean

Table 4 : Absolute gamma ray intensity values measured by the participants in the Euramet project 907; in %.

	148 keV		158 keV		185 keV		189 keV		210 keV		254 keV		291 keV	
	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc
E907- 2	0,012	0,005	0,005	0,001			0,002	0,001	0,0086	0,0012	0,0089	0,0014	0,0045	0,0008
E907- 3	DL=0,0031		DL=0,0032		DL=0,0041		DL=0,0042		DL=0,0043		0,013	0,002	DL=0,0053	
E907- 5														
E907- 6														
E907- 7	0,0052	0,0011	0,0069	0,0014			0,0096	0,0058	0,0046	0,0023	0,0155	0,0015	0,0090	0,0009
E907- 8	0,0029	0,00084	0,0046	0,0007			0,0053	0,0005	0,0054	0,0010	0,0159	0,0014	0,0054	0,0011
Chi2	3,0		1,1				2,5		2,5		5,2		6,9	
Chi2 crit:	4,6		4,6				4,6		4,6		3,8		4,6	
UWM:	0,00669		0,00549				0,0056		0,00621		0,01340		0,00631	
WM:	0,00385		0,00506				0,0050		0,00649		0,01345		0,00618	
Uc (int):	0,00067		0,00055				0,0005		0,00073		0,00076		0,00053	
Uc (ext) :	0,00115		0,00056				0,0008		0,00114		0,00172		0,00140	
LWM :	0,0038	0,0012	0,0051	0,0006			0,005	0,0008	0,0065	0,0011	0,0135	(e) 0,0025	0,0062	(e) 0,0017

	335 keV		346 keV		370 keV		385 keV		400 keV		443 keV		468 keV	
	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc
E907- 2	0,077	0,007	0,0033	0,0016	0,033	0,011	0,037	0,025	0,124	0,008	(o) 0,186	0,004	0,052	0,009
E907- 3	0,071	0,004	DL=0,0064		0,032	0,006	DL=0,0078		0,117	0,006	0,194	0,005	0,037	0,003
E907- 5	0,071	0,020			>0,0217	<0,0328			0,143	0,011	0,193	0,011	0,044	0,006
E907- 6									0,16	0,06	0,192	0,069		
E907- 7	0,0717	0,0015	0,0018	0,0018	0,0289	0,0026	DL=0,0023		0,13	0,01	0,1938	0,0023	0,0507	0,0027
E907- 8	0,0710	0,0024	0,0034	0,0023	0,0334	0,0021			0,125	0,003	0,1899	0,0037	0,0467	0,0021
Chi2	0,0		0,3		0,6				1,0		0,2		3,0	
Chi2 crit:	3,8		4,6		3,8				3,0		3,3		3,3	
UWM:	0,07116		0,00280		0,03186				0,13252		0,19259		0,04617	
WM:	0,07144		0,00276		0,03167				0,12446		0,19289		0,04577	
Uc (int):	0,00123		0,00105		0,00155				0,00236		0,00183		0,00139	
Uc (ext) :	0,00020		0,00053		0,00122				0,00232		0,00086		0,00239	
LWM :	0,0714	0,0012	0,0028	0,001	0,0317	0,0016			0,1245	0,0024	0,1929	0,0018	0,0458	0,0024

	476 keV		481 keV		498 keV		525 keV		530 keV		553 keV		571 keV	
	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc
E907- 2	0,045	0,016	0,023	0,007	0,037	0,014	0,1393	0,0045	0,042	0,005	0,019	0,005	0,020	0,004
E907- 3	DL=0,0069		0,014	0,006			0,1367	0,0044	0,022	0,003			0,012	0,004
E907- 5			>0,0187	<0,0288			$^{(o)}$ 0,178	0,009						
E907- 6			0,148	0,050			$^{(o)}$ 0,050	0,042						
E907- 7	DL=0,0018		0,0248	0,0013	DL=0,0018		0,1372	0,0050	0,0275	$^{(i)}$ 0,0012	0,0019	0,0008	0,0149	0,0017
E907- 8	0,0019	0,0008	0,0250	0,0012	0,0007	$^{(i)}$ 0,0005	0,1449	0,0026	0,0433	0,0014				
Chi2	3,5		1,0		3,5		1,3		31,2				0,9	
Chi2 crit:	6,6		3,8		6,6		3,8		3,8				4,6	
UWM:	0,02344		0,02175		0,01884		0,13952		0,03348				0,01575	
WM:	0,02344		0,02465		0,01884		0,14138		0,03338				0,01508	
Uc (int):	0,01146		0,00088		0,00968		0,00187		0,00086				0,00143	
Uc (ext) :	0,02156		0,00087		0,01816		0,00211		0,00480				0,00136	
LWM :	0,023	0,022	0,0247	0,0009	0,019	0,018	0,1414	0,0021	0,033	$^{(e)}$ 0,006			0,0151	0,0014

	602 keV		632 keV		645 keV		662 keV		669 keV		709 keV		713 keV	
	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc
E907- 2	97,5	0,7	0,098	0,007	7,386	0,058	0,040	0,004			$^{(o)}$ 1,325	0,019	2,205	0,029
E907- 3	97,8	0,9	0,096	0,004	7,42	0,07	DL=0,0063				1,358	0,009	2,273	0,015
E907- 5	97,6	0,7	0,106	0,007	7,420	0,053	<0,0157				1,362	0,011	2,270	0,018
E907- 6	$^{(o)}$ 91	1			$^{(o)}$ 7,00	0,11					1,350	0,065	$^{(o)}$ 2,12	0,08
E907- 7	97,84	0,34	0,1050	0,0012	7,417	0,028	0,0136	0,0009			1,3671	0,0056	2,28	0,01
E907- 8	98,1	1,5	0,1052	0,0023	$^{(o)}$7,33	0,11	0,0229	0,0011	0,1793	0,0029	1,350	0,021	2,21	0,04
Chi2	0,1		1,4		0,1		36,6				0,3		2,1	
Chi2 crit:	3,3		3,3		3,8		4,6				3,3		3,3	
UWM:	97,787		0,10209		7,4117		0,0254				1,35734		2,2475	
WM:	97,769		0,10440		7,4137		0,0190				1,36347		2,2694	
Uc (int):	0,260		0,00098		0,0214		0,0007				0,00426		0,0074	
Uc (ext) :	0,071		0,00115		0,0065		0,0045				0,00246		0,0107	
LWM :	97,77	0,26	0,1044	0,0011	7,414	0,021	0,019	0,005			1,3635	0,0043	2,269	0,011

	722 keV		735 keV		765 keV		775 keV		790 keV		816 keV		856 keV	
	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc
E907- 2	(o) 10,538	0,084	0,134	0,005	0,0114	0,003	0,0101	0,002	0,737	0,007	(o) 0,079	0,006	0,020	0,001
E907- 3	10,713	0,072	0,129	0,005	DL=0,0072		DL=0,0073		0,737	0,010	0,072	0,007	0,017	0,005
E907- 5	10,680	0,075	0,122	0,012	>0,0167	<0,0258			0,737	0,009	0,074	0,013	>0,0177	<0,0278
E907- 6	(o) 9,96	0,16	(o) 0,200	0,054					0,750	0,066				
E907- 7	10,72	0,04	0,1309	(i) 0,0016	0,0078	0,0012	0,0095	0,0005	0,742	0,004	0,0719	0,0036	0,0223	0,0007
E907- 8	10,71	0,17	0,1173	0,0022	0,0085	0,0013	0,0093	0,0013	0,727	0,012	0,0745	0,0017	0,0230	0,0015
Chi2	0,1		6,4		0,6		0,1		0,3		0,2		3,1	
Chi2 crit:	3,8		3,3		4,6		4,6		3,0		3,8		3,8	
UWM:	10,7067		0,1266		0,00925		0,00962		0,73830		0,07313		0,02049	
WM:	10,7122		0,1260		0,00836		0,00951		0,73906		0,07398		0,02108	
Uc (int):	0,0310		0,0013		0,00084		0,00044		0,00293		0,00150		0,00044	
Uc (ext) :	0,0087		0,0033		0,00063		0,00013		0,00173		0,00060		0,00078	
LWM :	10,712	0,031	0,126	(e) 0,005	0,0084	0,0008	0,00951	0,00044	0,7391	0,0029	0,0740	0,0015	0,0211	0,0008

	899 keV		937 keV		968 keV		976 keV		997 keV		1014 keV		1045 keV	
	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc
E907- 2	0,022	0,009	0,020	0,005	1,86	0,05	0,082	0,005	0,024	0,007	0		1,837	0,033
E907- 3	0,026	0,016	DL=0,0085		1,880	0,018	(o) 0,093	0,011	DL=0,0091		DL=0,0093		1,826	0,019
E907- 5	<0,0187				1,863	0,017	0,086	0,013					1,816	0,020
E907- 6					(i) 2,60	0,11							1,82	0,10
E907- 7	0,0171	0,0010	DL=0,0012		1,88	0,01	0,0843	0,0010	0,0014	0,0014	0,0025	0,0025	1,839	0,008
E907- 8	0,0171	0,0014	0,0030	(i) 0,0012	1,87	0,03	0,0824	0,0019	0,0037	(i) 0,0007	0,0068	0,0021	1,836	0,029
Chi2	0,2		5,3		0,4		0,4		5,4		1,8		0,3	
Chi2 crit:	3,8		6,6		3,3		3,8		4,6		6,6		3,0	
UWM:	0,02041		0,0116		1,8711		0,08360		0,00971		0,00463		1,8292	
WM:	0,01717		0,0116		1,8797		0,08379		0,00300		0,00497		1,8350	
Uc (int):	0,00079		0,0037		0,0064		0,00090		0,00097		0,00161		0,0063	
Uc (ext) :	0,00035		0,0085		0,0040		0,00054		0,00224		0,00215		0,0034	
LWM :	0,0172	0,0008	0,012	0,009	1,880	0,006	0,0838	0,0009	0,0030	0,0022	0,0050	0,0021	1,835	0,006

	1053 keV		1086 keV		1097 keV		1163 keV		1180 keV		1198 keV		1205 keV	
	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc
E907- 2			0,040	0,004	0,0335	0,008								
E907- 3	DL=0,0097		0,041	0,009			DL=0,0108				DL=0,0112		DL=0,0115	
E907- 5			(o) 0,049	0,008										
E907- 6														
E907- 7	0,0026	0,0026	0,0361	0,0012	DL=0,0019		DL=0,0019				DL=0,002		DL=0,016	
E907- 8	0,0038	0,0013	0,0369	0,0017	0,0028	(i) 0,0013	0,0016	0,0010	0,606	0,010	0,0030	0,0009	0,0142	0,0005
Chi2	0,2		0,4		7,3									
Chi2 crit:	6,6		3,8		6,6									
UWM:	0,00319		0,03850		0,01815									
WM:	0,00357		0,03660		0,01815									
Uc (int):	0,00116		0,00095		0,00569									
Uc (ext) :	0,00051		0,00057		0,01535									
LWM :	0,0036	0,0012	0,0366	0,0009	0,018	0,015								

	1235 keV		1253 keV		1263 keV		1269 keV		1301 keV		1325 keV		1355 keV	
	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc
E907- 2	0,027	0,006	0,041	0,009	0,042	0,004			0,031	0,004	1,597	0,030	1,039	0,029
E907- 3			DL=0,0117		0,029	0,010	DL=0,0118		0,046	0,010	1,565	0,024	1,036	0,020
E907- 5					0,030	0,008			0,036	0,009	1,564	0,018	1,029	0,022
E907- 6											(o)1,440	0,124	(o) 0,92	0,10
E907- 7	0,0046	(i) 0,0009	DL=0,0018		0,0404	0,0014	DL=0,0019		0,0332	0,0021	1,586	0,006	1,0394	0,0043
E907- 8	0,0116	0,0015	0,0005			0,0016	0,0028	0,0010	0,0376	0,0030	(o)1,76	0,03	(o) 1,06	0,02
Chi2	10,8		11,0						0,9		0,7		0,1	
Chi2 crit:	4,6		6,6						3,3		3,8		3,8	
UWM:	0,01456		0,0208						0,03669		1,57771		1,03606	
WM:	0,00867		0,0208						0,03442		1,58251		1,03894	
Uc (int):	0,00105		0,0061						0,00154		0,00581		0,00405	
Uc (ext) :	0,00346		0,0202						0,00144		0,00480		0,00112	
LWM :	0,0087	0,004	0,021			0,0014			0,0344	0,0015	1,583	0,006	1,0389	0,0040

	1368 keV		1376 keV		1385 keV		1428 keV		1436 keV		1445 keV		1453 keV	
	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc
E907- 2	2,585	0,041	0,508	0,020	0,070	0,006	0,048	0,007	1,222	0,024	0,328	0,007	0,031	0,007
E907- 3	2,571	0,025	0,471	0,015	0,050	0,011			1,238	0,019	0,303	0,013	DL=0,0163	
E907- 5	2,621	0,023	0,493	0,009	0,062	0,008			1,210	0,031	0,342	0,012		
E907- 6	$^{(o)}$ 2,41	0,11	0,47	0,09	$^{(o)}$ 0,18	0,07			$^{(o)}$ 1,08	0,09	0,35	0,08		
E907- 7	2,624	0,011	0,5019	$^{(i)}$ 0,0033	0,0682	0,0018	DL=0,0025		1,230	0,005	0,3286	$^{(i)}$ 0,0023	DL=0,0026	
E907- 8	2,63	0,05	0,465	0,008	0,059	0,002	0,0262	0,0016	$^{(o)}$ 1,31	0,02	0,367	0,006	0,077	$^{(i)}$ 0,002
Chi2	1,1		3,4		3,4		5,3		0,2		6,8		20,6	
Chi2 crit:	3,3		3,0		3,3		6,6		3,8		3,0		6,6	
UWM:	2,6058		0,4849		0,06202		0,0371		1,2249		0,3364		0,0539	
WM:	2,6154		0,4904		0,06416		0,0371		1,2296		0,3363		0,0539	
Uc (int):	0,0088		0,0038		0,00125		0,0048		0,0048		0,0030		0,0050	
Uc (ext) :	0,0093		0,0070		0,00232		0,0109		0,0024		0,0078		0,0229	
LWM :	2,615	0,009	0,490	$^{(e)}$ 0,012	0,0642	$^{(e)}$ 0,0041	0,037	0,011	1,2296	0,0048	0,336	0,008	0,054	0,023

	1488 keV		1505 keV		1526 keV		1557 keV		1565 keV		1579 keV		1622 keV	
	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc
E907- 2	0,669	0,017	0,051	0,016	0,410	0,018					0,430	0,018	0,040	0,003
E907- 3	0,669	0,014			0,395	0,012			DL=0,0105		0,413	0,014	0,042	0,008
E907- 5	0,676	0,015			$^{(o)}$ 0,432	0,016			>0,0187	<0,0298	0,404	0,008		
E907- 6	0,65	0,09			0,39	0,07							$^{(o)}$ 0,200	0,046
E907- 7	0,685	0,007	DL=0,002		0,4094	0,0025	DL=0,0017		0,0114	$^{(i)}$ 0,0007	$^{(o)}$0,1420	0,0012	0,0397	0,0008
E907- 8	0,666	0,012	0,0084	0,0028	0,398	0,007	0,013	0,007	0,0053	0,0009	$^{(o)}$0,353	0,007	0,0397	0,0012
Chi2	0,5		3,6		0,9				20,9		0,9		0,0	
Chi2 crit:	3,0		6,6		3,3				6,6		4,6		3,8	
UWM:	0,6692		0,02970		0,4005				0,00838		0,4155		0,04028	
WM:	0,6770		0,02970		0,4077				0,00838		0,4091		0,03971	
Uc (int):	0,0051		0,01118		0,0023				0,00066		0,0066		0,00066	
Uc (ext) :	0,0037		0,02130		0,0022				0,00304		0,0064		0,00012	
LWM :	0,677	0,005	0,030	0,021	0,4077	0,0023			0,0084	0,0030	0,409	0,007	0,0397	0,0007

	1657 keV		1690 keV		1720 keV		1757 keV		1851 keV		1918 keV		1950 keV	
	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc
E907- 2			45,56	1,09	0,095	0,005					0,055	0,004		
E907- 3	DL=0,0089		47,04	0,40	(o) 0,088	0,004			DL=0,0077		0,049	0,003		
E907- 5			47,10	0,35	0,098	0,006					0,052	0,008		
E907- 6			(o) 44,70	0,77	(o) 0,123	0,041	0,007	0,019	(r) 0,31	0,06	(o) 0,070	0,035		
E907- 7	DL=0,0012		47,65	0,18	0,0946	0,0007	DL=0,0009		0,0053	0,0006	0,0526	0,0005	DL=0,0006	
E907- 8	0,009	0,003	46,03	0,87	0,0955	0,0020			0,0008	0,0001	0,0527	0,0017	0,0528	0,0110
Chi2			2,2		0,2				28,9		0,3			
Chi2 crit:			3,3		3,8				6,6		3,3			
UWM:			46,68		0,09581				0,00304		0,05235			
WM:			47,39		0,09475				0,00304		0,05254			
Uc (int):			0,15		0,00065				0,00042		0,00049			
Uc (ext) :			0,22		0,00025				0,00225		0,00028			
LWM :			47,39	0,22	0,0947	0,0006			0,0030	0,0023	0,0525	0,0005		

	1970 keV		2015 keV		2039 keV		2078 keV		2090 keV		2099 keV		2108 keV	
	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc
E907- 2			0,013	0,002	0,062	0,004	0,028	0,003	5,15	0,19	0,045	0,003	0,051	0,003
E907- 3	DL=0,0016		0,008	0,001	0,063	0,003	0,023	0,001	5,44	0,08	0,056	0,001	0,047	0,001
E907- 5					0,062	0,006	0,017	0,002	5,45	0,06	0,052	0,003	0,056	0,004
E907- 6														
E907- 7			0,0090	0,0003	0,0622	0,0006	0,0201	0,0006	5,511	0,022	0,0439	(i) 0,0004	0,0421	(i) 0,0003
E907- 8			0,0092	0,0010	(o) 0,0751	0,0016	0,0212	0,0007	5,33	0,11	0,0525	0,0013	0,0456	0,0011
Chi2			1,8		0,0		4,5		1,8		17,8		6,2	
Chi2 crit:			3,8		3,8		3,3		3,3		3,3		3,3	
UWM:			0,00968		0,06220		0,02198		5,3766		0,04998		0,0482	
WM:			0,00907		0,06221		0,02120		5,4909		0,04849		0,0444	
Uc (int):			0,00026		0,00058		0,00039		0,0193		0,00062		0,0006	
Uc (ext) :			0,00034		0,00010		0,00082		0,0256		0,00260		0,0014	
LWM :			0,00907	0,00034	0,0622	0,0006	0,0212	(e) 0,0011	5,491	0,026	0,0485	(e) 0,0046	0,048	(e) 0,006

	2151 keV		2172 keV		2182 keV		2203 keV		2224 keV		2253 keV		2274 keV	
	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc
E907- 2					0,042	0,003	0,030	0,002	0,020	0,013				
E907- 3			0,0029	0,0003	0,040	0,001								
E907- 5					0,040	0,008								
E907- 6														
E907- 7	DL=0,0002		0,0014	0,0001	0,0413	0,0004	0,0004	(i) 0,0002	0,0002	(i) 0,0001	DL=0,0001		DL=0,0002	
E907- 8	0,0016	0,0008	0,0057	0,0002	0,0435	0,0010	0,0063	0,0003	0,0020	0,0003	0,0005	0,0001	0,0008	0,0003
Chi2			172,2		1,6		241,5		12,0					
Chi2 crit:			4,6		3,3		4,6		4,6					
UWM:			0,00335		0,04131		0,01210		0,00738					
WM:			0,00317		0,04145		0,00359		0,00107					
Uc (int):			0,00011		0,00035		0,00018		0,00019					
Uc (ext) :			0,00140		0,00045		0,00280		0,00067					
LWM :			0,0032	(e) 0,0018	0,04145	0,00045	0,0036	(e) 0,0032	0,0011	(e) 0,0009				

	2283 keV		2293 keV		2323 keV		2454 keV		2682 keV		2693 keV		2808 keV	
	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc	I (%)	Uc
E907- 2	0,023	0,014	0,080	0,007	0,0096	0,0043	0,0091	0,0034	0,0071	0,0033	0,0047	0,0020	0,0067	0,0027
E907- 3	0,0049	0,0004	0,028	(i) 0,001	DL=0,005		DL=0,0049		DL=0,004		0,0019	(i) 0,0001	DL=0,0033	
E907- 5			0,032	0,002							0,0024	0,0003		
E907- 6														
E907- 7	0,0045	0,0006	0,0335	0,0010	0,0020	(i) 0,0001	0,0015	0,0002	0,0017	0,0001	0,0032	0,0001	0,0007	0,0002
E907- 8	0,0062	0,0003	(o) 0,414	0,009	0,0042	0,0003	0,0018	0,0003	0,0019	0,0001	(o) 0,0434	0,0010	0,0009	0,0001
Chi2	3,5		20,3		12,0		2,9		2,8		22,6		2,9	
Chi2 crit:	3,8		3,8		4,6		4,6		4,6		3,8		4,6	
UWM:	0,00966		0,04337		0,00526		0,00413		0,00358		0,00305		0,00277	
WM:	0,00545		0,03123		0,00311		0,00159		0,00177		0,00251		0,00084	
Uc (int):	0,00023		0,00065		0,00024		0,00016		0,00006		0,00008		0,00010	
Uc (ext) :	0,00043		0,00295		0,00082		0,00028		0,00010		0,00038		0,00018	
LWM :	0,00545	0,00043	0,0312	0,0029	0,0031	(e) 0,0011	0,00159	0,00028	0,00177	0,00010	0,0025	0,0006	0,00084	0,00018

	2871 keV	
	I (%)	**Uc**
E907- 2		
E907- 3		
E907- 5		
E907- 6		
E907- 7	0,0002	0,0001
E907- 8		
Chi2		
Chi2 crit:		
UWM:		
WM:		
Uc (int):		
Uc (ext) :		
LWM :		

(i) This original uncertainty was increased in order to limit the relative weight to 50 %
(o) Outlier
(e) expanded uncertainty so range to include the most precise I (%)
(r) removed from analysis

^{125}Sb - Comments on evaluation
by R. G. Helmer and E. Browne

The initial ^{125}Sb decay data evaluation was done by R.G.Helmer in May 2004 . This current (revised) evaluation was carried out in November 2004. The literature available by November 2004 was included.

1. Decay Scheme

^{125}Sb decays by β^- emission to levels in ^{125}Te.

The γ ray at 109 keV depopulates the isomeric level at 144 keV (half-life of 57.4 days), so its intensity depends on any chemical separation and its grow-in time. It takes about 1 year for it to be in equilibrium with the other γ rays to within 1%. The level at 35 keV is primarily fed from higher-lying levels, but 27% of the 35-keV γ-ray intensity comes via the isomeric level when it is at equilibrium. So, for a chemically separated source, it needs about 8 months grow-in to be at equilibrium at the 1% level.

The (direct β-, and indirect, through γ rays) population of the isomer is 22.9 (9) % calculated from this adopted decay scheme.

2. Nuclear Data

The decay energy of 766.7 (21) keV is from the 2003 mass evaluation (2003Au03).

For the adopted decay scheme, the total radiation energy per decay is calculated to be 767 (8) keV, which agrees well with the decay energy of 766.7 (21) keV and confirms the internal consistency of this decay scheme.

The population of several additional levels has been reported, especially by 1998Sa55, but these levels are uncertain; they are : 402-, 538-, 652- and 728- keV. Verification of the associated γ rays is needed. Thus, β and γ transitions to and from these levels have not been included here.

The adopted parent half-life is 1007.54 (9) days, or 2.75855 (25) years, from the following data:

2.7 y	1950Le09	
2.6 (1) y	1960Kl04	
2.78 (4) y	1961Wy01	
2.71 (2) y	1965Fl02	
2.81 (5) y	1966La13	
1007.3 (3) d	1980Ho17	
1008.1 (8) d	1983Wa26	
1007.3 (3) d	1992Un01,	superseded by 2002Un02
1007.56 (10) d	2002Un02	
1007.54 (9) d	Weighted average	

Adopted value is the weighted average of the three precise values (which are from after 1970) which are not superseded. The reduced-χ^2 value for this average is 0.58 and the value from 2002Un02 has 89% of the relative weight.

The values from other evaluations are 2.75856 (25) years from 1999Ka26, which did not have available the value from 2002Un02, and 1007.48 (21) days from 2004Wo02 where the relative weight of the value from 2002Un02 was presumably reduced to 50%.

The level half-lives are also taken from the evaluation 1999Ka26 and are as follows:

Energy (keV)	Half-life
0	Stable
35	1.48 (1) ns
144	57.40 (15) d
321	0.673 (13) ns
443	19.1 (6) ps
463	13.2 (5) ps
525	<160 ns
636	40 (20) ps
642	≤ 70 ps
671	1.26 (6) ps

The references that provide measured values of the level half-lives are: 1965An05, 1966In02, 1967Vo21, 1968Ho05, 1968Ko08, 1969Ho42, 1970Ba69, 1970Be47, 1970Be51, 1970Ma20, 1972Be21, 1972La21, 1972Sa08, 1972Sa33, 1988GeZS, and 1992De26. Half-lives for the levels at 443, 463, and 671 keV were calculated from B(E2) values from Coulomb excitation studies (1999Ka26).

2.1 β^- Transitions

The probabilities for the β^- transitions branches are computed from the intensity balances from the γ-ray transitions for the excited states above 150 keV. Upper limits for the β^- probabilities to the 0- and 35-keV levels can be computed from the log*ft* systematics (1998Si17); these values are 0.002% and 1.9%, respectively. In the adopted level scheme it is assumed that both of these values are 0. The resulting values are :

Level (kev)	P_{β^-} (%)	Character	log *ft*
0	<0.002	unique 2nd forb.	>13.9
35	≡0	2nd forb.	>10.6
144	13.4(9)	unique 1st forb.	9.77
321	7.54 (9)	1st forb.	9.32
443	0.089 (10)	2nd forb.	10.79
463	40.3 (4)	allowed	8.04
525	1.251 (12)	1st forb.	9.23
636	18.07 (19)	allowed	7.23
642	5.82 (5)	allowed	7.66
671	13.58 (12)	allowed	6.93

For comparison, the measured values to the 144keV level are 13.6 (9)% by 1998Gr13, 13.4% by 1959Na06, and 13.7% by 1964Ma30.

2.2 γ Transitions

The γ-ray multipolarities and mixing ratios have been taken from 1999Ka26 and the internal-conversion coefficients are interpolated from the tables of 1978Ro22, except the E5, which is from 1976Ba63. These values are as given in the following table. The uncertainties in the internal-conversion coefficients are taken to be 3% of the value, unless otherwise given. The total theoretical conversion coefficient of the M4 109-keV γ ray, calculated from 1978Ro22, has been reduced by 2.5% as suggested by 1990Ne01.

Energy (keV)	Multi-polarity.	Δ	%E2 or M2	α	α_K
19	[M1]			11.3	0.0
35	M1+E2	0.029 (+3-2)	0.084 (18)	14.3	12.1
109	M4			354.6	182
117	E1			0.127	0.109
(144)	[E5]			265	39.8
172	M1(+E2)	-0.004 (8)	<0.014	0.151	0.129
176	M1+E2	-0.60 (2)	26.5 (18)	0.167	0.139
178	M1+E2			0.18 (4)	0.147 (26)
198	[E2]			0.154	0.123
204	M1+E2	+1.60 (3)	72 (3)	0.128	0.104
208	M1+E2	+0.105 (14)	1.1 (3)	0.092	0.0791
227	(M1+E2)			0.084 (13)	0.070 (11)
315	(E1)			0.00839	0.00726
321	E1			0.00798	0.0691
380	E2			0.0183	0.0154
408	M1+E2	+1.50 (7)	69 (6)	0.0152	0.0129
427	M1+E2	-0.538 (11)	22.4 (9)	0.0138	0.0119
443	M1+E2	-2.3 (1)	84 (7)	0.0118	0.0100
463	E2			0.0102	0.0086
497	[M2]			0.0318	0.0271
600	E2			0.00498	0.00421
606	E2			0.00485	0.00415
635	M1+E2	+0.332 (3)	9.9 (2)	0.00526	0.00455
672	E2			0.00373	0.00319

The references that provide data on the multipolarities and mixing ratios are: 1968An15 [from α_K], 1970Na12 [α_K, K/L], 1970Wy01 [γγ(θ)], 1971Kr11 [γ(θ) oriented nuclei], 1971Ro17 [γγ(θ)], 1971Sa24 [γγ(θ)], 1972Ba12 [γγ(θ)], 1972Br02 [L_i/L_j], 1975Ma32 [M_i/M_j], 1982Mu02 [α_K], 1982Si18 [γγ(θ)], 1983Si14 [γγ(θ)], 1997De38

[$\gamma\gamma(\theta)$)], 1998Ro20 [$\gamma\gamma(\theta)$], 1998Sa36 [α_K, K/L], 1998Sa55 [α_K], and 1999Sa73 [α_K].

The γ-ray energies have been reported by 1969Ch09, 1970Na12, 1973Gu10, 1976Wa13, 1990He05, 1998Sa55, and 2000He14, with the last three references giving the more precise values. The calibration details are not given in 1998Sa55, so it is not possible to compare these values with the others. The values of 2000He14 are on the most recent energy scale on which the energy of the strong γ ray from the decay of ^{198}Au is 411.80205 (17) keV, while those from 1990He05 are on a scale for which this energy is 411.8044 (11) keV. No correction is made here for this difference. The energies are taken from 2000He14 if they are available there, from 1990He05 as a second choice, and as indicated otherwise. (Often these values are from use of energy combinations so they can not be averaged with direct measurements). These values are: from 2000He14: 176.314 (2), 204.138 (10), 208.077 (5), 427.874 (4), 443.555 (9), 463.365 (4), 600.597 (2), 606.713 (3), 635.950 (3), and 671.441 (6); from 1990He05: 35.489 (5), 172.719 (8), 178.842 (5), 198.654 (11), 227.891 (10), 380.452 (8), and 408.065 (10); 1976Wa13 and 1998Sa55: 19.981 (6), 110.86 (7), 314.96 (8), and 497. 38 (9); 1973Gu10, 1976Wa13, and 1998Sa55: 109.27 (11), and 116.95 (7).

The recommended relative and absolute γ-ray emission probabilities are discussed in section 4.2.

3. Atomic Data

3.1 X rays and Auger electrons

The fluorescence yield data are from Schönfeld and Janßen (1996Sc06) and the EMISSION code; these values are ω_K, 0.875(4); mean ω_L, 0.086 (4); and η_{KL}, 0.917 (4).

The EMISSION code also supplies the Auger electron emission probabilities; these values are: KLL, 7.0 (4); KLX, 3.17 (17); and KXY, 0.359 (20).

4 Emissions

4.1 K x-rays

The relative K x-ray emission probabilities are from 1996Sc06 and the absolute probabilities have been computed from these relative probabilities, the above γ-ray emission probabilities, and internal -conversion coefficients by using the EMISSION code.

4.2 g rays

The measured relative γ-ray emission probabilities (or intensities) are given in the following table. The values for the 109-keV γ ray are for a source in equilibrium.

Part 1

Energy	68An15[a]	68Se11[b]	69Ch09	70Na12	73Gu10	74Il02[c]	76Wa13	77Ar10	77Ge12
19.9							0.068 (33)		
35.5				19.6 (20)		1.42 (9)			
58.3									
109.3		0.3	0.3 (1)	0.39 (4) [f]	0.18 (2)	0.36 (4)			
110.8		~ 0.05				0.170 (23)	0.0031 (3)		
117.0		0.75		1.13 (1) [f]	0.75 (4) [f]	0.96 (7)	0.866 (14)	0.89 (4)	0.910 (29)
172.6		0.8	0.9 (1)	0.90 (10)	0.65 (4)	0.47 (3)	0.618 (10)	0.65 (5)	
176.3		20.5	21.2 (11)	24.9 (20)	23.9 (8)	23.2 (13)	23.06 (7) [g]	22.9 (7)	23.9 (7)
178.7		~0.1			0.08 (1)	0.05 (1)	0.092 (14)	0.10 (2)	
198.6		~0.04			0.04 (1)		0.044 (10)	0.055 (10)	
204.1		0.9	1.0 (1)	1.15 (10)	1.21 (5)	1.10 (8)	1.097 (14)	0.99 (5)	1.15 (4)
208.1		0.7	0.8 (1)	0.85 (8)	0.90 (4)	0.83 (5)	0.802 (14)	0.79 (4)	0.829 (25)
227.9	0.4 (1)	0.4		0.44 (4)	0.47 (2)	0.64 (4)	0.448 (14)	0.45 (2)	
315.0							0.0143 (14)	0.020 (4)	
321.0	1.4 (2)	1.25	1.4 (1)	1.41 (10)	1.42 (5)	1.6 (1)	1.393 (14)	1.41 (7)	1.422 (16)
380.4	5 (1)	5	5.0 (4)	5.27 (40)	5.22 (17)	5.43 (32)	5.16 (3)	5.15 (20)	5.10 (5)
408.1	0.9 (4)	0.6		0.62 (6)	0.59 (3)	0.50 (3)	0.62 (2)	0.59 (3)	

Energy	68An15[a]	68Se11[b]	69Ch09	70Na12	73Gu10	74Il02[c]	76Wa13	77Ar10	77Ge12
427.9	100.	100.	100.	100.	100.	100.	100.0 (3)	100.	100.0 (10)
443.4	0.5 (3)	1		1.03 (10)	1.07 (4)	1.10 (7)	1.03 (2)	1.05 (5)	
463.4	33 (4)	35.5	35.3 (20)	35.4 (28)	35.3 (13)	35.2 (23)	35.50 (7)	35.2 (10)	35.26 (37)
497.0							0.0122(14)	0.011 (2)	
600.6		61	61.2 (34)	61.5 (49)	59.6 (18)	53.6 (32)	60.39 (10)	60.1 (18)	60.6 (6)
606.6		17	17.1 (12)	16.4 (12)	16.9 (6)	19.0 (11)	17.052 (34)	16.8 (5)	17.12 (17)
635.9	42 (2)	37	37.0 (22)	37.31 (30)	38.2 (12)	35.6 (23)	38.45 (7)	38.4 (11)	38.6 (4)
671.4	6.5 (5)	6	5.6 (5)	6.0 (5)	6.09 (20)	6.24 (38)	6.11 (14)	6.02 (24)	6.18 (6)

Part 2

Energy	79Pr08	80Ro22	83Si14	84Iw03	86Wa35	93Fa02	98Sa55	90He05
19.9			0.068 (2)			0.072 (6)	0.068 (3)	
35.5			14.53 (35)			14.79 (8) [d]	17.7 (2)	
58.3			0.091 (4)			0.093 (2)	0.0042 (20)	
109.3	0.26 (4)		0.232 (5)	0.241 (24)		0.235 (16)	0.232 (6)	
110.8	0.02 (1) [h]		0.0042 (3)				0.0039 (3)	
117.0	0.91 (5)	1.01 (12)	1.060(10) [f]	0.867 (25)		0.885 (5)[j]	0.945 (15)	0.867 (24)
172.6	0.74 (6)	0.89 (6)	0.86 (2) [f]	0.69 (4)		0.72 (4)	0.67 (4)	0.659 (11)
176.3	22.9 (6)	25.45 (60)	24.5 (8)	22.62 (21)	22.91 (41)	23.65 (34)	23.09 (20)	22.96 (24)

Energy	79Pr08	80Ro22	83Si14	84Iw03	86Wa35	93Fa02	98Sa55	90He05
178.7	0.11 (1)		0.130 (5)	0.11 (4)		0.099 (6)	0.121 (2) [j]	
198.6	0.06 (1)		0.081 (4) [f]	0.030 (11)		0.046 (9)	0.044 (3)	
204.1	1.12 (4)	1.19 (22)	1.14 (4)	1.08 (3)		1.19 (5)	1.014 (10)	1.080 (23)
208.1	0.80 (4)	0.96 (10)	0.82 (2)	0.788 (21)		0.89 (3)	0.860 (10)	0.825 (16)
227.9	0.42 (2)	0.42 (7)	0.44 (2)	0.433 (12)		0.465 (25)	0.442 (9)	0.443 (23)
315.0			0.013 (2)				0.0144 (15)	
321.0	1.48 (6)	1.46 (8)	1.30 (5)	1.391 (24)		1.45 (5)	1.43 (2)	1.41 (3)
380.4	5.18 (20)	5.26 (10)	6.02 (25) [f]	5.06 (4)	5.12 (15)	5.09 (3)	5.17 (4)	5.14 (5)
408.1	0.57 (4)	0.66 (8)	0.61 (3)	0.608 (21)		0.59 (2)	0.624 (7)	0.630 (19)
427.9	100.	100.	100.	100.0 (7)	100.	100.	100.	100.0 (8)
443.5	1.06 (2)	1.03 (8)	1.12 (5)	0.989 (23)		1.03 (1)	1.05 (11)	1.019 (29)
463.4	35.1 (8)	35.45 (84)	35.50 (7)	35.23 (14)	35.4 (9)	35.64 (10)	35.12 (18)	35.07 (28)
497.0			0.015 (3)	0.009 (8)		0.018 (3)	0.009 (1)	
600.6	60.4 (11)	59.3 (12)	60.50 (10)	59.54 (22)	60.95 (67)	59.70 (10)	59.22 (18)	59.09 (45)
606.6	16.6 (5)	16.25 (62)	17.2 (3)	16.94 (7)	16.97 (26)	16.98 (21)	16.92 (6)	16.70 (14)
635.9	38.7 (8)	37.7 (10)	39.1 (2)	37.87 (14)	37.47 (27)	38.78 (32)	38.32 (12)	37.52 (30) [h]
671.4	6.04 (16)	6.92 (14) [f]	5.9 (3)	6.039 (24)	5.65 (12)	5.97 (11)	6.03 (2)	6.05 (6)

Part 3 – Adopted relative and absolute values

Energy	Adopted	wtd. avg.	s int	reduced-χ^2	σ_{ext}	σ_{LWM}	P_γ (%) × 0.2955 (24)	90Lo03 eval.	1999Ka26 eval.
19.9	0.0683 (16)	0.0683	0.0016	0.14			0.0202 (5)	0.068 (2)	0.069 (3)
35.5	19.6 (6) [i]	16.0	0.13	43	0.9	1.7	5.79 (18)	14.53 (35)	15.2 (10)
58.3		[e]						0.091 (4)	0.05 (4)
109.3	0.231 (4)	0.2310	0.0036	1.3	0.0041		0.0683 (12)	0.233 (5)	
110.8	0.0037 (3)	0.00373	0.00017	3.6	0.00033		0.00109 (9)	0.0036 (6)	0.0035 (4)
117	0.890 (9)	0.890	0.006	2.5	0.009		0.263 (4)	1.03 (4)	0.887 (9)
172.6	0.65 (3)	0.649	0.007	4.6	0.014	0.031	0.192 (9)	0.75 (5)	0.646 (24)
176.3	23.09 (15)	23.09	0.09	2.6	0.15		6.82 (7)	23.06 (14)	23.11 (5)
178.7	0.116 (5)	0.116	0.002	5.0	0.005		0.0343 (15)	0.110 (9)	0.114 (8)
198.6	0.0448 (24)	0.0448	0.0024	0.9			0.0132 (7)	0.054 (11)	0.0432 (20)
204.1	1.06 (5)	1.061	0.007	4.6	0.015	0.047	0.313 (15)	1.105 (11)	1.070 (21)
208.1	0.833 (27)	0.833	0.006	2.3	0.009	0.027	0.246 (8)	0.808 (9)	0.837 (14)
227.9	0.443 (9)	0.443	0.005	0.5			0.131 (3)	0.437 (12)	0.443 (6)
315	0.0144 (9)	0.0144	0.0009	0.8			0.0043 (3)	0.0138 (9)	0.0136 (16)
321	1.409 (8)	1.409	0.008	0.9			0.416 (4)	1.40 (2)	1.404 (9)
380.4	5.145 (13)	5.145	0.012	1.2	0.013		1.520 (15)	5.13 (4)	5.124 (19)
408.1	0.617 (5)	0.617	0.005	0.7			0.182 (2)	0.611 (12)	0.623 (6)
427.9							29.55 (24)	100	100

Energy	Adopted	wtd. avg.	s int	reduced-χ^2	σ_{ext}	σ_{LWM}	P_γ (%) × 0.2955 (24)	90Lo03 eval.	1999Ka26 eval.
443.5	1.033 (7)	1.033	0.007	1.0			0.305 (4)	1.03 (2)	1.035 (6)
463.4	35.47 (4)	35.47	0.04	1.0			10.48 (9)	35.47 (5)	35.45 (10)
497	0.0109 (11)	0.0109	0.0007	2.4	0.0011		0.0032 (3)	0.013 (2)	0.014 (8)
600.6	60.1 (4)	60.07	0.05	6.0	0.13	0.43	17.76 (18)	60.36 (11)	59.62 (16)
606.6	16.997 (27)	19.997	0.027	1.0			5.02 (5)	17.03 (3)	16.83 (6)
635.9	38.31 (14)	38.31	0.05	4.7	0.11	0.14	11.32 (10)	38.36 (15)	37.9 (3)
671.4	6.036 (17)	6.036	0.014	1.5	0.017		1.783 (16)	6.06 (2)	6.049 (19)

[a] All values from this reference omitted from analysis since 5 out of 8 were outliers in an initial averaging.
[b] All values from this reference omitted from analysis since they do not have uncertainties.
[c] All values from this reference omitted from analysis since 9 out of 19 were outliers in an initial averaging.
[d] Uncertainty increased from 0.08 to 0.20 by evaluator.
[e] No value adopted; data are very inconsistent, namely, 0.091, 0.093, and 0.004.
[f] Omitted from average, outlier.
[g] Uncertainty increased from 0.07 to 0.20 by evaluator.
[h] Typographical error in reference.
[i] Equilibrium intensity deduced by evaluator from transition intensity balance.
[j] Uncertainty increased in analysis to reduce relative weight to 50%.

Other γ rays have been reported in various papers, but have not been included in the scheme adopted here. For those from 1998Sa55 the energies and relative emission probabilities are listed here and for the other references only the energies are given. These lines are:
1968An15: 122.4, 489.8;
1968Se11: 105.8, 391.5;
1973Gu10: 81.8, 122.4;
1974Il02: 81.8, 489.8;
1976Wa13: 146.1;
1979Pr08: 81.8, 122.1, 366.0, 402.0;
1983Si14: 642.1, 693.2, 729.8; and
1998Sa55: [I_γ]: 61.8 [0.0067 (27)]; 81.0 [0.017 (1)]; 132.8 [0.0029 (19)]; 209.3 [0.152 (9)]; 331.8 [0.0085 (8)]; 366.5 [0.027 (2)]; 401.9 [0.0221 (2)]; 489.7 [0.0046 (23)]; 491.2 [0.016 (8)]; 503.1 [0.013 (6)]; 538.6 [0.0047 (25)]; 617.4 [0.018 (2)]; and 652.8 [0.009 (3)].

The decay scheme normalization deduced here has assumed the sum of all the γ-ray transition probabilities (photons + conversion electrons) to the ground state and 35-keV level (not including that of the 35-keV γ ray) to be equal to 100%. The relative equilibrium intensity (0.231 (4)) of the 109-keV γ ray has been reduced by 5.7% in the calculation because of its apparent increase due to the 57-day half-life of the 144-keV isomer from where it decays. Also, its total M4 theoretical conversion coefficient of 363.7 has been reduced by 2.5% to 354.6 as recommended in 1990Ne01. This reduction is usually applied to theoretical M4 conversion coefficients evaluated for the Evaluated Nuclear Structure Data File (ENSDF). This procedure has produced a decay scheme normalization factor of 0.2955 (24). The resulting γ-ray emission intensities are given in the third from the last column of the table given above. The last two columns give the relative probabilities from the evaluations of 1990Lo03 and 1999Ka26. The agreement is very good except for the line at 35 keV, where evaluators have preferred to use a value deduced from a γ–ray probability balance. The relative equilibrium intensity of 19.6 (6) for the 35-keV γ ray has been obtained from a transition probability balance at the 35-keV level. Its absolute emission intensity is then 5.79 (18) %.

The γ ray at 109 keV depopulates the isomeric level at 144 keV (half-life of 58 days), so its intensity depends on any chemical separation and its grow-in time. It takes about 1 year for it to be in equilibrium with the other γ rays to within 1 %. The level at 35 keV is primarily fed from higher-lying levels, but 27% of the 35-keV γ-ray intensity comes via the isomeric level when it is at equilibrium. So, for a chemically separated source, it needs about 8 months grow-in to be at equilibrium at the 1% level.

The population of the isomer was measured to be 24.3 (3) % (1998Gr13) compared to the 22.9 (9) % calculated from this adopted scheme.

4.3 Conversion electrons

From the adopted γ-ray intensities, and the conversion coefficients, one obtains the following conversion electron emission probabilities:

γ energy (keV)	shell	electron energy	emission prob. (%)
19.80	L	14.86	0.184 (7)
	M	18.79	0.0368 (14)
	N	19.63	0.0077 (3)
35.49	K	3.675	70 (3)
	L	30.55	9.5 (4)
	M	34.48	1.9 (1)

γ energy (keV)	shell	electron energy	emission prob. (%)
	N	35.35	0.46 (2)
109.28	K	77.46	12.4 (5)
	L	104.33	9.2 (5)
	M	108.27	2.1 (1)
	N	109.11	0.45 (2)
116.96	K	85.14	0.0287 (11)
	L	112.02	0.00371 (15)
172.72	K	140.90	0.0248 (10)
	L	167.78	0.0032 (1)
176.31	K	144.50	0.95 (4)
	L	171.37	0.150 (6)
	M	175.30	0.031 (1)
178.84	K	147.03	0.0050 (8)
	L	173.90	0.0009 (3)
198.65	K	166.84	0.00161 (10)
204.14	K	172.32	0.0322 (19)
	L	199.19	0.0059 (4)
	M	203.13	0.00120 (7)
208.08	K	176.26	0.0192 (8)
	L	203.13	0.00248 (10)
227.89	K	196.08	0.0090 (15)
	L	222.95	0.0014 (5)
321.04	K	289.23	0.00284 (11)
380.45	K	348.64	0.0231 (9)
	L	375.51	0.0035 (1)
408.06	K	376.25	0.00232 (9)
427.87	K	396.06	0.35 (2)
	L	422.94	0.0450 (18)
	M	426.87	0.0090 (3)
443.56	K	411.74	0.00302 (12)

γ energy (keV)	shell	electron energy	emission prob. (%)
463.36	K	431.55	0.090 (4)
	L	458.43	0.0128 (5)
	M	462.36	0.0026 (1)
600.60	K	568.78	0.074 (3)
	L	595.66	0.0101 (4)
	M	599.59	0.0020 (1)
606.72	K	574.90	0.0206 (8)
	L	601.77	0.0028 (1)
635.95	K	604.14	0.0509 (20)
	L	631.01	0.0063 (2)
671.44	K	639.62	0.00564 (22)
	L	666.50	0.0008

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^{125}I - Comments on evaluation of decay data
by V. Chisté, E. Schönfeld and M.M. Bé

This evaluation was completed in July 2010. Literature by July 2010 was included.

1 Decay Scheme

Given the adopted Q_{EC} value of 185.77 keV, there are three levels in the daughter nuclide ^{125}Te available for the EC decay of the ^{125}I ground state. The level at 144.8 keV (Jπ=11/2-) would require a 3rd forbidden transition (ΔI = 3 and parity change) and one may expect log *ft >15* from systematics (Raman, 1973Ra10), which corresponds to a transition probability of < $1\cdot10^{-8}$ per disintegration.

A direct decay to the ground state of ^{125}Te (ΔI = 2, no parity change, non-unique 2nd forbidden) was not observed. Smith and Lewis (1966Sm05) have found that the transition probability of such a transition would be smaller than 0.01. From systematics (Raman, 1973Ra10), one may expect log *ft* > 11.0 which corresponds to a transition probability of $1\cdot10^{-6}$ per disintegration.

The adopted decay scheme of ^{125}I presented in this evaluation is complete. Good agreement is found between the effective Q value (185.66 (42) keV) calculated from the decay scheme data and that recommended from the atomic mass evaluation of Audi (2003Au03).

2 Nuclear Data

The Q_{EC} value of 185.77 (6) keV is taken from Audi (2003Au03), while the spins, parities and the lifetime of the excited 35-keV level (1.48 (1) ns) are from the ENSDF evaluation of J. Katakura (1999Ka26).

Experimental ^{125}I half-life values (in days) are given in Table 1:

Table 1: Experimental values of ^{125}I half-life.

Reference	Experimental value (days)	Comments
A. F. Reid (1946Re**)	56	Not used: no uncertainty.
G. Friedlander (1951Fr21)	60.0 (5)	
M. Ia. Kuznetsova (1958Ku**)	60	Not used: no uncertainty.
C. M. E. Matthews (1960Ma36)	57.4 (2)	
G. I. Gleason (1963Ge**)	58.8 (2)	Private communication. Cited by 1965An07
H. Leutz (1964Le05)	60.25 (6)	
S. C. Anspach (1965An07)	59.83 (11)	Superseded by 2002Un02.
C. R. Richmond (1966Ri14)	58.76 (13)	
F. Lagoutine (1968La10)	59.89 (18)	Superseded by 1995Ra32 (2).
J. F. Emery (1972Em01)	60.18 (17)	
W. Künding (1979Kü**)	59.666 (16)	
H. Houtermans (1980Ho17)	59.156 (20)	
D. D. Hoppes (1982HoZJ)	59.47 (21)	Superseded by 2002Un02.
H. Kubo (1983Ku**)	59.56 (17)	
H. Schrader (1987Sc20)	59.39 (2)	
B. R. S. Simpson (1989Si19)	59.40 (5)	
P. de Felice (1990De09)	59.38 (3)	
M. J. Woods (1990Wo03)	59.416 (10)	
T. Altzitzoglou (1991Al05)	59.37 (6)	

G. Ratel (1995Ra32) - 1	59.29 (7)	SIR: result of AECL.
G. Ratel (1995Ra32) - 2	59.90 (11)	SIR: result of LNHB.
G. Ratel (1995Ra32) - 3	59.26 (3)	SIR: result of NCR.
M. P. Unterweger (2002Un02)	59.49 (13)	
Recommended value	**59.388 (28)**	χ^2 = 3.3

The first twelve values are only cited for reasons of completeness (1946Re**, 1951Fr21, 1958Ku**, 1960Ma36, 1963Ge**, 1964Le05, 1965An07, 1966Ri14, 1968La10, 1972Em01, 1979Kü**, 1980Ho17). The values of 1982HoZJ, 1983Ku**, 1987Sc20, 1989Si19, 1990De09, 1990Wo03, 1991Al05, 1995Ra32 (1, 2 and 3) and 2002Un02 are in good agreement and this indicates that the true value is very close to 59,4 d. Taking this into account, the evaluators can classify the older values (1946Re** until 1980Ho17) (when looking at the uncertainty given by the authors) into values which are too low (1960Ma36 by 10 σ, 1966Ri14 by 4 σ, 1980Ho17 by 12 σ) or too high (1964Le05 by 14 σ, 1968La10 by 10 σ, 1972Em01 by 5 σ, 1979Kü** by 17 σ). These values have a large spread. The evaluators consider it to be senseful to calculate an average of these values only after enlarging their uncertainties by reasonable (but more or less arbitrarily chosen) factors. Values of 1946Re** and 1958Ku** are excluded because no uncertainty is given. Value of 1951Fr21 is a good value but because of its large uncertainty it does not contribute very much to the average.

As there are enough new accurate values the evaluators do not include all these old values into the averaging procedure. A weighted average of the eleven remaining values, of 1982HoZJ until 2002Un02, was calculated using the LWEIGHT computer code (version 3). The largest contribution to the weighted average comes from the value of M. J. Woods (1990Wo03), with a statistical weight of 63 %. The LWEIGHT computer code increases the uncertainty for the 1990Wo03 value from 0.010 to 0.013 in order to reduce its relative weight from 63 % to 50 %.

The adopted half-life value is 59.388 days with a final uncertainty of 0.028 days, expanded to include the most precise value of M. J. Woods (1990Wo03). The reduced-χ^2 value is 3.3.

2.1 Electron Capture Transition.

The energy of the electron capture transition has been obtained from the Q(EC) value (2003Au03) and the level energy given by J. Katakura (1999Ka26).

The adopted electron-capture transition probability and the associated uncertainty were deduced from the γ-ray transition probability balance at 35-keV level of the decay scheme.

The adopted P_K, P_L and P_M values were calculated from the table of Schönfeld (1995ScZY) using the adopted Q_{EC} value (program EC-Capture). The adopted P_K value of 0.8011 (17) can be compared with some experimental determination (Table 2):
Der Mateosian (1953De26) found P_L/P_K = 0.23 (3). Leutz and Ziegler (1964Le05) found $(P_L + P_M + P_N)/P_K$ = 0.2547 (33) and 0.2539 (21) using two different extrapolation methods. The mean value 0.2543 (27) corresponds to P_K = 0.797 (3). Smith and Lewis (1966Sm05) found for the above ratio 0.253 (5). Karttunen et al. (1969Ka08) measured $P_K\omega_K$ = 0.685 (18) (2 σ) whereas Plch and Zderadicka (1974Pl03) found 0.685 (12) and Tolea et al. (1974To04) 0.699 (30).

Table 2: Adopted and measured values of P_K.

1	0.797 (3)	Leutz and Ziegler (1964Le05) measured value.
2	0.798 (3)	Smith and Lewis (1966Sm05) measured value.
3	0.783 (11)	Karttunen et al. (1969Ka08) measured, recalculated and uncertainty related to 1 σ.
4	0.783 (15)	Plch and Zderadicka (1974Pl03) measured, recalculated.
5	0.799 (34)	Tolea et al. (1974To04) measured, recalculated.
6	0.801	Tolea et al. (1974To04); calculated from theory.
7	0.825 (35)	Kalyani et al. (1996Ka48) measured value.
8	0.8011 (17)	calculated from theory and adopted in the present evaluation.

Values 3, 4 and 5 are recalculated using the present adopted value of ω_K.

2.2 γ Transitions

The γ-ray transition probability for the 35-keV gamma-ray was calculated using the γ-ray emission intensity and the relevant internal conversion coefficient (see **5.2 Gamma Emissions**).

Multipolarity of the 35-keV γ-ray transition is M1 + E2. The mixing ratio (δ) was deduced by comparison between the experimental and theoretical total internal coefficients, the later calculated using the BrIcc computer code (2008Ki07).

The total coefficient of 35-keV γ-ray can be deduced from:

$$\alpha_T = \frac{P_{(\gamma+ce)35}}{I_{\gamma 35}} - 1$$

where:

- $P_{(\gamma+ce)35}$ (100 %) is the transition probability of 35-keV γ-ray.
- $I_{\gamma 35}$ (= 6.63 (6) %) is the weighted average of the experimental values of absolute emission intensity shown in Table 5 (see **5.2 Gamma Emissions**).

Table 3 shows the final results of experimental α_T, as well as the mixing ratio δ deduced from the comparison between experimental α_T value (column 2) and theoretical values of 13.63 (M1) and 77.3 (E2) given by the BrIcc computer code.

Table 3: Adopted conversion coefficient and mixing ratio.

E_γ (keV)	α_T experimental (given by equation above)	δ (mixing ratio)
35.4922 (5)	14.08 (14)	0.085 (13)

Then the internal conversion coefficients (ICC) and the associated uncertainties have been obtained using the BrIcc computer program with “the frozen orbital approximation” (2008Ki07).

These α_T and mixing ratio values can be compared with the experimental results:

- Geiger et al. (1965Ge04) compared their measured conversion electron results $L_1 / L_2 / L_3 = 1 / 0.089\ (4) / 0.024\ (2)$ with the theoretical ratios derived from the table of Sliv and Band and found: 99.965 (20) % M1 + 0.035 (20) % E2.

- Mazets et al. (1966Ma49) found in the ^{125}Sb decay $L_1 / L_2 / L_3 = 10.7 / 1.0 / 0.2$ corresponding to 99.92 (3) % M1 + 0.08 (3) % E2.

- Karttunen et al. (1969Ka08) deduced from a comparison of experimental results with those of the Hager-Seltzer theory that a possible E2 admixture is smaller than 0.4 %.

- Casey et al. (1969Ca01) measured $L_1 / L_2 / L_3$ = 1 / 0.106 (22) / 0.041 (2).

- Coursol (1979CoZG) measured more precisely $L_1 / L_2 / L_3$ = 1 / 0.0820 (13) / 0.0190 (10) and derived from analysis an E2 admixture of 0.03 (2) %.

- Brabec et al. (1982Ba16) measured $L_1 / L_2 / L_3$ = 1.00 (1) / 0.0954 (18) / 0.0229 (49) and derived from analysis of these and other data δ = 0.029 (+ 3 - 2) and 99.916 (+ 18 - 11) % M1 and 0.084 (+ 18 - 11) % E2.

The experimental conversion coefficient values of the 35.5 keV transition are compiled in the following table (Table 4).

	1 (1952Bo16)	2 (1969Ka08)	3 (1970Ma51)	4 (1979CoZG)$^{\mu}$	Adopted values (given by BrIcc)
α_K	11.7 (25)	11.78 (11)	11.8 (3)	11.90 (31)	11.70 (17)
α_L	1.6 (5)	1.62			1.91 (8)
α_M	0.3 (1)	0.25			0.386 (16)
α_N		0.044			0.075 (3)
α_O					0.00766 (23)
α_T	13.6 (26)*	13.65 (28)£		14.25 (64)	14.08 (22)

*$\alpha_T = \alpha_K + \alpha_L + \alpha_M$.

£ Value from the article.

µ The original uncertainties, given in this paper, are 3σ.

1 - Bowe and Axel (1952Bo16): α_L and α_M calculated from α_K and the measured ratio K / L / M = 0.80 (5) / 0.11 (2) / 0.020 (4). ($\alpha_T = \alpha_K + \alpha_L + \alpha_M$)
2 - Karttunen et al. (1969Ka08): α_K recalculated from $\alpha_K\omega_K$ with ω_K (0.875 (4)) as adopted here. The originally published value is α_K = 12.01 (18) (2σ uncertainty). The values of α_L, α_M, α_N are calculated from α_K using the ratio K / L / M / N = 80 / 11 / 1.7 / 0.3 as measured by Narcisi (1959Na06).
3 - Marelius et al. (1970Ma51).
4 - Coursol (1979CoZG, see also IAEA TecDoc-619 (1991)): measured values and the original uncertainties are 3σ (include in the Table 4).

3 Atomic Data

Atomic values, ω_K, ϖ_L, ϖ_M and n_{KL} and X-ray and Auger electron relative probabilities are from Schönfeld and Janβen (1996Sc06)

4 Electron emissions

The conversion electron emission probabilities have been deduced from the ICC and γ-ray emission probability values.

5 Emissions

5.1 K x-rays

The X-ray absolute intensities were deduced from the decay data using the EMISSION computer code.

For the total K X ray emission intensities some experimental values (per 100 % disintegrations) have been found:

1	137.9 (27)	Karttunen et al. (1969Ka08)
2	139.3 (25)	Tolea et al. (1974To04)
3	137.9 (23)	Plch and Zderadicka (1974Pl03)
4	138.3 (20)	Konstantinov et al. (1989Ko**), recalculated from $P(\mathrm{KX} + \gamma) = 1.45$ (2)
5	138.3 (12)	Weighted mean of four experimental values (1-4). $\chi^2 = 0.07$
6	137.9 (10)	Adopted value.

5.2 Photon emissions

The energy of the 35-keV γ-ray given in section 5.2 is from J. Katakura (1999Ka26).
The experimental absolute 35-keV γ-ray emission intensities from the decay of ^{125}I are given in the table 5.

Table 5: Absolute experimental γ-ray emission intensities for the 35-keV transition.

Reference	**Absolute γ-ray intensity (%)**	**Comments**
J. C. Bowe (1952Bo16)	7 (2)	
E. Karttunen (1969Ka08)	6.83 (14)	Original uncertainty = 2σ.
N. F. Coursol (1979CoZG)¤	6.56 (9)	Original uncertainty = 3σ.
W. B. Mann (1985Ma**)	6.67 (22)	Not used: evaluated value.
A. Iwahara (1990Iw04)	6.68 (14)	Superseded by 2006Da20
U. Schötzig (1992ScZZ)	6.55 (13)	
M. A. L. da Silva (2006Da20)	6.67 (14)	
Recommended value	**6.63 (6)**, $\chi^2 = 0.78$	

¤ see also IAEA TecDoc-619 (1991).

The adopted value is the weighted average of 6.63 % with an external uncertainty of 0.06 %. The reduced-χ^2 value is 0.78.

6 References

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^{127}Sb - Comments on evaluation of decay data

by A. L. Nichols

Evaluated: February - March 2012

Evaluation Procedure

Limitation of Relative Statistical Weight Method (LWM) was applied to average the measured decay data when appropriate.

Decay Scheme

A reasonably complex decay scheme was constructed from the gamma-ray studies of 1967Ra13 and 1967Ta05. An earlier study involved the use of low-resolution NaI(Tl) detectors (1962Uh01), and these data have been set aside from consideration in this particular evaluation. The gamma-ray emission probabilities were expressed in terms of the emission probability of the 685.09-keV gamma ray (100 %), and weighted mean data were derived as appropriate. ^{127}Sb undergoes beta decay to both ^{127m}Te (defined as level 2, with a half-life of 106.1 days) and the ground state of ^{127}Te (half-life of 9.35 hours) – under these circumstances, the recommended ^{127}Sb decay scheme is rightly defined as ending effectively with the population of these two particular nuclear levels, while the subsequent IT and beta decay of ^{127m}Te are not included in the data file.

Nuclear Data

^{127}Sb undergoes beta decay to various nuclear levels of ^{127}Te, populating both ^{127m}Te (beta branch of 16.8 (6) %) and the ^{127}Te ground state (beta branch of 83.2 (6) %), latter more specifically by gamma decay only. These two daughter states possess significant half-lives of 106.1 days (^{127m}Te) and 9.35 hours (^{127}Te), and therefore their recommended decay data have been assembled as separate files.

Half-life (^{127}Sb)

The recommended half-life has been determined from the measurements of Sleight and Sullivan (1950Sl17), Bosch and Munczek (1957Bo96), Dropesky and Orth (1962Dr01), Uhler *et al.* (1962Uh01), Hagebø (1967Ha27), Takemoto *et al.* (1967Ta05), and Panontin and Sugarman (1972Pa13). A value of 3.85 days was derived in terms of LWM, with the uncertainty increased to the lowest experimental value of ± 0.07 days.

Half-life measurements (^{127}Sb).

Reference	Half-life (days)
1939Ab02	3.3* (80 h)
1946Gr06	4.0* (95 h)
1950Sl17	3.9 ± 0.1 (93 ± 3 h)
1957Bo96	3.7 ± 0.1 (88 ± 2 h)
1962Dr01	3.89 ± 0.07 (93.4 ± 1.7 h)
1962Uh01	3.9 ± 0.1 (94 ± 2 h)
1967Ha27	3.80 ± 0.08† (91.2 ± 0.3 h)
1967Ta05	3.75 ± 0.10
1972Pa13	3.91 ± 0.07 (93.8 ± 1.6 h)
Recommended value	3.85 ± 0.07‡

* no uncertainty quoted – not included in LWM analysis.

† possible systematic error proposed by 1967Ha27 – author suggests that the measured half-life may be too long by as much as 2 %; other measurements indicate this possibility may not be the case, although the uncertainty has been adjusted from ± 0.013 to ± 0.08 days as a sensible precaution.

‡ uncertainty increased from ± 0.03 to the lowest experimental value of ± 0.07 days.

Q values

Q^- to the ^{127}Te ground state of 1582 (5) keV was adopted from the evaluated tabulations of 2011AuZZ, which compares with a value of 1581 (5) keV from 2003Au03. A value of 88.23 (7) keV was adopted for the energy of the ^{127m}Te nuclear level (2011Ha31), and was used to derive Q^- to ^{127m}Te of 1494 (5) keV.

Gamma Rays

Energies

Although gamma-ray energies have been measured to good accuracy by 1967Ra13 and 1967Ta05, the determination of the nuclear-level energies of ^{127}Te from a combination of decay data and the emissions from seven nuclear reactions are judged to be more robust (2011Ha31). Therefore, gamma transition energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 2011Ha31 were adopted, and used to determine the energies of the gamma-ray transitions between the depopulating-populating levels.

Adopted energies, spins and parities of the nuclear levels of ^{127}Te.

Nuclear level number	Nuclear level energy (keV)	Spin and parity
0	0.0	3/2 +
1	61.161 ± 0.019	1/2 +
2	88.23 ± 0.07 (^{127m}Te)	11/2 −
3	340.87 ± 0.06	(9/2 −)
4	473.26 ± 0.04	5/2 +
5	501.928 ± 0.010	3/2 +
6	631.40 ± 0.06	7/2 −
7	685.09 ± 0.07	7/2 +
8	762.64 ± 0.05	3/2 +
9	782.62 ± 0.03	5/2 +
10	786.13 ± 0.06	7/2 −
11	924.02 ± 0.18	7/2 +
12	1077.13 ± 0.17	5/2, 7/2, 9/2
13	1140.20 ± 0.07	5/2 +
14	1154.70 ± 0.09	5/2 +
15	1206 ± 5*	3/2 +, 5/2 +
16	1289.79 ± 0.08	5/2 +
17	1309.25 ± 0.07	3/2 +, 5/2+
18	1323.4 ± 0.8	
19	1378.58 ± 0.07	5/2 +

* Value of (1206.3 ± 0.7) keV adopted from the energy of the proposed depopulating γ transition (423.7 (7) keV) to the 782.62 (3)-keV nuclear level.

A number of gamma rays with very low emission probabilities have been observed only by 1967Ta05, and four of these particular transitions cannot be placed in the proposed decay scheme: 74.6-, 405.0-, 675.6- and 789.5-keV gamma rays. After inspection of the spectra (1967Ta05), these particular gamma rays have not been included in the recommended set of decay data.

Gamma-ray energies.

transition	E_γ (keV)		
	1967Ra13	**1967Ta05**	**Recommended**
$\gamma_{1,0}$ (Te)	61.0 (3)	61.1 (1)	61.16 (2)
–	–	74.6 (7)	unplaced/rejected
$\gamma_{10,6}$ (Te)	154.3 (5)	154.4 (7)	154.7 (1)
$\gamma_{3,2}$ (Te)	252.4 (3)	252.5 (5)	252.64 (9)
$\gamma_{9,5}$ (Te)	280.4 (5)	280.5 (10)	280.7 (1)
$\gamma_{6,3}$ (Te)	290.8 (5)	290.3 (15)	290.5 (1)
$\gamma_{11,6}$ (Te)	293.3 (9)	–	292.6 (2)
$\gamma_{9,4}$ (Te)	310.0 (7)	309.0 (10)	309.4 (1)
$\gamma_{12,7}$ (Te)	391.8 (5)	391.5 (7)	392.0 (2)
–	–	405.0 (10)	unplaced/rejected
$\gamma_{4,1}$ (Te)	412.1 (5)	411.6 (2)	412.10 (5)
$\gamma_{15,9}$ (Te)	–	423.7 (7)	423.7 (7)
$\gamma_{5,1}$ (Te)	441.0 (9)	440.7 (7)	440.77 (2)
$\gamma_{10,3}$ (Te)	445.1 (5)	444.9 (3)	445.3 (1)
$\gamma_{11,4}$ (Te)	451.0 (7)	451 (1)	450.8 (2)
$\gamma_{13,7}$ (Te)	–	456 (1)	455.1 (1)
$\gamma_{4,0}$ (Te)	473.0 (4)	473.0 (2)	473.26 (4)
$\gamma_{5,0}$ (Te)	502.8 (6)	501.5 (15)	501.93 (1)
$\gamma_{6,2}$ (Te)	543.3 (5)	543.0 (2)	543.2 (1)
$\gamma_{11,3}$ (Te)	584.2 (11)	–	583.2 (2)
$\gamma_{12,4}$ (Te)	603.5 (5)	603.6 (2)	603.9 (1)
$\gamma_{17,7}$ (Te)	–	624.0 (10)	624.2 (1)
$\gamma_{13,5}$ (Te)	637.8 (5)	638.5 (7)	638.3 (1)
$\gamma_{14,5}$ (Te)	652.3 (9)	653.5 (7)	652.8 (1)
$\gamma_{13,4}$ (Te)	667.5 (9)	666.9 (3)	666.9 (1)
–	–	675.6 (5)	unplaced/rejected
$\gamma_{14,4}$ (Te)	682.3 (10)	–	681.4 (1)
$\gamma_{7,0}$ (Te)	685.7 (5)	685.2 (3)	685.09 (7)
$\gamma_{10,2}$ (Te)	698.5 (5)	698.5 (3)	697.9 (1)
$\gamma_{9,1}$ (Te)	722.2 (5)	723.4 (7)	721.5 (1)
$\gamma_{19,6}$ (Te)	745.9 (5)	745.4(15)	747.2 (1)*
$\gamma_{8,0}$ (Te)	763.7 (8)	–	762.7 (1)
$\gamma_{9,0}$ (Te)	783.7 (5)	783.8 (3)	782.6 (1)
–	–	789.5 (15)	unplaced/rejected
$\gamma_{16,4}$ (Te)	817.0 (6)	817.3 (5)	816.5 (1)
$\gamma_{18,5}$ (Te)	820.6 (6)	820.1 (3)	821.5 (8)
$\gamma_{11,0}$ (Te)	924.4 (9)	923.5 (7)	924.0 (2)
$\gamma_{13,0}$ (Te)	1141.6 (8)	1141.2 (7)	1140.2 (1)
$\gamma_{14,0}$ (Te)	–	1155.2 (10)	1154.7 (1)
$\gamma_{16,0}$ (Te)	1290.3 (8)	1291.5 (15)	1289.8 (1)
$\gamma_{19,0}$ (Te)	1377.9 (9)	–	1378.6 (1)

* Significant adjustment has been made from 745.5 to 747.2 keV to give a recommended energy that can be satisfactorily placed in the proposed decay scheme.

Emission Probabilities

Although judged to be a rather limited data set, a reasonably consistent decay scheme was derived from the relative gamma-ray emission probabilities measured by Ragaini *et al.* (1967Ra13) and Takemoto *et al.* (1967Ta05). These relative emission probabilities were normalised to the 685.09-keV gamma ray (100 %).

Although the 61.16-keV gamma ray has been quantified by both 1967Ra13 and 1967Ta05, the assignment of this gamma transition in the decay scheme permits an accurate relative emission probability to be calculated from the gamma population-depopulation balance of the 61.161-keV nuclear level (with no populating beta transition). However, the observed gamma depopulation of the 762.64-keV nuclear level ($3/2^+$) is problematic, since no β^- or γ feeding of this level has been proposed – this unsatisfactory situation needs to be addressed in future experimental studies.

Nuclear-level studies by means of the ^{126}Te(n,γ) and (d,p) reactions have provided additional insight into the γ depopulation of many of the proposed ^{127}Te nuclear levels (2005Ho15). Thus, there is strong evidence for the depopulation of the 685.09-keV nuclear level by 212.2- and 183.7-keV gamma rays along with the main 685.09-keV gamma emission, but no detection of an equivalent 623.9-keV M3 gamma transition. The measurements of 2005Ho15 have been used to support the placing of gamma transitions and introduction of nuclear-level assignments throughout the proposed decay scheme.

Relative gamma-ray emission probabilities.

transition	**E$_\gamma$ (keV)**	P_γ^{rel}		
		1967Ra13	**1967Ta05**	**Recommended**[*]
$\gamma_{1,0}$ (Te)	61.16 (2)	3.9 (3)	3.22 (4)	3.22 (4)[†]
–	74.6 (7)	–	0.11 (7)	unplaced/rejected
$\gamma_{10,6}$ (Te)	154.7 (1)	0.4 (2)	0.32 (7)	0.33 (7)
$\gamma_{3,2}$ (Te)	252.64 (9)	23.1 (9)	23.5 (4)	23.4 (4)
$\gamma_{9,5}$ (Te)	280.7 (1)	1.8 (4)	1.5 (1)	1.5 (1)
$\gamma_{6,3}$ (Te)	290.5 (1)	5.5 (3)	5.1 (2)	5.2 (2)
$\gamma_{11,6}$ (Te)	292.6 (2)	0.8 (4)	–	0.8 (4)
$\gamma_{9,4}$ (Te)	309.4 (1)	0.7 (3)	0.57 (10)	0.58 (10)
$\gamma_{12,7}$ (Te)	392.0 (2)	2.6 (2)	2.7 (3)	2.6 (2)
–	405.0 (10)	–	0.32 (5)	unplaced/rejected
$\gamma_{4,1}$ (Te)	412.10 (5)	10.4 (11)	9.6 (5)	9.7 (5)
$\gamma_{15,9}$ (Te)	423.7 (7)	–	0.28 (10)	0.28 (10)
$\gamma_{5,1}$ (Te)	440.77 (2)	1.9 (9)	0.7 (3)	1.9 (9)[‡]
$\gamma_{10,3}$ (Te)	445.3 (1)	11.8 (3)	11.8 (5)	11.8 (3)
$\gamma_{11,4}$ (Te)	450.8 (2)	0.5 (2)	1.1 (6)	0.6 (2)
$\gamma_{13,7}$ (Te)	455.1 (1)	–	0.3 (2)	0.3 (2)
$\gamma_{4,0}$ (Te)	473.26 (4)	70.1 (19)	70.1 (32)	70.1 (19)
$\gamma_{5,0}$ (Te)	501.93 (1)	2.1 (7)	1.7 (3)	1.8 (3)
$\gamma_{6,2}$ (Te)	543.2 (1)	8.0 (12)	7.4 (3)	7.4 (3)
$\gamma_{11,3}$ (Te)	583.2 (2)	0.9 (5)	–	0.9 (5)
$\gamma_{12,4}$ (Te)	603.9 (2)	12.1 (3)	11.7 (3)	11.9 (3)
$\gamma_{17,7}$ (Te)	624.2 (1)	–	0.18 (6)	0.18 (6)
$\gamma_{13,5}$ (Te)	638.3 (1)	1.2 (4)	1.0 (1)	1.0 (1)
$\gamma_{14,5}$ (Te)	652.8 (1)	1.0 (2)	0.7 (1)	0.8 (1)
$\gamma_{13,4}$ (Te)	666.9 (1)	2.0 (2)	1.0 (1)	1.5 (5)

transition	E_γ (keV)	P_γ^{rel}		
		1967Ra13	1967Ta05	Recommended[*]
–	675.6 (5)	–	0.18 (9)	unplaced/rejected
$\gamma_{14,4}$ (Te)	681.4 (1)	1.5 (7)	–	1.5 (7)
$\gamma_{7,0}$ (Te)	685.09 (7)	100	100.0	100
$\gamma_{10,2}$ (Te)	697.9 (1)	9.9 (2)	9.0 (2)	9.5 (5)
$\gamma_{9,1}$ (Te)	721.5 (1)	5.1 (3)	4.9 (2)	5.0 (2)
$\gamma_{19,6}$ (Te)	747.2 (1)	0.4 (2)	0.3 (1)	0.3 (1)
$\gamma_{8,0}$ (Te)	762.7 (1)	0.2 (1)	–	0.2 (1)
$\gamma_{9,0}$ (Te)	782.6 (1)	41.1 (9)	42.4 (12)	41.6 (9)
–	789.5 (15)	–	0.23 (4)	unplaced/rejected
$\gamma_{16,4}$ (Te)	816.5 (1)	1.1 (5)	0.75 (8)	0.76 (8)
$\gamma_{18,5}$ (Te)	821.5 (8)	0.6 (3)	0.32 (6)	0.33 (6)
$\gamma_{11,0}$ (Te)	924.0 (2)	1.4 (2)	1.29 (7)	1.30 (7)
$\gamma_{13,0}$ (Te)	1140.2 (1)	1.0 (2)	1.1 (3)	1.0 (2)
$\gamma_{14,0}$ (Te)	1154.7 (1)	–	0.11 (6)	0.11 (6)
$\gamma_{16,0}$ (Te)	1289.8 (1)	1.0 (3)	0.97 (9)	0.97 (9)
$\gamma_{19,0}$ (Te)	1378.6 (1)	0.2 (1)	–	0.2 (1)

[*] LWM of the measurements of 1967Ra13 and 1967Ta05, with the uncertainty increased to the lowest measured value when necessary.

[†] adopted on the basis of the γ population-depopulation balance of the 61.161-keV nuclear level, with no β^- transition.

[‡] adopted from 1967Ra13, and in agreement with γ population-depopulation balance of the 501.93-keV nuclear level, with no β^- transition.

Multipolarities, Internal Conversion Coefficients and Internal-Pair Formation Coefficients

The nuclear level scheme specified by Hashizume (2011Ha31) has been used to define the multipolarities of the gamma transitions on the basis of known spins and parities. A significant number of important gamma-ray transitions possess (M1 + E2) multipolarity, and somewhat disparate studies have been undertaken to determine many of their mixing ratios (1972Kr15, 1974So03, 1985De04). Furthermore, assessments have been made of a more limited number of these mixing ratios by Krane (1977Kr13). These various data have been assessed by the evaluator, and specific selections have been made as follows:

61.16-keV gamma ray, 80.6%M1 + 19.4%E2, as derived from consideration of γ population-depopulation of the 61.161-keV nuclear level; 154.7-keV gamma ray, 92%M1 + 8%E2; 252.64-keV gamma ray, 18%M1 + 82%E2; 280.7-keV gamma ray, 99.2%M1 + 0.8%E2; 290.5-keV gamma ray, 86%M1 + 14%E2; 292.6-keV gamma ray, 98.5%E1 + 1.5%M2; 309.4-kev gamma ray, 99%M1 + 1%E2; 392.0-keV gamma ray, 97.8%M1 + 2.2%E2; 440.77-keV gamma ray, 80%M1 + 20%E2; 445.3-keV gamma ray, 50%M1 + 50%E2;
450.8-keV gamma ray, 67%M1 + 33%E2; 473.26-keV gamma ray, 96%M1 + 4%E2;
501.93-keV gamma ray, 89.6%M1 + 10.4%E2; 603.9-keV gamma ray, 98%M1 + 2%E2; 638.3-keV gamma ray, 85%M1 + 15%E2; 652.8-keV gamma ray, 94.6%M1 + 5.4%E2; 782.6-keV gamma ray, 95.8%M1 + 4.2%E2; 1140.2-keV gamma ray, 98%M1 + 2%E2; and
1289.8-keV gamma ray, 99.96%M1 + 0.04%E2.

Additional (M1 + E2) gamma transitions were arbitrarily assigned a mixing ratio of 1.0 ± 0.5 (50%M1 + 50%E2) in this reasonably comprehensive exercise (423.7, 455.1, 624.2, 666.9, 681.4, 762.7 and 816.5 keV). The 583.2- and 747.2-keV gamma rays were identified as E1 transitions, while the 412.10-, 543.2-, 685.09-, 697.9-, 721.5- and 924.0-keV gamma rays were defined as E2 transitions. These data were used to determine recommended internal conversion coefficients from the frozen orbital approximation of Kibédi *et al.* (2008Ki07), based on the theoretical tabulations of Band *et al.* (2002Ba25, 2002Ra45). Internal-pair formation coefficients were calculated by means of the methodology described by Kibédi *et al.* (2008Ki07).

Gamma-ray emissions: measured mixing ratios of (M1 + E2) transitions and (E1 + M2) transition.

E_{γ} (keV)	δ				
	1972Kr15	**1974So03**	**1977Kr13**	**1985De04**	**Recommended**
M1 + E2 transitions					
154.7 (1)	−	−	−	0.34 ± 0.21 or $-2.30^{+0.81}_{-2.02}$	0.3 ± 0.2
252.64 (9)	− 0.56 ± 0.10 or − 1.53 ± 0.24	− 1.61 ± 0.39	− 1.55 ± 0.20	− 0.31 ± 0.03 or − 2.55 ± 0.20	− 2.1 ± 0.5[*]
280.7 (1)	–	–	–	− 0.09 ± 0.02 or 7.80 ± 1.20	− 0.09 ± 0.02
290.5 (1)	$0.27^{+0.21}_{-0.13}$ or 6^{+68}_{-3}	1.87 ± 0.51	1.9 ± 0.5	0.40 ± 0.03	0.40 ± 0.03
309.4 (1)	–	–	–	0.10 ± 0.03 or − 2.13 ± 0.30	0.10 ± 0.03
392.0 (2)	$0.55^{+0.51}_{-0.19}$ or $2.8^{+2.5}_{-1.5}$ if $J^{\pi}(1077) = 5/2^{+}$ − 0.29 ± 0.14 or – 2.1 ± 0.7 if $J^{\pi}(1077) = 9/2^{+}$	−	−	0.15 ± 0.02 − 0.31 ± 0.02	0.15 ± 0.02
440.77 (2)	–	–	–	$0.51^{+0.38}_{-0.22}$ or $-18.30^{+14.30}_{-\infty}$	0.5 ± 0.3
445.3 (1)	0.4 ± 0.2	− 3.14 ± 0.76	− 1.0 ± 0.3	− 1.16 ± 0.30	− 1.0 ± 0.5
450.8 (2)	–	–	–	$0.65^{+0.76}_{-0.12}$ or $1.16^{+0.22}_{-0.63}$	0.7 ± 0.5
473.26 (4)	− 0.29 ± 0.06 or − 1.56 ± 0.19	−	− 0..29 ± 0.06	− 0.10 ± 0.01 or − 2.50 ± 0.05	− 0.20 ± 0.10[†]
501.93 (1)	–	–	–	0.34 ± 0.08 or 1.50 ± 0.22 $0.34^{+0.90}_{-0.24}$ or $2.13^{+0.38}_{-0.90}$	0.34 ± 0.08
603.9 (1)	0.00 ± 0.07 or 1.65 ± 0.25 if $J^{\pi}(1077) = 5/2^{+}$ pure E2 if $J^{\pi}(1077) = 9/2^{+}$	−	−	0.14 ± 0.08 or − 2.32 ± 0.50 if $J^{\pi}(1077) = 5/2^{+}$ 0.05 ± 0.08	0.14 ± 0.08
638.3 (1)	−	−	−	− 0.42 ± 0.03 or – 5.50 ± 0.84	− 0.42 ± 0.03
652.8 (1)	−	−	−	0.24 ± 0.07 or $2.08^{+0.26}_{-0.43}$	0.24 ± 0.07
697.9 (1)	− 0.21 ± 0.03 or $-3.3^{+0.7}_{-0.3}$	−	–	−	defined as 100% E2
782.6 (1)	0.21 ± 0.01 or − 11.7 ± 0.9	−	0.21 ± 0.01	−	0.21 ± 0.01
1140.2 (1)	$-0.14^{+0.14}_{-0.11}$ or $-2.2^{+0.9}_{-0.6}$	−	−	−	− 0.14 ± 0.12
1289.8 (1)	$0.02^{+0.07}_{-0.09}$ or $-3.6^{+1.6}_{-0.9}$	−	−	−	$0.02^{+0.07}_{-0.09}$
E1(+M2) transition					
292.6 (2)	−	−	−	0.12 ± 0.13	0.12 ± 0.13

[*] LWM of 1972Kr15, 1974So03 and 1985De04 measurements.

[†] LWM of 1972Kr15 and 1985De04 measurements.

Gamma-ray emissions: recommended energies, multipolarities, theoretical internal conversion coefficients (frozen orbital approximation), and internal-pair formation coefficients.

E_γ (keV)	Multipolarity	α_K	α_L	α_{M+}	α_{IPF}	α_{tot}
61.16 (2)	80.6%M1 +19.4% E2 δ = 0.49 (6)[‡]	2.93 (12)	0.99 (14)	0.28 (4)	−	4.2 (2)
154.7 (1)	92%M1 + 8%E2 δ = 0.3 (2)	0.182 (14)	0.026 (5)	0.006	−	0.214 (20)
252.64 (9)	(18%M1 + 82% E2) δ = − 2.1 (5)	0.0541 (12)	0.0090 (4)	0.0021	−	0.0652 (17)
280.7 (1)	99.2%M1 + 0.8%E2 δ = − 0.09 (2)	0.0351 (5)	0.00445 (7)	0.00115	−	0.0407 (6)
290.5 (1)	(86%M1 + 14%E2) δ = 0.40 (3)	0.0326 (5)	0.00430 (7)	0.0010	−	0.0379 (6)
292.6 (2)	98.5%E1(+ 1.5%M2) δ = 0.12 (13)	0.0103 (60)	0.00136 (16)	0.000326	−	0.012 (7)
309.4 (1)	99%M1 + 1%E2 δ = 0.10 (3)	0.0273 (4)	0.00345 (5)	0.00085	−	0.0316 (5)
392.0 (2)	(97.8%M1 + 2.2%E2) δ = 0.15 (2)	0.01490 (21)	0.00187 (3)	0.00045	−	0.01722 (25)
412.10 (5)	E2	0.01210 (17)	0.001775 (25)	0.000435	−	0.01431 (20)
423.7 (7)	50%M1 + 50%E2 δ = 1.0 (5)	0.0117 (4)	0.00158 (4)	0.00042	−	0.0137 (4)
440.77 (2)	80%M1 + 20%E2 δ = 0.5 (3)	0.0109 (3)	0.001395 (22)	0.000305	−	0.0126 (3)
445.3 (1)	50%M1 + 50%E2 δ = − 1.0 (5)	0.0102(4)	0.001369 (23)	0.000431	−	0.0120 (4)
450.8 (2)	67%M1 + 33%E2 δ = 0.7 (5)	0.0101 (4)	0.001318 (20)	0.000382	−	0.0118 (4)
455.1 (1)	50%M1 + 50%E2 δ = 1.0 (5)	0.0097 (4)	0.001287 (19)	0.000313	−	0.0113 (4)
473.26 (4)	96%M1 + 4%E2 δ = − 0.20 (10)	0.00928 (14)	0.001159 (17)	0.000281	−	0.01072 (16)
501.93 (1)	89.6%M1 + 10.4%E2 δ = 0.34 (8)	0.00795 (13)	0.000997 (14)	0.000243	−	0.00919 (14)
543.2 (1)	E2	0.00553 (8)	0.000761 (11)	0.000189	−	0.00648 (9)
583.2 (2)	E1	0.001622 (23)	0.000196 (3)	0.000052	−	0.00187 (3)
603.9 (1)	(98%M1 + 2%E2) δ = 0.14 (8)	0.00513 (8)	0.000634 (10)	0.000156	−	0.00592 (9)
624.2 (1)	(50%M1 + 50%E2) δ = 1.0 (5)	0.0043 (3)	0.000550 (24)	0.000150	−	0.0050 (4)
638.3 (1)	85%M1 + 15%E2 δ = − 0.42 (3)	0.00438 (7)	0.000544 (8)	0.000136	−	0.00506 (8)
652.8 (1)	94.6%M1 + 5.4%E2 δ = 0.24 (7)	0.00423 (7)	0.000522 (8)	0.000128	−	0.00488 (8)
666.9 (1)	50%M1 + 50%E2 δ = 1.0 (5)	0.0037 (3)	0.000464 (23)	0.000036	−	0.0042 (3)
681.4 (1)	50%M1 + 50%E2 δ = 1.0 (5)	0.00347 (25)	0.000440 (22)	0.00009	−	0.0040 (3)

E_γ (keV)	Multipolarity	α_K	α_L	α_{M+}	α_{IPF}	α_{tot}
685.09 (7)	E2	0.00303 (5)	0.000399 (6)	0.000091	−	0.00352 (5)
697.9 (1)	E2	0.00289 (4)	0.000380 (6)	0.000090	−	0.00336 (5)
721.5 (1)	E2	0.00266 (4)	0.000348 (5)	0.000082	−	0.00309 (5)
747.2 (1)	E1	0.000951 (14)	0.0001142 (16)	0.0000278	−	0.001093 (16)
762.7 (1)	50%M1 + 50%E2 δ = 1.0 (5)	0.00265 (20)	0.000332 (19)	0.000078	−	0.00306 (22)
782.6 (1)	95.8%M1 + 4.2%E2 δ = 0.21 (1)	0.00277 (4)	0.000339 (5)	0.000081	−	0.00319 (5)
816.5 (1)	50%M1 + 50%E2 δ = 1.0 (5)	0.00225 (17)	0.000282 (17)	0.000068	−	0.00260 (19)
821.5 (8)	−	−	−	−	−	−
924.0 (2)	E2	0.001491 (21)	0.000189 (3)	0.000045	−	0.001725 (25)
1140.2 (1)	98%M1 + 2%E2 δ = − 0.14 (12)	0.001179 (20)	0.0001427 (23)	0.0000348	0.00000150 (2)	0.001358 (23)
1154.7 (1)	M1 + E2	−	−	−	−	−
1289.8 (1)	99.96%M1 + 0.04%E2 δ = $0.02^{+0.07}_{-0.09}$	0.000901 (13)	0.0001087 (16)	0.0000265	0.0000188 (3)	0.001055 (15)
1378.6 (1)	M1 + E2	−	−	−	−	−

‡ adopted on the basis of the required transition probability in order to achieve γ population-depopulation balance for the 61.161-keV nuclear level.

A normalisation factor of 0.354 (4) was calculated from the internal conversion coefficients and relative emission probabilities of the gamma-ray transitions populating the 88.23-keV metastable (^{127m}Te) and ground (^{127g}Te) states, summed in conjunction with direct beta feeding to the 88.23-keV metastable state of (2.0 ± 0.5) %, as measured by 1967Ta05 (direct beta feeding to the ^{127}Te ground state was assumed to be zero on the basis of spin and parity considerations):

$$\left[\sum^{88.23\ keV} P^{rel}_{\gamma+ce} \; + \; \sum^{0.0\ keV} P^{rel}_{\gamma+ce}\right] x\ F \; + \; \beta_{0,2} \; = \; 100\ \%$$

$$[41.8\ (7) + 235.25\ (238)]\ F \; + \; 2.0\ (5)\ \% \; = \; 100\ \%$$

$$F \; = \; 98.0\ (5) / 277.05\ (248) \; = \; 0.354 \pm 0.004$$

Beta-particle Emissions

Energies and emission probabilities

Beta-particle energies were calculated from the structural detail of the proposed decay scheme. Nuclear-level energies adopted from Hashizume (2011Ha31) and a Q_{β^-} value of 1582 (5) keV from the evaluated tabulations of 2011AuZZ were used to determine the energies and uncertainties of the beta-particle transitions.

The emission probability of the highest-energy beta-particle was measured by 1967Ta05 to be (2.0 ± 0.5) %, and this value was adopted to calculate the normalization factor of the relative gamma-ray emission probabilities. Direct beta population of the 762.64-, 501.93-, 61.161- and 0.0-keV nuclear levels of ^{127}Te were defined as zero on the basis of spin and parity considerations. All other beta-particle emission probabilities were calculated on the basis of achieving population-depopulation balances with the relevant relative gamma transition probabilities, as derived from the relative gamma-ray emission probabilities, internal conversion coefficients, and normalization factor of 0.354 ± 0.004.

Beta-particle emission probabilities per 100 disintegrations of ^{127}Sb.

Transition	E_β (keV)	P_β	Transition type	log*ft*
$\beta^-_{0,19}$	203 ± 5	0.18 ± 0.04	allowed	7.42 ± 0.11
$\beta^-_{0,18}$	259 ± 5	0.12 ± 0.02	[allowed]	7.93 ± 0.08
$\beta^-_{0,17}$	273 ± 5	0.06 ± 0.02	(allowed)	8.30 ± 0.15
$\beta^-_{0,16}$	292 ± 5	0.61 ± 0.04	allowed	7.39 ± 0.04
$\beta^-_{0,15}$	376 ± 5	0.10 ± 0.04	(allowed)	8.53 ± 0.18
$\beta^-_{0,14}$	427 ± 5	0.85 ± 0.25	allowed	7.79 ± 0.13
$\beta^-_{0,13}$	442 ± 5	1.35 ± 0.21	allowed	7.64 ± 0.07
$\beta^-_{0,12}$	505 ± 5	5.17 ± 0.14	(allowed)	7.251 ± 0.021
$\beta^-_{0,11}$	658 ± 5	1.27 ± 0.25	allowed	8.26 ± 0.09
$\beta^-_{0,10}$	796 ± 5	7.72 ± 0.21	1st forbidden non-unique	7.766 ± 0.018
$\beta^-_{0,9}$	799 ± 5	17.2 ± 0.3	allowed	7.425 ± 0.015
$\beta^-_{0,7}$	897 ± 5	34.4 ± 0.4	allowed	7.304 ± 0.013
$\beta^-_{0,6}$	951 ± 5	4.00 ± 0.21	1st forbidden non-unique	8.33 ± 0.03
$\beta^-_{0,4}$	1109 ± 5	22.6 ± 0.8	allowed	7.826 ± 0.019
$\beta^-_{0,3}$	1241 ± 5	2.4 ± 0.3	(1st forbidden non-unique)	8.98 ± 0.06
$\beta^-_{0,2}$	1494 ± 5	2.0 ± 0.5	1st forbidden unique	10.21 ± 0.11

$\sum$ 100.03

The proposed decay scheme is heavily dependent upon the absolute emission probability of the highest-energy β⁻ decay to the 88.23-keV ^{127m}Te nuclear level, as measured by Takemoto et al. (1967Ta05) to be (2.0 ± 0.5) %. There are also a number of gaps and uncertainties concerning some of the gamma-ray emissions. Under such unsatisfactory circumstances, spectroscopic measurements of the absolute γ-ray emission probabilities would assist greatly in addressing these specific issues, and so provide the means of deriving an evaluated decay scheme with much greater confidence.

Branching Fractions

^{127}Sb(β$^-$)^{127m}Te: summation of the γ and $\beta^-_{0,2}$ transitions populating the 88.23-keV metastable state.

BF(^{127}Sb(β$^-$)^{127m}Te) =

$$\sum_{i=1}^{M}\left[P_\gamma^{rel}(697.9\,keV)(1+\alpha) + P_\gamma^{rel}(543.2\,keV)(1+\alpha) + P_\gamma^{rel}(252.64\,keV)(1+\alpha)\right] x\,F + \beta_{0,2}$$

= {41.8 (7) x 0.354 (4)} + 2.0 (5) % = 14.8 (3) % + 2.0 (5) % = 16.8 (6) % [0.168 (6)]

^{127}Sb(β$^-$)^{127}Te: summation of the γ transitions populating the 0.0-keV ground state (no direct population of the ground state by β$^-$ decay).

BF(^{127}Sb(β$^-$)^{127}Te) =

$$\sum_{i=1}^{M}\left[P_\gamma^{rel}(1+\alpha)\right] x\,F$$

= 235.25 (238) x 0.354 (4) = 83.3 (13) % [0.833 (13)]

But lower value of 83.2 % [0.832] and uncertainty of ± 0.6 % [± 0.006] adopted to achieve a precise balance with the equivalent BF for ^{127}Sb(β^-)^{127m}Te. BF(^{127}Sb(β^-)^{127}Te) = 83.2 (6) % [0.832 (6)].

Atomic Data

The X-ray and Auger electron data have been calculated using evaluated X-ray data (1999ScZX, 2003De44), gamma-ray data, and atomic data from 1977La19, 1996Sc06 and 1998ScZM. Both the X-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.01, 28 January 2003). This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

K and L X-ray emission probabilities per 100 disintegrations of ^{127}Sb.

			Energy (keV)	Photons per 100 disint.
XL		(Te)	3.335 – 4.829	0.462 (23)
	XL_l	(Te)	3.335	0.0089 (4)
	XL_α	(Te)	3.759 – 3.770	0.235 (10)
	XL_η	(Te)	3.605	0.00355 (19)
	XL_β	(Te)	4.030 – 4.302	0.184 (7)
	XL_γ	(Te)	4.572 – 4.829	0.0248 (10)
XK_α	$XK_{\alpha2}$	(Te)	27.2020 (2)	1.11 (4)
	$XK_{\alpha1}$	(Te)	27.4726 (2)	2.06 (7)
$XK'_{\beta1}$	$XK_{\beta3}$	(Te)	30.9446 (3)	0.591 (21)
	$XK_{\beta1}$	(Te)	30.9960 (4)	
	$XK''_{\beta5}$	(Te)	31.236	
$XK'_{\beta2}$	$XK_{\beta2}$	(Te)	31.7008 (5)	0.128 (6)
	$XK_{\beta4}$	(Te)	31.774	
	$XKO_{2,3}$	(Te)	31.812	

Electron energies were determined from electron binding energies tabulated by Larkins (1977La19) and the evaluated gamma-ray energies. Absolute electron emission probabilities were calculated from the evaluated absolute gamma-ray emission probabilities and associated internal conversion coefficients.

Data Consistency

Q_{β^-} values of 1582 (5) and 1494 (5) keV have been adopted for the β^- decay of ^{127}Sb to the ground and metastable states of ^{127}Te, respectively, based on the atomic mass evaluation of Audi and Wang (2011AuZZ) and the nuclear-level energy of ^{127m}Te (2011Ha31). An effective Q-value derived from these data has been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{127}Sb beta-decay process (i.e. β^-, electron, γ, etc.):

$$\text{effective Q-value} = \sum (Q_i \times BF_i) = 1567\ (13)\ \text{keV}$$

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 1560\ (15)\ \text{keV}$$

The percentage deviation from the effective Q-value is (0.5 ± 1.3) %, which supports the derivation of a consistent decay scheme.

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^{127}Te - Comments on evaluation of decay data

by A. L. Nichols

Evaluated: February - May 2012

Evaluation Procedure

Limitation of Relative Statistical Weight Method (LWM) and other analytical procedures were applied to average the measured decay data when appropriate.

Decay Scheme

A simple decay scheme was constructed primarily from the gamma-ray studies of 1970Ap02 and 1965Au01 in which Ge(Li) gamma-ray detectors were used. An earlier study involved the use of low-resolution NaI(Tl) detectors (1956Kn20), and these data have not been considered in this particular evaluation. The gamma-ray emission probabilities were expressed in terms of the emission probability of the 417.99-keV gamma ray (100 %), and weighted mean data were derived as appropriate.

Nuclear Data

^{127}Te undergoes beta decay to various nuclear levels of ^{127}I through five β^- and nine subsequent γ emissions.

Half-life (^{127}Te)

The recommended half-life has been determined from the measurements of Seaborg *et al.* (1940Se01), Knight *et al.* (1956Kn20), Majumdar and Chatterjee (1963Ma20), Qaim and Ejaz (1968Qa02), and Bormann *et al.* (1970Bo22). A value of 9.35 hours was derived in terms of LWM, with the uncertainty increased from ± 0.06 to the lowest measured value of ± 0.10 hour.

Half-life measurements (^{127}Te).

Reference	Half-life (hours)
1940Se01	9.3 ± 0.5
1956Kn20	9.35 ± 0.10
1963Ma20	9.36 ± 0.20
1968Qa02	9.23 ± 0.13
1970Bo22	9.48 ± 0.13
Recommended value	9.35 ± 0.10*

* uncertainty increased from ± 0.06 to the lowest measured value of ± 0.10 hour.

Q values

Q^- of 702 (4) keV was adopted from the evaluated tabulations of 2011AuZZ, which compares with an earlier value of 702 (3) keV from 2003Au03.

Gamma Rays

Energies

Gamma transition energies were deduced from the structural details of the proposed decay scheme. The ^{127}I nuclear-level energies of 2011Ha31 were adopted, and used to determine the energies of the gamma-ray transitions between the depopulating-populating levels. Many of the lower-energy nuclear levels recommended by 2011Ha31 are primarily based on accurate gamma-ray energy measurements of the equivalent EC decay of ^{127}Xe by 1977Ge10 (observed gamma-ray emissions at 57.61 (2), 145.252 (10), 172.132 (10), 202.860 (10) and 374.991 (12) keV).

Adopted energies, spins and parities for the nuclear levels of ^{127}I.

Nuclear level number	Nuclear level energy (keV)	Spin and parity	^{127}Te radionuclidic decay
0	0.0	5/2 +	^{127}Te and ^{127m}Te
1	57.608 ± 0.011	7/2 +	^{127}Te and ^{127m}Te
2	202.860 ± 0.008	3/2 +	^{127}Te
3	374.992 ± 0.009	1/2 +	^{127}Te
4	417.99 ± 0.06	5/2 +	^{127}Te
5	618.31 ± 0.13	3/2 +	^{127}Te
6	628.69 ± 0.16	7/2 +	^{127m}Te
7	650.92 ± 0.08	9/2 (+)	^{127m}Te
8	716.50 ± 0.06	(11/2 +)	^{127m}Te

Gamma-ray energies identified with β^- decay of ^{127}Te.

Transition	E_γ (keV)			
	1956Kn20	**1965Au01**	**1970Ap02**	**Recommended**[*]
$\gamma_{1,0}$ (I)	58.5 (1)	57.6 (5)	57.63 (8)	57.608 (11)
$\gamma_{2,1}$ (I)	145 (2)	145 (5)	145.2 (1)	145.252 (14)
$\gamma_{3,2}$ (I)	–	–	172.1 (5)	172.132 (12)
$\gamma_{2,0}$ (I)	203 (3)	203 (1)	202.9 (1)	202.860 (8)
$\gamma_{4,2}$ (I)	215 (4)	214 (1)	215.1 (1)	215.13 (6)
$\gamma_{4,1}$ (I)	360 (4)	360.0 (5)	360.3 (1)	360.38 (6)
$\gamma_{3,0}$ (I)	–	–	375.0 (4)	374.991 (9)
$\gamma_{4,0}$ (I)	418 (2)	417.0 (5)	417.9 (1)	417.99 (6)
$\gamma_{5,0}$ (I)	–	–	618.6 (3)	618.31 (13)

[*] nuclear level energies of 2011Ha31 were used to determine the recommended energies of the gamma-ray transitions – gamma recoil of negligible impact on these data.

Emission Probabilities

Although judged to be a rather limited data set, a reasonably consistent decay scheme was derived from the relative gamma-ray emission probabilities measured by Auble and Kelly (1965Au01) and Apt *et al.* (1970Ap02) for a mixture of ^{127}Te and ^{127m}Te in secular equilibrium. These relative emission probabilities were normalised to the 100 % value assigned to the 417.99-keV gamma ray.

The 57.608-keV gamma-ray emission is common to both ^{127}Te and ^{127m}Te and has only been quantified by 1965Au01 and 1970Ap02 in terms of ^{127}Te-^{127m}Te mixture in secular equilibrium. However, the assignment of this gamma transition in the decay scheme of ^{127}Te permits an accurate relative emission probability to be calculated from the gamma population-depopulation balance of the 57.608-keV nuclear level, assuming no direct beta population of this particular $7/2^+$ level ($3/2^+ \rightarrow 7/2^+$ would constitute a second forbidden non-unique transition):

$$TP_\gamma(57.608\text{ keV}) = TP_\gamma(145.252\text{ keV}) + TP_\gamma(360.38\text{ keV}) = 0.59\ (9)\ F + 13.9\ (2)\ F$$

$$= 14.49\ (22)\ F,$$

where *TP* is the transition probability of the relevant gamma ray, and
F is the normalisation factor for the relative γ-ray emission probabilities.

Thus, the relative γ-ray emission probability P_γ^{rel}(57.608 keV) can be expressed as follows:

$$P_\gamma^{rel}(57.608\text{ keV}) = \frac{TP_\gamma^{rel}(57.608\ keV)}{(1\ +\ \alpha_{tot})} = \frac{14.49\ (22)}{(1\ +\ 3.72\ (6))} = 3.07\ (6)$$

Relative gamma-ray emission probabilities for ^{127}Te, as adopted from measurements of a mixture of ^{127}Te and ^{127m}Te in secular equilibrium.

Transition	E_γ (keV)	P_γ^{rel}		
		1965Au01	1970Ap02	Recommended[*]
$\gamma_{1,0}$ (I)[†]	57.608 (11)	61 (1)	56 (5)	3.07 (6)[‡]
$\gamma_{2,1}$ (I)	145.252 (14)	0.51 (6)	0.33 (3)	0.40 (6)
$\gamma_{3,2}$ (I)	172.132 (12)	–	0.03 (2)	0.03 (2)
$\gamma_{2,0}$ (I)	202.860 (8)	5.4 (2)	5.86 (21)	5.6 (2)
$\gamma_{4,2}$ (I)	215.13 (6)	3.9 (2)	3.91 (17)	3.9 (2)
$\gamma_{4,1}$ (I)	360.38 (6)	14.8 (1)	13.6 (1)	13.6 (2)
$\gamma_{3,0}$ (I)	374.991 (9)	–	0.03 (2)	0.03 (2)
$\gamma_{4,0}$ (I)	417.99 (6)	100	100	100
$\gamma_{5,0}$ (I)	618.31 (13)	–	0.013 (2)	0.013 (2)

[*] weighted mean of appropriate measurements of 1965Au01 and 1970Ap02, from which NRM values were adopted.
[†] gamma transition common to the β^- decay of both ^{127}Te and ^{127m}Te.
[‡] derived from γ population-depopulation balance of the 57.608-keV nuclear level, assuming no direct population by β^- decay on the basis of spin-parity considerations ($3/2^+ \rightarrow 7/2^+$).

Two specific numerical procedures were used to analyse the limited and somewhat disparate data set of P_γ^{rel} measurements of mixtures of ^{127}Te and ^{127m}Te in secular equilibrium: limitation of relative statistical weight method (LWM), and normalised residual method (NRM)

E_γ (keV)	Analytical method	P_γ^{rel}	$\chi^2/(N-1)$	$\chi^2/(N-1)_{critical}$
57.608 (11)	LWM NRM	61 (1) 61 (1)	0.96 0.96	6.63 3.84
145.252 (14)	LWM NRM	0.42 (9) 0.40 (6)	4.50 2.63	6.63 3.84
202.860 (8)	LWM NRM	5.6 (2) 5.6 (2)	2.52 2.52	6.63 3.84
215.13 (6)	LWM NRM	3.9 (2) 3.9 (2)	0.00 0.00	6.63 3.84
360.38 (6)	LWM NRM	14.2 (6) 13.6 (2)	72 3.85	6.63 3.84

Multipolarities and Internal Conversion Coefficients

The nuclear level scheme specified by Hashizume (2011Ha31) has been used to define the multipolarities of the gamma transitions on the basis of known spins and parities. Many of the gamma-ray transitions possess (M1 + E2) multipolarity, and assessments have been made of a significant number of these mixing ratios by Krane (1977Kr13, 1980Kr22). Various proposed mixing ratios have been assessed by the evaluator, and specific selections have been made as follows:

- 57.608-keV gamma ray, 99.3 % M1 + 0.7 % E2;
- 172.132-keV gamma ray, 99.3 % M1 + 0.7 % E2;
- 202.860-keV gamma ray, 79 % M1 + 21 % E2;
- 215.13-keV gamma ray, 96.0 % M1 + 4.0 % E2;
- 360.38-keV gamma ray, 96.4 % M1 + 3.6 % E2; and
- 417.99-keV gamma ray, 99.4 % M1 + 0.6 % E2.

Additionally, the 618.31-keV (M1 + E2) gamma transition was arbitrarily assigned a mixing ratio of 1.0 ± 0.5 (50 % M1 + 50 % E2) in this reasonably comprehensive exercise. Both the 145.252- and 374.991-keV gamma rays were defined as E2 transitions. These data were used to determine recommended internal conversion coefficients from the frozen orbital approximation of Kibédi *et al.* (2008Ki07), based on the theoretical tabulations of Band *et al.* (2002Ba25, 2002Ra45).

Gamma-ray emissions: mixing ratios of (M1 + E2) transitions.

E_γ (keV)	δ				
	1965Au01	**1967Ge10**	**1977Kr13**	**1980Kr22**	**Recommended**
57.608 (11)	−	− 0.084 (6) (M1 + 0.7(1)%E2)	− 0.084 (6) (M1 + 0.7(1)%E2)	− 0.083 (5) (M1 + 0.7(1)%E2)	− 0.083 ± 0.005* (M1 + 0.7(1)%E2)
172.132 (12)	−	−	− 0.084 (7) (M1 + 0.7(1)%E2)	− 0.085 (6) (M1 + 0.7(1)%E2)	− 0.085 ± 0.006* (M1 + 0.7(1)%E2)
202.860 (8)	−	+ 0.52 (5) (M1 + 21(3)%E2)	+ 0.52 (5) (M1 + 21(3)%E2)	−	+ 0.52 ± 0.05† (M1 + 21(3)%E2)
215.13 (6)	− 0.20 (2) or > 200	−	− 0.203 (15)	−	− 0.203 ± 0.015† (M1 + 4.0(5)%E2
360.38 (6)	0.18 (8) or 2.29 (7)	−	+ 0.194 (15)	−	+ 0.194 ± 0.015† (M1 + 3.6(5)%E2)
417.99 (6)	−	−	− 0.08 (3)	−	− 0.08 ± 0.03† (M1 + 0.6(3)%E2)
618.31 (13)	−	−	−	−	1.0 ± 0.5 (50%M1 + 50%%E2)

* adopted directly from 1980Kr22.
† adopted directly from 1977Kr13.

Gamma-ray emissions: recommended energies, multipolarities, and theoretical internal conversion coefficients (frozen orbital approximation).

E_γ (keV)	Multipolarity	α_K	α_L	α_{M+}	α_{tot}	
57.608 (11)	99.3%M1 + 0.7%E2 δ = − 0.083 (5)	3.16 (5)	0.449 (8)	0.111	3.72 (6)	β^-
145.252 (14)	E2	0.357 (5)	0.0907 (13)	0.0233	0.471 (7)	β^-
172.132 (12)	99.3%M1 + 0.7%E2 δ = − 0.085 (6)	0.1419 (20)	0.0185 (3)	0.0046	0.1650 (24)	β^-
202.860 (8)	79%M1 + 21%E2 δ = + 0.52 (5)	0.0965 (17)	0.0142 (5)	0.0036	0.1143 (22)	β^-
215.13 (7)	96.0%M1 + 4.0%E2 δ = − 0.203 (15)	0.0782 (11)	0.01031 (16)	0.00249	0.0910 (13)	β^-
360.38 (7)	96.4%M1 + 3.6%E2 δ = + 0.194 (15)	0.0201 (3)	0.00256 (4)	0.00054	0.0232 (4)	β^-
374.991 (9)	E2	0.01671 (24)	0.00257 (4)	0.00062	0.0199 (3)	β^-
417.99 (6)	99.4%M1 + 0.6%E2 δ = − 0.08 (3)	0.01381 (20)	0.001741 (25)	0.000429	0.01598 (23)	β^-
618.31 (13)	50%M1 + 50%E2 δ = 1.0 (5)	0.0047 (4)	0.00061 (3)	0.00019	0.0055 (4)	β^-

A normalisation factor of 0.009 97 (11) was calculated from the internal conversion coefficients and relative emission probabilities of the gamma-ray transitions populating the ground states of ^{127}Te and ^{127}I. An important feature of these calculations is the measurement of the ratio of the 417.99-keV γ-ray emission probability of ^{127}Te to the total β^- emission probability of ^{127}Te and ^{127m}Te in secular equilibrium by Apt *et al.* (1970Ap02), which has been adopted in the evaluation:

$$\frac{P_\gamma(417.99\ keV)}{\sum(\,^{127}Te + \,^{127m}Te)\beta^-} = \frac{100\,F}{[(122.33(43) + X) + 273.80(586)]\ F} = 0.0097(1),$$

where F is the normalisation factor for the relative γ-ray emission probabilities, and X is the relative emission probability of the β^- decay of ^{127}Te directly to the ground state of ^{127}I.

$$100 = 0.0097\,(1)\,[396.13\,(588) + X]$$

$$X = \frac{100}{0.0097(1)} - 396.13\,(588) = 10309\,(106) - 396.13\,(588) = 9913\,(106)$$

Therefore, within the β^- decay of ^{127}Te:

$$\sum(^{127}Te)\beta^- = 9913(106)\,F + 122.33(43)\,F = 100\,\%$$

$$F = 100 / 10035\,(106) = 0.009\,97 \pm 0.000\,11$$

Beta-particle Emissions

Energies and emission probabilities

Beta-particle energies were determined from the structural detail of the proposed decay scheme. Nuclear-level energies adopted from Hashizume (2011Ha31) and a Q_{β^-} value of 702 (4) keV from the evaluated tabulations of 2011AuZZ were used to deduce the energies and uncertainties of the beta-particle transitions.

Absolute beta-particle emission probabilities were derived from γ population-depopulation of the various nuclear levels of ^{127}I, based on the relative emission probabilities of the γ rays, their normalisation factor of 0.009 97 (11), and the theoretical internal conversion coefficients. The $\beta^-_{0,0}$ emission directly to the ground state of ^{127}I can be derived by two routes:

(i) relative β^- emission probabilities determined from γ population-depopulation of the nuclear levels of ^{127}I

$$P_{\beta^-_{0,0}} = 100 - \sum^{all\ other\ \beta^-} P^{rel}_{\beta^-}\ x\ F$$

$$P_{\beta^-_{0,0}} = 100 - [122.33\,(43)\ \text{x}\ 0.00997\,(11)] = 100 - 1.220\,(14)$$
$$= (98.780 \pm 0.014)\ \%$$

(ii) relative γ-ray emission probabilities populating the ground state of ^{127}I directly

$$P_{\beta^-_{0,0}} = 100 - \sum^{\gamma\ to\ ground\ state} P^{rel}_{\gamma}\,(1 + \alpha_{tot})\ x\ F$$

$$P_{\beta^-_{0,0}} = 100 - [0.013\,(2) + 101.598\,(23) + 0.03\,(2) + 6.2\,(2) + 14.5\,(3)]\ \text{x}\ 0.00997\,(11)$$
$$= 100 - [122.341\,(361)\ \text{x}\ 0.00997\,(11)] = 100 - 1.220\,(14)$$
$$= (98.780 \pm 0.014)\ \%$$

Beta-particle emission probabilities per 100 disintegrations of ^{127}Te.

Transition	**E_β (keV)**	**P_β**	**Transition type**	**log*ft***
$\beta^-_{0,5}$	84 ± 4	0.00013 ± 0.00002	allowed	8.38 ± 0.10
$\beta^-_{0,4}$	284 ± 4	1.19 ± 0.02	allowed	6.086 ± 0.022
$\beta^-_{0,3}$	327 ± 4	0.0006 ± 0.0003	allowed	9.58 ± 0.22
$\beta^-_{0,2}$	499 ± 4	0.025 ± 0.003	allowed	8.57 ± 0.06
$\beta^-_{0,0}$	702 ± 4	98.780 ± 0.014	allowed	5.490 ± 0.010

∑ 99.996 (25)

The proposed decay scheme is heavily dependent on the γ-ray studies of Apt *et al.* (1970Ap02), particularly their measurement of 0.0097 (1) for the $P_{\gamma}(417.99\ keV)/\sum\beta^{-}$ ratio, and an estimate of 18.8 for the (^{127}Te + ^{127m}Te in secular equilibrium / ^{127}Te) ratio as applied to the 57.608-keV gamma-ray emission probability – current evaluation generates latter ratio of 18.9 (58/3.07). There is a lack of γ-ray spectroscopy measurements of ^{127}Te (and ^{127m}Te) decay with HPGe detectors that would assist greatly in quantifying the absolute γ-ray emission probabilities with much greater confidence, and hence derive a more satisfactory decay scheme.

Atomic Data

The X-ray and Auger electron data have been calculated from the evaluated X-ray data (1999ScZX, 2003De44), gamma-ray data, and atomic data from 1977La19, 1996Sc06 and 1998ScZM. Both the X-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.01, 28 January 2003). This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

K and L X-ray emission probabilities per 100 disintegrations of ^{127}Te.

			Energy (keV)	Photons per 100 disint.
XL		(I)	3.485 – 5.060	0.011 9 (6)
	XL$_{l}$	(I)	3.485	0.000 226 (8)
	XL$_{\alpha}$	(I)	3.927 – 3.938	0.005 97 (18)
	XL$_{\eta}$	(I)	3.779	0.000 088 (3)
	XL$_{\beta}$	(I)	4.221 – 4.508	0.004 76 (11)
	XL$_{\gamma}$	(I)	4.801 – 5.060	0.000 678 (17)
XK$_{\alpha}$	XK$_{\alpha2}$	(I)	28.3175 (4)	0.030 9 (7)
	XK$_{\alpha1}$	(I)	28.6123 (3)	0.057 4 (12)
XK$'_{\beta1}$	XK$_{\beta3}$	(I)	32.2397 (3)	0.016 5 (4)
	XK$_{\beta1}$	(I)	32.2951 (4)	
	XK$''_{\beta5}$	(I)	32.544	
XK$'_{\beta2}$	XK$_{\beta2}$	(I)	33.042 (2)	0.003 74 (12)
	XK$_{\beta4}$	(I)	33.120	
	XKO$_{2,3}$	(I)	33.166	

Electron energies were obtained from the electron binding energies tabulated by Larkins (1977La19) and the evaluated gamma-ray energies. Absolute electron emission probabilities were calculated from the evaluated absolute gamma-ray emission probabilities and associated internal conversion coefficients.

Data Consistency

A Q$_{\beta^-}$ value of 702(4) keV has been adopted from the atomic mass evaluation of Audi and Wang *et al.* (2011AuZZ). This value has been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{127}Te beta-decay process (i.e. β^{-}, electron, γ, etc.):

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 702\ (4)\ \text{keV}$$

Percentage deviation from the Q-value of Audi and Wang is (0.0 ± 0.9) %, which supports the derivation of a highly consistent decay scheme.

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^{127m}Te - Comments on evaluation of decay data

by A. L. Nichols

Evaluated: February – May 2012

Evaluation Procedure

Limitation of Relative Statistical Weight Method (LWM) and other analytical procedures were applied to average the measured decay data when appropriate.

Decay Scheme

A simple decay scheme was constructed primarily from the gamma-ray studies of 1965Au01 and 1970Ap02 in which Ge(Li) gamma-ray detectors were used. An earlier study involved the use of low-resolution NaI(Tl) detectors (1956Kn20), and these data have not been considered in this particular evaluation. The relative emission probabilities of gamma rays emitted from mixtures of ^{127}Te and ^{127m}Te in secular equilibrium were quantified by 1965Au01 and 1970Ap02 in terms of the emission probability of the 417.99-keV gamma ray (100 %) in the β^- decay of ^{127}Te, and weighted mean data were derived as appropriate.

Nuclear Data

^{127m}Te undergoes IT decay directly to the ground state of ^{127}Te, with a small β^- branch to a number of nuclear levels of ^{127}I defined in terms of four β^- and five subsequent γ emissions.

Half-life (^{127m}Te)

The recommended half-life has been determined from the measurements of Seaborg *et al.* (1940Se01), Knight *et al.* (1956Kn20), Andersson *et al.* (1965An05), and Eastman and Krane (2008Ea01). A value of (106.1 ± 0.7) days was preferred as recommended by the Rajeval technique, rather than adopt the value determined by the LWM.

Half-life measurements (^{127m}Te).

Reference	Half-life (days)
1940Se01	92 ± 2
1951Co34	~ 115*
1956Kn20	105 ± 2
1965An05	109 ± 2
2008Ea01	106.1 ± 0.7
Recommended value	106.1 ± 0.7†

* no uncertainty quoted, and therefore not included in the averaging procedures.

† Rajeval analysis adopted, in alignment with the measurement of Eastman and Krane.

Various procedures were considered in the analysis of the disparate data set: limitation of relative statistical weight method (LWM), normalised residual method (NRM), Rajeval technique, bootstrap method, and Mandel-Paule approach:

Analytical method	**Half-life (days)**	**$\chi^2/(N-1)$**	**$\chi^2/(N-1)_{critical}$**
LWM	104 ± 4	19.56	3.78
NRM	106.2 ± 0.6	2.47	2.60
Rajeval	106.1 ± 0.7	0.82	–
Bootstrap	104 ± 5	22.23	–
Mandel-Paule	103 ± 8	25.58	–

Q values

The nuclear-level energy of ^{127m}Te was adopted as Q_{IT} (88.23 (7) keV from 2011Ha31). A Q^- value of 790 (4) keV was obtained by summing the evaluated Q^- for the ground-state β^- decay taken from the tabulations of 2011AuZZ (702 (4) keV) with the nuclear-level energy for the metastable state of 88.23 (7) keV.

Gamma Rays

Energies

Gamma-ray transition energies were deduced from the structural details of the proposed decay scheme. The ^{127}Te and ^{127}I nuclear-level energies of 2011Ha31 were adopted, and used to determine the energies of the gamma-ray transitions between the depopulating-populating levels.

Adopted energies, spins and parities for the nuclear levels of ^{127}Te and ^{127}I.

Nuclear level number	**Nuclear level energy (keV)**	**Spin and parity**	**^{127}Te radionuclidic decay**
^{127}Te nuclear level:			
0	0.0	3/2 +	^{127m}Te
1	61.161 ± 0.019	1/2 +	–
2	88.23 ± 0.07	11/2 –	^{127m}Te
^{127}I nuclear level:			
0	0.0	5/2 +	^{127}Te and ^{127m}Te
1	57.608 ± 0.011	7/2 +	^{127}Te and ^{127m}Te
2	202.860 ± 0.008	3/2 +	^{127}Te
3	374.992 ± 0.009	1/2 +	^{127}Te
4	417.99 ± 0.06	5/2 +	^{127}Te
5	618.31 ± 0.13	3/2 +	^{127}Te
6	628.69 ± 0.16	7/2 +	^{127m}Te
7	650.92 ± 0.08	9/2 (+)	^{127m}Te
8	716.50 ± 0.06	(11/2 +)	^{127m}Te

Gamma-ray energies identified with the IT and β^- decay modes of ^{127m}Te.

Transition	**E_γ (keV)**			
	1956Kn20	**1965Au01**	**1970Ap02**	**Recommended**[*]
$\gamma_{1,0}$ (I)	58.5 (1)	57.6 (5)	57.63 (8)	57.608 (11)
$\gamma_{2,0}$ (Te)	–	87 (1)	88.26 (8)	88.23 (7)
$\gamma_{7,1}$ (I)	–	591 (1)	593.3 (1)	593.31 (8)
$\gamma_{6,0}$ (I)	–	–	628.6 (3)	628.69 (16)
$\gamma_{7,0}$ (I)	–	–	651.0 (2)	650.92 (8)
$\gamma_{8,1}$ (I)	–	657 (1)	658.9 (1)	658.89 (6)

[*] nuclear level energies of 2011Ha31 were used to determine the recommended energies of the gamma-ray transitions – gamma recoil of negligible impact on these data.

Emission Probabilities

Although judged to be a rather limited data set, a reasonably consistent decay scheme was derived from the relative gamma-ray emission probabilities measured by Auble and Kelly (1965Au01) and Apt *et al.* (1970Ap02) for a mixture of ^{127}Te and ^{127m}Te in secular equilibrium. These relative emission probabilities were normalised to the 100 % value assigned to the 417.99-keV gamma ray, which is identified exclusively with the β^- decay of ^{127}Te.

Relative gamma-ray emission probabilities for ^{127m}Te, as adopted from measurements of a mixture of ^{127}Te and ^{127m}Te in secular equilibrium.

Transition	E_γ (keV)	P_γ^{rel}		
		1965Au01	1970Ap02	Recommended*
$\gamma_{1,0}$ (I)†	57.608 (11)	61 (1)	56 (5)	58 (1)‡
$\gamma_{2,0}$ (Te)	88.23 (7)	25 (1)	12 (1)	8.56 (16)#
[$\gamma_{4,0}$ (I)]	417.99 (6)	[100]	[100]	^{127}Te decay only [100]
$\gamma_{7,1}$ (I)	593.31 (8)	0.22 (4)	0.24 (2)	0.24 (2)
$\gamma_{6,0}$ (I)	628.69 (16)	–	0.009 (2)	0.009 (2)
$\gamma_{7,0}$ (I)	650.92 (8)	–	0.03 (1)	0.03 (1)
$\gamma_{8,1}$ (I)	658.89 (6)	1.43 (6)	1.30 (10)	1.40 (6)

* weighted mean of appropriate measurements of 1965Au01 and 1970Ap02 (identical LWM and NRM values).

† gamma transition common to the β^- decay of both ^{127}Te and ^{127m}Te.

‡ determined from a weighted mean value of 61 (1) and subtraction of 3.07 (6) contribution from ^{127}Te β^- decay.

\# calculated from IT branching fraction of 0.9727 (7), a normalisation factor of 0.00997 (11) for the relative γ-ray emission probabilities, and theoretical internal conversion coefficients of M4 88.23-keV γ transition.

Two specific numerical procedures were used to analysis the limited and somewhat disparate data set of P_γ^{rel} measurements of mixtures of ^{127}Te and ^{127m}Te in secular equilibrium: limitation of relative statistical weight method (LWM), and normalised residual method (NRM).

E_γ (keV)	Analytical method	P_γ^{rel}	$\chi^2/(N-1)$	$\chi^2/(N-1)_{critical}$
57.608 (11)	LWM	61 (1)	0.96	6.63
	NRM	61 (1)	0.96	3.84
593.31 (8)	LWM	0.24 (2)	0.20	6.63
	NRM	0.24 (2)	0.20	3.84
658.89 (6)	LWM	1.40 (6)	1.24	6.63
	NRM	1.40 (6)	1.24	3.84

The 57.608-keV gamma-ray emission is common to both ^{127}Te and ^{127m}Te and has only been quantified by 1965Au01 and 1970Ap02 in terms of ^{127}Te-^{127m}Te mixture in secular equilibrium, with a relative emission probability of 61 (1). Nevertheless, an accurate relative emission probability of 3.07 (6) can be determined from the gamma population-depopulation balance of the 57.608-keV nuclear level in the β^- decay of ^{127}Te, based on the assumption of no direct beta transition to this particular $7/2^+$ level ($3/2^+ \rightarrow 7/2^+$ would represent a second forbidden non-unique transition). Hence, an equivalent relative emission probability of 58 (1) can be calculated for the 57.608-keV gamma ray in the β^- decay of ^{127m}Te.

Multipolarities and Internal Conversion Coefficients

The nuclear level scheme specified by Hashizume (2011Ha31) has been used to define the multipolarities of the gamma transitions on the basis of known spins and parities. Detailed internal-conversion coefficient studies have been carried out by Kalinauskas *et al.* (1972Ka31, 1972Ka61) and Soni *et al.* (1977So06) on the 88.23-keV gamma ray that arises from the IT decay mode. These measurements of various ICC ratios and quantification of α_K are given below, and have been compared with equivalent theoretical internal conversion coefficients obtained from the frozen orbital approximation for M4 gamma transition (M4 BrIccFO).

Comparison of measured internal-conversion coefficient data with BrIcc frozen orbital calculations for the 88.23-keV M4 gamma transition.

	Ratios				α_K
	K : L : M : N+O	$L_I : L_{II} : L_{III}$	$M_I : M_{II+III} : M_{IV+V}$	(N+O) : L	
1972Ka31	0.99 (5) : 1 : 0.248 (24) : 0.050 (4)	0.599 (19) : 0.144 (8) : 1	1 : 2.29 (14) : 0.093 (23)	−	−
M4 BrIccFO	0.960 (21) : 1 : 0.238 (5) : 0.050 (1)	0.596 (14) : 0.137 (3) : 1	1 : 1.98 (4) : 0.0694 (15)		
1972Ka61	−	−	−	0.050 (4)	−
M4 BrIccFO				0.050 (1)	
1977So06	−	−	−	−	484 (23)
M4 BrIccFO					486 (7)

Mixing ratios for the 57.608- and 593.31-keV gamma transitions with (M1 + E2) multipolarity have been determined by 1965Au01 and 1967Ge10, and the data assessed by Krane (1977Kr13, 1980Kr22). Specific mixing ratios have been selected to give the following multipolarities: (99.3 % M1 + 0.7 % E2) for the 57.608-keV gamma ray, and (95 % M1 + 5 % E2) for the 593.31-keV gamma ray. An additional (M1 + E2) gamma transition of 628.69 keV was arbitrarily assigned a mixing ratio of 1.0 ± 0.5 (50 % M1 + 50 % E2). The 650.92- and 658.89-keV gamma rays were defined as E2 transitions. These data were used to determine recommended internal conversion coefficients from the frozen orbital approximation of Kibédi *et al.* (2008Ki07), based on the theoretical tabulations of Band *et al.* (2002Ba25, 2002Ra45).

Gamma-ray emissions from β^- decay: multipolarities and mixing ratios of (M1 + E2) transitions.

E_γ (keV)	δ				
	1965Au01	**1967Ge10**	**1977Kr13**	**1980Kr22**	**Recommended**
57.608 (11)	−	− 0.084 (6) (M1 + 0.7(1)%E2)	− 0.084 (6) (M1 + 0.7(1)%E2)	− 0.083 (5) (M1 + 0.7(1)%E2)	− 0.083 ± 0.005* (M1 + 0.7(1)%E2)
593.31 (8)	− 0.24 (13) or − 5.68 (9)	−	− 0.23 (3) (M1 + 5(1)%E2)	− 0.23 (3) (M1 + 5(1)%E2)	− 0.23 ± 0.03* (M1 + 5(1)%E2)
628.69 (16)	−	−	−	−	1.0 ± 0.5 (50%M1 + 50%E2)
650.92 (8)	−	−	−	−	E2
658.89 (6)	−	−	−	−	E2

* Adopted directly from 1980Kr22.

Gamma-ray emissions: recommended energies, multipolarities, and theoretical internal conversion coefficients (frozen orbital approximation).

Transition	E_γ (keV)	Multipolarity	α_K	α_L	α_{M+}	α_{tot}	
$\gamma_{1,0}$ (I)	57.608 (11)	99.3%M1 + 0.7%E2 δ = − 0.083 (5)	3.16 (5)	0.449 (8)	0.111	3.72 (6)	β^-
$\gamma_{2,0}$ (Te)	88.23 (7)	M4	486 (7)	506 (8)	146 (3)	1138 (17)	IT
$\gamma_{7,1}$ (I)	593.31 (8)	95%M1 + 5%E2 δ = − 0.23 (3)	0.005 78 (9)	0.000 722 (11)	0.000 178	0.006 68 (10)	β^-
$\gamma_{6,0}$ (I)	628.69 (16)	50%M1 + 50%E2 δ = 1.0 (5)	0.004 5 (4)	0.000 58 (3)	0.000 12	0.005 2 (4)	β^-
$\gamma_{7,0}$ (I)	650.92 (8)	E2	0.003 62 (5)	0.000 488 (7)	0.000 122	0.004 23 (6)	β^-
$\gamma_{8,1}$ (I)	658.89 (6)	E2	0.003 51 (5)	0.000 472 (7)	0.000 118	0.004 10 (6)	β^-

A normalisation factor of 0.009 97 (11) was calculated from the internal conversion coefficients and relative emission probabilities of the gamma-ray transitions populating the ground states of ^{127}Te and ^{127}I. An important feature of these calculations is the measurement of the ratio of the 417.99-keV γ-ray emission probability of ^{127}Te to the total β^- emission probability of ^{127}Te and ^{127m}Te in secular equilibrium by Apt *et al.* (1970Ap02), which was adopted in the evaluation:

$$\frac{P_\gamma(417.99\ keV)}{\sum(^{127}Te+\ ^{127m}Te)\beta^-} \;=\; \frac{100\ F}{[(122.33\ (43)+X)\ +\ 273.80\ (586)]\ F} \;=\; 0.0097\ (1),$$

where F is the normalisation factor for the relative γ-ray emission probabilities, and
X is the relative emission probability of the β^- decay of ^{127}Te directly to the ground state of ^{127}I.

$$100 \;=\; 0.0097\ (1)\ [396.13\ (588) + X]$$

$$X \;=\; \frac{100}{0.0097\ (1)} - 396.13\ (588) \;=\; 10309\ (106) \;-\; 396.13\ (588) \;=\; 9913\ (106)$$

Therefore, within the β^- decay of ^{127}Te:

$$\sum(^{127}Te)\beta^- \;=\; 9913\ (106)\ F \;+\; 122.33\ (43)\ F \;=\; 100\ \%$$

$$F \;=\; 100\ /\ 10035\ (106) \;=\; 0.009\ 97 \pm 0.000\ 11$$

Beta-particle Emissions

Energies and emission probabilities

Beta-particle energies were determined from the structural detail of the proposed decay scheme. Nuclear-level energies were adopted from Hashizume (2011Ha31), along with Q_{IT} and Q_{β^-} values of 88.23 (7) and 702 (4) keV, respectively, from 2011Ha31 and the evaluated tabulations of 2011AuZZ, and used to deduce the energies and uncertainties of the beta-particle transitions.

Emission probabilities were derived from γ population-depopulation of the various nuclear levels of ^{127}I, based on the relative γ-ray emission probabilities, their normalisation factor of 0.009 97 (11), and the theoretical internal conversion coefficients. Direct beta decay to the ground state of ^{127}I would constitute a third forbidden non-unique transition ($11/2^- \rightarrow 5/2^+$), and has been assumed to be zero.

Beta-particle emission probabilities per 100 disintegrations of ^{127}Te^{m}.

Transition	E_β (keV)	P_β	Transition type	log*ft*
$\beta^-_{2,8}$	74 ± 4	0.014 1 ± 0.000 6	1st forbidden non-unique	8.61 ± 0.08
$\beta^-_{2,7}$	139 ± 4	0.002 7 ± 0.000 2	1st forbidden non-unique	10.18 ± 0.05
$\beta^-_{2,6}$	161 ± 4	0.000 09 ± 0.000 02	1st forbidden unique	11.30 ± 0.11
$\beta^-_{2,1}$	732 ± 4	2.71 ± 0.07	1st forbidden unique	9.873 ± 0.017
		∑ 2.73 (7)		

The proposed decay scheme is heavily dependent on the γ-ray studies of Apt *et al.* (1970Ap02), particularly their measurement of 0.0097 (1) for the $P_\gamma(417.99\ keV)/\sum\beta^-$ ratio, and an estimate of 18.8 for the (^{127}Te + ^{127m}Te in secular equilibrium / ^{127}Te) ratio as applied to the 57.608-keV gamma-ray emission probability – current evaluation generates a latter value of 18.9 (58/3.07). There is a lack of γ-ray spectroscopy measurements of ^{127m}Te (and ^{127}Te) decay with HPGe detectors that would assist greatly in quantifying the absolute γ-ray emission probabilities with much greater confidence, and hence derive a more satisfactory decay scheme.

Branching Fractions and P_γ^{rel}(88.23-keV IT decay)

^{127m}Te(β^-)^{127}I: summation of the β^- emissions deemed to populate specific nuclear levels of ^{127}I, based on the population-depopulation of the observed γ-ray emissions, their relative emission probabilities and associated normalisation factor of 0.009 97 (11), and the theoretical internal conversion coefficients. Direct beta decay to the ground state of ^{127}I has been assumed to be zero (spin and parity changes of $11/2^- \rightarrow 5/2^+$ would constitute a third forbidden non-unique transition).

$$\sum(^{127m}Te)\beta^- \;=\; 273.80\ (586)\ F$$

where F is the normalisation factor for the relative emission probabilities of the γ rays.

Thus, BF(^{127m}Te(β^-)^{127}I) = 273.80 (586) x 0.009 97 (11) = 2.73 (7) % [0.0273 (7)]

^{127m}Te(IT)^{127}Te: derived directly from ^{127m}Te(β^-)^{127}I branching fraction.

BF(^{127m}Te(IT)^{127}Te) = 100 − 2.73 (7) = 97.27 (7) % [0.9727 (7)]

P_γ^{rel}(88.23-keV IT decay):

IT branch = 97.27 (7) = $TP_\gamma^{abs}(88.23\ keV)$

where $TP_\gamma^{abs}(88.23\ keV)$ is the absolute transition probability of the 88.23-keV gamma emission.

$$P_\gamma^{rel}(88.23\ keV) = \frac{TP_\gamma^{abs}(88.23\ keV)}{(1+\alpha_{tot}) * F} = \frac{97.27\ (7)}{1139\ (17) * 0.00997\ (11)} = 8.56\ (16)$$

Atomic Data

The X-ray and Auger electron data have been calculated using evaluated X-ray data (1999ScZX, 2003De44), gamma-ray data, and atomic data from 1977La19, 1996Sc06 and 1998ScZM. Both the X-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.01, 28 January 2003). This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

K and L X-ray emission probabilities per 100 disintegrations of ^{127m}Te.

			Energy (keV)		Photons per 100 disint.
XL		(Te)	3.335 – 4.829		7.0 (3)
	L_l	(Te)	3.335		0.146 (5)
	L_α	(Te)	3.759 – 3.770		3.86 (11)
	L_η	(Te)	3.605		0.036 9 (13)
	L_β	(Te)	4.030 – 4.302		2.45 (5)
	L_γ	(Te)	4.572 – 4.829		0.333 (8)
XK_α	$XK\alpha_2$	(Te)	27.2020 (2)		10.3 (3)
	$XK\alpha_1$	(Te)	27.4726 (2)		19.3 (5)
$XK'_{\beta1}$	$XK\beta_3$	(Te)	30.9446 (3)	)	5.51 (15)
	$XK\beta_1$	(Te)	30.9960 (4)	)	
	$XK\beta_5$	(Te)	31.236	)	
$XK'_{\beta2}$	$XK\beta_2$	(Te)	31.7008 (5)	)	1.20 (5)
	$XK\beta_4$	(Te)	31.774	)	
	XKO_{23}	(Te)	31.182	)	
XL		(I)	3.485 – 5.060		0.177 (9)
	XL_l	(I)	3.485		0.003 36 (11)
	XL_α	(I)	3.927 – 3.938		0.089 (3)
	XL_η	(I)	3.779		0.001 30 (5)
	XL_β	(I)	4.221 – 4.508		0.070 7 (17)
	XL_γ	(I)	4.801 – 5.060		0.010 1 (3)
XK_α	$XK_{\alpha2}$	(I)	28.3175 (4)		0.459 (12)
	$XK_{\alpha1}$	(I)	28.6123 (3)		0.852 (21)
$XK'_{\beta1}$	$XK_{\beta3}$	(I)	32.2397 (3)	)	

	$XK_{\beta 1}$	(I)	32.2951 (4)	)	0.245 (7)
	$XK''_{\beta 5}$	(I)	32.544	)	
$XK'_{\beta 2}$	$XK_{\beta 2}$	(I)	33.042 (2)	)	
	$XK_{\beta 4}$	(I)	33.120	)	0.055 5 (19)
	$XKO_{2,3}$	(I)	33.166	)	

Electron energies were obtained from electron binding energies tabulated by Larkins (1977La19) and the evaluated gamma-ray energies. Absolute electron emission probabilities were calculated from the evaluated absolute gamma-ray emission probabilities and associated internal conversion coefficients.

Data Consistency

Q-values of 88.23 (7) and 790 (4) keV have been adopted for the IT and β^- decay, respectively, based on the atomic mass evaluation of Audi and Wang (2011AuZZ) and the nuclear-level energy of ^{127m}Te (2011Ha31). An effective Q-value derived from these data has been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{127}Sb beta-decay process (i.e. β^-, electron, γ, etc.):

$$\text{effective Q-value} \quad = \quad \sum (Q_i \times BF_i) \quad = \quad 107.4\ (6)\ \text{keV}$$

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 106.1\ (9)\ \text{keV}$$

The percentage deviation from the effective Q-value is (1.2 ± 1.0) %, which indicates the derivation of a reasonably consistent decay scheme.

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^{129}I - Comments on evaluation of decay data
by V. P. Chechev and V. O. Sergeev

1- Decay Scheme

The 2nd unique forbidden β^--transition to the $1/2^+$ ground state of ^{129}Xe was not observed. In 1954 Der Matiosian and Wu (1954De17) showed experimentally that this β^--branch intensity did not exceed 1 %. This limit gives a log $f_{2u}t$ = 14.9 (or log f_0t = 15.8), which is consistent with the log $f_{2u}t$ values of 14.6 – 15.8 tallied in 1998Si17 for ten cases from A=22 to A=138, excluding ^{10}Be, with 13.8, and ^{209}Po, with 14.36. The highest value of 15.8 corresponds to 0.13% for the transition considered.

Therefore, we have adopted the probability of the 2nd unique forbidden β^--transition to the $1/2^+$ ground state of ^{129}Xe $P(\beta^-_{0,0})$ = 0.05(5)% with the uncertainty which provides the limits from 0 to 1% according to 1954De17.

2- Nuclear Data

The Q value has been computed on the basis of the spectrometric measurement of the $\beta^-_{0,1}$ energy by N. Coursol (1979CoZG) and the evaluated gamma-ray energy. This measurement gives a more accurate Q value than 194(3) keV, presented in the atomic mass evaluation (1995Au04).

The following four experimental values for the ^{129}I half-life are available (in units of 10^7 years).

1.72(9)	1951 Ka16
1.56(6)	1957Ru65
1.57(4)	1972Em01
1.97(14)	1973Ku17

Use of the LRSW method leads to a higher uncertainty (0.047) in 1972Em01. Our recommended value has been obtained as the weighted mean with the external uncertainty 0.06 expanded due to the Student's factor (or MBAYS uncertainty) : 1.61(7). Thus our recommended value for the ^{129}I half-life is 1.61(7) × 10^7 years.

2.1. b$^-$-Transitions

The energy of the $\beta^-_{0,1}$ transition has been adopted from 1979CoZG (Coursol). For the probabilities $P(\beta^-_{0,1})$ and $P(\beta^-_{0,0})$ see discussion in sect.1.Decay Scheme.

2.2. Gamma-ray Transitions and Internal Conversion Coefficients

The correction for recoil has not changed the γ-ray transition energy.

The emission probability of the γ-ray transition (photons + electrons) has been adopted as 99.5(5)%.(see discussion in sect.1).

The multipolarity of the γ-ray transition was measured in 1965Ge04 (M1) and 1974Ra26 (M1 + 0.073(27)% E2).

ICC's have been interpolated from theoretical values of 1978Ro22 for the adopted multipolarity of M1 + 0.07(3)% E2. The uncertainties in the theoretical values are as follows: 1% for α_K and 3% for α_L, α_M, α_{NO}. The ratio α_{NO}/α_M has been taken from 1971Dr11. The ICC interpolated from other tables (1968Ha53, 1969Ha61, 1978Band) agree with the adopted values within the limits of the stated uncertainties.

The interpolated value α_K^{theory} = 10.59(11) can be compared with the following experimental values: 10.6 (1968ReZY), 9.8(9) (1970Gy01), 10.2(4) (1970SaZI), 10.2(5) (1977Ra23), and 10.6(4) (1985Ba73), which have an unweighted average of 10.3.

3. Atomic Data

3.1. Fluorescence yields

The fluorescence yields have been taken from 1996Sc06 (Schönfeld and Janβen).

3.2. X rays

X-ray energies are based on the wavelengths given in the compilation of 1967Be65 (Bearden).

The relative K x-ray emission probabilities have been taken from 1996Sc06 and 1999Schönfeld.

3.3. Auger Electrons

The energies of Auger electrons are from 1977La19 (Larkins) and 1998Schönfeld.

The ratios P(KLX)/P(KLL) and P(KXY)/P(KLL) have been taken from 1996Sc06.

4. Electron emissions

The energies of the conversion electrons have been calculated from the γ-ray transition energy given in sect. 2.2 and the electron binding energies. Their absolute emission probabilities have been calculated using the conversion coefficients given in 2.2 and the absolute γ-ray emission probability.

For the L-shell the ratios $L_1:L_2:L_3$ = 100:8.9(4):3.13(14) obtained from theoretical conversion coefficients can be compared with the experimental $L_1:L_2:L_3$ = 100:10.0(4):3.1(3) from ^{129}Cs → ^{129}Xe decay (1965Ge04).

Values of the emission probabilities of K-Auger electrons have been calculated using our recommended P(ceK) and P(ceL) values and atomic data given in 3.1.

The maximum energy of β^- particles with energy of 151 keV has been taken from 1979CoZG(Coursol). The average energy of β^- particles calculated with the LOGFT program, which uses an allowed spectral shape, is 40.6(3) keV. The SPEBETA program gives a different value of 37 keV (2001 Be). In 2001Be the shape factor $C(W) = q^2 + (0.10\pm0.01)p^2$ was used that given by E. der Matiosian and C. S. Wu (1953DE10) (measurement with a magnetic spectrometer). The value of 37 keV is supported also by the calculation of Kolobachkin et.al. (See the book "Beta emissions of fission products", authors: V. M. Kolobachkin, P. M. Rubtsov, V. G. Alexankin and P. A. Ruzhanskiy . – Moscow, Atomizdat, 1978, p.189. In Russian). They found 36 keV for the average energy of β^- particles of ^{129}I. So we adopt 37(1) keV as the recommended value.

5. Photon Emissions

5.1 X-Ray Emissions

Our recommended value for the total K x-ray absolute emission intensity has been calculated as $P_{XK}^{eval.} = \omega_K \alpha_K P_\gamma(39.6) = 69.8(11)\%$, based on the adopted value of ω_K, a theoretical value of α_K, and our recommended value of $P_\gamma(39.6) = 7.42(8)\%$. This K x-ray emission probability agrees well with the result of the measurement $P_{XK}^{exp.} = 70.2(8)\%$ in 1985Ba73, relative to P_γ (39.6) = 7.46% (or 69.8(8)%, relative to P_γ (39.6) = 7.42%), and it also agrees with the less accurate experimental result from 1977Ra23: 73(6)%.

The absolute emission probabilities of the K x-ray components have been deduced from the total P_{XK} using the relative probabilities from sect. 3.2.

The total absolute emission probability of L x-rays has been deduced using the adopted values of ϖ_L and n_{KL} and the recommended values of $P(ce_K) = 78.6(12)$ and $P(ce_L) = 10.8(4)\%$.

5.2. Gamma Emissions

A γ-ray energy of 39.578(4) keV has been adopted from 1985Ba73 from an accurate measurement made with a planar HPGe detector. The adopted value coincides with 39.578(2) keV for the energy of the first excited level in ^{129}Xe (1996Te01), deduced from the decay of ^{129}Cs.

Other less accurate experimental values of E($\gamma_{1,0}$) are (in keV): 39.58(3) (1965Ge04), 39.6(2) (1966Re10), 39.4(3) (1967Gr05), 39.58(5) (1972Ta15), and 39.581(15) (1976Me16).

The absolute γ-ray emission probability (P_γ) has been computed as $P(\beta_{1,0})/(1+\alpha_T)$. The uncertainty in P_γ includes the uncertainty of 0.5% in $P(\beta_{1,0})$, and 1% in α_T.

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^{131}I – Comments on evaluation of decay data
by V. Chisté and M. M. Bé

1) Decay Scheme

^{131}I disintegrates by β^- emission via the excited levels of ^{131}Xe, included the isomeric state ^{131}Xe^m ($T_{1/2}$ = 11,930(16) d) .
The state of ideal balance, where the activity of ^{131}I is equal to the activity of ^{131}Xe^m, is obtained in 13,994(1) days :

$$tm = \frac{1{,}44 \times T_{1/2}(^{131}I) \times T_{1/2}(^{131}Xe^m) \times \ln\left(T_{1/2}(^{131}Xe^m) / T_{1/2}(^{131}I)\right)}{T_{1/2}(^{131}Xe^m) - T_{1/2}(^{131}I)}$$

The decay of Xe-131m will interfere with the decay of I-131 only with the 163,9 keV gamma line. For this line, the gamma emission intensity is given at *tm* (see above).

2) Nuclear Data

The Q value is from Audi and Wapstra (1995Au04)

Level energies, spins and parities are from Yu. V. Sergeenkov (1994Se07).

The measured ^{131}I half-life values are, in days:

$T_{1/2}$

Reference	Value (d)	Comments
Livingood (1938Li01)	8,0 (2)	
Sreb (1951Sr10)	8,1409 (62)	
Sinclair (1951Si26)	8,04 (4)	
Lockett (1953Lo19)	8,06 (2)	
Seliger (1953Se45)	8,075 (22)	
Bartholomew (1953Ba03)	8,05 (1)	
Burkinshaw (1958Bu12)	8,054(10)	
Keene (1958Ke24)	8,067(7)	
Kemeny (1968Ke32)	8,04(4)	
Zoller (1971Zo46)	8,117(12)	
Emery (1972Em09)	8,040(1)	
Karsten (1974Ka18)	8,031(4)	
Lagoutine (1978La13)	8,020(3)	
Houtermans (1980Ho21)	8,0213(9)	
Hoppes (1982Ho45)	8,020(2)	Superseded by 1992Un03
Walz (1983Wa15)	8,0207(1)	Superseded by 2003Sc49
Unterweger (1992Un03)	8,0197(22)	
Silva (2004Si04)	7,999 (9)	
Schrader (2004Sc49)	8,0252(6)	

The half-life weighted average has been calculated by the Lweight program (version 3).

The evaluator has chosen to take only the seven most recent values (74Ka18, 78La13, 80Ho21, 92Un03, 2004Si04 and 2004Sc49) for the calculation. The Silva(2003Si04) value is rejected by the Lweight program, based on the Chauvenet's criterion. The largest contribution to the weighted average comes from the value of Schrader (2004Sc49), amounting to 63%. The program Lweight 3 increases the uncertainty for the 2004Sc49 value from 0,0006 to 0,00079 in order to reduce its relative weight from 63% to 50%.

The adopted value is the weighted mean : *8,0233 d*, with an uncertainty of *0,0019* (expanded so range includes the most precise value of Schrader (2004Sc49)) and a χ^2 of 4.

2.1) b$^-$ Transitions

The β^- probabilities and the associated uncertainties have been deduced from γ transition intensity balance at each level of the decay scheme, assuming no β^- transition to the ground state. The values of log ft have been calculated with the program LOGFT for the Allowed, 1st Forbidden and 1st Unique Forbidden transitions.

2.2) Gamma Transitions

Probabilities

For the 163 gamma transition probability, the adopted value is 1,086(7), measured by Meyer (1974Me21). Other transition probabilities have been calculated from the gamma emission intensities and the internal conversion coefficients.

Mixing ratios and internal conversion coefficients

For the 177, 272, 318, 324, 325, 364, 404 and 722 keV gamma transitions, the adopted δ (mixing ratio) are from Krane's evaluation (1977Kr06) of experimental values deduced from angular distribution and correlation data. For other transitions, the values of δ are from Yu. V. Sergeenkov (1994Se07).
The internal conversion coefficients have been calculated using the ICC Computer Code (program Icc99v3a – GETICC dialog). The adopted values have been interpolated from Rösel tables. For the 163 gamma transition (isomeric state), the adopted value is from the new tables of Band (2001Go04) (see "**Comments on evaluation**" for ^{131}Xe^m).

For the 364 keV gamma transition, many values of δ^2 have been found in the literature, as shown in the following table:

Reference	**Value of** d^2	**Value of** a$_T$
Johnson et al – Phys. Rev. 120(1960)1777	44,89(25)	2,285 10^{-2}
Daniel et al – Z. Phys. 179(1964)62	22,09(9)	2,290 10^{-2}
Langhoff et al – Nucl. Phys. A158(1970)657	11,56(36)	2,299 10^{-2}
Krane et al – Phys. Rev. C5(1972)1671	10,89(36)	2,299 10^{-2}
Koene et al – Nucl. Phys. A219(1974)563	20,521(14)	2,290 10^{-2}
Irving et al – J. Phys. G5(1979)1595	14,40(9)	2,295 10^{-2}
Naviliat-Cuncic et al – Nucl. Phys. A514(1990)145	14,40(9)	2,295 10^{-2}
Krane et al - Atomic Data and Nuclear Data Tables 19(1977)363	20,521(14) (adopted value)	2,29 10^{-2}

It can be shown that even with values of δ^2 quite different the resulting α_T values are close, and their differences are smaller than 1 % ; thus the adopted uncertainty on the ICC value is 1 %.

For the 325 keV gamma transition, a value of δ^2 (=19(3)) measured by Koene (1975Ko31) is not close to the adopted one (δ^2 = 0,053(2)) which is from Krane's evaluation, and the two resulting α_T values deviate from 3 %, that correspond to the uncertainty taken into account for the α_T, α_K and α_L values for this transition.

For the 404 keV gamma transition, a value of δ^2 (= 66(32)) has been found in the literature, from Irving (79Ir09). The calculated α_T (=0,01664) for this δ^2 is far from the adopted one (α_T = 0,0179) and the resulting α_T value deviates from the adopted one of 7 %.

For the 722 keV gamma transition, the following values of δ^2 have been found in the literature:

Reference	**Value of** d^2	**Value of** a_T
Koene – Nucl. Phys. A219(1974)563	0,0428	0,00461
Irving – J. Phys. G5(1979)1595	0,0144	0.00464
Krane - et al - Atomic Data and Nuclear Data Tables 19(1977)363	0,0428 (adopted value)	0,0046

The adopted uncertainty on the α_T, α_K and α_L values for the 722 keV transition is 1 % .

For the other transitions, measurements aren't precise, and only ranges of values are given for δ^2.

Calculations of ICC uncertainties for the other transitions:

* For the pure transitions (known E2: 284, 503, 636 keV; presumed E1/ or E2: 232, 295, 302, 642 keV), uncertainties in α_T, α_K and α_L calculated values with ICC Computer Code (program Icc99v3a) are taken to be 3 % .

* For the mixed gamma transitions with unknown mixing ratio (M1+ **X%** E2) (85 and 358 keV), the uncertainties for α_T, α_K and α_L are taken to be 3 % from each possibility and the average values are adopted as uncertainties.

* For the transitions with known δ, the uncertainties calculations were made as follow : α_T was calculated for a pure M1(or M3) transition and for a pure E2 transition. The difference between these values, normalized by α_T, is the uncertainty (%) of α_T. The same method was used for α_K and α_L uncertainties.

3) Atomic Data

Atomic values (ω_K, ϖ_L and n_{KL}) are from Schönfeld (1996Sc33).

The X-ray and Auger electron emission probabilities have been calculated from γ-ray and conversion-electron data by using the program EMISSION.

4) Radiation emissions

4.2) Gamma ray emissions

Gamma ray energies (in keV) are from Yu. V. Sergeenkov *et al.* (1994Se07) and R. A. Meyer (1990Me15). Energy values are in keV.

The measured emission intensities listed in Table 1 are given in values relative to that of the 364 keV line.

The sets of values from 1952Be19, 1963Ju13, 1963Ha04, 1964Da19, 1967Ga32 and 1967Yt26 were omitted in several cases from the analysis due to discrepancies with those mentioned in Table 1.

Emission probability values from Meyer (1974Me21) have been converted to 100 for the 364 keV line by the evaluator.

The normalization factor to convert the relative emission intensities to absolute intensities was calculated using the formula:

$$N = \left(\frac{100 - P_{abs}(163 keV)}{(\Sigma(1 + a_T)P_{rel})} \right) \times 100$$

where the sum was done over all gamma transition probabilities to the ground state.

For the 163 gamma transition probability, $P_{abs}(163\ keV)$, an absolute value of 1,086 (7), determined by Meyer, has been accepted.

From the calculated α_T and the evaluated relative emission intensities (Table I), the deduced normalization factor is ***81,2 (8)***. The uncertainties were calculated through their propagation on the above formula.

4.2) Conversion electrons

The conversion electron emission probabilities were deduced from the gamma -ray emission probabilities using theoretical ICC values. To our knowledge, there are no measured values for the conversion electron emission probabilities.

Energy conservation

The available energy for one disintegration is 970,8 (6) keV (Q^{-}), the total average energy calculated from the data of this evaluation is 969 (6) keV confirming the consistency of the decay scheme.

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Table 1 – Gamma emission intensities, relative and absolute values

Ref	**80,1853**	**85,918**	**177,214**	**232,175**	**272,501**	**284,3047**	**295,848**	**302,444**	**318,093**
52Be19	2,71(19) (O)					6,6(25) (O)			
63Ju13	2,6(4) (O)					6,0(10) (O)			
63Ha04	3,5(8) (O)		0,29(6) (O)			7,9(8) (O)			
64Da19	3,1(2) (O)		0,27(10) (O)			6,6(3) (O)			
66Mo26	3,10(18) £		0,313(26)			7,4(6)			
67Ga32	2,72(15) (O)		0,36(2) (O)		0,08(1)	7,05(40) (O)			0,110(15) (O)
67Yt26	3,4(4) (O)	~ 0,1	0,38(8) (O)		~ 0,07	8,2(8) £			~ 0,05
72Si12	3,210(5)		0,30(2)			7,49(5)			0,110(5)
74Me21	3,226(37)	0,00011(6)	0,3263(25)	0,0017(10)	0,0695(12)	7,457(12)	0,00087(50)	0,0056(11)	0,0980(37)
89Ch45	3,26(7)		0,334(6)	0,0039(5)	0,0735(18)	7,56(8)	0,0022(10)	0,0057(8)	0,096(2)
90Me15	3,23(6)	0,00011(6)	0,326(7)	0,0017(10)	0,0695(19)	7,46(15)	0,00087(50)	0,0056(11)	0,0980(42)
Adopted	3,212(9)	0,00011(6)	0,3269(22)	0,00317(47)	0,0705(9)	7,461(12)	0,00102(33)	0,0056(6)	0,0980(15)
N	4	2	5	3	4	5	3	3	4
chi2/N-1**	0,247	0	0,8923	3,23	1,55	0,4973	0,7862	0,004016	2,253
Method	LWM, int. unc.		LWM, int. unc.	LWM, int. unc.	LWM, int. unc.	LWM, int. unc.	LWM, int. unc.	LWM, int. unc.	LWM, int. unc.
Absolute Val.	2,607(27)	0,000089(49)	0,2654(32)	0,00257(38)	0,0572(9)	6,06(6)	0,00083(27)	0,00455(49)	0,0796(15)

(O) = omitted value
£ = Data rejection parameters for deviation weighted average (Chauvenet's criterion)
ext. unc. = external uncertainty
int. unc. = internal uncertainty

Table 1 – Gamma emission intensities, relative and absolute values (Cont.)

Ref	**324,6307**	**325,791**	**358,419**	**364,49**	**404,816**	**503,005**	**636,991**	**642,7237**	**722,909**
52Be19				100			11,6(19) (O)		3,5(31) £
63Ju13							9,0(10) (O)		3,0(4) £
63Ha04		0,35(8) (O)		100		0,52(17) (O)	8,8(7) (O)		2,05(16) (O)
64Da19		0,26(10) (O)		100		0,54(5) (O)	8,3(3) (O)		1,9(1) (O)
66Mo26		0,279(25)		100		0,45(6)	9,1(11)		2,05(26)
67Ga32	0,04(1) (O)	0,45(3) £	0,020(4) (O)	100	0,080(7) (O)	0,36(2) (O)	8,0(4) (O)	0,180(15) (O)	2,10(15) (O)
67Yt26		0,37(5) (O)		100	~ 0,06	0,37(8) (O)	8,2(8) (O)		1,8(2) (O)
72Si12		0,32(1)		100	0,022(5) £	0,30(5) £	7,79(10) £	0,13(1) (O)	1,79(9) £
74Me21	0,0273(50)	0,3089(50)	0,01129(25)	100	0,0695(25)	0,4442(37)	8,945(25)	0,2705(25)	2,221(12)
89Ch45	0,025(8)	0,361(5)	0,0304(11)	100	0,066(2)	0,438(5)	8,75(9)	0,269(5)	2,19(2)
90Me15	0,0273(50)	0,309(8)	0,01129(33)	100	0,0695(28)	0,444(12)	8,95(21)	0,270(7)	2,22(7)
Adopted	0,0269(32)	0,329(32)	0,0121(27)	100	0,0679(14)	0,4421(29)	8,940(23)	0,2702(21)	2,213(10)
N	3	5	3		3	4	4	3	4
chi2/N-1**	0,03458	17,05	14,47		0,8191	0,3456	2,353	0,03637	0,723
Method	LWM, int. unc.	LWM, exp. unc.	LWM, ext. unc.		LWM, int. unc.	LWM, int. unc.	LWM, int. unc.	LWM, int. unc.	LWM, int. unc.
Absolute Val.	0,0218(26)	0,267(26)	0,0098(22)	81,2(8)	0,0551(13)	0,3589(43)	7,26(8)	0,2193(28)	1,796(20)

(O) = omitted value
£ = Data rejection parameters for deviation weighted average (Chauvenet's criterion)
ext. unc. = external uncertainty
int. unc. = internal uncertainty

^{131}Xe^{m} – Comments on evaluation of decay data
by V. Chisté and M. M. Bé

1) Decay Scheme

^{131}Xe^{m} decays by a strongly converted gamma transition.

2) Nuclear Data

Level energy, spin and parity are from Yu. V. Sergeenkov (94Se07).

The ^{131}Xe^{m} measured half-life values are, in days:

$T_{1/2}$

Reference	Value (d)
Andersson (64An08)	11,8 (1)
Knauf (66Kn09)	11,94 (4)
Emery (72Em09)	12,00 (2)
Meyer (74Me21)	11,770 (12)
Hoffman (75Ho12)	11,92 (3)
Tam (90Ta02)	11,9 (2)
Unterweger (92Un03)	11,934(21)

The half-life weighted average was calculated with the Lweight program (version 3)

The value from Meyer (74Me21) was omitted from the analysis because it disagrees with the other values. The Emery (72Em09) and Anderson (64An08) values were rejected by the Lweight program, based on Chauvenet's criteria. The adopted value is the weighted mean : *11,930 d*, with an internal uncertainty of *0,016* and a χ^2 of 0,08.

2.1) Gamma Transitions

The only gamma transition is of M4 multipolarity. The various theoretical conversion coefficients for this transition (Band *et al.* , Hager *et al.* , Rösel *et al.*) differ by 2 – 4 %. The value interpolated from the new Band *et al.* tables (ICC Computer Code (program Icc99v3a)) was adopted, following the recommendations of Gorozhankin (2002Go00).

The uncertainties in α_T, α_K and α_L have been estimated as 3%.

3) Atomic Data

Atomic quantities (ω_K, ϖ_L and n_{KL}) are from Schönfeld (96Sc33).

The X-ray and Auger electron emission probabilities have been calculated from γ-ray and conversion electron data by using the program EMISSION.

4) Radiation emissions

4.1) Conversion electrons

The conversion electron emission probabilities were deduced from the ICC values and from the gamma-ray emission probability.
The total conversion electron emission probability is deduced from :

$P_{ek} = 100 - P\gamma = 100 - (1{,}98 \pm 0{,}06) = 98{,}02 \pm 0{,}06$

To our knowledge, there are no measured values for the conversion electron emission probabilities.

4.2) Gamma-ray emissions

Gamma-ray emission energy is from Yu. V. Sergeenkov et al. (94Se07) and R. A. Meyer (90Me15).

The gamma-ray emission intensity has been deduced from the transition probability and using the theoretical α_T to be : ***1,98(6)***.

We have not found measured values for this emission, the ^{131}Xe^{m} radioisotope being alone.

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^{132}Te -Comments on evaluation of decay data

by A. L. Nichols

Evaluated: December 2007/March 2009

Evaluation Procedure

Limitation of Relative Statistical Weight Method (LWM) was applied to average the measured decay data when appropriate (see below).

Decay Scheme

A simple decay scheme was constructed from the gamma-ray studies of 1966Fr02 and 1981Yo02. An earlier study involved the use of low-resolution NaI(Tl) detectors, and these data have been set aside from consideration in this particular evaluation [1958Ch28]. The gamma-ray emission probabilities were expressed in terms of the emission probability of the 228.327-keV gamma ray (100 %), and weighted mean data were derived as appropriate.

All 100 % of the beta decay goes directly to the 277.86-keV nuclear level of ^{132}I, and the resulting four gamma cascade dominates the decay scheme.

Nuclear Data

^{132}Te undergoes beta decay to the 277.86-keV nuclear level of ^{132}I that undergoes gamma decay to the ground state of ^{132}I predominantly through the 49.72- and 228.327-keV gamma transitions.

Half-life (^{132}Te)

The recommended half-life has been determined from the measurements of Cheever *et al.* (1958Ch28), Andersson *et al.* (1965An05), Baba *et al.* (1971BaZW) and Walz *et al.* (1983Wa26). A value of 3.230 (13) days was derived in terms of LWM, with the uncertainty increased to the lowest measured value of ± 0.013.

Half-life measurements (^{132}Te).

Reference	Half-life (days)
1956Fl15	2.8 ± 0.1*
1958Ch28	3.2 ± 0.2
1965An05	3.26 ± 0.03
1971BaZW	3.28 ± 0.02
1983Wa26	3.204 ± 0.013
Recommended value	3.230 ± 0.013

* set aside from the LWM analysis as an outlier.

Gamma Rays

Energies

Gamma-ray transition energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 2005Kh07 were adopted, and used to determine the energies of the gamma-ray transitions between the populated-depopulated levels, apart from the 228.327-keV gamma ray which was taken from 1979Bo26.

Emission Probabilities

Although judged to be a rather limited data set, a reasonably consistent decay scheme was derived from the relative gamma-ray emission probabilities measured by Fransson and Bemis (1966Fr02) and Yousif *et al*. (1981Yo02). These relative emission probabilities were normalised to the 228.327-keV gamma ray (100 %). The 49.72-keV gamma ray has only been quantified by 1966Fr02, and therefore the relative emission probability of this low-energy gamma ray was calculated from the population-depopulation balance of the 49.72-keV nuclear level (with no populating beta transition). A value of 2.1 (2) % was adopted for the relative emission probability of the 111.80-keV gamma ray on the basis of the population-depopulation balance of the 161.52-keV nuclear level (with no populating beta transition) and the measurement of Fransson and Bemis. Finally, the possible existence of a low-intensity 161.5-keV gamma transition from the 161.52-keV nuclear level to the ground state of I-132 was discarded on consideration of the population-depopulation of the 161.52-keV nuclear level.

Relative gamma-ray emission probabilities (%).

transition	**E$_\gamma$ (keV)**	P_γ^{rel}		
		1966Fr02	1981Yo02	Recommended
$\gamma_{2,0}$ (I)	49.72 (1)	16.3 (11)	17.02 (34)*	17.14 (4)*
$\gamma_{4,2}$ (I)	111.80 (8)	2.1 (2)	1.98 (5)	2.1 (2)‡
$\gamma_{5,4}$ (I)	116.34 (13)	2.2 (2)	2.23 (6)	2.23 (6)
$\gamma_{5,2}$ (I)	228.327 (3)	100 (6)	100 (2)	100 (2)

* deduced from decay scheme and calculated branching ratio (not measured directly).

‡ adopted from 1966Fr02 and on the basis of the population-depopulation balance of the 161.52-keV nuclear level.

Gamma-ray emissions: recommended energies, relative emission probabilities, multipolarities and theoretical internal conversion coefficients (frozen orbital approximation).

E$_\gamma$ (keV)	P_γ^{rel}	**Multipolarity**	**α_K**	**α_L**	**α_{M+}**	**α_{tot}**
49.72 (1)	17.14 (4)	M1	4.83 (7)	0.64 (1)	0.15 (1)	5.62 (8)
111.80 (8)	2.1 (2)	M1 + E2 δ = 0.58 (6)	0.562 (17)	0.115 (9)	0.033 (4)	0.71 (3)
116.34 (13)	2.23 (6)	M1 + E2 δ = 0.53 (5)	0.489 (13)	0.093 (6)	0.024 (1)	0.606 (20)
228.327 (3)	100 (2)	E2	0.0802 (12)	0.0151 (2)	0.0037 (1)	0.0990 (14)

Multipolarities and Internal Conversion Coefficients

The nuclear level scheme specified by Khazov *et al*. (2005Kh07) has been used to define the multipolarities of the gamma transitions on the basis of known spins and parities. Somewhat disparate mixing ratios were obtained by Fransson and Bemis (1966Fr02) and Yousif *et al.* (1981Yo02). All of the multipolarities recommended by Yousif *et al.* were adopted with improved uncertainties introduced for the (M1 + E2) transitions. These data were used to determine the internal conversion coefficients of the 49.7-, 111.8-, 116.3- and 228.327-keV gamma rays from the theoretical tabulations of Band *et al.* (2002Ba85, 2002Ra45) by means of the methodology of Kibédi *et al.* (2008Ki07) in which the frozen orbital approximation was adopted.

A normalisation factor of 0.8812 (13) was calculated from the internal conversion coefficients and relative emission probabilities of the gamma-ray transitions depopulating the 277.86-keV nuclear level of ^{132}I, assuming that there is no direct beta feeding to other levels as implied from the various spins and parities:

$$\sum P_{\gamma+ce}^{rel} = 100\%$$

$$P_\gamma(116.34\text{ keV}) + P_\gamma(228.327\text{ keV})\ F = 100$$

$$[3.58(10) + 109.90(14)]\ F = 100$$

$$F = 0.8812 \pm 0.0013$$

Beta-particle Emission

Energy and emission probability

The single beta-particle energy was calculated from the structural detail of the proposed decay scheme. A nuclear level energy of 277.86(6) keV adopted from Khazov *et al.* (2005Kh07) and a Q_{β^-} value of 518 ± 4 keV from Audi *et al.* (2003Au03) were used to determine the energy and uncertainty of this beta-particle transition.

Beta-particle Emission Probability per 100 Disintegrations of ^{132}Te.

Transition	E_β (keV)	P_β	Transition type	log*ft*
$\beta^-_{0,5}$	240 ± 4	100	allowed	4.85

Atomic Data

The x-ray and Auger electron data have been calculated using the evaluated gamma-ray data, and the atomic data from 1977La19, 1996Sc06, 1998ScZM and 1999ScZX.

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^{133}I - Comments on evaluation of decay data
by M. Galán

1) Decay Scheme

^{133}I disintegrates by β^- emission to excited levels in ^{133}Xe, included the isomeric state ^{133}Xe^m at 233 keV ($T_{1/2}$ = 2,198 (13) d).
^{133}I ground state has $J^\pi = 7/2^+$ (1976FU06).

2) Nuclear Data

The Q value is from AME2003 (2003Au03): Q (β^-) = 1757 (4) keV.

Level energies have been obtained from a least -squares fit to γ-ray energies (GTOL computer code) from 1976ME16. The energy of the isomeric level is from the ^{133}Xe^m evaluation. Spin and parities are from 1995RA12 except for the1386-keV level. For this level the adopted value is J^π (1386) = $7/2^+$ as proposed by 1976ME16 based on M1+E2 to $5/2^+$ (deduced from δ(856) = +3,7 (3) (1974KO26 and 1977KR13)). J^π for 743-, 875-, 911-, and 1236-keV levels are uncertain.

The measured ^{133}I half-life values, in hours, are:

Reference	Value (h)	Comments
1968RE04	20,9 (1)	
1966EI01	20,8 (2)	
1965AN05	20,3 (3)	Rejected by Chauvenet's criterion
1955WA35	20,9 (3)	
1953KA28	20,8 (2)	

LWeight for Excel Code	
Nb of input values	4
Reduced χ^2	0,10
Weighted Mean	20,86
Internal uncertainty	0,09
External uncertainty	0,03

Ave Tool Code		
Nb of input values		4
	Mean	Reduced χ^2
LWM	20,87 (8)	0,11
NRM	20,87 (8)	0,11
RT	20,87 (8)	

The half-life was calculated by the Lweight for Excel code (version 2004) and by AveTool code. In both codes the value of 1965AN05 was rejected based on the Chauvenet's criterion. Ave Tool was run again without the value from 1965AN05. The results of the three statistical methods LWM (Limitation of

Relative Statistical Weight), NRM (Normalised Residual Method) and RT (Rajeval Technique) given by AveTool are also shown in the table. The recommended value is 20,87 (8) h.

2.1) b Transitions

The energies of the β transitions were deduced from the Q value and the level energies in ^{133}Xe, the later deduced from γ-ray transition energies. Some experimental values (1966Ei01) with the adopted ones are compared in the table:

Beta Transition	Adopted (keV)	1966Ei01 (keV)
$\beta_{0,9}$	521 (4)	500 (30)
$\beta_{0,6}$	882 (4)	890 (30)
$\beta_{0,3}$	1227 (4)	1230 (30)
$\beta_{0,1}$	1524 (4)	1540 (30)

The β^- probabilities and associated uncertainties have been deduced from γ-ray transition intensity balance at each level of the decay scheme, assuming no β^- transition to the ground state. These values are compared to the β^- emission probabilities measured by 1966EI01, 1971SA09 and 1976ME16. The lg *ft* values were calculated using the program LOGFT for the Allowed, 1st Forbidden and 1st Unique Forbidden β^- transitions.

Beta Transition	Adopted (%)	1966EI01 (%)	1971SA09 (%)	1976ME16 (%)
$\beta_{0,13}$	0,414 (15)	0,5	0,5	0,42
$\beta_{0,12}$	1,25 (4)	3,5	1,1	1,26
$\beta_{0,11}$	0,397 (12)	0,4	0,3	0,4
$\beta_{0,10}$	3,75 (7)	3,7	2,9	3,68
$\beta_{0,9}$	3,12 (6)	3,3	3,2	3,16
$\beta_{0,8}$	0,58 (5)	0,5	0,5	0,62
$\beta_{0,7}$	0,026 (18)	-	-	-
$\beta_{0,6}$	4,16 (13)	2,3	3,5	4,1
$\beta_{0,5}$	1,81 (6)	-	2,3	1,81
$\beta_{0,3}$	83,44 (21)	85,4	83,2	83,5
$\beta_{0,1}$	1,07 (6)	1,4	1,4	1,07

A beta transition of about 1080 keV to the 680-keV level was observed by 1966EI01 with a β^- probability = 0,3 %. 1971SA09 reported 0,2 % β^- probability for this transition.

2.2) g-ray Transitions

Transition Probabilities

For the 233-keV gamma transition probability, the adopted value is 2,88 (2) % measured by 1976ME16. Other transition probabilities have been calculated from the γ-ray emission probabilities using the recommended internal conversion coefficients.

Mixing ratios and internal conversion coefficients

For the 233-keV γ-ray transitions the adopted δ (mixing ratio) is from ^{133}Xe^{m} evaluation. The adopted δ values for the 417-, 422-, 529-, 680- and 1298-keV are from 1977KR13. The adopted values were deduced from angular correlation data. For the 768-, 820 and 856 γ-ray transitions the adopted δ values are from 1974KO26 obtained by directional distributions of γ-rays. For the 909-keV line a δ(909) = +0,40 (6) has been adopted, as was reported by 1974KO26 if the $J^{\pi}(1589) = 5/2^{+}$.

The internal conversion coefficients (ICC) were calculated using the BrIcc computer code, which interpolated ICC values from tables of Band *et al.* (2002BA85).

Only experimental measurements of α_K and K/L values were found for the internal transition of 233-keV (see ^{133}Xe^{m} evaluation).

3) Atomic Data

Atomic values (ω_k, ϖ_L and η_{KL}) are from 1996SC06.

ω_K	0,888 ± 0,005
ϖ_L	0,097 ± 0,005
η_{KL}	0,902 ± 0,004

The X-ray and Auger electron emission probabilities have been deduced from γ-ray and conversion electron data by using the computer code EMISSION. Results were verified with RADLST computer code.

4) Electron Emissions

The conversion electron emission probabilities have been computed from γ-ray emission probabilities and theoretical ICC values.

5) Photon Emissions

Energies

γ-ray energies and uncertainties are from level scheme. The isomeric transition γ-ray energy is from 2000HE14 (see ^{133m}Xe evaluation).

g-ray emissions

The gamma emission intensities are from 1976ME16. A 2 % was increased by the evaluator in the uncertainty to account for uncertainty calibration, as cited by 1976ME16. Other experimental measurements are shown in table 1. In table 1 the absolute intensity values reported by 1974KO26 are just compared to the absolute intensity values recommended in this evaluation. The evaluator has not used the values of 1974KO26 in the present evaluation because detailed information, such as the detector calibration and uncertainty, calculation procedure or experimental conditions under which the absolute gamma intensities were achieved, are absent.

The normalization factor has been deduced from the decay scheme using the formulas:

$$N = \frac{100 - P_{g+ce}(233keV)}{\sum_i I_{g_i}\left[1 + a_{Ti}\right]} \quad \text{and} \quad dN^2 = \left(\frac{\partial N}{\partial P_{g+ce}}\right)^2 + \sum_i \left(\frac{\partial N}{\partial I_{g_i}} dI_{g_i}\right)^2 + \sum_i \left(\frac{\partial N}{\partial a_{T_i}} da_{T_i}\right)^2,$$

where the sum is over all γ-ray transitions to the ground state (g.s.), thus considering no direct β^- feeding to the g.s. For the 233-keV γ transition probability, $P_{\gamma+ce}$(233 keV), an absolute value of 2,88 (2) %, determined by 1976ME16, has been accepted. From the estimated α_T (BrIcc) and the evaluated relative γ emission intensites (Table 1) the deduced normalization factor is 0,0863 (16). This result was checked with the value of 0,0863 (16) reported by GABS computer code.

In Table 5.2 Gamma Emissions. The absolute gamma emission intensity of 0,293 (4) % for the 233 -keV line has been estimated by the evaluator from $P_{\gamma+ce}$ = 2,88 (2) % and α_T = 8,84 (12).

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[Q value]

Reference	$g_{150,39}$	$g_{176,97}$	$g_{203,7}$	$g_{245,95}$	$g_{262,702}$	$g_{267,173}$	$g_{345,43}$	$g_{361,09}$	$g_{372,05}$	$g_{381,59}$
1959HO97							-			
1966EI01					0,18 (5)					
1971SA09					5,0	1,5	3,0			
1976ME16	0,34 (7)	0,9 (2)	0,05	0,4 (1)	4,13 (7)	1,35 (6)	1,2 (2)	1,3 (4)	0,11 (6)	0,52 (5)
Recommended	0,34 (7)	0,9 (2)	0,05	0,4 (1)	4,13 (11)	1,35 (7)	1,2 (2)	1,3 (4)	0,11 (6)	0,52 (5)
1974KO26					0,35 (3)	0,10 (2)	0,06 (2)	0,16 (3)	0,16 (3)	
Absolute	**0,029 (6)**	**0,078 (18)**	**0,00432 (8)**	**0,035 (9)**	**0,356 (12)**	**0,117 (7)**	**0,104 (18)**	**0,11 (4)**	**0,009 (6)**	**0,045 (5)**

Reference	$g_{386,85}$	$g_{417,56}$	$g_{422,901}$	$g_{438,87}$	$g_{510,530}$	$g_{510,82}$	$g_{522,40}$	$g_{529,872}$	$g_{537,73}$	$g_{554,8}$
1959HO97								1000		
1966EI01			4,0 (10)		24,8 (37)			1000		
1971SA09		1,6	3,0		17 (4)					
1976ME16	0,68 (5)	1,77 (11)	3,58 (6)	0,46 (5)	21,0 (2)	< 0,1	< 1	1000 (4)	0,41 (8)	< 0,01
Recommended	0,68 (5)	1,77 (11)	3,58 (9)	0,46 (5)	21,0(5)	< 0,1	< 1	1000 (20)	0,41 (8)	< 0,01
1974KO26		0,12 (2)	0,26 (2)		1,85 (5)			87,7 (2)		
Absolute	**0,059 (5)**	**0,153 (10)**	**0,309 (10)**	**0,040 (5)**	**1,81 (6)**	**0,004 (5)**	**0,04 (5)**	**86,3 (2)**	**0,035 (7)**	**0,0004 (5)**

Reference	$g_{556,17}$	$g_{567,1}$	$g_{617,974}$	$g_{648,76}$	$g_{670,10}$	$g_{678,65}$	$g_{680,247}$	$g_{706,578}$	$g_{768,382}$	$g_{789,59}$
1959HO97								20		
1966EI01			3,0 (8)				10 (2)	17,3 (26)	5,9 (15)	
1971SA09			4,2				8,8	18	5,4	0,6
1976ME16	0,23 (3)	0,04 (3)	6,25 (6)	0,65 (15)	0,49 (6)	0,25 (8)	7,47 (9)	17,3 (2)	5,29 (9)	0,58 (4)
Recommended	0,23 (3)	0,04 (3)	6,25 (14)	0,65 (15)	0,49 (6)	0,25 (8)	7,47 (17)	17,3 (4)	5,29 (14)	0,58 (4)
1974KO26			0,53 (2)				0,61 (2)	1,47 (4)	0,43 (2)	0,04 (1)
Absolute	**0,020 (3)**	**0,003 (3)**	**0,539 (15)**	**0,056 (13)**	**0,042 (6)**	**0,022 (7)**	**0,645 (19)**	**1,49 (4)**	**0,457 (15)**	**0,050 (4)**

Reference	$g_{820,506}$	$g_{856,278}$	$g_{875,329}$	$g_{909,67}$	$g_{911,49}$	$g_{1018,1}$	$g_{1035,58}$	$g_{1052,296}$	$g_{1060,07}$	$g_{1087,71}$
1959HO97			90					10		
1966EI01	2,2 (6)	13,7 (21)	58 (5)	4 (1)				7,2 (18)	1,6 (4)	
1971SA09	2,0	14	52	4,4				5,7	1,0	
1976ME16	1,78 (6)	14,3 (4)	51,8 (2)	2,46 (7)	0,53 (7)	0,07 (3)	0,10 (2)	6,39 (7)	1,59 (6)	0,14 (2)
Recommended	1,78 (6)	14,3 (4)	51,8 (11)	2,46 (9)	0,53 (7)	0,07 (3)	0,10 (2)	6,39 (15)	1,59 (7)	0,14 (2)
1974KO26	0,15 (1)	1,18 (4)	4,42 (11)	0,25 (2)				0,54 (2)	0,14 (1)	
Absolute	**0,154 (6)**	**1,23 (4)**	**4,47 (12)**	**0,212 (9)**	**0,046 (6)**	**0,006 (3)**	**0,0086 (18)**	**0,551 (16)**	**0,137 (7)**	**0,0121 (18)**

Reference	$g_{1236,441}$	$g_{1298,223}$	$g_{1327,2}$	$g_{1350,38}$	$g_{1386,15}$	$g_{1589,94}$
1959HO97	20	40				
1966EI01	17,2 (26)	27,4 (41)		1,6 (4)		
1971SA09	18	25		1,8		0,5
1976ME16	17,3 (2)	27,0 (2)	< 0,005	1,72 (4)	0,10 (3)	0,034 (5)
Recommended	17,3 (4)	27,0 (6)		1,72 (5)	0,10 (3)	0,034 (5)
1974KO26	1,45 (4)	2,25 (6)		0,14 (1)		
Absolute	**1,49 (4)**	**2,33 (7)**	**0,00022 (22)**	**0,148 (5)**	**0,0086 (26)**	**0,0029 (4)**

The 1959HO97 values were reported to I(529) = 100. In the table they have been reported to 1000 for the I(529).

1966Ei01 did not observe the 744-keV level, so they reported I(509,8) = 25 % for the γ-transition from the 1385- to the 875-keV levels instead for the 744-233 keV transition. The 1966EI01 values were reported to I(529) = 100. In the table they have been reported to 1000 for the I(529). The uncertainty in the 1966EI01 values are estimated by the evaluator following the notes given by the authors: ± 8 % for relative intensities > 5; ± 15 % for relative intensities >1; ± 25 % for relative intensities <1.

The 1971SA09 values were reported to I(529) = 100. In the table they have been reported to 1000 for the I(529).

In 1974KO26 the absolute γ emission probabilities are given but the details of the measurements are absent.
For the relative γ intensities less than (<) a certain value, the adopted absolute value is the result given by GABS computer code.

^{133}Xe - Comments on evaluation of decay data
by M. Galán

1) Decay Scheme

^{133}Xe disintegrates by β^- emission to excited levels in ^{133}Cs.
^{133}Xe ground state has $J^\pi = 3/2^+$. The isomeric state is at 233 keV and has $J^\pi = 11/2^-$ (1989RA17).

2) Nuclear Data

The Q value is from AME2003 (2003AU03): Q β^- = 427,4 (24) keV.

Level energies have been obtained from a least-squares fit to γ-ray energies (GTOL computer code). Spin and parities are from 1995RA12.

The half-life of the 81-keV level has been deduced (using the AveTool computer code) from the values reported in 1965GE14, 1963GO17, 1962TH12, 1959BO56, 1958AL98, 1955LE18 and 1953GR07. Half-lives for other levels are from 1995RA12.

The measured ^{133}Xe half-life values, in days, are:

Reference	Value (d)	Comments
2002UN02, 1992UN01	5,2475 (5)	
1975HO18	5,25 (2)	
1975WO10	5,250 (13)	
1974CA27	5,245 (6)	
1974FOZY	5,240 (6)	
1972EM01	5,29 (1)	Rejected by Chauvenet's criterion
1968AL16	5,312 (25)	Rejected by Chauvenet's criterion
1950MA15	5,270 (2)	Rejected by Chauvenet's criterion

	Mean	Reduced χ^2
LWM	5,2474 (5)	0,44
NRM	5,2474 (5)	0,44
RT	5,2474 (5)	

The AveTool computer code has been used with these seven input values. This code calculates averages using three statistical methods: LWM (Limitation of Relative Statistical Weight), NRM (Normalised Residual Method) and RT (Rajeval Technique).
The values in 1950MA15, 1968AL16, 1972EM01 were rejected based on the Chauvenet's criterion. For the remaining values, the largest contribution to the weighted average comes from the value of Unterweger (2002UN02). The LWM method increased the uncertainty of this value 3.895 times in order to reduce its relative weight to 50 %.
The recommended value is therefore the LWM mean, **5,2474 (5) *d***. Its uncertainty has been expanded to 0,009 d, so the half-life range includes the most precise value of 5,2475 d (1992UN01, 2002UN02).

2.1) b Transitions

The energies of the β transitions have been deduced from the Q value and the level energies in ^{133}Cs, the later deduced from γ-ray transition energies. The adopted values have been verified against those produced by the computer code GTOL.

All beta transitions of ^{133}Xe are allowed. The β^- probabilities and associated uncertainties have been deduced from γ-ray transition intensity balance at each level of the decay scheme, assuming no β^- transition to the ground state.

$$\%b_{0,3} = P_{g+ce}(384) + P_{g+ce}(303) + P_{g+ce}(223) = 0{,}0029(4) + 0{,}0061(8) + 0{,}000187(69) = 0{,}0092(9)$$

$$\%b_{0,2} = P_{g+ce}(80) + P_{g+ce}(161) - P_{g+ce}(384) = 0{,}78(8) + 0{,}088(10) - 0{,}000187(69) = 0{,}87(8)$$

$$\%b_{0,1} = 100 - \left[\%b_{0,3} + \%b_{0,2}\right] = 100 - \left[0{,}0092(9) + 0{,}87(8)\right] = 99{,}12(8)$$

These values have been compared to the β^- emission probabilities measured by 1952BE55, 1961ER04 and 1986SC34. Also, the lg *ft* values have been calculated using the program LOGFT for allowed β^- transitions, and compared to values reported in these references.
Such a comparison is given in the following table:

Reference	$\%\beta_{0,1}$	Lg *ft*	$\%\beta_{0,2}$	Lg *ft*	$\%\beta_{0,3}$	Lg *ft*
1959JH17	0,1	5,7	2	7	98	5,6
1961ER04	0,006	-	0,71	7,5	99,28	5,7
1986SC34	0,0073	-	0,79	-	99,2	-
Recommended	0,0092 (9)	6,84	0,87 (8)	7,31	99,12 (8)	5,62

2.2) g-ray Transitions

Transition Probabilities

The γ-ray transition probabilities have been calculated from the γ-ray emission probabilities using our recommended internal conversion coefficients.

Mixing ratios and internal conversion coefficients

For the 81, 223, 302 and 384 keV γ-ray transitions the adopted δ (mixing ratio) are from 1977KR13. The adopted values were deduced from angular correlation data. For the 80 and 161 γ-ray transitions the adopted δ values are from 1995RA12.

The internal conversion coefficients (ICC) have been calculated using the BrIcc computer code, which interpolated ICC values from tables of Band et al. (2002BA85). Associated uncertainties are 1,4 %.

3) Atomic Data

Atomic values (ω_k, ϖ_L and η_{KL}) are from 1996SC06.

ω_K	0,894 ± 0,004
ϖ_L	0,104 ± 0,005
η_{KL}	0,895 ± 0,004

The X-ray and Auger electron emission probabilities have been deduced from γ-ray and conversion electron data by using the computer code EMISSION. Results were verified with the RADLST computer code. Differences between these results were < 1 %.

4) Electron Emissions

The conversion electron emission probabilities have been computed from γ-ray emission probabilities and theoretical ICC values.

5) Photon Emissions

Energies

γ-ray energies and uncertainties are from 2000HE14. These values have been deduced on a revised energy scale.

g-ray emissions

The available experimental relative gamma emission intensities are:

Reference	g**79,6**	g**81**	g**161**	g**223**	g**303**	g**384**
1958PL55	-	-	-	-	0,010	0,005
1959JH17	-	100	1,4	-	0,084	0,043
1961ER04	0,8 (1)	100	0,109 (10)	0,0004 ($^{+4}_{-3}$)	0,0123 (12)	0,0062 (9)
1968AL16	100 1,6 (7)	98,2 (59)	0,174 (9)	0,000647 (613)	0,0135 (4)	0,00618 (19)
1992MA05	100		0,242 (25)	0,00044 (18)	0,0193 (7)	0,000901 (41)
Weighted average			0,182	0,00046	0,0155	
Reduced χ^2			6,55	0,1	24	
Internal uncertainty			0,008	0,00017	0,0004	
External uncertainty			0,022	0,00006	0,0021	
Recommended	0,76 (9)	99,24 (9)	0,182 (22)	0,00046 (17)	0,0155 (21)	0,0076 (10)

1968AL16 relative intensities were reported to the group $\gamma_{79,6}+\gamma_{81}$=1000. In the table they have been reported to 100 for that of the group $\gamma_{79,6}+\gamma_{81}$.

1995MA02 relative intensities were reported to the group $\gamma_{80}+\gamma_{81}$ and multiplied 10 ^{5}. In this table they have been reported to 100 for that of group $\gamma_{79,6}+\gamma_{81}$.

To evaluate all relative intensities, the group $\gamma_{79,6}+\gamma_{81}$ has been taken as the reference line as measured 1968AL16 and 1992MA05.
The 79.6 keV line has been deduced using the ratio $\gamma_{79,6}/\gamma_{161}$ from ^{133}Ba decay (Chechev and Kuzmenko, 2004).

$$g_{79.6} = 0{,}182(22)\times\left.\frac{4{,}27(8)}{1{,}028(8)}\right|_{^{133}Ba} = 0{,}76(9)$$

Therefore, $g_{81} = 100 - 0{,}76(9) = 99{,}24(9)$

The relative γ-ray emission intensities for the 384 keV γ-ray has been deduced from the 303 keV γ-ray emission probability and the averaged ratio $\gamma_{384}/\gamma_{303}$ measured by:

Reference	$\gamma_{384}/\gamma_{303}$
1958PL55	0,50 (11)
1959JH17	0,512 (13)
1961ER041	0,504 (88)
1968AL16	0,458 (20)
1992MA05	0,467 (27)
Weighted mean	0,492
Reduced χ^2	1,53
Internal uncertainty	0,010
External uncertainty	0,012
Recommended	0,492 (12)

So that, $g_{384} = g_{303} \times \left.\frac{g_{384}}{g_{303}}\right|_{w.m.} = 0{,}0155(21) \times 0{,}492(12) = 0{,}0076(10)$

The normalization factor has been deduced from the decay scheme using the formulas:

$$N = \frac{100}{\sum_i I_{g_i}\left[1 + a_{T_i}\right]} \qquad \text{and} \qquad dN^2 = \sum_i \left(\frac{\partial N}{\partial I_{g_i}} dI_{g_i}\right)^2 + \sum_i \left(\frac{\partial N}{\partial a_{T_i}} da_{T_i}\right)^2,$$

where the sum is over all γ-ray transitions to the ground state (g.s.), thus considering no direct β^- feeding to the g.s. Therefore:

$$N = \frac{100}{99{,}24(9)\times\left[1+1{,}698(24)\right] + 0{,}182(22)\times\left[1+0{,}294(5)\right] + 0{,}0076(10)\times\left[1+0{,}0202(3)\right]}$$

The deduced normalization factor is 0,373 (3).

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^{133}Xe^{m} - Comments on evaluation of decay data
by M. Galán

1) Decay Scheme

^{133}Xe^{m} disintegrates by a strong converted γ-transition to the ground state of ^{133}Xe.

2) Nuclear Data

The 233-keV isomeric state has $J^{\pi} = 11/2^{-}$ (1989RA17).

The measured ^{133}Xe^{m} half-life values, are:

Reference	Value (days)
1975HO18	2,19 (5)
1974FOZY	2,188 (8)
1968AL16	2,191 (29)
1961ER04	2,26 (2)
1951BE11	2,30 (8)
Number of input values	5
Reduced χ^2	3,22
Weighted Mean	2,198
Internal uncertainty	0,007
External uncertainty	0,013
NRM	2,200 (11)
RT	2,191 (8)
Adopted value	2,198 (13)

The AveTool program has been used with these five input values. This program calculates averages using three statistical methods: LWM (Limitation of Relative Statistical Weight), NRM (Normalised Residual Method) and RT (Rajeval Technique).
The recommended value for the ^{133}Xe^{m} half-life is the LWM mean of 2,198 d with an external uncertainty of 0,013 d.

2.1) Gamma-ray Transitions

The evaluated γ-ray transition energy is the photon energy plus the nuclear recoil energy.

The 233-keV γ-ray has an M4 multipolarity. The various theoretical conversion coefficients for this transition (Band *et al.* Häger and Seltzer, Rösel *et al.*) differ about 2 % from each other. The ICCs (α_T, α_K, α_L) have been interpolated from the new Band *et al.* tables (2002BA85) using the BrIcc Computer Code. The uncertainties on these conversion coefficients are estimated to be 1,4 %.

Some experimental values together with the theoretical values are shown in the table:

Reference	α_K	K/L+M
Experimental		
1954BE55	4,4 (14)	2,32 (15)
1968AL16	7,68 (25)	2,04 (12)
1972AC02	7,4 (14)	2,54 (20)
Theoretical		
1968HA52	6,37 (9)	2,51 (5)
1978RO22	6,35 (9)	2,44 (4)
2002BA85	6,25 (9)	2,41 (3)

3) Atomic Data

Atomic values (ω_k, ϖ_L and η_{KL}) are from 1996SC06.

ω_K	0,888 ± 0,005
ϖ_L	0,097 ± 0,005
η_{KL}	0,902 ± 0,004

The X-ray and Auger electron emission probabilities have been calculated from γ-ray and conversion electron data using the programs RADLST and EMISSION. Differences bet ween these results were < 0,6 %.

4) Radiation emissions

4.1 Conversion electrons

The conversion electron emission probabilities have been deduced from the ICC values and from the γ-ray emission probability.
The total conversion electron emission probability has been deduced from:
$P_{ce} = 100 - P_{\gamma} = 100 - 10{,}16\ (13) = 89{,}84\ (13)$

4.2 g-Ray Emissions

Various measurements of the γ-ray energy have been found in the bibliography:

Reference	Value (keV)
1976ME16	233,221 (15)
1972AC02	233,2 (4)
1952BE55	232,8 (3)
1951BE11	232,8 (4)
Number of input values	4

Reduced χ^2	1,02
Weighted Mean	233,219
Internal uncertainty	0,015
External uncertainty	0,015
NRM	233,219 (15)
RT	233,11 (12)
Adopted value	233,219 (15)

The recommended value is the LWM mean of 233,219 keV with an external uncertainty of 0,015.

The γ-ray emission intensity is given by:

$P\gamma = 100 / (1 + \alpha) = 100 / [1 + 8,84\ (13)] = 10,16\ (13)$ %.

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^{133}Ba - Comments on evaluation of decay data

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This evaluation was done in May 1999, and revised in April 2000. The literature available by April 2000 was included. The half-life was revised in January 2004 using new references available by 2004.

1. Decay Scheme

Since ^{133}Ba has spin and parity 1/2$^+$, it decays primarily by allowed ε branches to the 1/2$^+$ and 3/2$^+$ levels at 437 and 383 keV. As to the intensities of the other possible ε branches to the levels at 0, 81 and 161 keV they can be estimated from log *ft* systematics. From that of 1998Si17, one expects the log *ft* of the unique 2nd forbidden decay to the ground state to be greater than 13.9 which corresponds to a branch of less than 0.0005%. Similarly, the log *ft* of the 2nd forbidden decays to the 81- and 161-keV levels are expected to be greater than 10.6 which corresponds to branches of less than 0.7% and 0.3%, respectively. Our evaluations for these two branches from the gamma intensity balance agree very well with this expectation (see section 2.1)

From the measured γ-ray emission probabilities and the internal conversion coefficients, the intensity balances at the 81- and 161 keV levels give branching to these levels of 0.0(16) % and 0.11(18)%, respectively.

Therefore, all of these unobserved β branches can be considered negligible.

For comparison see also the evaluations made by R. B. Firestone (1990Fi03), A. L.Nichols (1993Nichols) and Shaheen Rab (1995Ra12) as well as the analysis by F. E. Chukreev (1992Chukreev).

Q value is from Audi and Wapstra (1995Au04).

The ^{133}Ba half-life values available from 1961 are, in days:

3908(73)	1961Wy01	
2849(37)	1968La10	Rejected, large deviation from mean
3894(44)	1968Re04	
3781(15)	1970Wa19	Rejected, revised in 1983Wa26
3981(37)	1972Em01	Rejected by Chauvenet's criterion
4127(260)	1973Ll01	Rejected by Chauvenet's criterion
3850(55)	1979HaYC	
3785(27)	1980RuZY	
3848.0(11)	1980Ho17	
3828(11)	1982HoZJ	Rejected, revised in 1992Un01
3885.9(43)	1983Ki08	
3842(18)	1983Wa26	
3853.6(36)	1992Un01	Rejected, revised in 2002Un02
3848.9(7)	1997Ma75	
3854.7(28)	2002Un02	
3840.5(65)	2003Schrader	
3849.7(22)	Mean value	

The values before 1961 were struck off due to their large uncertainties (more then 1 year).

The values of 1970Wa19, 1982HoZJ and 1992Un01 had been omitted since they have been replaced by later values from the same group when the data set of the thirteen remained values was formed.

Then the value of 1968La10 (7.8 ±0.1 y) was omitted on statistical considerations because of a great contribution into the χ^2 value (27 σ from adopted value).

Use of the LWEIGHT computer program on the remaining twelve half-life values led to subsequent omitting outliers of 1973Ll01 and then 1972Em01 by Chauvenet's criterion. The uncertainty of 1997Ma75 was increased to 0.98 days to adjust weights according to the Limitation of Relative

Statistical Weight method. In consequence the LWEIGHT program chose the weighted average of 3849.7 days and external uncertainty of 2.2 days.

It should be noted that in the weighted average of the two values of 1980Ho17 and 1997Ma75 have altogether 90% of the relative weight. Since these two values agree, any weighted average will be about 3849 days that differs slightly from an unweighted average of about 3856 days.

The adopted value for the ^{133}Ba half-life is 3849.7(22) in days and 10,540(6) in years.

2.1. Electron Capture Transitions

The energies of the electron capture, ε , transitions have been calculated from the Q value and the level energies deduced from gamma transition energies (see also 1995Ra12) .

The electron capture probabilities $\varepsilon_{0,4}$ and $\varepsilon_{0,3}$ have been calculated from the intensity balance for the 437 level and the 384 level, respectively, using the evaluated $P_{\gamma+ce}$ values. Similarly, the electron capture probabilities $\varepsilon_{0,2}$ and $\varepsilon_{0,1}$ are obtained from the intensity balance for 161 and 81 keV levels respectively, as (0.11±0,18) and (0.0±1.6) per 100 disintegrations. Hence the upper limits for them are ($P\varepsilon_{0,2} < 0.3$) and ($P\ \varepsilon_{0,1} < 2$) per 100 disintegrations. However the upper limit for $\varepsilon_{0,1}$ can be decreased with use of the correlation of $P\varepsilon_{0,1} = 100 - P\varepsilon_{0,4} - P\varepsilon_{0,3} - P\varepsilon_{0,2} = 0.0(7)$, i.e. , $P\varepsilon_{0,1} < 0.7$ per 100 disintegrations.

The P_K, P_L and P_M values for transitions $\varepsilon_{0,4}$ and $\varepsilon_{0,3}$ to the 437 keV and 384 keV levels, respectively, have been computed from the tables of Schönfeld (1998Sc28).

The available experimental P_K values are:

	$P_K(\varepsilon_{0,4})$	$P_K(\varepsilon_{0,3})$	$P_K(\varepsilon_{0,2})$	$P_K(\varepsilon_{0,1})$
1968Na16	0.68(5)			
1972Sc08	0.72(4)	0.80(7)		
1974Da09	0.76(6)	0.87(14)		
1975Ni07	0.75(10)			
1983Si17	0.75(4)	0.80(4)	0.92(13)	0.95(6)
1983Si22	0.71(11)	0.79(5)		
1988BeYQ	0.78(4)			
1990Da11	0.76(4)			
1990Bh01	0.730(12)	0.81(3)	0.91(7)	0.94(6)
1992Sa28	0.65(3)	0.74(4)	0.79(3)	0.88(4)
adopted	0.672(5)	0.7734(21)	0.79(3)	0.88(4)

Most of these values were obtained in 1974 -1990 using the method of the X-, gamma-ray sum peak measurements. The results exceed the theoretical P_K values for the allowed $\varepsilon_{0,4}$, $\varepsilon_{0,3}$ - transitions and depend also on adopted conversion coefficients α_K and fluorescence yield ω_K.

The new measurement results obtained in 1992 agree better with the adopted values of P_K. Hence for P_K of the 2nd forbidden transitions $\varepsilon_{0,2}$, $\varepsilon_{0,1}$ we have adopted the values of 1992Sa28 (as the expression in 1998Sc28 do not apply to 2nd forbidden transitions).

2.2. Gamma Transitions and Internal Conversion Coefficients

The evaluated energies of gamma transitions are the energies of gamma rays with adding the recoil energy .

The probabilities of gamma transitions $P_{\gamma+ce}$ have been computed using the evaluated absolute gamma-ray emission probabilities and the total internal conversion coefficients (ICC). The ICC have been evaluated using the information of the multipolarity admixture coefficients from 1977Kr13, 1980Kr22 and 1995Ra12 and the theoretical values from 1978Ro22.

3. Atomic Data

3.1. Fluorescence yields

The fluorescence yields are taken from 1996Sc06 (Schonfeld and Janβen).

3.2. X Radiations

The X-ray energies are based on the wave lengths in the compilation of 1967Be65 (Bearden). The relative KX-ray emission Kβ/Kα and $K\alpha_2/K\alpha_1$ probabilities are taken from 1996Sc06. In order to calculate the $K\beta'_1/K\alpha_1$ and $K\beta'_2/K\alpha_1$ ratios the value of $K\beta'_2/K\beta'_1$ measured in 1989Ma60 (0,2525(23)) has been adopted.

3.3. Auger Electrons

The energies of Auger electrons are from 1977La19 (Larkins).

The ratios P(KLX)/P(KLL) and P(KLY)/P(KLL) are taken from 1996Sc06.

4. Photon Emissions

4.1. X-Ray Emissions

The total absolute emission probability of KX -rays (P_{XK}) has been computed using the adopted value of ω_K, the evaluated total absolute emission probability of K conversion electrons (Pce_K) and the electron capture ($P\varepsilon_K$). The absolute emission probabilities of the KX -ray components have been computed from P_{XK} using the relative probabilities from 1996Sc06 and 1989Ma60 for $K\beta'_2/K\beta'_1$ and 1996Sc06 for all others.

The measured values of the total absolute emission probability of KX -rays ($P_{XK}\times100$) are given below in comparison with the calculated (adopted) value:

1972Sc08	1977Sc31	1989Egorov	Adopted
123.1(17)	117.4(22)	119.7(11)	119.7(13)

The total absolute emission probability of LX -rays has been computed using total absolute sums Pce_L, Pce_K, $P\varepsilon_K$, $P\varepsilon_L$ and atomic data of section 3 (ω_K, ϖ_L, n_{KL}).

4.2. Gamma-Ray Emissions

The γ-ray energies are taken from the evaluation 2000He14 where the values are deduced on the revised energy scale. For the γ-ray of 81 keV see also the measurement of 1991We08.

The γ-ray absolute emission probabilities have been computed using the evaluated γ-ray relative probabilities and the absolute emission probability for the γ-ray 356 keV of 0.6205(19) measured in 1980Chauvenet, 1983Ch11. This experimental value for the most intensive γ-ray in the decay of ^{133}Ba was obtained as a result of the international intercomparison ICRM -S- 6 (1980Chauvenet). It is more preferable for normalizing of gamma-ray absolute emission probabilities than having been obtained from a ground state intensity balance 0.621(10) -because of uncertainties in multipolarity admixtures (and thus in ICC) as well as possible ambiguity in determination of some spins (see 1992Chukreev).

At the same time the relative gamma ray emission probabilities from ICRM -S-6 measured at the fifteen laboratories are used below in Table 1 equally with other measurements for averaging all the available data (the evaluation technique is given in 2000Ch01). The measurements of ICRM -S-6 have been lettered CRP and deduced from absolute emission probabilities published in 1980Chauvenet excluding an activity uncertainties ~0.2 %.

5. Electron Emissions

The energies of the conversion electrons have been calculated from the gamma-transition energies given in 2.2 and the electron binding energies.

The emission probabilities of the conversion electrons have been calculated using the conversion coefficients given in 2.2. The values of the emission probabilities of K-Auger electrons have been calculated using the transition probabilities given in 2.1 and 2.2, the atomic data given in 3. and the conversion coefficients given in 2.2.

Table 1. The experimental and evaluated values for γ-ray relative emission probabilities

	γ53	γ80	γ81	γ161	γ223	γ276	γ303	γ356	γ384
1967Bl15	3,8(8)	3,8(4)	53(4)	1,1(3)	0,7(3)	11,0(7)†	30(2)	100	14,5(1)
1968Al16	3,3(5)	-	-	1,20(6)†	0,74(6)	12,0(4)†	30,6(9)†	100	14,2(5)
1968Bo04	4,2(2)†	4,0(4)	58,2(15)	1,07(5)	0,78(6)	11,8(3)	29,8(8)	100	14,3(10)
1968Do10	3,2(4)	5,5(7)†	52(7)	0,99(10)	0,72(8)	11,6(8)	29,4(2)	100	14,3(10)
1968No01	3,78(9)	4,9(6)	60(7)	1,21(5)†	0,80(3)†	11,61(17)	29,75(29)	100	14,18(26)
1969Gu15	2,91(5)	4,54(7)	53,7(17)	1,13(15)	-	11,2(3)	29,3(5)	100	14,03(26)†
1972Sc08	3,54(5)	3,9(2)	52,6(10)	1,16(5)	0,74(4)	11,4(3)	30,2(6)	100	14,4(3)
1973In06	-	-	-	0,98(7)	0,76(5)	11,6(5)	29,6(11)	100	14,9(6)†
1973Legrand	-	3,7(4)	56(6)	1,4(2)†	0,66(2)†	11,35(25)	29,4(6)	100	14,3(3)
1973Mc18	-	-	-	-	-	11,43(23)	29,3(6)	100	14,5(3)
1977Ge12	3,0(4)	5,6(15)†	52(4)	1,12(8)	0,85(7)†	11,7(8)	29,87(21)	100	14,4(11)
1977Sc31	3,49(8)	4,29(12)	55,8(16)	0,97(3)	0,73(3)	11,41(16)	29,4(3)	100	14,33(21)
1978He21	3,54(18)	3,1(3)†	49,2(26)	1,08(4)	0,745(25)	11,7(4)	29,8(4)	100	14,36(20)
1978Vylov	3,57(12)	4,16(18)	54,6(17)	0,98(8)	0,71(4)	11,4(3)	28,8(8)†	100	14,3(5)
1980Ro22	-	-	-	1,03(7)	0,72(5)	11,69(16)	29,9(4)	100	14,79(27)†
1983Yo03	-	-	-	1,035(28)	0,756(16)	11,57(7)	29,55(18)	100	14,36(9)
1987Lakshn	2,96(9)	4,67(14)	55,3(16)	-	-	-	-	100	-
1989Da11	3,6(5)	3,7(5)	52,3(7)	1,032(10)	0,713(8)	11,51(8)	29,51(23)	100	13,99(9)†
1990Me15	3,48(7)	3,77(9)	51,2(4)	1,05(3)	0,71(2)	11,3(2)	29,2(3)	100	14,5(2)
1998Hw07	-	-	-	0,950(18)	0,715(10)	11,64(13)	29,31(40)	100	14,52(17)
CRP-1	-	-	-	1,11(9)	0,85(5)†	11,7(4)	29,9(11)	100	14,5(5)
CRP-2	3,56(14)	-	53,1(19)	0,99(4)	0,729(28)	11,7(3)	30,1(9)	100	14,4(5)
CRP-3	3,53(8)	4,20(12)	54,8(12)	1,031(24)	0,69(3)	11,51(14)	29,5(3)	100	14,37(16)
CRP-4	3,53(7)	4,18(11)	54,6(12)	1,037(20)	0,730(22)	11,48(14)	29,5(4)	100	14,41(16)
CRP-5	3,9(7)	4,00(15)	51,5(19)	1,020(27)	0,728(22)	11,5(3)	29,5(9)	100	14,2(5)
CRP-6	3,45(8)	4,73(12)	57,6(14)	1,020(25)	0,728(18)	11,68(28)	29,7(7)	100	14,5(4)
CRP-7	3,56(8)	4,73(12)	58,9(15)	1,070(27)	0,738(18)	11,50(28)	29,6(7)	100	14,3(4)
CRP-8	-	-	-	-	-	11,22(27)	29,3(6)	100	14,53(28)
CRP-9	-	-	-	-	-	11,22(24)	29,3(5)	100	14,26(25)
CRP-10	-	-	-	-	-	11,48(25)	29,3(5)	100	14,20(22)
CRP-11	-	-	-	-	-	11,57(19)	29,4(4)	100	14,34(26)
CRP-12	3,69(18)	4,37(16)	55,3(18)	1,050(19)	0,741(15)	11,53(16)	29,5(4)	100	14,36(20)
CRP-13	2,92(16)	-	-	-	0,75(3)	11,9(4)	30,2(11)	100	14,6(5)
CRP-14	3,53(8)	4,39(11)	55,9(12)	1,015(20)	0,735(10)	11,61(13)	29,6(4)	100	14,34(18)

	γ53	γ80	γ81	γ161	γ223	γ276	γ303	γ356	γ384
CRP-15	3,36(18)	-	-	1,05(4)	0,758(28)	11,7(5)	29,6(10)	100	14,3(4)
CRP-16	3,26(17)	-	-	1,05(4)	0,764(26)	11,7(4)	29,7(6)	100	14,3(3)
CRP-19	3,53(5)	-	-	1,063(17)	0,725(17)	11,61(12)	29,7(3)	100	14,53(13)
CRP-20	3,53(6)	4,05(8)	55,1(9)	1,05(5)	0,72(4)	11,49(21)	29,4(6)	100	14,51(22)
CRP-21	3,62(6)	4,15(12)	55,8(9)	1,039(15)	0,705(11)	11,57(17)	29,5(4)	100	14,40(20)
Nunber of input values	27	20	24	29	28	36	36		34
Reduced χ^2	7,21	5,54	4,08	1,68	0,79	0,37	0,29		0,20
Weighted average	3,45	4,27	53,4	1,032	0,726	11,54	29,55		14,41
Internal uncertainty	0,017	0,029	0,23	0,0048	0,0035	0,030	0,064		0,037
External uncertainty	0,046	0,068	0,47	0,0062	0,0031	0,018	0,035		0,016
Adopted value	3,45(5)[a]	4,27(8)[a]	53,1(5)[b]	1,028(8)[c]	0,730(5)[c]	11,54(7)[a]	29,55(18)[a]	100	14,41(9)[a]

† Omitted as outliers

[a] The least uncertainty of experimental values

[b] Adopted value has been changed slightly from the weighted average for a precise ground state intensity balance to get. Such a small change only for one gamma-ray supports the adopted experimental value of 62,05(19) % for the 356 keV γ-ray absolute emission probability and confirms the decay scheme. The adopted uncertainty of 0,5 is external.

[c] Computed using the absolute emission probability measured in 1996Mi26.

In that work a special precise measurements of the absolute emission probabilities only for the two weak 161 and 223 keV gamma-rays were made by using a 4πβ(ppc)-γ(HPGe) coincidence system.

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^{134}Cs - Comments on evaluation of decay data
by M.-M. Bé

This evaluation was completed in February 2012.

1 Decay Scheme

^{134}Cs decays by β^- emission (99.9997 %) to excited levels of ^{134}Ba. A very weak electron capture (EC) branch to the 847-keV level of ^{134}Xe (0.0003 %) has been pointed out by Van Hise *et al.* (1975Va12).

The overall consistency of the decay scheme was checked by calculating the total energy carried away by the various emissions as determined below, it was found to be 2059 (1) keV per disintegration when the available energy is 2058.97 (33) keV.

2 Nuclear Data

Q values are from Audi (2011AuZZ).

The spins and parities are from A. A. Sonzogni (2004So32).

The ^{134}Cs half-life values are summarized in the tables below.
The results where converted from *a* ⇔ *d*, with 1 *a* = 365.242 198 78 *d*.

Published measured values not used in the evaluation because less precise or superseded (as a rule only one result per laboratory is considered in the statistical process):

Reference	$T_{1/2}$ (a)	Remarks
1938Alexeeva	≥ 1	
1951Glendenin	2.3 (3)	
1957Geiger	2.07 (2)	
1957Merrit	2.19 (2)	
1958Bayly	2.15 (+8, -4)	
1958Edwards	2.26 (5)	
1961Wyatt	2.07 (2)	
1963Dietz	2.046 (4)	Superseded by 1973Di01
1965Flynn	1.99 (2)	
1978Bulovic	2.04 (3)	
	$T_{1/2}$ (d)	
1982HoZJ	754.19 (15)	Superseded by 2002Un02
1992Un01	753.88 (11)	Superseded by 2002Un02

Measured values used in the evaluation:

Reference	$T_{1/2}$ (d)	Remarks
1972La14	751.7 (15)	2.058 (12) a ; 3 σ uncertainty
1973Di01	753.1 (44)	2.062(5) a ; 3 σ uncertainty divided by 3
1980RuZY	753.78 (30)	
1980Ho17	754.50 (7)	Unrealistic uncertainty
1997Ma75	754.52 (18)	
2002Un02	753.88 (15)	Uc questionable
χ^2 crit.	0.3	
χ^2 /(n-1)	0.4	
UWM	753.96	
WM	754.29	
Adopted	754.0 (5)	Or 2.0644 (14) *a*

In this set of data it is difficult to assess an uncertainty.
In Lagoutine *et al.*, they usually determined the uncertainty as: $\sigma = 3 \times u_{stat} + u_{sys}$
Where u_{stat} is the statistical component and u_{sys} the systematic component, their uncertainty cannot be simply divided by 3.
The uncertainty claimed by Houtermans (1980Ho17) is manifestly unrealistic.
The uncertainty given by Unterweger (2002Un02) was recently questioned (2012Un**).

Hence, the adopted value is the simple mean with an uncertainty which covers the most precise value.

2.1 β^- and Electron Capture transitions

The energies of β^- transitions were deduced from the Q values and the level scheme of ^{134}Ba.

The β^- transition probabilities were calculated from the gamma transition probability balance at each level of the decay-scheme. They are compared below with experimental results.

Comparison of adopted and measured values, as published in the two latest publications, of the β^- intensities, in %.

Ref	89-keV	415-keV	658-keV	891-keV	1454-keV
1968Hs01	27 (2)	3.0 (5)	70 (2)	0.045 (15)	0.008 (4)
1963Va06	28	1	71	0.045	0.005
Adopted	27.27 (3)	2.498 (8)	70.19 (8)	~0	0.06 (6)

A weak electron capture branch with 0.0003 % probability was observed by Van Hise *et al.* (1975Va12) from the measurement of a gamma ray with energy 847 keV, however this ray was not confirmed in later works, especially in the very precise measurements carried out by Miyahara (2002Mi06).

2.2 γ–ray Transitions

The γ-ray transitions probabilities were deduced from the γ-ray emission intensities and the internal conversion coefficients calculated with the BrIcc program v2.3-2011 (2008Ki07) for the "frozen approximation".
The multipolarities are from Chand *et al.* (1990Ch47) who measured the γ-γ directional correlations for seven cascades in ^{134}Ba.

Comparison between calculated and some measured K conversion coefficients, $\times 10^{-3}$:

Ref	242-keV	475-keV	563-keV	569-keV	604-keV	795-keV
1965Br02		9.4 (1)	5.6 (6)	8.2 (9)	4.85 (20)	2.5 (3)
1968Ab01			6	7.5		2.9
1968Na11		9.84 (208)	6.40 (73)	8.80 (99)	5.07 (50)	2.90 (33)
1990Ch47	71 (24)	9.34 (72)	6.05 (45)	7.93 (42)	5.03	2.71 (10)
1998Ga24						2.59 (5)
Adopted	72.2 (12)	9.6 (4)	6.03(9)	8.05 (12)	5.03 (7)	2.58 (4)

Ref	801-keV	1038-keV	1167-keV	1365-keV
1965Br02	2.6 (4)	1.62 (18)	1.05 (10)	0.72 (7)
1968Ab01	2.4			
1968Na11	2.78 (58)	1.68 (20)	1.05 (13)	0.79 (9)
1990Ch47	2.49 (12)	1.74 (9)	1.11 (6)	0.855 (32)
1990Ma29		1.515 (20)		0.842 (18)
1998Ga24	2.66 (8)			
Adopted	2.54 (4)	1.79 (6)	1.122 (16)	0.820 (12)

3 Atomic Data

Atomic values for ω_K, ϖ_L, and η_{KL}, are from Schönfeld and Janssen (1996Sc06).
The X-ray and Auger electron emission intensities were derived from the decay scheme data, they are compared with the measured values of Chand (1988Ch44).

	Chand **	Adopted
Kα	0.722 (15)	0.676 (6)
K'β1	0.1386 (39)	0.1289 (19)
K'β2	0.0312 (39)	0.0325 (8)

** Values converted with $I_{\gamma 604}$ = 97.63 (8) %

4 Radiation Emissions

4.1 γ-ray emissions

The measured values of the gamma-ray energies are listed below. No significant discrepancies were observed. The adopted gamma-ray transition energies are the weighted means calculated using the Lweight program (version 3), values published in 1967Le** have been omitted because often not consistent with the others.

Measured and adopted energies of gamma-ray emissions, in keV.

Ref	242	326	475	563	569	604
1965Br02			475.26 (10)	563.11 (12)	569.24 (12)	604.64 (12)
1967Ra10	242.694 (41)	326.51 (10)	475.355 (38)	563.325 (41)	569.371 (47)	604.744 (27)
1968Ab01			475.2 (5)	563.2 (5)	569.38 (56)	604.67 (50)
1968Na11			475.57 (42)^{O}	563.1 (5)	569.30 (51)	604.83 (54)^{O}
1975Va12	242.89 (5)	326.45 (10)	475.35 (5)	563.26 (5)	569.29 (3)	604.660 (20)
1976Gr11				563.227 (15)	569.315 (15)	604.699 (15)
1985GoZK			475.365 (2)	563.250 (3)	569.333 (3)	604.721 (2)
1987Wa28	242.738 (8)^{I}	326.589 (13)	475.364 (3)	563.240 (4)	569.328 (3)	604.720 (3)
χ^2 crit	**4.6**	**4.6**	**3**	**2.6**	**2.6**	**2.8**
χ^2 /n-1	**4.9**	**1.2**	**0.3**	**1.5**	**0.8**	**2.1**
WM	**242.755**	**326.585**	**475.3646**	**563.2462**	**569.3301**	**604.7201**
Adopted	**242.76 (5)**	**326.585 (14)**	**475.365 (2)**	**563.246 (3)**	**569.330 (2)**	**604.720 (3)**

Ref	795	801	1038	1167	1365
1965Br02	795.80 (16)	801.80 (16)	1038.46 (20)	1167.65 (25)	1364.97 (28)
1967Ra10	795.806 (50)	801.86 (28)	1038.61 (49)	1167.99 (39)	1365.08 (32)
1968Ab01	795.68 (49)^{O}	801.54 (50)^{O}	1038.17 (60)	1167.42 (50)	1364.93 (50)
1968Na11	796.02 (71)^{O}	802.00 (71)	1038.02 (92)	1168.4 (10)	1365.4 (12)^{O}
1975Va12	795.760 (20)	801.84 (3)	1038.50 (5)	1167.86 (6)	1365.13 (10)
1976Gr11	795.845 (22)	801.932 (22)	1038.571 (26)	1167.938 (26)	1365.152 (32)
1985GoZK	795.867 (4)^{I}	801.956 (4)		1167.968 (5)	1365.200 (5)
1987Wa28	795.859 (5)	801.948 (5)	1038.610 (7)	1167.968 (5)	1365.185 (7)
χ^2 crit	**3**	**2.8**	**2.8**	**2.6**	**2.8**
χ^2 /n-1	**5.8**	**2.8**	**1.3**	**1.1**	**1**
WM	**795.860**	**801.950**	**1038.605**	**1167.967**	**1365.1941**
Adopted	**795.86 (1)**	**801.950 (6)**	**1038.605 (8)**	**1167.967 (4)**	**1365.194 (4)**

^{I} Increased uncertainty ; ^{O} Outlier ; ^{U} unweighted mean

The measured relative γ ray intensities used for the statistical process are listed below. The different sets of data are consistent, then the adopted relative gamma-ray emission intensities are the weighted means, except as noted, calculated with the Lweight program (version 3).
The intensity of 847-keV gamma-ray in ^{134} Xe (0.0003 %) and an upper intensity limit for the 232 keV gamma-ray of ^{134}Ba (0.0012 %) are from Van Hise *et al.* (1975Va12).

The normalization factor has been deduced from the decay scheme using the formulas:

$$N = \frac{100}{\sum_i I_{\gamma_i}\left[1+\alpha_{T\,i}\right]} \qquad \text{and} \qquad dN^2 = \sum_i \left(\frac{\partial N}{\partial I_{\gamma_i}} dI_{\gamma_i}\right)^2 + \sum_i \left(\frac{\partial N}{\partial \alpha_{T_i}} d\alpha_{T_i}\right)^2 ,$$

where the sum is over all γ-ray transitions to the ^{134}Ba ground state, thus considering no direct β^- feeding to the ground state.
Te relative emission intensities involved in these formulas are: the 847-, 1168- and 604-keV gamma-ray transitions, and α_{847}, α_{1168} and α_{1168} their internal conversion coefficients.
The calculated normalization factor is 0.9763 (8).

Then, the absolute intensity of the 604-keV γ ray is 97.63 (8) %, it can be compared with the experimental result of 97.65 (13) % obtained by Miyahara *et al.* (2002Mi06).

Measured and adopted relative emission intensities of gamma-ray emissions. The values are in %.

Ref	**242-keV (4,3)**	**326-keV (5,4)**	**475-keV (4,2)**	**563-keV (2,1)**	**569-keV (5,3)**	**604-keV (1,0)**
1962Ha10				8.0 (12)	12.0 (15)^{0}	100
1965Br02			1.54 (15)	8.5 (8)	14.6 (14)^{0}	100 (5)
1967Le**			1.53 (31)	8.2 (7)	15.2 (7)	100
1967Ra10	0.020 (10)	0.020 (10)	1.54 (16)	9.1 (9)	16.1 (11)	100
1968Ab01			1.43 (20)^{0}	8.9 (10)	15.3 (16)	100
1968Na11			1.67 (11)^{0}	8.8 (5)	13.6 (7)^{0}	100 (3)
1970Ho06	0.0224 (20)		1.60 (8)^{0}	9.0 (5)	16.3 (10)	100 (6)
1975Va12	0.0215 (8)^{i}	0.015 (6)	1.50 (4)	8.59 (5)	15.82 (11)	100
1976De**			1.55 (3)	8.55 (12)	15.76 (23)	100
1980Yo05				8.57 (3)	15.78 (6)	100.0 (4)
1987Wa28	0.0322 (20)	0.0180 (15)	1.520 (10)	8.53 (6)	15.71 (10)	100.0 (7)
1988CH44	0.0294 (20)	0.0170 (17)	1.520 (20)	8.54 (7)	15.75 (3)	100.0 (7)
2002Mi06			1.503 (11)	8.530 (18)	15.728 (23)	100.00 (8)
χ^2 crit	**3.3**	**3.8**	**2.6**	**2.2**	**2.4**	
χ^2 /n-1	**7.2**	**0.14**	**0.4**	**0.4**	**0.3**	
UWM	**0.0251**	**0.0175**	**1.525**	**8.600**	**15.745**	
WM	**0.0247**	**0.0175**	**1.515**	**8.544**	**15.741**	
adopted	**0.0247 (32)**	**0.0175 (11)**	**1.515 (7)**	**8.544 (14)**	**15.741 (17)**	**100.00 (8)**

Ref	**795-keV (3,1)**	**801-keV (5,2)**	**1038-keV (4,1)**	**1167-keV (2,0)**	**1365-keV (5,1)**
1962Ha10					
1967Le**	87.3 (10)	8.9 (6)	1.12 (20)[o]	2.25 (20)[o]	3.37 (31)
1965Br02	90 (9)	9.0 (15)	1.06 (10)	1.99 (17)	3.5 (3)
1967Ra10	90 (7)	9.1 (8)[o]	1.04 (8)	2.00 (22)	3.3 (3)
1968Ab01	90 (9)	9.4 (10)[o]	1.1 (6)[o]	1.94 (20)	3.4 (3)
1968Na11	89 (4)	8.1 (4)[o]	1.06 (6)	2.06 (14)	3.55 (19)
1970Ho06	88 (4)	8.9 (4)	1.01 (6)	1.90 (10)	3.29 (17)
1975Va12	87.6 (4)	8.95 (4)	1.025 (10)	1.850 (27)	3.11 (4)
1976De**	87.4 (9)	8.85 (12)	1.023 (13)	1.84 (2)	3.09 (3)
1980Yo05	87.5 (3)	8.89 (3)	1.008 (5)	1.827 (8)	3.074 (13)
1987Wa28	87.5 (6)	8.97 (8)	1.016 (7)	1.841 (13)	3.109 (20)
1988CH44					
2002Mi06	87.54 (6)	8.898 (20)	1.021 (8)	1.834 (7)	3.094 (10)
χ^2 crit	**2.3**	**2.6**	**2.5**	**2.4**	**2.3**
χ^2 /n-1	**0.05**	**0.4**	**0.6**	**0.7**	**1.4**
UWM	**88.35**	**8.920**	**1.029**	**1.908**	**3.262**
WM	**87.539**	**8.905**	**1.0150**	**1.834**	**3.092**
adopted	**87.54 (6)**	**8.905 (15)**	**1.0150 (33)**	**1.834 (5)**	**3.092 (8)**

[i] – Increased uncertainty to reduce its weight to 50 %.

[o] - Outlier

Omitted data in the statistical process:

- Ewan (1964Ew04), superseded by Brown (1965Br02);
- van Wijngaarden (1963Va06) because they were not able to separate the 563-569 keV lines and 795-801 keV lines;
- Bashandy (1966Ba57) because they are significantly discrepant with other results;
- Stelson (1973St14) because there are no details in the publication, the values are only mentioned in the decay scheme;
- Verhaeghe (1954Ve09) and Yamanoto (1960Ya**) given without uncertainties;
- Meyer (1990Me15), same as Van Hise (1975Va12).

4.2 Electron emissions

The conversion electron emission intensities have been obtained from the γ-ray emission intensities and theoretical ICC values.

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^{135}Xe^{m} - Comments on evaluation of decay data
M. Galán

1) Decay Scheme

^{135}Xe^{m} disintegrates by IT (99,996 (2) %) to the ground state of ^{135}Xe and by β^- (0,004 (2) %) to ^{135}Cs excited levels. β^- branching has been reported by several authors: < 0,25 % (1976FE04); 0,004 % (1974MEZV and 1982WA21). 1974FOZY reported a transition from the 526 keV -level in ^{135}Xe to the 786,9 keV- level in ^{135}Cs with a lg *ft* = 8,7.
The β-decay scheme is that proposed by 1974MEZV (see also 2008SI01).
The ^{135}Xe^{m} isomeric state is at 526 keV and has $J_\pi = 11/2^-$ (1989RA17, 2008SI01).

2) Nuclear Data

$Q^-(^{135}\mathrm{Xe}^m)$ = 1692 (4) keV has been deduced using a value of $Q(^{135}\mathrm{Xe})$ = 1165 (4) keV from 2003Au03.

The measured ^{135}Xe^{m} half-life values are:

Reference	Value (min)
1960AL12	15,8 (4)
1960KO02	15,65 (10)
1968AL16	15,2 (7)
1968TO20	15,4 (9)
1971HA13	15,287 (22)
1975FU12	15,29 (5)
Number of input values	6
Reduced χ^2	2,84
Weighted Mean	15,303
Internal uncertainty	0,020
External uncertainty	0,034
Adopted value	15,30 (3)

None of the values has been rejected by Chauvenet's criterion. The largest contribution to the weighted average comes from the value of Hawkings (1971HA13).
The recommended value for the ^{135}Xe^{m} half-life is the LWM mean of 15,30 with an external uncertainty of 0,03 d.

DECAY OF ^{135}Xe^{m} to ^{135}Xe

2.1) Gamma-ray Transition

Transition Energy

The evaluated γ-ray transition energy is equal to the photon energy plus the nuclear recoil energy.

Isomeric Transition Probability

The 526-keV γ-ray has M4 multipolarity. The ICCs have been interpolated from the recent tables of Band *et al.* (2002BA85) using the BrIcc Computer Code. The uncertainties on these theoretical conversion coefficients (average deviations from the experimental values) are estimated to be 1,4 %.
Some experimental values (1960AL12, 1972AC02) together with the theoretical values (Band *et al.* 2002; Häger and Seltzer, 1968) are shown in the following table:

Reference	α_K	K/L
1960AL12	0,21 (5)	5,8 (11)
1972AC02	0,198 (12)	
1968HA52	0,193	
2002BA85	0,1908 (27)	5,25 (10)

A beta branching has been estimated as 0,004 (2) % (see below- **DECAY OF ^{135}Xe^{m} to ^{135}Cs**). Thus the recommended value of P(IT) is 99,996 (2) %.

3) Atomic Data

Atomic fluorescence yields (ω_k, ϖ_L and n_{KL}) are from 1996SC06

The X-ray and Auger electron emission probabilities have been calculated from γ-ray and conversion electron data using the EMISSION code.

4) Radiation emissions

4.1) Conversion electrons

The conversion electron emission probabilities have been deduced from the ICC values and from the γ-ray emission probability.
The total conversion electron emission probability is:
$P_{ce} = P(IT) - P_{\gamma} = 19,16\ (25)\ \%$

4.2) g-Ray Emission

Various measurements of the γ-ray energy found in the bibliography are given below:

Reference	Value (keV)
1960AL12	527,4 (8)
1960KO02	528 (3)
1972AC02	526,5 (3)
1979BO26	526,579 (7)
1982WA21	526,561 (7)
Number of input values	5
Reduced χ^2	3,32
Weighted Mean	526,570
Internal uncertainty	0,0050
External uncertainty	0,0054

The recommended value is the LWM mean of 526,570 keV with an external uncertainty of 0,005.

The absolute γ-ray emission probability is given by:
$P_{\gamma} = 100 / (1 + \alpha_T) =$ 80,84 (20) %.

b$^-$ DECAY OF ^{135}Xe^{m} to ^{135}Cs

2.1) Gamma-ray Transition

Transition Energy

The γ-ray transition energies are from 1974MEZV.

Mixing ratios and internal conversion coefficients

Neither mixing ratios nor internal conversion coefficients have been measured for these γ-ray transitions.

2.2) Gamma-ray Emission

γ-Ray *Emission Probabilities*

Only Meyer (1974) reported γ-ray intensities associated with a possible ^{135}Xe^{m} ß-decay. The γ-ray relative intensities measured by 1974MEZV are those given in the following table ("?" purports "uncertain γ"):

Transition energy (keV)	I_{γ}	Photons per 100 disint.
786,91	44 (22)	0,003 6 (18)
1133	3?	0,000 24
1192	0,4?	0,000 032
1358	2?	0,000 16

In the second column relative intensities I_{γ} are relative to 10^{6} photons of 526 keV -$\gamma_{1,0}$(Xe) as reported in 1974MEZV. A 50 % uncertainty in Iγ(787) has been assumed.
For the absolute γ intensities the total conversion coefficient of 0,237 (3) for the 526 keV transition has been taken into account. Then the absolute γ intensities are estimated by multiplying the relative intensities by 100/123,7.

2.3) b **Transitions**

The energies of the β^- transitions have been deduced from the Q value and the level energies in ^{135}Cs (2008Si01). The adopted values have been verified against those produced from a least -squares fit to gamma-ray energies by the computer code GTOL.

As no direct β^- transition to the ground state was reported by Meyer, the normalization factor was deduced assuming no feeding to the g.s. by using the equation:
$[I\gamma(526)\ (1 + \alpha(526)) + I\gamma\ (787)\ (1 + \alpha(787)]\ N = 100\ \%$

The β^- emission probabilities in Sec. 2.1 are from the absolute gamma-ray emission probabilities, as given in the following table:

Transition	Energy (keV)	P(β) %	Log *ft*
$ß_{1,1}$	905,1	0,003 6 (18)	8,7
$ß_{1,2}$	559	0,000 24	9,2
$ß_{1,3}$	500	0,000 032	9,9
$ß_{1,4}$	334	0,000 16	8,7

Lg *ft*'s were calculated with the LOGFT computer code. The adopted beta branching ratio is 0,004 (2) %.

The possible 1692-keV ß transition

If there exits a beta transition to the ground state this might be a 1 st forbidden unique transition. The lg f_1t value is > 8,5. Using the lg f tables of Gove and Martin (1971) or the LOGFT code, we have:

$\lg f_1/f_0 = 0{,}935$ and $\lg f_1 = 3{,}35$.

Now, $\lg(f_1 t) = \lg(f_1) + \lg(t)$ and $t = \frac{T_{1/2}(s)}{B.R.}$, with these two expressions we can estimate the ß branching ratio.

So, $\lg(t) > 8{,}5 - 3{,}35 = 5{,}15$ $\longrightarrow$ $t > 1{,}42 \times 10^5$

Finally we get, $B.R. < \frac{920}{1{,}42 \times 10^5} = 0{,}0065$ or B.R.< 0,65 % for the upper limit of the beta branching. If we consider this beta feeding to the ground state, then the normalization factor can be estimated as:
$[I\gamma(526)\ (1 + \alpha(526)) + I\gamma\ (787)\ (1 + \alpha(787)]\ N = 100\ \% - 0{,}65\ \%$

Then the values would be:
P(IT)= 99,346 (2) %
β^-= 0,0035 (18) %
P_γ= 80,31 (20) %

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^{137}Cs - Comments on evaluation of decay data
by R.G. Helmer and V.P. Chechev

This evaluation was completed by R.G. Helmer in September 1996 with minor editing done in February 1998. Updating ^{137}Cs half-life and editing were done by V.P. Chechev in February 2006. The literature available by February 2006 was included.

1 Decay Scheme

There are as many as 2 supposed excited levels in ^{137}Ba below the decay energy that have not been reported in the ^{137}Cs decay and observed only in ^{136}Ba(d, p)-reaction (1997Tu04 evaluation). Since the possible 907 and 1044 levels do not have J^{π} assignments, and the de-exciting γ rays have not been reported, arguments about their feeding can not be made.

The decay scheme is internally consistent and essentially complete since the total decay energy computed by RADLIST is 1174 (3) keV compared to the Q value of 1175.63 (17) keV, a difference of 1.8 (28) keV.

The J^{π} values and half-lives of the excited levels in ^{137}Ba are from the evaluation of 1997Tu04.

2 Nuclear Data

Q value is from 2003Au03.

The experimental ^{137}Cs half-life values available are, in days (values published in years have been converted to days):

12053 (1096)	1951FlAA,	omitted from analysis
10957 (146)	1955Br06,	omitted from analysis
9715 (146)	1955Wi21,	omitted from analysis
10446 (+73-37)	1958MoZY,	omitted from analysis
11103 (146)	1961Fa03	
10592 (365)	1961Gl08	
10994 (256)	1962Fl09	
10840 (18)	1963Go03	
10665 (110)	1963Ri02	
10738 (66)	1964Co35	
10921 (183)	1965Fl01	
11286 (256)	1965Fl01	
11220 (47)	1965Le25	
11030 (110)	1966Re13,	replaced by 1972Em01
11041 (58)	1968Re04,	replaced by 1972Em01
11191 (157)	1970Ha32	
10921 (16)	1970Wa19,	replaced by 1983Wa26
11023 (37)	1972Em01	
11034 (29)	1973Co39	
11020.8 (41)	1973Di01	
10906 (33)	1978Gr08	
11009 (11)	1980Ho17	
10449 (147)	1980RuZX,	replaced by 1990Ma15
10678 (140)	1980RuZY,	replaced by 1990Ma15

10678 (140)	1982RuZV,	replaced by 1990Ma15
11206 (7)	1982HoZJ,	replaced by 1992Un01
10921 (19)	1983Wa26	
10941 (7)	1989KoAA	
10967.8 (45)	1990Ma15	
10940.8 (69)	1992Go24	
11015 (20)	1992Un01,	replaced by 2002Un02
11018.3 (95)	2002Un02	
10970 (20)	2004Sc04	
10976 (30)	**Adopted**	

If the four values from before 1960 are omitted as well as replaced values, the data set for analysis includes 21 values. The large reduced-χ^2 value (16.3) indicates that these data are quite discrepant; therefore, the adopted value will depend on the method of analysis.

Since no value in this data set contributes more than 50% of the relative weight, the Limitation of Relative Statistical Weight (LRSW) method does not adjust any of the input uncertainties; however, it may expand the final uncertainty to include the more precise value. The Normalized Residual (NORM, 1994Ka08) and RAJEVAL (1992Ra08) methods adjust the input uncertainties for the more discrepant values.

In 1997-1998 R.G. Helmer chose the Normalized Residual (NR) analysis for obtaining the recommended half-life value of 10964(9). That choice was based on a desire for reducing a large relative weight of the value from 1973Di01 and its big contribution to χ^2 value and also to avoid an expansion of the final uncertainty by use of the LRSW analysis. It was stated that the low evaluation result met the tendency of the last measurements (by 1992) and evaluation results to be lower. (Details of Helmer's analysis can be found in the book of 1999BeAA).

The updated NIST value, obtained as a result of continued measurements of six sources (2002Un02), changes the situation. This high value with a small uncertainty (half of that in 1992Un01) has shown that the discrepancy among the most recent and accurate measurements is still kept. Therefore, a small uncertainty of the evaluation result seems to be unrealistic.

Thus, at present we can use the LRSW analysis as one of the methods for the evaluation of the ^{137}Cs half-life.

The weighted average of the twenty one values is 10981.8, with an internal uncertainty of 2.3, a reduced χ^2 of 16.3, and an external uncertainty of 9.5. The unweighted average is 10967(37). The LWEIGHT computer program using the LRSW analysis has chosen the weighted average and expanded the final uncertainty to 39 so range includes the most precise value of 11020.8. Hence, use of the LRSW analysis leads to the evaluation of 10982(39) days for the ^{137}Cs half-life.

This evaluation agrees well with the recent independent evaluations. Woods and Collins (2004Wo02) used 11 experimental values since 1968 and recommended the value of 10990(40) days by similar evaluation technique. Helene and Vanin (2002He06) presented in their paper a very promising statistical procedure (BOOTSTRAP method) to deduce a best value and its standard deviation for a discrepant set of data. They used 19 experimental ^{137}Cs half-life values and obtained the evaluation result as 10987(30) days.

The NORM and RAJEVAL statistical procedures lead to the evaluation results of 10962(7) and 10971(6) days, with the small uncertainties. The Bayesian procedures (BAYS and MBAYS, 1994Ka08) give the equal result of 10982(10) days. Thus, different methods of statistical analysis have led to discrepant results. In such a way the best (the less worst ?) choice is derived from the BOOTSTRAP method. It gives an intermediate result (calculation of Helene and Vanin, 2006) between the unadjusted weighted mean and the adjusted values from different procedures and its uncertainty encompasses all the statistical results.

The adopted value of the ^{137}Cs half-life is **10976(30) days, or 30.05(8) years.**

2.1 Beta - Transitions

The emission probability (in %) of the β^- transition to the ground state has been measured as follows:

4.8 (3)	1957Ri41,	σ increased to 0.6
7.6 (8)	1958Yo01	
6.5 (2)	1962Da05,	σ increased to 0.6
4.8 (10)	1965Me03	
6.0 (5)	1966Hs02	
5.4 (3)	1969Ha05	
6.4 (5)	1978Gr09	
5.57 (7)	1983Be18	
5.69 (19)	Value from LRSW analysis	
5.64 (28)	Adopted value from sect. 4.2	

The uncertainties for early values of 1957Ri41 and 1962Da05 were increased by the evaluator to 0.6 to make them comparable with those of the values measured in the 1966 - 1978 period.

The LRSW analysis gives an internal uncertainty of 0.14, a reduced-χ^2 value of 2.03, and an external uncertainty of 0.19. In this analysis the uncertainty of the 1983Be19 value was increased from 0.07 to 0.19 in order to reduce its relative weight from 78% to 50%.

The average β^- energies and log *ft* values have been calculated using the LOGFT computer program.

The shape of the β^- spectra has been measured by 1983Be18, 1978Ch22, 1978Gr09, 1969Sc23, and 1966Hs02, which is useful in the determination of the relative β^- branch intensities.

The very detailed treatment of the expression for the shape of the β^- spectrum for the 2nd forbidden transition to the ground state argues that the measurement of 1983Be18 should replace all of the previous values. If this were done the $P_{\beta-}(0)$ would decrease by 0.12% and $P_{\beta-}(662)$ would increase by this amount. The $P_\gamma(662)$ would then increase by about 0.08%. However, the value of 1983Be18 has only been allowed to contribute 50% of the relative weight, as is our common practice. It should also be noted that this paper has additional influence since its data are also used in determining the α_T (662) value that is used in the calculation of $P_\gamma(662)$.

The adopted value $P_{\beta-}(662)$ has been computed from the final adopted $P_\gamma(662)$ value. [The uncertainty has increased due to the inclusion of the uncertainty in α_T (662) twice.]

2.2 Gamma Transitions

The adopted α_T (662) value of 0.1102 (19) is from a LRSW analysis of the 5 measured values recommended in the 1985HaZA evaluation, except that the value of 1983Be18 is used in place of value of 1978Ch22; these values are 0.1100 (11) (1965Me03), 0.1121 (5) (1969Ha05), 0.1105 (10) (1973LeZJ), 0.1100 (6) (1975Go28), and 0.1083 (5) (1983Be18, where the uncertainty has been increased to match the lowest other value). For this average, internal uncertainty = 0.0003, the reduced-χ^2 = 7.3, and the external uncertainty = 0.0008. The final uncertainty was increased by the LRSW analysis from 0.0008 to 0.0019 to include the 2 most precise values. Due to the large discrepancies among the 12 measured α values reported, 1985HaZA chose not to recommend any value.

The theoretical α_T value interpolated from the tables of 1978Ro21 is 0.1143 34; but 1990Ne01 has suggested that the α_T values for M4's from 1978Ro21 should be multiplied by 0.975 which gives 0.1114; this agrees with the adopted value to 1.1% which is much smaller than the uncertainty in either value. The theoretical total ICC value interpolated from the tables of 1993Ba60 $\alpha_T(662)=0.1116$.

Other measurements of α_T listed in 1985HaZA include 0.114 (2) (1957Ri41), 0.114 (30) (1962Da05), 0.109 (20) (1963Bo31), 0.1167 (15) (1965Pa17), 0.112 (11) (1965Ra12), 0.1092 (8) (1978Ch22), and 0.114 (3) (1978Gr09).

The adopted value α_K(662) of 0.0896 (15) is from the LRSW analysis of the 4 values recommended in the 1985HaZA evaluation, except for the value of 1983Be18 which is used in place of that from 1978Ch22; these values are 0.0894 (10) (1965Me03), 0.0916 (4) (1969Ha05), 0.0901 (9) (1973LeZJ), and 0.0881 (2) (1983Be18). The LRSW analysis increases the uncertainty of the 1983Be18 value from 0.0002 to 0.00034 to reduce its relative weight from 75% to 50%. For this average, the internal uncertainty = 0.0002, the reduced-χ^2 = 14.8, and the external uncertainty = 0.0009. The final uncertainty was increased by the LRSW analysis from 0.0009 to 0.0015 to include the most precise value.

The theoretical value α_K(662) interpolated from the tables of 1978Ro21 is 0.0929 28; but 1990Ne01 has suggested that the α_K values for M4's from 1978Ro21 should be multiplied by 0.975 which gives 0.0906; this agrees with the adopted value to 1.1% which is much smaller than the uncertainty in either value. The theoretical α_K(662) value interpolated from the tables of 1993Ba60 α_K (662)=0.0907.

Other measured values of α_K listed in 1985HaZA are 0.097 (3) (1951Wa19), 0.095 (5) (1952He33), 0.11 (1) (1953Do31), 0.096 (5) (1954AZ01), 0.095 (8) (1957Mc34), 0.093 (1957Ri41), 0.092 (6) (1959Wa17), 0.0976 (55) (1958Yo01), 0.093 (6) (1959Hu23), 0.093 (6) (1960De17), 0.095 (4) (1961Hu12), 0.093 (3) (1962Da05), 0.0957 (10) (1965Pa17), 0.092 (9) (1965Ra12), 0.093 (7) (1966Hs01), 0.094 (5) (1966Hu02), 0.093 (9) (1967Ba80), 0.0925 (27) (1967HaZX), 0.0922 (22) (1973Wi10), 0.0901 (10) (1971BrAA), 0.0888 (70) (1978Ch22), and 0.093 (3) (1978Gr09).

3 Atomic Data

The data are from Schönfeld and Janßen (1996Sc06).

3.1 X Radiations

The data are from Schönfeld and Janßen (1996Sc06).

3.2 Auger Electrons

The data are from Schönfeld and Janßen (1996Sc06).

4 Radiation Emissions

4.1 Electron Emission

The β^- data are from RADLIST or LOGFT. The Auger and conversion electron data are from Schönfeld (1996Sc06) calculations. For comparison, these emission probabilities and those from RADLIST (with the atomic data from Schönfeld) are:

Electrons per decay

	Schönfeld	RADLIST
L Auger	0.0728 (12)	0.0728 (22)
K Auger	0.0076 (4)	0.0076 (3)
K-662	0.07644	0.076 (3)
L-662	0.01387	0.0142 (6)

4.2 Photon Emissions

The 662-keV γ-ray energy is from 2000He14 and that for the 283-keV γ is from 1997WaZZ, but more precise values of 283.46 6 and 283.53 4 are available from (n,n'γ) studies.

The intensity of the 662-keV γ ray has been deduced in two ways, (1) the ratio of the measured γ emission rate and the measured source decay rate and (2) from the probability of β- decay to the 662-keV level and α_T (662). These two values are independent as long as they involve independent measurements. Of the many papers that quote P_γ values, several are listed in section 2.1 as giving $P_{\beta\text{-}}(0)$ values and are not included here. References 1965Me03 and 1978ChZZ have been replaced by 1978MeZM and 1983Be18, respectively. This leaves the following three values of $P_\gamma(662)$ to consider:

85.3 (10)	1973LeZJ
86.0 (9)	1975Go28
84.7 (7)	1978MeZM
85.2 (5)	Weighted average with reduced-χ^2 = 0.65

[It should be noted that in the evaluation of 1991BaZS the value of 1973LeZJ is quoted as 0.8456 (8), which is the value from 1978Ch22. The evaluation of 1997Tu04 adopts the 1991BaZS result and repeats this error.]

The second value of $P_\gamma(662)$ comes from the average $P_{\beta\text{-}}(0)$ = 5.69% (19) in section 2.1 and the α_T (662) = 0.1102 (19) in section 2.2, $P_{\beta\text{-}}(662)/[1.0+\alpha(662)]$ = 84.95% (22). Then, the adopted value is taken to be the weighted average of the values 84.95% (22) and 85.2% (5) which is 84.99% (20).

The decay of ^{137}Cs to the first excited level in ^{137}Ba at 283 keV was observed in 1996Bi23 and 1997WaZZ. The γ-ray intensity relative to that of the 662-keV γ ray is 0.00053 (14) (1996Bi23) and 0.00061 (10) (1997WaZZ) which gives an average of 0.00058 (8) and a corresponding transition intensity of 0.00061 (8).

The final $P_{\beta\text{-}}$ values are adjusted to be in agreement with this result and are $P_{\beta\text{-}}(662)$ = 94.36% (28) and $P_{\beta\text{-}}(0)$ = 5.64% (28). [The uncertainties here are overestimated because the contribution from α_T (662) has been included twice.]

The X-ray emission probabilities are from the γ-ray emission probability, the internal-conversion coefficients, and the atomic data of 1996Sc06. The difference between the Schönfeld values given and the RADLIST values are within the uncertainties:

Photons per decay

	Schönfeld	RADLIST
$K_{\alpha2}$	0.0195 (4)	0.0195 (7)
$K_{\alpha1}$	0.0358 (7)	0.0359 (13)
K_β	0.0132 (3)	0.0132 (5)
Total K	0.0685 (13)	0.0686 (16)

Double-decay processes which might occur in lieu of the 662-keV γ ray have been studied; two γ's (1960Be20, 1992BaAA, 1993Ba46); a K shell electron plus a γ (1969Lj01, 1971Lj01); and two electrons (1971Lj02, 1971Po04). The paper of 1993Ba46 suggests an upper limit of the ratio of 2γ emission to 1γ emission of 5.10^{-7}.

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^{139}Ce - Comments on evaluation of decay data by M.M. Bé, R. G. Helmer, E. Schönfeld

1 Decay Scheme

This evaluation was completed in September 1996 and reviewed in 2007. The literature available by December 2007 was included.
This decay scheme is complete since the only excited level below the ^{139}Ce decay energy is populated (1989Bu12).

2 Nuclear Data

A Q value of 270 (3) keV is deduced from P_K measurements (see §2.1). It can be compared with a Q value of 264.6 (20) keV from measurement of the internal bremsstrahlung spectrum of 1996Hi14.

The ^{139}Ce half-life values available are, in days:

140	(1)	1948Po01	# (Pool and Krisberg as quoted in 1965An07)
137.5	(3)	1965An07	(Anspach et al.)
137.2	(4)	1972Em01	(Emery et al.)
137.63	(10)	1973MeYE	# (Merritt), replaced by 1982RuZV
137.65	(7)	1976Me	# (Merritt), replaced by 1982RuZV
137.66	(4)	1976Va30	(Vaninbroukx and Grosse)
137.59	(4)	1978La21	(Lagoutine et al.), uncertainty quoted as 0.12 at 3σ level
137.65	(3)	1980RuZY	# (Rutledge et al.), replaced by 1982RuZV
137.74	(8)	1982HoZJ	# (Hoppes et al.), replaced by 1992Un01
137.65	(3)	1982RuZV	(Rutledge et al.)
137.8	(2)	1982RyZX	(Rytz) BIPM value in NBS-SP-626
137.73	(9)	1992Un01	(Unterweger et al.)
137.641	(20)	Weighted average & adopted	

The value of 1948Po01 was omitted due to its large uncertainty. Omitting this value and the several (#) that were replaced by latter values, one has seven values to consider. The weighted average of these seven values is 137.641 with an internal uncertainty of 0.020 and a reduced-χ^2 of 0.83. No adjustments were made in the Limitation of Relative Statistical Weight method since the largest relative weight is less than 50 %, namely 44 % for the 1982RuZV value; also the set is consistent.

2.1 Electron Capture Transitions

The energies of the electron-capture transitions (ε) are calculated from the Q value and the level energies. The ε branch to the ground state is 2nd forbidden. From the log *ft* systematics (1998Si17), the expected log *ft* value is > 10.6 and the corresponding limit is $P_\varepsilon(0) < 0.008$ % compared to the measured limit of $P_\varepsilon(0) < 1$ % (1956Ke23) and $P_\varepsilon(0) < 0.000097$ % (1993Mi20) . If asymmetric uncertainties are used, the evaluator suggests the other ε branch probability is 99.9973 +27-53. If only symmetric uncertainties are used, 99.9973 (27) is suggested.

The P_K value for transition to the 165-keV level was deduced from the 17 measured values.

The available measured P_K values are listed in the following table as given in the original papers:

Value (uc)		ω_K	Reference	
0.87	(4)	Independant	Outlier	1954Pr31 (Pruett)
0.73	(2)	Independent		1956Ke23 (Ketelle)
0.68	(2)	Independent		1967Ma07 (Marelius)
0.75	(1)	Independent		1968Ad08 (B.Adamowicz)
0.69	(2)	Independent		1968Va08 (E.Vatai)
0.705	(20)	0.92 (1)		1972Ca07 (Campbell)
0.78	(3)	Independent		1972Sc08 (Schmidt-Ott)
0.73	(3)	(Martin ?)		1975Da08 (Dasmahapatra)
0.726	(10)	Independent		1975Ha43 (Hansen)
0.705	(20)	0.906 (26)		1975Pl06 (Plch)
0.801	(34)	0.906 (26)	Outlier	1976Ha36 (Hartl)
0.76	(3)	0.906 (26)		1978Se **(Sergienko)
0.710	(24)	0.926		1987BeYL (Begzhanov)
0.68	(2)	0.91 (3)		1988Ko** (Konstantinov)
0.74	(3)	0.905 (4)		1994Ku43 (Kumar)
0.704	(6)	0.907, Kβ =0.193		1996Hi14 (Hindi)
0.714	(25)	0.906 (26)		1997Ka** (Kalyani)
Critical χ^2	2			
Reduced χ^2	2.4			
WM	0.716	External Unc.= 0.006 Expanded Unc. = 0.012		
Adopted	**0.716**	**0.006**		

Two values (1954Pr31 and 1976Ha36) were found outlier due to Chauvenet's criterion. The remaining set of 15 values is slightly discrepant with a reduce χ^2 of 2.4.
The most important contribution comes from the Hindi's value amounting for 40 %, this value was deduced from the measurement of the Q value.

From this P_K value of 0.716 (6), a Q value of 270 (3) keV is derived.
A value of Q=279 (7) was obtained in 2003Au03 using the same methodology but with a reduce set of 10 P_K values (from 1954Pr31 to 1976Ha36).

See 1988Ri08 (Riisager) for possible effects on the capture rates of the finite widths of the atomic levels.

2.2 Gamma Transitions

The probability for the 165-keV γ- transition is equal to the probability of the preceding ε- transition.

The γ- ray is mostly M1 and the %E2 is taken to be 0.0. The reported δ(E2/M1) are: +0.034 (34) [1963Ha07 from (γ, θ, T) and polarization]; 0.045 (+26-45) (1965Ge04 from $L_1/L_2/L_3$); 0.029 (+18-29) with the nuclear penetration parameter λ = 2.8 (13) (1979Ha21 from analysis of published data); and < 0.0055 with λ = 4.2 (8) (1977Ry01 from analysis of published measured data and a new calculation of a values). Also, λ = 3.1 (7) with δ = 0.0 (1975Pl06 from experimental α_K and other published α data) and λ = 3.6 (18) with δ = 0.0 (1975Mo12). The weighted average of these four λ values is 3.5 (5) with a reduced-χ^2 = 0.46. Since much of the data used to determine these λ values are common to the various calculations, the values are correlated. Therefore, the uncertainty is increased to the smallest of the four uncertainties, and the value 3.5 (7) is recommended.

The K-shell and total internal-conversion coefficients are from the 1985HaZA evaluation. This evaluation lists the following values :

			Retained in 85HaZA analysis	
a_K	a	**Reference**	a_K	a
0.22		1954Mi56		
0.20 (4)		1954Nu12		
0.20 (5)		1954Pr31		
0.22 (1)		1956Ke23		
0.263		1962Be31		
0.2148 (12)	0.2514 (11)	1962Ta03	yes	yes
0.209 (27)		1967HaZX		
	0.254 (6)	1971Ar43		yes
	0.2446 (12)	1973Le29+1973LeYP		
0.207 (9)		1975Mo12	yes [as 0.214 (5)]	
0.214 (2)	0.251 (2)	1975Pl06	yes	yes
0.2152 (33)	0.2520 (50)	1976Ha11	yes	yes
	0.2519 (6)	1977Sc**		yes [as 0.2519(10)]
0.2146 (10)	**0.2516 (7)**	**1985HaZA recommended and adopted here**		
	0.261 (4)	2005KiZW		Theory for M1 “Frozen orbital”
	0.337 (5)	2005KiZW		Theory for E2 “Frozen orbital”
	0.267	1978Ro22		Theory for M1
	0.264	1968Ha52		Theory for M1
	0.339	1978Ro22		Theory for E2
	0.339	1968Ha52		Theory for E2

The theoretical values are for $\lambda = 0.0$. The α_L and α_M values were computed from the adopted α_K value and the K/L and K/M ratios from the M1 theoretical values interpolated from the table of Rösel (1978Ro22).
Since this transition is hindered and the aspect of nuclear penetration effect discussed by various authors (1975Mo12, 1977Ry01, 1979Ha21, …) the adopted α values are the experimental ones.

3 Atomic Data

The fluorescence yield data are from 1996Sc06 (Schönfeld and Janssen).

3.1 X Radiation

The x-ray energies are based on the wave lengths in the compilation of 1967Be65 (Bearden). The relative K x-ray emission probabilities are taken from 1996Sc06. The value for $P(X_L)/P(K_{\alpha 1})$ is derived from the emission probabilities (sect. 4.2).

3.2 Auger Electrons

The ratios P(KLX)/P(KLL) and P(KXY)/P(KLL) are taken from 1996Sc06. The value for P(eAL)/P(KLL) is derived from the emission probabilities (sect. 4.1).

4 Radiation Emission

4.1 Electron Emission

The electron emission probabilities are calculated from the X and γ-ray emission probabilities in sects. 2.1 and 4.2, the atomic data of sect. 3, and the internal-conversion coefficients of sect. 2.2.

4.2 Photon Emissions

The γ-ray energy is from the evaluation 2000He14 where the values are on a scale on which the strong line from the decay of ^{198}Au is 411.80205 (17).
The γ-ray emission intensity is calculated as $I_e(165)/[1 + \alpha(165)] = 79.90$ (4) which agrees well with the

measured value of 79.95 (6) as quoted in 1982RuZV and those of 79.88 (8) given in 1975Wa**.

Measured relative values, to the 165-keV γ line, of the X-ray emission intensities can be compared with the value deduced from the decay scheme data:

X-ray	Dasmahapatra	Kumar	Campbell	Plch	Decay scheme
γ - 165,40	100	100			79,90 (4)
Kα	80,6 (35)	79,39 (111)			
Kβ1	16,10 (69)	14,30 (21)			
Kβ2	4,35 (19)				
K X				79,4 (9)	80,3 (8)
K X/γ			1,010 (25)	0,99 (1)	1,005 (10)

Detailed measured values of the X-ray emissions carried out by 2001Sc08 are also compared with the values deduced from the decay scheme data:

X-ray	E (keV)	Schönfeld (2001Sc08)	Decay scheme
Ll	4,124	0,40 (11)	0,222 (6)
Lη + Lα	4,52 – 4,65	5,86 (5)	5,78 (13)
Lβ1 + Lβ4 + Lβ3	5,04 – 5,14	4,26 (15)	4,21 (9)
Lβ6 + Lβ2 + Lβ5	5,21 – 5,45	1,07 (4)	1,066 (25)
Lγ5 + Lγ1 + Lγ6	5,62 – 5,88	0,538 (18)	0,565 (15)
Lγ2 + Lγ3 + Lγ4	6,06 – 6,25	0,335 (15)	0,340 (9)
Total L X		12,46 (20)	12,19 (18)
Kα2	33,03	23,05 (28)	22,80 (24)
Kα1	33,44	41,96 (50)	41,9 (4)
K'β1	37,72 – 38,07	12,46 (15)	12,47 (18)
K'β2	38,73 – 38,83	3,11 (4)	3,16 (8)
Total K X		80,6 (6)	80,3 (8)

All the X ray intensities are strongly dependant of the adopted P_K value, the comparisons made in the two tables above show a good agreement between the measured values and those deduced from the decay scheme data. This suggests that the adopted decay scheme is consistent.

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^{140}Ba - Comments on evaluation of decay data
by R. G. Helmer

1 Decay Scheme

There are 34 reported levels in ^{140}La below the ß$^-$ decay energy, so some levels in addition to the six reported here may be weakly populated in this decay.

2 Nuclear Data

Q value is from Audi and Wapstra 1995 mass evaluation (1995Au04).

The half-life values available are, in days:

12.80 (5)	1965Si17
12.789 (6)	1971Ba28
12.746 (10)	1982DeYX, replaced by 1983Wa26
12.753 (2)	1982HoZJ, replaced by 1992Un01 and 2002Un02
12.739 (22)	1983Wa26
12.751 (5)	1983Wa26
12.7527 (23)	1992Un01 and 2002Un02
12.753 (4)	Adopted value

The value of 1971Ba28 disagrees with all of the later values, so the evaluator increased its uncertainty from 0.006 to 0.020. In the Limitation of Relative Statistical Weight, LRSW, method (1985ZiZY, 1992Ra09), the uncertainty of 1992Un01 is increased from 0.0023 to 0.0047 to reduce its weight from 81% to 50%. Then, the weighted average is 12.753 days with a σ_{int} of 0.003, a reduced-χ^2 of 1.17, and an σ_{ext} of 0.004; these values are adopted. If the original uncertainty for the 1971Ba28 value is used, the reduced-χ^2 is 10.3.

2.1 b$^-$ Transitions

The probabilities for the β^- branches are from the intensity balances from the γ-ray transitions; this is straightforward because one has a direct measurement of some of the γ-ray emission probabilities (1977De34, 1975Ha50, and 1976Li06). The limits for the very weak β^- branches are:

Level (keV)	Comment
0	This is a nonunique 3rd forbidden transition. The log *ft* systematics of 1998Si17 list only one nonunique 3rd forbidden β^- decay and it has a log *ft* of 17.5. If we assume that this class of decays all have log $ft \geq 15$, the corresponding $I_{\beta-}$ is $\leq 1.10^{-5}$ %.
63	Similarly, this β^- branch is unique 3rd forbidden for which 1973Ra10 lists log *ft* values of 18.1 and 20.9. (The corresponding values in 1998Si17 are the log $f^{3u}t$ values of 20.7 and 21.4.). If we assume that this class has log $ft > 18$, $I_{\beta-}$ is $< 1\ 10^{-8}$ %. The intensity balance from the adopted decay scheme gives 0.00019 % (16). This nonzero value, at the 1σ level, suggests that either (1) the true $P_\gamma(63)$ and $\alpha(63)$ are both at the low end of the 1σ range, or (2) there is a very weak γ ray from either the 467 (an M3 γ) or 581 level (an E4 γ) to the 63 level. Such a γ ray would only need to be about 1% as intense as the weakest γ rays reported in this energy

region.

2.2 g Transitions

The multipolarities are from the adopted γ data in the Nuclear Data Sheets (1994Pe19). Mixing is 0.010% (6) E2 for 13-keV gamma; mixing is less than or equal to 0.008% E2 for 29-keV gamma; mixing is less than or equal to 0.064% E2 for 162 gamma; mixing is less than or equal to 1% E2 for 304-keV gamma.

See sect. 4.2 for comments on the γ-ray and level energies and the normalization of relative photon emission probabilities to absolute values.

3 Atomic Data

The data are from Schönfeld and Janßen (1996Sc06).

3.1 and 3.2

The desired data were computed by RADLST with the Schönfeld atomic data (1996Sc06, 1996ScZX).

4 Emissions

4.1 Electron Emission

Data were computed by the RADLST program, except the average β^- energies are from the LOGFT program.

4.2 Photon Emission

The level energies were computed from a least-squares fit to the measured γ-ray energies, corrected for recoil, which simultaneously includes all of the individual values from 1990Me03, 1982Ad02, 1970Ju04, 1970Ke09 (including values quoted from 1961Ge01), 1969Ka33, and 1966Mo16; plus the 537-keV value from 1979Bo26; and excluding the 30-keV value from 1966Mo16 and all unplaced lines. γ rays of 183 and 275 keV are reported by 1990Me03, but their nuclide assignment was questionable, so they have been omitted. The uncertainties in the deduced level and γ-ray energies include a factor of the square root of the reduced-χ^2 value.

The γ-ray energies from these references are:

1990Me03	1982Ad02	1979Bo26	1970Ke09	1961Ge01	1970Ju04 *	1969Ka33	1966Mo16
	13.85(5)			13.846(15)			
29.961(5) 8	29.955(2)				29.9653(7)		30.45(3)
63.185(6) *							
99.49(2)							
113.514(31)	113.55(3)		113.56(3)	113.54(3)			
118.837(3)	118.905(22)			118.84(3)	118.81 (5)	118.84(12)	119.0(5)
132.687(1)	132.716(14)			132.69(3)	132.68 (3)	132.84(12)	
162.660(1)	162.672(2)	162.369(6) ?			162.656(3)	162.64(5)	163.10(9)
183.83(9)							
275.18(18)							
304.849(3)	304.874(7)		304.840(20)		304.83(3)	304.83(6)	304.82(3)
418.44(4)							
423.722(1)	423.732(4)		423.69(3)	423.70(9)		423.81(8)	423.69(4)
437.575(2)	437.589(9)		437.55(3)	437.50(9)		437.60(3)	437.55(5)
						467.57(5)	
537.261(9)	537.311(3)	537.261(33)	537.250(20)	537.17(10)		537.32(8)	537.38(3)
551.08(4)	551.2(5)						

* from ^{139}La(n,γ)

The reduced-χ^2 = 6.0 for this fit, which implies that the uncertainties are generally too small by a factor of 2.4, or more likely, for some energies the uncertainties are too small by a larger factor. Since a major portion of this reduced -χ^2 value is from the data of 1990Me03, their uncertainties of 0.001 keV were increased to 0.002 keV and the fit repeated. The reduced -χ^2 value was then 5.2 and the χ^2 value is 259. These large values can result from inconsistencies between the values for one γ ray and/or inconsistencies between different γ rays. These cases are illustrated in the following table which shows the conflicts within the values for the 118, 162, and 537 keV, whereas for the 304 - and 423-keV lines, only one values has a large contribution to the χ^2 value. The lines in this table provide 172 to the χ^2 value of 259.

Reference	E_γ [a]	ΔE_γ	final E_γ	δ/σ [b]
1990Me03	118.837 (3)	0.068 (22)	118.849 (4)	-3.9
1982Ad02	118.905 (22)			+2.6
1990Me03	162.660 (2)	0.012 (3)	162.6628 (24)	-1.4
1982Ad02	162.672 (2)	0.016 (4)		+4.6
1970Ju04	162.656 (3)	0.44 (9)		-2.3
1966Mo16	163.10 (9)			+4.9
1990Me03	304.849 (3)	0.025 (8)	304.872 (4)	-7.8
1982Ad02	304.874 (7)			+0.2
1990Me03	423.722 (2)	0.010 (4)	423.721 (4)	+0.6
1982Ad02	423.732 (4)			+2.8
1990Me03	537.261 (9)	0.050 (10)	537.303 (6)	-4.7
1982Ad02	537.311 (3)			+2.6

[a] Difference between the E_γ on the line and the one on the next line.
[b] δ is (E_γ - final E_γ) and s is the uncertainty in E_γ.

This method of analysis does not give an average value for each individual line from the data for that line. Rather, the final γ-ray energies are computed from the deduced level energies, corrected for recoil. This also means that precise energies are obtained for some γ rays for which no precise measuremenrs have been made.

The adopted energies are: 13.849 (4), 29.9656 (15), 63.184 (13), 99.479 (13), 113.582 (7), 118.849 (4), 132.6972 (25), 162.6628 (24), 304.872 (4), 423.721 (4), 437.569 (3), 537.303 (6), and 551.152 (8) keV.

For the relative γ-ray emission probabilities, the following data were used. Many values have been scaled from their original normalizations. All the values of 1966Mo16 are omitted since they do not have uncertainties. Several lines from 1969Ka33 are not included here because they have not been reported again; these are at 144, 177, 498, 512, 602, 637, and 661 keV. The weighted averages from the LRSW method have been adopted.

γ-ray energy (keV	1991Ch05	1990Me03	1982Ad02	1977Ge12	1977De34	1976Li06	1975Ha50	1970Ke09	1969Ka33	Adopted
L x	54.1(22)		32(6)							53 (7)
13.8	4.69(12)	5.0(7)	4.9(6)						7.2(25)	4.71(12)
29.9	58.4(10)	61.0(40)	60(3)					55(8)	72(12)	58.7(9)
K a	6.10(18)		6.5(5)						10.0(20)	6.4 (5)
K ß	1.47(7)		1.60(15)						<2.0(3)	1.49 (6)
43.8	0.054(7)		<0.007					<0.005		
63.1		0.00012(6)								0.00012(6)
99.4		0.00008(5)								0.00008(5)
113.6	0.072(6)	0.066(5)	0.077(16)					0.074(8)		0.070(3)
118.9	0.25(1)	0.250(3)	0.27(3)				1.56(16)	0.28(3)	0.21(2)	0.248(7)
132.7	0.81(2)	0.83(2)	0.90(8)				2.14(31)	0.84(5)	0.83(7)	0.824(13)
162.7	25.3(3)	25.45(29)	28.0(8)	26.4(8)	25.5(3)	25.9(7)	27.6(16)	25.1(10)	28.4(9)	25.65 (26)
304.9	17.54(15)	17.6(2)	17.8(5)	17.67(18)	17.63(21)	18.5(7)	17.9(19)	17.2(7)	17.3(7)	17.61(9)
418.4		0.015(1)	<0.04							
423.7	12.65(12)	12.7(1)	12.8(5)	12.73(14)	12.92(16)	13.0(6)	14.8(12)	12.7(5)	12.8(6)	12.74(6)
437.6	7.91980	7.91(4)	7.80(25)	7.82(9)	7.91(16)	8.5(5)	8.9(4)	7.8(3)	7.8(4)	7.90(4)
467.7	0.29(3)	<0.002	<0.01							
537.3	100(1)	100.0(3)	100(-)	100.0(10)	100.0(9)	100.0(23)	100.0(23)	100.0(20)	100	100.0
551.2	0.028(4)	0.0128(8)	0.027(9)							0.020 (8)
848.9			0.02							

For the lines at 43.8 and 467 keV, there are limits that are much lower than the other reported values, so they are not included in the decay scheme. Other lines that are not adopted are 418 and 848 for which only one value has been reported.

These relative emission probabilities have been scaled by **0.2439 (22)** to obtain absolute values based on the measured γ-emission rates for five lines and the source activity by 1977De34. Other normalization factors are 0.257 (6) (1975Ha50) and 0.236 (5) (1976Li06) where both were determined for the 1596 line from ^{140}La decay. The discrepancy between the latter two values is 9% and may result from difficulties in determining the γ efficiency at 1596 keV where there is a dearth of efficiency calibration lines. If the three values are averaged, the weighted mean is dominated by the 1977De34 value and is 0.2442 with σ_{int}=0.0019 and σ_{ext}=0.0036.

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^{140}La - Comments on evaluation of decay data
by R. G. Helmer

1 Decay scheme

There are many levels in ^{140}Ce below the β^- decay energy of 3762 keV that are not reported in these decay data, so some other levels may be weakly populated. However, all of the known levels (1994Pe19) below 2600 keV are populated in this decay.

If the γ rays from the decay of ^{140}La are used to determine the amount of ^{140}Ba that is present in a sample, a correction must be made for the fact that their decay rates are different. After they have come into "equilibrium," the ^{140}La decay rate is larger by a factor of
$T_{1/2}(^{140}Ba) / [T_{1/2}(^{140}Ba - T_{1/2}(^{140}La)] = 1.1516$ (7), so the deduced amount of ^{140}Ba should be divided by 1.1516.

The J^π are from the ^{140}Ce Adopted Levels of the Nuclear Data Sheets (1994Pe19).

2 Nuclear Data

Q value is from Audi and Wapstra 1995 mass evaluation (1995Au04).

The half-life values available are, in hours:

40.224 (20)	1954Ki08	
40.31 (6)	1954Ya02	
40.27 (5)	1957Pe09	
40 (2)	1960Wi10	
40.23 (3)	1965Si17	
40.2 (2)	1967Ka12	
40.2 (2)	1968Re04	
40.272 (7)	1977DeYO,	superseded by 1983Wa26
40.232 (67)	1978Da21	
40.280 (6)	1980Ho17	
40.295 (5)	1980Ol03	
40.279 (17)	1982HoZJ,	superseded by 1992Un01
40.270 (29)	1983Wa26	
40.284 (5)	1989Ab18	
40.293 (12)	1992Un01 and 2002Un02	
40.34 (4)	2002Ad02	
40.284 (4)	Weighted average, adopted	

The adopted value of 40.284 (4) hours, or 1.67850 (17) days, is the weighted average of the fourteen unsuperseded values, the internal uncertainty is 0.0027, and the reduced-χ^2 is 1.88.

2.1 b$^-$ Transitions

The level energies used to compute the β^- transition energies are from a least-squares fit to the γ-ray energies.

The probabilities for the β^- branches are from the balances from the γ-ray transition probabilities at each level.

The β^- branches to the levels at 0, 1903, and 2107 keV are nonunique 3rd forbidden. The log *ft* systematics of 1998Si17 give only one value, 17.5, for this class of β decays. From the data of 1998Si17, it is reasonable to assume a lower limit of log *ft* > 15 for this class. The corresponding $I_{\beta-}$ limits are then $< 1. \times 10^{-4}$ % ; $< 1. \times 10^{-5}$ %, ; and $< 1. \times 10^{-5}$ %, respectively. Although there have been many analyses of the β^- spectrum, only 1966Dz05 has reported a branch to the ground state. Their intensity of 5×10^{-5} % (2) is compatible with the limit from the log *ft* systematics; however, since others have not seen this branch, this value is assumed to be too large. In any case, the value is negligible in determining the normalization of the γ-ray emission probabilities. These three $I_{\beta-}$ are all set to zero in this scheme.

The average β^- energies and the log *ft*'s are from the LOGFT program.

2.2 Gamma Transitions and Internal Conversion Coefficients

The multipolarities and mixing ratios are from the Adopted γ data in the Nuclear Data Sheets (1994Pe19). For the 131-keV : M1 + 1.7% (+14-5) E2 ; 241-keV : M1 + 0.2% (+8-2)E2 ; 266-keV : M1 + 99.8% (+2-5) E2 ; 328-keV : M1 + 0.24% (6) E2 ; 751-keV : M1 + 11.5% (17) E2 ; 815-keV : M1 + 0.005% (+20-5) E2; 867-keV : E1 + 0.16% (+20-12) M2 ; 925-keV : M1 + 1.0% (+9-6) E2.
See sect. 4.2 for comments on normalization of relative photon emission probabilities to absolute values.

3 Atomic data

3.1 Fluorescence yields

The data are from Schönfeld and Janßen (1996Sc06).

3.2 X-ray radiations

Relative emission probabilities are from Schönfeld and Janßen (1996ScZX).

4 Radiations

4.1 Electron Emission

The conversion electron data were computed from the internal-conversion coefficients interpolated from the tables of Rösel (1978Ro21) and of Band (1976Ba63) and the multipolarities are from the evaluation of 1994Pe19. The adopted internal pair coefficient for the 1596 -keV γ ray is 0.000106 (1) deduced from the measured value of $\alpha(\text{pair})/\alpha_K = 0.156$ (15) from 1968Be57; the theoretical value is 0.000115 (1979Sc31).

4.2 Photon Emissions

The γ-ray energies were determined from the reported values in Table 1. All of these 197 energies were entered into a simultaneous least-squares fit to determine the energies of the 18 excited levels. The possible γ rays at 936 and 2533 keV, which were reported only once, are not included in the adopted decay scheme or the list of γ rays. The adopted γ-ray energies were then computed from the differences between these level energies, with the corrections for recoil. As a result, the consistency of the several values for a single γ ray is not determined, but the consistency of the whole set is determined. For this fit, the reduced-χ^2 value is 1.07 indicating that the input uncertainties are quite reasonable. This method occasionally produces γ-ray energy uncertainties that are much smaller than would be determined from the measurements for that γ ray alone.

The relative γ-ray intensities were determined from the data in Table 2. Several of these sets of data were published as emission probabilities and have been scaled by the evaluator to obtain values relative to the 1596-keV γ ray. The Limitation of Relative Statistical Weight method, as implemented in the LWEIGHT program, was used to compute the average values. In this calculation, if a particular value contributes more than 50% of the relative weight and the initial fit has a reduced-χ^2 of more than the critical reduced-χ^2 for the number of input values, the uncertainty of the most precise value is increase to reduce its relative weight to 50%. The critical reduced-χ^2 values are: 6.6 for 2 input values; 4.6 for 3; 3.8 for 4; 3.3 for 5; 3.0 for 6; 2.5 for 9; 2.4 for 10; 2.3 for 11; and 2.2 for 12 or 13. Some values have been deleted from the averaging, as indicated in the table and the evaluator has arbitrarily increased a few input uncertainties.

At the time many of these measurements were made, there was a lack of good Ge-detector efficiency calibration standards in the region of 1596 keV. Therefore, the evaluator has introduced an energy-dependent scaling factor based on the emission probabilities from 1977De34 for thirteen lines from 266 to 2521 keV. This factor, which is shown in Table 2 and varies by 3%, corrects for this assumed systematic deviation of the Ge detector efficiencies. The total γ-ray feeding of the ground state is set to 100%, with no direct β^- decay, to obtain a normalization factor of 0.9540 (8) to convert these relative γ emission probabilities to absolute probabilities as given in the last column of Table 2.

Table 1. Measured g-ray energy values

1964Re09	1967Ka12	1968Ba18	1968Gu05	1970Ka18	1970Ke06	1972GeZG	1978Ar28	1979Bo26	1980Ka32	1982Ad02	Adopted
	24.595(4)										24.595(4)
	64.130(7)	64.135(10)									64.129(4)
	68.916(6)	69.0(3)									68.923(5)
	109.417(6)	109.418(7)				109.47(20)				109.422(11)	109.417(4)
	131.122(8)	131.121(8)				131.15 (20)			130.97(20)	131.117(8)	131.121(4)
	173.550(11)	173.536(12)				173.50(20)			173.49(17)	173.543(9)	173.546(5)
241.97(3)	241.961(22)	241.966(12)				241.90(8)	241.88(10)		242.06(9)	241.933(30)	241.959(6)
266.52(6)	266.547(22)	266.551(14)				266.61(6)	266.58(10)		266.67(7)	266.543(12)	266.554(5)
		306.9(2)				306.5(4)			307.1(2)	306.9(2)	307.08(4)
328.789(15)		328.768(12)	328.752(30)		328.745(15)	328.76(5)	328.80(10)	328.746(25)	328.78(5)	328.762(8)	328.761(4)
	397.8(3)	397.79(11)				397.66(10)			397.8(1)	397.52(5)	397.674(6)
432.55(8)	432.62(6)	432.530(29)			432.490(20)	432.52(4)	432.51(10)		432.66(4)	432.493(12)	432.513(8)
				438.5 (4)					438(1)	438.5(5)	438.178(6)
									445(1)	445.5(5)	444.57(4)
487.027(24)	487.042(29)	487.029(19)	487.032(30)		486.995(30)	487.009(30)	487.09(10)	487.15(25)	486.99(3)	487.021(12)	487.022(6)
		618.2(7)				617.7(3)			618.2(1)	618.12(5)	618.12(4)
752.42(33)	751.75(8)	751.83(8)				751.655(35)	751.66(10)		751.65(4)	751.637(18)	751.653(7)
815.82(10)	815.85(7)	815.80(9)			815.735(40)	815.775(30)	815.80(10)		815.78(4)	815.772(19)	815.781(6)
867.9(5)	867.87(15)	867.82(14)				867.842(35)	867.85(10)		867.80(4)	867.856(20)	867.839(16)
	919.63(15)	919.5(2)				919.54(4)	919.63(10)		919.48(6)	919.550(23)	919.533(10)
924.1(6)	925.24(9)	925.20(17)				925.188(35)	925.21(10)		925.14(6)	925.189(21)	925.198(7)

				936.9(4)							none
	950.9(3)	951.1(4)		951.4(4)		951.00(6)			950.95(6)	950.987(26)	950.988(20)
										992.9(5)	992.64(18)
						1045.2(3)			1045.0(1)	1045.05(24)	1045.02(9)
						1097.2(3)			1097.2(2)	1097.20(23)	1097.58(9)
									1303.3(1)	1303.5(4)	1303.34(7)
						1404.5(2)			1404.9(2)	1405.20(17)	1404.66(9)
1596.34(25)	1596.49(24)	1596/6(2)	1596.20(4)		1596.170(25)	1596.17(6)	1596.22(10)		1596.17(6)	1596.210(35)	1596.203(13)
										1877.29(19)	1877.33 (18)
	1903.15(30)								1903 (1)		1903.28(4)
						1924.2(3)			1924.4(1)	1924.62(13)	1924.5 (2)
									2082.9(2)	2083.2(5)	2083.219(14)
	2348.1(7)	2348.8 (6)				2347.80(6)			2347.82(6)	2347.88(5)	2347.847(14)
				2465.3(8)					2464.0(1)	2464.1(5)	2464.031(20)
2519.7(34)	2521.7(5)	2522.2(4)				2521.32(6)	2522.03(10)		2521.36(6)	2521.40(5)	2521.390(14)
				2533.4(7)							none
	2547.1(8)	2548.6(8)		2547.5(6)		2547.14(6)			2547.19(7)	2547.34(11)	2547.180(23)
	2900(2)	2899.7(5)		2899.7(8)		2899.5(2)			2899.5(2)	2899.61(16)	2899.53(7)
	3119(2)	3118.3(7)		3119.0(8)		3118.52(15)			3118.4(2)	3118.51(16)	3118.49(10)
	3322(4)	3319.7(25)		3319.6(9)		3319.4(6)			3319.3(3)	3320.4(6)	3319.52(24)

Table 2. Measured relative g-ray emission probabilities – Part 1 : references from 1962 to 1975

E_γ	1962Ha14	1967Ka12	1968Ba18	1969KuZV	1970Ka18	1974HeYW	1975Ha50
K_α					2.4 (7)		
K_β					0.36 (8)		
64					~ 0.01		
68			0.065 (13)		0.064 (16)		
109		0.50 (20)	0.27 (4)	0.23 (2)	0.210 (15)	0.17 (4)	0.20 (4)
131		1.05 (15)	0.61 (9)	0.47 (3)	0.50 (3)	0.42 (5)	0.58 (4)
173			0.13 (5)		0.130 (20)	0.60 (20)	
241		0.83 (10)	0.45 (6)	0.58 (6)	0.410 (30)	0.51 (8)	0.66 (3)
266		0.83 (10)	0.56 (6)	0.53 (4)	0.490 (30) @	0.50 (5)	0.34 (3)
307			0.022 (11)		0.035 (17)		
328		25.4 (20)	21.4 (11)	22.4 (4)	19.4 (1) @	19.6 (13)	18.8 (5)
397			0.054 (25)		0.110 (35)	0.12 (3)	
432		3.5 (3)	3.11 (16)	3.06 (9)	2.85 (15)	2.94 (20)	3.0 (2)
438					0.021 (10)		
444					~ 0.25		
487		49.6 (32)	49.4 (25)	48.2 (5)	45.0 (2) @	44.7 (30)	39.7 (5)
618		0.4 (3)	0.044 (22)		~ 0.045		
751		4.5 (4)	4.40 (22)	4.66 (23)	4.40 (20)	4.5 (3)	4.9 (2)
815		23.5 (20)	24.1 (12)	24.9 (2)	23.5 (7)	24.2 (15)	26.8 (11)

867		5.6 (5)	5.64 (28)	5.91 (24)	5.60 (30)	5.7 (3)	6.5 (1)
919		2.5 (6)	2.73 (16)	2.59 (10)	2.64 (16)	2.89 (20)	3.4 (2)
925		6.8 (6)	7.24 (43)	6.94 (21)	7.10 (30)	7.2 (4)	7.9 (3)
950		0.8 (3)	0.56 (5)	0.62 (9)	0.550 (30)	0.56 (4)	
992							
1045							
1097							
1303							
1405							
1596	100.	100.	100.	100.	100.	100.	100.
1877						0.05 (2)	
1924						0.023 (5)	
2083							
2347	0.86 (17)	1.0 (2)	0.901 (45)	0.85 (6)	0.90 (6)	0.89 (6)	
2464					0.0018 (6) #		
2521	3.0 (6)	3.5 (2)	3.52 (18)	3.37 (10)	3.60 (18)	3.59 (18)	4.9 (4)
2547		0.11 (2)	0.122 (9)		0.110 (7)	0.110 (6)	
2899	0.082 (17)	0.060 (10)	0.070 (5)		0.065 (6)	0.073 (8)	
3118	0.035 (10)	0.030 (10)	0.027 (3)		0.027 (4)	0.028 (3)	
3320			0.008 (4)		0.0047 (15)	0.050 (3)	

Table 2. Measured relative g-ray emission probabilities – Part 2 : references from 1976 to 1991

E_γ (keV)	1976Li06	1977De34	1977Ge12	1978Ar28	1980Ka32	1982Ad02	1991Ch05	Wtd. Avg.	reduced χ^2	scaling factor	Adopted	Emission probability (%)
K_α						1.77 (6)	1.72 (4)	1.74 (3)		1.027	1.79 (3)	1.71 (3)
K_β						0.45 (2)	0.395 (14)	0.406 (16)	2.8	1.027	0.417 (16)	0.398 (15)
64						0.011 (4)	0.015 (2)	0.0142 (18)		1.027	0.146 (18)	0.139 (17)
68					0.070 (16)	0.080 (6)	0.079 (2)	0.0785 (19)		1.027	0.0806 (19)	0.0769 (18)
109	0.20 (9)				0.170 (10) @	0.220 (10)	0.230 (4)	0.221 (6)	1.9	1.027	0.227 (6)	0.217 (6)
131	0.46 (9)				0.44 (1) @	0.48 (3)	0.49 (1) *	0.479 (15)	2.9	1.027	0.492 (15)	0.469 (14)
173					0.120 (10)	0.110 (10)	0.133 (4)	0.129 (5)	2.2	1.027	0.132 (5)	0.126 (5)
241	0.52 (18)	0.6 (1)		0.51 (9)	0.450 (10)	0.460 (30)	0.434 (8) *	0.445 (10)	2.7	1.027	0.457 (10)	0.436 (10)
266	0.53 (6)	0.7 (1)		0.50 (3)	0.520 (10)	0.500 (30)	0.488 (8)	0.502 (9)	2.3	1.027	0.516 (19)	0.492 (9)
307					0.022 (6)	0.020 (5)	0.026 (7)	0.022 (3)		1.027	0.023 (3)	0.022 (3)
328	21.2 (6)	22 (2)	21.46 (22)	21.5 (6)	21.5 (4)	21.7 (4)	21.1 (3)	21.2 (3)	5.0	1.027	21.8 (3)	20.8 (3)
397					0.078 (3)	0.070 (5)	0.077 (5)	0.0763(24)	1.15	1.027	0.0784 (25)	0.0748 (24)
432	3.0 (4)	3.5 (2)	3.08 (3)	2.96 (16)	3.05 (3)	2.97 (15)	3.04 (3)	3.056 (17)	1.01	1.027	3.139 (17)	2.995 (16)
438					0.006 (3) *	<0.0014	0.041 (10)	0.0 18 (10)	4.1	1.027	0.018 (10)	0.017 (10)
444					0.005 (3)	0.0036 (12)	0.003 (1)	0.0034 7)		1.027	0.0035 (7)	0.0033 (7)
487	46.2 (11)	47 (2)	47.7 (5)	47.3 (9)	46.6 (9)	46.4 (8)	47.7 (6)	47.0 (4)	2.6	1.027	48.3 (4)	46.1 (4)
618					0.049 (6)	0.014 (3) #	0.039 (4)	0.042 (3)	1.12	1.015	0.043 (3)	0.041 (3)
751	4.40 (17)	4.6 (1)	4.65 (5)	4.37 (22)	4.45 (5)	4.36 (16)	4.54 (4)	4.536 (25)	1.10	1.015	4.604 (25)	4.392 (24)

815	23.8 (6)	24.2 (4)	24.85 (25)	24.1 (5)	24.0 (4)	23.5 (7)	24.4 (2)	24.49 (13)	1.43	1.015	24.86 (13)	23.72 (12)
867	6.0 (5)	5.8 (3)	5.90 (6)	5.69 (10	5.69 (6)	5.56 (19)	5.77 (7)	5.77 (3)		1.015	5.85 (3)	5.58 (3)
919	3.1 (4)	2.6 (2)	2.91 (4)	2.57 (14)	2.83 (4)	2.80 (9)	2.79 (3)	2.812 (24)	1.65	1.015	2.862 (24)	2.730 (23)
925	7.3 (8)	7.2 (3)	7.42 (8)	7.25 (16)	7.26 (8)	7.10 (21)	7.23 (7)	7.27 (4)		1.015	7.38 (4)	7.04 (4)
950	0.63 (12)	0.67 (6)			0.553 (7)	0.56 (3)	0.544 (7)	0.549 (5)		1.015	0.557 (5)	0.531 (5)
992						0.009 (3)	0.014 (5)	0.0103 (26)		1.015	0.0105 (26)	0.0100 (25)
1045					0.024 (4)	0.016 (4)	0.026 (15)	0.0202 (29)	1.08	1.015	0.021 (3)	0.020 (3)
1097					0.024 (5)	0.022 (5)	0.024 (5)	0.0233 (29)		1.015	0.024 (3)	0.023 (3)
1303					0.046 (6)	0.050 (7)	0.044 (7)	0.047 (4)		1.000	0.047 (4)	0.045 (4)
1405					0.066 (9)	0.068 (8)	0.062 (7)	0.065 (5)		1.000	0.065 (5)	0.062 (5)
1596	100.0	100.0 (3)	100 (1)	100.0 (3)	100.0	100.	100.0 (15)	100.0		1.000	100.0	95.40 (8)
1877						0.042 (6)	0.043 (4)	0.043 (3)		1.000	0.043 (3)	0.041 (3)
1924					0.014 (3)	0.006 (2)	0.014 (2)	0.0115 (28)	5.0	1.000	0.012 (3)	0.011 (3)
2083					0.045 (3)	0.007 (2) #	0.031 (2)	0.038 (7)	11	1.000	0.038 (7)	0.036 (7)
2347		0.90 (4)	0.891 (16)		0.89 (1)	0.89 (3)	0.89 (3)	0.890 (7)		0.996	0.886 (7)	0.845 (7)
2464					0.012 (1)	0.008 (1)	0.012 (2)	0.0102 (14)	4.4	0.996	0.0102 (14)	0.0097 (13)
2521		3.5 (2)	3.62 (7)	3.65 (18)	3.58 (5)	3.61 (9)	3.63 (4)	3.591 (25)		0.996	3.577 (25)	3.412 (24)
2547			0.109 (3)		0.105 (2)	0.109 (5)	0.106 (3)	0.1070 (13)		0.996	0.1066 (13)	0.1017 (12)
2899			0.069 (1)		0.070 (1)	0.069 (3)	0.070 (2)	0.0695 (6)		0.996	0.0692 (6)	0.0660 (6)
3118			0.027 (1)		0.027 (1)	0.028 (2)	0.026 (1)	0.0269 (5)		0.996	0.0268 (5)	0.0256 (5)
3320					0.0040 (3)	0.0045 (4)	0.0040 (3)	0.00413 (19)		0.996	0.00411 (19)	0.00392 (18)

Comments on Table 2 :

* Uncertainties were increased in LRSW analysis to reduce relative weight to 50%; this change is only made if the reduced-χ^2 is greater than the associated critical value. These changes were: 131 keV, 1991Ch05 0.010 to 0.012; 241, 1991Ch05 0.008 to 0.0087; and 438 keV, 1980Ka32 0.003 to 0.007.

@ Uncertainties were increased by evaluator due to large deviation from average. These changes were: 109 keV, 1980Ka32 0.01 to 0.02; 131, 1980Ka32 0.01 to 0.02; 266, 1970Ka18 0.03 to 0.06; 328, 1970Ka18 0.1 to 0.3; and 487, 1970Ka18 0.2 to 0.5.

$^{\#}$ Deleted from calculation.

The K x-ray intensities are from the measured data.

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^{141}Ce - Comments on evaluation of decay data
by E. Schönfeld and V.P. Chechev

This evaluation was completed in 1998; it has been updated in February 2012. The literature available by this latter date has been included.

1. Decay Scheme and Decay Energy

^{141}Ce decay scheme is complete as there are no other excited levels of ^{141}Pr below the decay energy Q^-, except for the 7/2+ single level with an energy of 145.443 keV (2001Tu02).
Q^- value has been taken from the atomic mass adjustment by Audi and Wang (2012Au06).

2. Half-Life

The following values of the ^{141}Ce half-life presented in Table 1 were considered here:

Table 1. Results of ^{141}Ce half-life measurements (in days)

Reference	Author(s)	Value	Comments
1949Wa23	Walker	32.11 (23)	Omitted; uncertainty strongly underestimated in an unknown amount
1950Fr58	Freedman and Engelkemeir	**32.50 (20)**	
1957Ke26	Ketelle and Brozi	32.51 (2)	Omitted; uncertainty strongly underestimated in an unknown amount
1965An07	Anspach *et al.*	32.550 (7)	Omitted; superseded in 1992Un01
1967Ob01	O'Brien and Eldridge	32.38 (2)	Omitted; uncertainty strongly underestimated in an unknown amount
1971Ba28	S. Baba and H. Baba	**32.60 (20)**	
1971De11	Debertin	32.51 (6)	Omitted; superseded in 1983Wa26
1972Em01	Emery *et al.*	**32.45 (13)**	
1973MeYE	Merritt and Taylor	32.51 (6)	Omitted; superseded in 1980RuZY
1976Va30	Vaninbroukx and Grosse	**32.501 (13)**	
1980RuZY	Rutledge *et al.*	**32.50 (3)**	
1983Wa26	Walz *et al.*	**32.51 (10)**	
1992Un01	Unterweger *et al.*	32.510 (24)	Omitted; superseded in 2002Un02
2002Un02	Unterweger	**32.510 (24)**	

From the seven values (in boldface) used in the data analysis, the LWEIGHT computer program has consistently identified two outliers (1971Ba28 and 1972Em01), and deduced a weighted mean (32.503) and an internal uncertainty (0.011) with χ^2/ν = 0.03. This result suggests that the uncertainties had been overestimated.

The recommended value for the ^{141}Ce half-life is **32.503 (11) days**.

3. β^- Transitions

The energy of the $\beta^-_{0,1}$ - transition has been deduced from the Q^- value and the 145 keV ^{141}Pr level energy.
The emission probability of the $\beta^-_{0,1}$ - transition is equal to $P_{\gamma+ce}$ for the 145 keV gamma-ray transition.
The probability of feeding the ground state was deduced from the relation $1-P(\beta^-_{0,1})$.

4. Gamma-Ray Transition

The energy was taken from the recommended data by Helmer and van der Leun (2000He14).
The emission probability $P_{\gamma+ce}$ was deduced using the relation $P_{\gamma+ce} = P_\gamma\ (1 + \alpha_T)$. (For P_γ see Section 7.2).
The multipolarity (M1+E2) is based on the measurements of conversion electrons of 1961Co04, 1961Ne12, 1965Ge04, 1966Di02, 1966Pa09, 1968Ge02, 1972Ca07, 1975Le09, 1979Ha09, 1992Sc24.
The E2/M1 mixing ratio δ = 0.068 (5) is a weighted average of measurements from 1962Sc11 (0.068 (8)), 1963Ha07 (0.066 (22)) and 1979Ha21 (0.069 (7)).
The internal conversion coefficients (ICC) α_T , α_K , α_L , α_L , α_M , α_N , α_O , α_P and their associated uncertainties were interpolated from theoretical values of Band *et al.* (2002Ba85) using the BrIcc computer program (2008Ki07) for the “frozen orbital” approximation, version 2.3S.

The values of the total conversion coefficient α_T , measured and deduced (1966 - 1992); are presented below. A value for the total conversion coefficient of the 145 keV gamma transition was obtained from special coincidence measurements by Hansen *et al.* (1979Ha09) and Schönfeld *et al.* (1992Sc24). Another useful quantity used by them was the measured ratio of the emission probabilities of KX rays and the 145-keV gamma ray.

Total conversion coefficient α_T

1966Di02	0.440 (11)	Dingus *et al.*	deduced from α_K
1966Pa09	0.441 (9)	Pancholi	deduced from α_K
1975Le09	0.421 (21)	Legrand *et al.*	measured
1979Ha09	0.439 (13)	Hansen *et al.*	measured
1979Ha09	0.448 (7)	Hansen *et al.*	deduced from X_K/γ ratio
1979Ha09	0.436 (17)	Hansen *et al.*	coinc. meas., extrapol. technique
1992Sc24	0.452 (8)	Schönfeld *et al.*	coinc. meas., special technique
1992Sc24	0.435 (7)	Schönfeld *et al.*	deduced from X_K/γ ratio
	0.449 (7)	**Present evaluation** (BrIcc)	

5. Atomic Data

The fluorescence yields, X-ray energies and relative emission probabilities, and Auger electron energies and relative emission probabilities based on data in 1996Sc06 and 1977La19 are from the SAISINUC computer program.

6. Electron Emissions

The energies of the conversion electrons were obtained from the gamma-ray transition energy and the atomic electron binding energies in 1977La19.

The emission probabilities of the conversion electrons were deduced using the evaluated P(γ) and internal conversion coefficient values for the various atomic shells.

The total absolute emission probabilities of K and L Auger electrons were calculated using the EMISSION computer program (1996Sc06, 2000Sc47).

7. Photon Emissions

7.1 X - Ray emissions

The Pr KX- and LX- absolute emission probabilities given in the Tables Section (Table 5.1) were deduced using the computer program EMISSION. Measured values of P_{X_K} / P_γ are compared with a value of 0.350 (6), which was deduced using the computer program EMISSION.

0.338 (5)	Nemet (1961Ne12)
0.347 (12)	Nemet (1961Ne12)
0.342 (9)	Campbell *et al.* (1971Ca49)
0.334 (9)	Campbell and Mc Nelles (1972Ca07)
0.349 (5)	Hansen *et al.* (1979Ha09)
0.339 (5)	Schönfeld *et al.* (1992Sc24)
0.350 (6)	**Present evaluation**

The recommended value in the present evaluation is in good agreement with the experimental results, especially with the value from 1979Ha09.

7.2 Gamma-Ray Emission

The recommended 145 keV gamma-ray absolute emission probability is the weighted mean of 4 values (2, 3, 4, 6). The following values (based on absolute activity determinations) were considered:

1	0.493 (6)	Eldridge	1966El09
2	0.4844 (41)	Legrand *et al.*	1975Le09
3	0.482 (3)	Hansen *et al.*	1979Ha09
4	0.485 (4)	Rutledge *et al.*	1980RuZY
5	0.489 (4)	Schötzig *et al.*	1980Sc07
6	0.480 (5)	Schönfeld *et al.*	1992Sc24
	0.4829 (19)	LWM (2, 3, 4, 6) recommended value. $\chi^2/\nu = 0.28$.	

Value 1 was not used when calculating the average because the uncertainty seems to be underestimated by an unknown amount. Value 5 was also not used because it is considered to be superseded by value 6. The remaining 4 values were used to calculate a weighted mean. (The uncertainty of value 2 is stated to be 3 σ but is has been assumed here to be 1 σ as this seems to be more realistic and comparable to the other values).

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^{147}Nd - Comments on evaluation of decay data
by V. Chisté and M. M. Bé

This evaluation was completed in March 2011, including all publications by this date.

1 Decay Scheme

^{147}Nd disintegrates 100 % by beta minus emissions to excited levels of ^{147}Pm. If a transition to the ground state level exists, it is less than 0.15 % (1971Na11, 1966Be09).

A good agreement was found between the effective Q value (890 (60) keV) calculated from the decay scheme data and the adopted and recommended value from the mass adjustment of Audi (20012Au06), confirming the consistency of the adopted decay scheme.

2 Nuclear Data

The Q^- value is from the atomic mass evaluation of Audi *et al.* (2009AuZZ).

Experimental ^{147}Nd half-life values (in days) are given in Table 1:

Table 1: Experimental values of ^{147}Nd half-life.

Reference	Experimental value (d)	Comments
W. Bothe (1946Bo25)	11.1 (2)	
W. S. Emmerich (1951Em23)	11.1 (5)	
E. Kondaiah (1951Ko01)	11.6 (3)	
J. A. Marinsky (1951Ma**)	11.0 (3)	
W. C. Rutledge (1952Ru10)	11.9 (3)	Outlier
H. W. Wright (1957Wr37)	11.06 (4)	
R. G. Wille (1960Wi10)	11.5 (5)	
D. C. Hoffman (1963Ho15)	11.02 (5)	
S. Baba (1971Ba28)	10.98 (1)	
Recommended value	**10.987 (11)**	$\chi^2 = 1.4$

A weighted average has been calculated using LWEIGHT computer program (version 3). The Rutledge value (1952Ru10) has been shown to be outlier, based on the Chauvenet's criterion and thus was omitted in the final calculation. The largest contribution to the weighted average comes from the value of S. Baba (1971Ba28), with a statistical weight of 90 %.

The adopted value is the weighted average of 10.987 d with an external uncertainty of 0.011 d. The reduced-χ^2 value is 1.4.

2.1 β- Transitions

The maximum energies of the β^- transitions in the decay of ^{147}Nd → ^{147}Pm have been obtained from the Q^- value (2009AuZZ) and the level energies given in Table 2 from N. Nica (2009Ni02).

Table 2: ^{147}Pm levels populated in the decay of ^{147}Nd and the adopted β^- transition probabilities.

Level Number	Level energy, (keV) [µ]	Spin and Parity [a]	Half-life [*]	Adopted $P_{\beta-}$ (%)
0	0	$7/2^+$		0 (5)
1	91.1049 (20)	$5/2^+$	2.50 (5) ns	81 (5)
2	408.54 (5)	$9/2^+$		
3	410.512 (13)	$3/2^+$	0.139 (14) ps	0.715 (34)
4	489.255 (16)	$7/2^+$		0.781 (15)
5	531.012 (15)	$5/2^+$	0.083 (15) ns	14.6 (9)
6	632.93 (7)	$1/2^+$		0.0190 (27)
7	641.27 (8) [µ]			
8	649.03 (4)	$11/2^-$	27 (3) ns	0.258 (19)
9	680.44 (4)	$7/2^+$		0.0897 (28)
10	685.890 (15)	$5/2^+$	0.25 (10) ns	2.184 (16)

[*] Given by N. Nica (2009Ni02).

[a] Given by N. Coursol et al. (1987Table).

[µ] Not used in this evaluation. No direct experimental evidences for this level, only speculative propositions: an unobservable weak β transition of ^{147}Nd decay (1997Sa53) or one 573-kev γ-ray transition (^{148}Nd(2p,nγ)^{147}Pm), 1977Ko24) that populated it.

The adopted β^- transition probabilities and the associated uncertainties (Table 2) were deduced from the γ transition probability balance at each level of the decay scheme.

For the ground state level, the adopted β^- transition probability of 0 (5) % is in agreement with the experimental values of < 0.15 % (1966Be09, 1971Na11) and < 0.25 % (1962Sh02).

The values of log ft and average β^- energies have been calculated with the program LOGFT for all β^- transitions.

2.2 γ Transitions

The γ-ray transition probabilities were calculated using the γ-ray emission intensities and the relevant internal conversion coefficients (see **5.2 γ Emissions**).

For all γ transitions, the internal conversion coefficients (ICC) and the associated uncertainties were interpolated from theoretical values of I. M. Band et al. (2002Ba85) using the BrIcc computer program (2008Ki07) for the “frozen orbital” approximation.

For multipolarities and mixing ratios, the evaluators used:

1) Multipolarities of γ-ray transitions listed in the Table 3 are from N. Nica (2009Ni02).

Table 3: Multipolarities of γ-ray transitions.

	Multipolarity	E_γ (keV)
^{147}Pm	[M2]	31.3 (2)
	[E2]	53.1 (2), 541.83 (7)
	[E3]	36.75 (10)
	[M1,E2]	80.82 (27), 149.3 (2), 154.7 (2), 191.0 (3), 589.35 (4), 680.52 (15)
	M2	159.7 (2), 649.04 (8)
	E1	240.5 (2)
	E2	410.48 (3)
	E3	117.95 (8)

	Multiplicity	E_γ (keV)
	M1 + E2	196.64 (4), $|\delta|$ = 0.20 (8) (1977Al34) 271.87 (6), $|\delta|$ = 0.10 (3) (1979Se05) 408.52 (6), $|\delta|$ = 0.57 (3)

2) For other γ-ray transitions, the adopted mixing ratios (δ) are the weighted means of the δ values found in the literature (given by 1977Kr13) and shown in Table 4. A good agreement has been found between the experimental values of K and L internal coefficients and the calculated ones obtained by using the evaluated δ values and the BrIcc program.

Table 4: Experimental and recommended conversion coefficients and mixing ratios for the γ-ray transitions.

E_γ (keV)	$|\delta|$ experimental (mixing ratio)	α experimental	α theoretical (given by BrIcc)
91.105 (2)	0.10 (9) (1957Bi86)[*] 0.229 (143) (1961Ar09) 0.089 (11) (1961Ew02)[*] 0.13 (2) (1961We07)[µ] 0.18 (6) (1963Ph02) 0.28 (9) (1967Ba06) 0.67 (15) (1967Ba22)[@] 0.089 (5) (1969Ba32) 0.13 (2) (1970Bl12) 0.082 (10) (1977Al34)	α_K = 1.73 (6) (1997Sa53)	α_K = 1.714 (24)
Recommended value	$|\delta|$ = 0.090 (5)	Reduced χ^2 = 1.7	
120.48 (5)	0.12 (3) (1963Ph02) 0.158 (15) (1970Bl12) 0.050 (21) (1977Al34)	α_K = 0.79 (3) α_L = 0.113 (6) (1997Sa53)	α_K = 0.772 (11) α_L = 0.112 (4)
Recommended value	$|\delta|$ = 0.116 (42)	Reduced χ^2 = 8	
275.374 (15)	0.077 (14) (1960Bo17)[*] 0.13 (1) (1960Bo17)[*] 0.11 (11) (1961Ar09) 0.089 (11) (1961Ew02)[*] 0.14 (2) (1961We07)[µ] 0.05 (7) (1963Sp07)[*] 0.16 (4) (1966Go25)[*] 0.34 (12) (1967Ba06)[@] 0.112 (6) (1969Ba32) 0.58 (25) (1970Bl12)[@] 0.17 (4) (1974Bh02)[*] 0.16 (4) (1976Si08)[*] 0.14 (3) (1977Al34) 0.107 (7) (1979Se05)	α_K = 0.081 (3) α_L = 0.0109 (6) (1997Sa53)	α_K = 0.0792 (11) α_L = 0.01095 (16)
Recommended value	$|\delta|$ = 0.112 (5)	Reduced χ^2 = 1.8	
319.411 (18)	0.40 (2) (1957Li40)[*] 0.38 (1) (1960Bo17)[*] 0.27 (1) (1960Ma03)[*@] 9.95 (11) (1961Ar09)[@] 0.36 (2) (1961We07)[µ] 0.38 (6) (1963Ph02)[*] 0.39 (4) (1963Sp07)[*] 0.34 (2) (1966Go25)[*] 0.31 (10) (1967Ba06)[@] 0.55 (5) (1969Ba32)[@] 0.35 (4) (1970Bl12)	α_K = 0.052 (2) α_L = 0.0079 (4) (1997Sa53)	α_K = 0.0514 (8) α_L = 0.00734 (11)

E_γ (keV)	|δ| experimental (mixing ratio)	α experimental	α theoretical (given by BrIcc)
	0.011 (16) (1974Bh02)[*,@] 0.38 (2) (1976Si08)[*] 0.41 (3) (1977Al34)		
Recommended value	|δ| = 0.378 (9)	Reduced χ^2 = 0.9	
398.155 (20)	0.31 (3) (1960Bo17)[*] 0.50 (7) (1966Go25)[*] 0.17 (7) (1970Bl12) 0.18 (6) (1974Bh02)[*] 0.30 (3) (1977Al34)	α_K = 0.0292 (11) (1997Sa53)	α_K = 0.0293 (5)
Recommended value	|δ| = 0.297 (37)	Reduced χ^2 = 3.9	
439.895 (22)	0.63 (5) (1960Bo17)[*] 0.70 (12) (1961Sa13)[*] 0.82 (65) (1961We07)[μ] 0.59 (7) (1963Sp07)[*] 0.56 (5) (1966Go25)[*] 0.62 (6) (1968Ra28)[*] 0.70 (9) (1969Ba32) 0.6 (1) (1970Bl12) 0.62 (7) (1974Bh02)[*] 0.59 (5) (1976Si08)[*] 0.77 (10) (1977Al34)[@]	α_K = 0.0212 (9) α_L = 0.0028 (2) (1997Sa53)	α_K = 0.0210 (4) α_L = 0.00300 (5)
Recommended value	|δ| = 0.609 (21)	Reduced χ^2 = 0.4	
489.24 (3)	0.79 (+23,-45) (1977Al34) 1.2 (+28,-8) (1961Sa13)[*]	α_K = 0.018 (1) (1997Sa53)	α_K = 0.0152 (16) α_K = 0.014 (4)
Recommended value	|δ| = 0.79 (+23,-45)		
531.016 (22)	0.75 (25) (1957Bi86)[*] 0.95 (30) (1961We07)[μ] 0.69 (32) (1969Ba32) 0.40 (3) (1977Al34)	α_K = 0.0133 (3) (1997Sa53)	α_K = 0.01374 (23)
Recommended value	|δ| = 0.407 (35)	Reduced χ^2 = 1.4	
594.80 (3)	0.66 (15) (1961Sa13)[*] 0.34 (16) (1963Sp07)[*] 0.66 (9) (1968Ra28)[*] 0.48 (8) (1974Bh02)[*]	α_K = 0.0071 (5) (1997Sa53)	α_K = 0.00995 (23)
Recommended value	|δ| = 0.55 (6)	Reduced χ^2 = 1.5	
685.90 (4)	0.95 (30) (1961We07)[μ] 0.87 (29) (1967Ba06) 1.05 (65) (1969Ba32) 0.95 (30) (1977Al34)	α_K = 0.0068 (4) (1997Sa53)	α_K = 0.0063 (4)
Recommended value	|δ| = 0.92 (20)	Reduced χ^2 = 0.04	

[@] Value has been shown to be outlier, based on the Chauvenet's criterion and thus was omitted in the final calculation.
[μ] Not used: superseded by 1969Ba32.
[*] Given by 1977Kr13.

3 Atomic Data

Atomic values, ω_K, ϖ_L, ϖ_M and n_{KL} are from Schönfeld and Janβen (1996Sc06).
The X-ray and Auger electron emission probabilities are calculated from the data set values using the program EMISSION.

4 Electrons Emissions

The conversion electron emission probabilities were deduced from the ICC values and the γ-ray emission intensities.

5 Photon emissions

5.1 K x-rays

The X-ray absolute intensities were deduced from the decay data using the EMISSION computer code and are compared in Table 5 with measured values found in the literature. The experimental and calculated values are in agreement within the uncertainty limits, supporting the overall consistency of the decay scheme data.

Table 5: Experimental and recommended (calculated) values of X-ray absolute intensities (%).

	J. Goswamy (1995Go**)	Recommended values
Kα_2 x-ray	12.3 (5)	12.9 (9)
Kα_1 x-ray	21.6 (9)	23.5 (15)
K β_1 x-ray	6.4 (3)	7.3 (5)
K β_2 x-ray	1.64 (6)	1.87 (13)

5.2 Gamma emissions

The energies of the γ-rays given in section 5.2 are from N. Nica (2009Ni02).

The experimental relative γ-ray emission intensities from ^{147}Nd have been obtained from all the available relative values. The normalization factor to convert relative γ-ray emission probabilities to absolute values is calculated with the formula:

$$\text{Normalization} = \frac{100 - P_{\beta-}(g.s.)}{\sum(1 \ + \alpha_T)P_{rel}} = 0.127\ (9)$$

where the sum is to be done over all the gamma transitions to the ground state, and $P_{\beta-}$ (g.s.) = 0 (5) %, deduced from the probability balance at the ground state (g.s.) level (see Table 2, **2.1 β^- Transitions).** From the theoretical α_T and the evaluated relative emission intensities (Table 6), the calculated normalization factor is 0.127 (9).

The experimental γ-ray emission probabilities relative to 100 for the 531-keV γ-ray are given in Table 6.

The adopted relative γ-ray intensity values are the weighted means calculated by the LWEIGHT program (version 3).

It should be noted that in the 50-150 keV region, only a few points of calibration exist to establish an efficiency curve for γ-ray detectors. Then the γ-ray intensity measurements in this region cannot lead to results with uncertainties better than 2-4 %. For this reason, the values of γ-ray intensities relative to the 91-keV γ-ray (Table 7) were omitted from averaging. The use of these values renormalized to the 531-keV γ-ray would introduce an increase of the uncertainties.

Our recommended relative and absolute γ-ray emission probabilities are given in Table 8.

Table 6: Experimental data sets of the relative γ-ray emission intensities (%).

Reference **Energy (keV)**	**1966Ar16**	**1967Ca18**	**1967Do07**	**1967Hi04**	**1967Ja05**	**1974Ra30**	**1979Vo09**	**1997Sa53**	**1998Po****	**Evaluated**	Reduced χ^2
31.3 (2)											
36.75 (10)											
53.1 (2)											
80.82 (27)								0.0068 (9)		0.0068 (9)	
91.105 (2)	275 (50)[μ]	211 (42)	248 (13)	227 (35)	300 (100)[μ]	220 (14)	239 (5)	210.0 (43)		224 (14)	4.6
117.98 (5)								0.120 (10)		0.120 (10)	
120.48 (5)	2.6 (4)	2.5 (5)	2.1 (2)	3.3 (5)	8 (1)[μ]	3.3 (5)	3.05 (10)	2.810 (46)		2.84 (11)	3.5
149.3 (2)								0.0290 (30)		0.0290 (30)	
154.7 (2)					< 0.5			0.0310 (30)		0.0310 (30)	
159.7 (2)								0.0400 (30)		0.0400 (30)	
191.0 (3)								0.0280 (30)		0.0280 (30)	
196.64 (4)	1.3 (2)	1.30 (13)	1.0 (1)[μ]	1.5 (6)	2 (1)[μ]	1.4 (4)	1.38 (6)	1.420 (15)		1.416 (14)	0.3
230.77 (8)											
240.5 (2)								0.320 (20)		0.320 (20)	
271.87 (6)								0.099 (7)		0.099 (7)	
275.374 (15)	6.6 (7)	6.5 (6)	6.1 (5)	6.8 (14)	7 (2)	6.7 (7)	6.05 (10)	6.81 (8)	6 (1)	6.10 (9)	0.4
310							< 0.1				
319.411 (18)	15.0 (15)	14.2 (14)	15.8 (10)	16.3 (24)	15 (5)	16.5 (10)	15.0 (3)	15.91 (17)	15 (2)	15.68 (15)	1.2
398.155 (20)	7.0 (7)	6.4 (6)	6.7 (5)	6.8 (11)	5 (2)μ	6.5 (7)	6.59 (10)	6.82 (8)		6.73 (6)	0.6
408.52 (6)								0.140 (10)		0.140 (10)	
410.48 (3)	1.3 (1)	1.30 (13)	0.9 (2)	1.2 (5)	1.0 (6)	1.2 (3)	0.93 (5)	1.120 (13)		1.077 (47)	2.7
439.895 (22)	8.8 (9)	9.2 (9)	9.7 (6)	9.3 (11)	8 (2)[μ]	9.8 (2)	9.19 (14)	9.54 (10)		9.47 (9)	1.3
489.24 (3)	0.70 (8)	1.5 (8)	1.2 (3)	1.1 (5)	1.0 (5)	1.4 (4)	1.12 (6)	1.160 (14)		1.07 (9)	3.9
531.016 (22)	100	100	100	100	100	100	100	100	100	100	
541.83 (7)	0.20 (5)							0.140 (20)		0.148 (21)	1.2
589.35 (4)	0.40 (6)[μ]		0.26 (6)	0.31 (14)		0.29 (8)	0.30 (3)	0.290 (20)		0.291 (16)	0.09
594.80 (3)	2.2 (2)	2.20 (22)	1.6 (2)[μ]	1.9 (4)	2 (1)	2.0 (3)	1.92 (6)	2.120 (26)	2.0 (3)	2.089 (28)	1.5
649.04 (8)								0.0390 (30)		0.0390 (30)	
680.52 (15)			< 0.05	0.23 (16)		0.06	0.30 (5)	0.220 (10)		0.223 (11)	1.2
685.90 (4)	7.0 (7)	6.6 (7)	5.0 (4)[μ]	5.9 (10)	6 (1)	6.7 (6)	6.1 (2)	6.63 (7)		6.57 (7)	1.2

μ: the experimental value has been shown to be an outlier value by the Lweight program.

Table 7: Omitted experimental data sets of the relative γ-ray emission intensities (%).

Reference Energy (keV)	1963Ph02	1967Ba21	1971Si20	1974HeYW	1995Go**	2010Gh**
31.3 (2)						
36.75 (10)	106 (16)					
53.1 (2)	7.5 (10)					
80.82 (27)	8 (1)					
91.105 (2)	100	100	100	100	100	100
117.98 (5)						
120.48 (5)	2.0 (2)	1.4 (1)	1.42 (18)	1.42 (15)	1.64 (5)	1.540 (3)
149.3 (2)						
154.7 (2)					0.0250 (10)	< 0.034
159.7 (2)	1.5 (2)					
191.0 (3)						
196.64 (4)	1.6 (2)	0.72 (7)	0.73 (12)	0.73 (6)	0.610 (12)	1.012 (27)
230.77 (8)						
240.5 (2)						
271.87 (6)						
275.374 (15)	2.5 (2)	3.0 (2)	3.05 (20)	2.87 (18)	2.720 (40)	3.320 (5)
310	< 2	< 0.2	0.13 (5)			
319.411 (18)	7.0 (6)	6.8 (5)	7.60 (70)	7.0 (4)	6.80 (12)	8.010 (12)
398.155 (20)	< 2.5	3.1 (3)	3.35 (25)	3.12 (30)	3.050 (43)	3.680 (7)
408.52 (6)						
410.48 (3)	3.7 (3)	0.8 (1)	0.55 (15)	0.50 (3)	0.360 (20)	0.790 (2)
439.895 (22)	4.5 (4)	4.2 (3)	5.1 (3)	4.3 (3)	4.20 (9)	5.200 (7)
489.24 (3)	< 0.2	0.7 (1)	0.6 (1)	0.55 (3)	0.49 (11)	0.530 (7)
531.016 (22)	58 (2)	47 (3)	53.5 (15)	46.9 (26)	45.9 (10)	47.20 (24)
541.83 (7)						
589.35 (4)		0.13 (2)	0.20 (2)	0.164 (16)	0.1580 (25)	0.224 (6)
594.80 (3)	1.6 (1)	0.9 (1)	1.1 (1)	0.95 (6)	0.850 (13)	0.586 (14)
649.04 (8)						
680.52 (15)			0.17 (8)	0.070 (15)	0.0560 (31)	0.072 (5)
685.90 (4)	4.7 (1)	3.3 (2)	3.5 (2)	2.91 (18)	2.850 (41)	2.430 (5)

Table 8: Recommended relative and absolute γ-ray intensities (%).

Eγ (keV)	**Relative γ-ray intensity (%)**	**Absolute γ-ray intensity (%)**
31.3 (2)		
36.75 (10)		
53.1 (2)		
80.82 (27)	0.006 8 (9)	0.000 86 (11)
91.105 (2)	224 (14)	28.4 (18)
117.98 (5)	0.120 (10)	0.015 2 (13)
120.48 (5)	2.84 (11)	0.361 (14)
149.3 (2)	0.029 0 (30)	0.003 68 (38)
154.7 (2)	0.031 0 (30)	0.003 94 (38)
159.7 (2)	0.040 0 (30)	0.005 08 (38)
191.0 (3)	0.028 0 (30)	0.003 56 (38)
196.64 (4)	1.416 (14)	0.179 8 (18)
230.77 (8)		
240.5 (2)	0.320 (20)	0.040 6 (25)
271.87 (6)	0.099 (7)	0.012 6 (9)
275.374 (15)	6.10 (9)	0.775 (11)
310		
319.411 (18)	15.68 (15)	1.991 (19)
398.155 (20)	6.73 (6)	0.855 (8)
408.52 (6)	0.140 (10)	0.017 8 (13)
410.48 (3)	1.077 (47)	0.137 (6)
439.895 (22)	9.47 (9)	1.203 (11)
489.24 (3)	1.07 (9)	0.136 (11)
531.016 (22)	100	12.7 (9)
541.83 (7)	0.148 (21)	0.018 8 (27)
589.35 (4)	0.291 (16)	0.037 0 (20)
594.80 (3)	2.089 (28)	0.265 3 (36)
649.04 (8)	0.039 0 (30)	0.004 95 (38)
680.52 (15)	0.223 (11)	0.028 3 (14)
685.90 (4)	6.57 (7)	0.834 (9)

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^{147}Pm - Comments on evaluation of decay data
by V. Chisté and M. M. Bé

This evaluation was completed in May 2011, including all publications by this date.

1 Decay Scheme

^{147}Pm disintegrates 100 % by beta minus emissions to the ^{147}Sm ground state mainly.

A good agreement was found between the effective Q value (224.5 (4) keV) calculated from the decay scheme data and the adopted and recommended value from the mass adjustment of Audi (2003Au03).

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).

Experimental ^{147}Pm half-life values (in years) are given in Table 1:

Table 1: Experimental values of ^{147}Pm half-life.

Reference	Experimental value (a)	Comments
E. A. Melaika (1955Me52)	2.52 (8)	Outlier.
R. P. Schuman (1956Sc87)	2.66 (2)	Outlier.
W. F. Merritt (1957Me47)	2.64 (2)	
J. P. Cali (1959Ca**)	2.7 (1)	Outlier.
E. I. Wyatt (1961Wy01)	2.50 (3)	Superseded by 1968Re04.
F. P. Roberts (1963Ro20)	2.67 (6)	Superseded by 1965Wh04.
S. C. Anspach (1965An07)	2.618 (7)	
J. F. Eichelberger (1965Ei04)	2.6226 (20)	Superseded by 1967Jo07.
K. F. Flynn (1965Fl02)	2.60 (2)	
E. J. Wheelwright (1965Wh04)	2.620 (5)	
K. C. Jordan (1967Jo07)	2.6234 (4)	
S. A. Reynolds (1968Re04)	2.62 (1)	
Recommended value	**2.6234 (4)**	**χ^2 = 0.64**

A weighted average has been calculated using LWEIGHT computer program (version 3). The Melaika (1955Me52), Schuman (1956Sc87) and Cali (1959Ca**) values have been shown to be outlier, based on the Chauvenet's criterion and thus were omitted in the final calculation. The largest contribution to the weighted average comes from the value of K. C. Jordan (1967Jo07), with a statistical weight of 98 %.

The adopted value is the weighted average of 2.6234 a with an internal uncertainty of 0.0004 a. The reduced-χ^2 value is 0.64.

For ^{147}Sm, the experimental half-life values (in years) are given in Table 2:

Table 2: Experimental values of ^{147}Sm half-life.

Reference	Experimental value (10^{11} a)	Comments
W. F. Libby (1934Li03)	0.92 (6)	Corrected for (Sm nat./Sm-147) = 0.1498 by R. D. MacFarlane (1961Ma05).
R. Hosemann (1936Ho**)	1.5 (1)	Corrected for (Sm nat./Sm-147) = 0.1498 by R. D. MacFarlane (1961Ma05).
P. Cuer (1946Cu**)	1.3 (1)	
E. Picciotto (1949Pi**)	1.00 (5)	Corrected for (Sm nat./Sm-147) = 0.1498 by R. D. MacFarlane (1961Ma05).
G. Beard (1954Be69)	1.25 (6)	Superseded by 1958Be78.
G. E. Leslie (1956Le55)	1.15 (6)	
G. Beard (1958Be78)	1.06 (4)	Corrected for wrong Sm content by P. M. Wright (1961Wr02). Original value: 1.28 (4). Superseded by 1987Al28.
M. Karras (1960Ka**)	1.14 (5)	Superseded by 1960Ka23.
M. Karras (1960Ka23)	1.17 (5)	
R. D. MacFarlane (1961Ma05)	1.15 (5)	Superseded by 1970Gu14.
P. M. Wright (1961Wr02)	1.05 (2)	
D. Donhoffer (1964Do01)	1.04 (3)	
K. Valli (1965Va16)	1.08 (2)	
M. C. Gupta (1970Gu14)	1.06 (2)	
B. Al-Bataina (1987Al28)	1.05 (4)	
J. B. Martins (1992Ma56)	1.06 (4)	Corrected for wrong Sm content by F. Begemann (2001Be81). Original value: 1.23 (4).
N. Kinoshita (2003Ki26)	1.17 (2)	Questioned by 20099Ko15.
K. Kossert (2009Ko15)	1.070 (9)	
Recommended value	**1.079 (12)**	**χ^2 = 3.9**

The first 3 values (1934Li03, 1936Ho** and 1946Cu**) have been shown outliers, based on the Chauvenet's criterion and thus were omitted in the final calculation. With the eleven remaining values (1949Pi**, 1956Le55, 1960Ka23, 1961Wr02, 1964Do01, 1965Va16, 1970Gu14, 1987Al28, 1992Ma56, 2003Ki26 and 2009Ko15), a weighted average has been calculated using LWEIGHT computer program (version 3). The largest contribution to the weighted average comes from the value of K. Kossert (2009Ko15), with a statistical weight of 46 %.

The adopted value is the weighted average of $1.079 \cdot 10^{11}$ a with an external uncertainty of $0.012 \cdot 10^{11}$ a. The reduced-χ^2 value is 3.9.

2.1 β- Transitions

The maximum energies of the β^- transitions in the decay of ^{147}Pm → ^{147}Sm have been obtained from the Q^- value (2003Au03) and the level energies from N. Nica (2009Ni02) (Table 3).

Table 3: ^{147}Sm levels populated in the decay of ^{147}Pm and adopted β^- transition probabilities.

Level Number	Level energy, (keV)[a]	Spin and parity	Half-life*	Adopted $P_{\beta-}$ (%)
0	0	$7/2^-$	$1.060\ (11) \cdot 10^{-11}$ s	99.994 56 (13)
1	121.223 (12)	$5/2^-$	0.798 (17) ns	0.005 42 (13)
2	197.298 (11)	$3/2^-$	1.25 (3) ns	0.000 000 40 (7)

* Given by N. Nica (2009Ni02),

[a] from least-squares fit to E_γ's.

The adopted β^- transition probabilities and the associated uncertainties (Table 3) were deduced from the γ transition probability balance at each level of the decay scheme.

The values of log ft and average β^- energies have been calculated with the program LOGFT for the unique 1st and 1st forbidden β^- transitions.

2.2 γ Transitions

The γ-ray transition probabilities were calculated using the γ-ray emission intensities and the relevant internal conversion coefficients (see **4.2 γ Emissions**).

For all γ transitions, the internal conversion coefficients (ICC) and the associated uncertainties were interpolated from theoretical values of I. M. Band et al. (2002Ba85) using the BrIcc computer program (2008Ki07) for the “frozen orbital” approximation.

For multipolarity and mixing ratio of the γ-ray transitions, the evaluators used:

1) The multipolarities of the 76- and 197-keV γ-ray transitions are from N. Nica (2009Ni02):

76-keV γ-ray: M1 + E2, $\delta = 0.655\ (34)$;
197-keV γ-ray: E2.

2) For the 121-keV γ-ray transition, the adopted mixing ratio (δ) is the weighted mean of the δ values found in the literature and shown in the Table 4.

Table 4: Experimental and recommended mixing ratio and ICC.

E_γ (keV)	δ experimental (mixing ratio)	Comments
121.220 (7)	0.25 (21) (1958An36) -0.06 (2) (1962Al19)[a] -0.33 (4) (1962Sc09) 0.34 (3) (1966Av02) -0.35 (4) (1966Go26)[£] -0.38 (3) (1970Va38) -0.40 (+26,-15) (1971Be53) -0.278 (20) (1989Ad10)	Calculated* from K/L = 6.2 (6). Calculated by 1977Kr13 (γγ(θ)). Calculated* from L_1:L_2:L_3 = 1.0 (2): 0.24 (4): 0.16 (2). Calculated* from K: L_{1+2}:L_3 = 450 (40): 73 (7): 10 (1). Calculated by 1977Kr13 (γγ(θ)). Superseded by 1970Va38. Calculated by 1977Kr13 (γγ(θ)). Calculated by 1977Kr13 (γγ(θ)).
Recommended value	- 0.317 (19), $\chi^2 = 1.7$	α_K(BRICC – 121-keV γ-ray) = 0.815 (12).

[a] Outlier value, based on the Chauvenet’s criterion and thus was omitted in the final calculation.

[£] Superseded by 1970Va38.

* Using BriccMixing program, version 2.2a (same package of BrIcc computer program).

3 Atomic Data

Atomic values, ω_K, ϖ_L, n_{KL} and the X-ray relative probabilities are from Schönfeld and Janβen (1996Sc06).

4 Photon Emissions

4.1 X-ray Emissions

The X-ray absolute intensities were deduced from the decay data using the EMISSION computer code.

4.2 Gamma emissions

The energies of the γ-rays given in Table 5 were derived from the ^{147}Sm adopted levels (Table 2).

The experimental absolute values of the 121-keV γ-ray emission intensities in the decay of ^{147}Pm are given in the table 5.

Table 5: Absolute experimental γ-ray emission intensities for the 121-keV transition.

Reference	**Absolute γ-ray intensity (10^{-3} %)**	**Comments**
H. Langevin-Joliot (1956La17)	3.0 (5)	
N. Starfelt (1957St05)	3.4 (5)	
R. S. Mowatt (1970Mo02)	2.73 (18)	
D. McConnon (1971Mc09)	2.93 (14)	
H. H. Hansen (1973HaHY)	3.0 (3)	
U. Schötzig (1990Sc08)	2.65 (6)	
Recommended value	**2.72 (6)**	**χ^2 = 1.33**

The adopted value is the weighted average of $2.72 \cdot 10^{-3}$ % with an external uncertainty of $0.06 \cdot 10^{-3}$ %. The reduced-χ^2 value is 1.33.

For the 197-keV γ-ray emission, the adopted value of the γ-ray relative intensity ($1.2\ (2) \cdot 10^{-4}$) comes from the unique measurement found in the literature given by P. H. Barrett (1969Ba33).

Our recommended γ-ray emission probabilities are given in Table 6.

Table 6: Recommended relative and absolute γ-ray intensities (%).

Eγ (keV)	**Relative γ-ray intensity (%)**	**Absolute γ-ray intensity (%)**
(76.073 (10))[a]	$4.1\ (7) \cdot 10^{-6}$	$1.1\ (2) \cdot 10^{-8}$
121.220 (17)	100	$2.72\ (6) \cdot 10^{-3}$
197.299 (12)	$1.2\ (2) \cdot 10^{-4}$	$3.3\ (5) \cdot 10^{-7}$

[a] not observed in this decay scheme.

The 76-keV γ-ray transition has been observed in the ^{147}Eu electron capture decay, but not in the ^{147}Pm β^- decay. From the ^{147}Eu electron capture decay (1989Ad10):
I_γ(76 keV)/I_γ(197 keV) = 0.0344 (11) and
I_γ(197 keV) = $1.2\ (2) \cdot 10^{-4}$. Then I_γ(76 keV) = $4.1\ (7) \cdot 10^{-6}$.
This very weak transition was included in the decay scheme.

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^{152}Eu – Comments on evaluation of decay data

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Evaluation Procedures

We used the *Limitation of Relative Statistical Weights* (LWM) method (1985ZiZY, 1992Ra08) for averaging quantities throughout this evaluation. This method provides a uniform approach for the analysis for discrepant data.

Decay Scheme

^{152}Eu decays by electron capture (EC) to ^{152}Sm, and by β^- to ^{152}Gd. Only excited levels are populated in the daughter nuclei since decay to the respective ground states are highly hindered by spin selection rules. Therefore, we used the sum of the total γ-ray transition emission probabilities (photons + electrons) to the ground states of ^{152}Sm and ^{152}Gd to normalize the decay scheme of ^{152}Eu. We have deduced the following branchings: 72.1(3)% (EC), and 27.9(3)% (β^-). This normalization is virtually the same as that based on the measurement of the absolute γ-ray emission probabilities (See **Gamma Rays**).

Nuclear Data

We have considered the following measured values of the half-life of ^{152}Eu for deducing a recommended value.

1.	4934.1 (23) d	2004Sc04	Duration of measurement: about 26 years
2.	4936.6 (20) d	1998Si12	Duration of measurement: 20 years
3.	4948 (7) d	1997Ma75	Duration of measurement: about 2 years
4.	4945.5 (23) d	1992Un01	Duration of measurement: 13.5 years
5.	4943 (4) d	1986Wo05	
6.	4792(37) d	1983Ba29	
7.	4939 (6) d	1983Wa26	
8.	4892.3 (82) d	1980RuZX	
9.	4785 (19) d	1978La21	
10.	4821 (110) d	1972Em01	

Our recommended value of 4939 (6) d (or 13.522 (16) a) is a weighted average (LWM) ($\chi^2/\nu=12$) of the results from 2004Sc04, 1997Ma75, 1992Un01, 1986Wo05, and 1980RuZX. Values given by 1978La21, 1972Em01, and 1983Ba29 have not been included because they significantly disagree with most of the other results, suggesting that they may have be en affected by systematic uncertainties. 1983Wa26 and 1998Si12 have been superseded by 2004Sc04 (same research groups, PTB).

Electron Capture, Positrons (b$^+$), and b$^-$ Transitions

EC and positron transition energies to levels in ^{152}Sm have been deduced from Q(EC) = 1874.3 (7) keV (1995Au04) and the individual level energies. Transition probabilities (P_{EC}) are from γ-ray transition probability balance at each level. They are given as branchings (P_{EC} x 100) in Sections 2.1 – 2.3. Fractional atomic sub-shell electron-capture probabilities (i.e., P_K, P_L, P_M, P_N) are theoretical values (1998Sc28) calculated with the computer program EC-CAPTURE [1].

Positrons are energetically possible and allowed by spin selection rules to the 121- and 366-keV levels only. Their transition probabilities, presented here as branchings ($P_{\beta+} \times 100$), have been deduced from theoretical β^+/EC ratios (1957Zw01).

β^- endpoint energies for the decay to levels in ^{152}Gd have been deduced from Q(β^-)=1818.8 (11) keV (1995Au04). Their transition probabilities, presented here as branchings ($P_{\beta-} \times 100$), have been deduced from γ-ray transition probability balance at each level.

Gamma Rays

Energies. The precise energies of strong γ rays given here are from 2000He14. These values are based on a revised energy scale that uses the new fundamental constants and wave lengths deduced from an updated value of the lattice spacing in Si crystals (1987Co39). All other (less precise) energies are values adjusted to the new energy scale and recommended in 1996Ar09 evaluation.

Emission Probabilities. For a γ-ray transition, its absolute transition probability (photons + electrons) is given by $P_\gamma(1 + \alpha) \times 100$, where P_γ is the absolute γ-ray emission intensity, and α, its theoretical (1978Ro22, [4]) conversion coefficient. We have deduced the P_γ values used here as follows:

1 By averaging (LWM) the experimental relative emission intensities reported by 1970No06, 1970Ri19, 1971Ba63, 1972Ba05, 1977Ge12, 1980Sh15, 1984Iw03, 1986Me10, 1989Da12, 1990Me15, 1990St02, 1992Ya12, 1993Ka30, 1998Hw07, and from the fourteen measurements (ICRM01, ICRM02, ICRM08, ICRM10, ICRM12, ICRM15, ICRM16, ICRM17, ICRM18, ICRM20, ICRM25, ICRM27, ICRM28, and ICRM29) of the study participants [5] from the International Committee on Radioactivity Measurements (ICRM), which 1991BaZS considered reliable. These data are presented in Table 1 and Table2.

2. By normalizing the above mentioned relative emission intensities to absolute values. We normalized these scales by using $P_\gamma(1408) = 0.2085$ (8), which was determined from an inter-comparison of measured absolute emission intensities produced by participants from various laboratories and coordinated by the ICRM [5]. This value agrees very well with $P_\gamma(1408) = 0.2086$ (21), deduced by evaluators from the sum of the relative γ-ray transition probabilities (photons + electrons) to the respective ground states of ^{152}Sm and ^{152}Gd. The larger uncertainty in the latter value is due mostly to that in the conversion coefficient of the 121-keV γ-ray (taken as 3%). We used 47.46 (20) for the relative intensity of the 1086-keV γ ray that de-excites the 1086-keV level in ^{152}Sm. We deduced this value from our recommended relative emission intensity of 48.63 (20) for the 1086-"doublet" (See Table 2) and subtracting 1.17 (4) for the contribution of the 1084-keV γ ray (1990Me15). The excellent agreement between these two normalizations confirms the completeness and self-consistency of the ^{152}Eu decay scheme and the good quality of our recommended data. We have preferred not to statistically combine these normalizations because of the correlations that exist between them. Absolute γ-ray emission intensities (P_γ) are given in Section 4.1.

Conversion Coefficients. Values given in Section 2.3 are the result of theoretical calculations (1978Ro22, [4]), interpolated for the recommended transition energies presented here, and for adopted multipolarities and mixing ratios from the 1996Ar09 evaluation, uncertainties have been taken being 3 %. For transitions with E0 multipolarity, the adopted values are derived from experiments.

Atomic Data

X-Rays. X-ray energies and relative emission probabilities are from Schönfeld and Rodloff [6]. Absolute X-ray emission probabilities have been calculated with the computer program EMISSION [2] using absolute γ-ray emission probabilities from Section 4.1, theoretical conversion coefficients (1978Ro22) from Section 2.3, and fluorescence yields from 1996Sc06. These calculated X-ray emission probabilities agree well with the experimental results shown in Table 2, and thus support the correctness of our recommended γ-ray data and the self-consistency of the ^{152}Eu decay scheme.

Electron Emission

Conversion-electron energies are from γ-ray energies given in Section 4.2 and the atomic binding energies reported by Larkins [7]. Absolute electron emission intensities are from γ-ray emission probabilities given in Section 4.1, and the theoretical (1978Ro22) conversion coefficients presented in Section 2.3.

Energies of K-Auger electrons are from Schönfeld and Rodloff [8]. Absolute emission intensities of Auger electrons are values calculated with the computer program EMISSION [2] using absolute γ-ray emission intensities from Section 4.2, theoretical conversion coefficients (1978Ro22) given in Section 2.3, and the electron-capture probabilities presented in Section 2.1. The same emission probabilities, but renormalized to a scale where P_{KLL} = 1.0, are given as relative emission probabilities in Section 3.2.

Total Average Radiation Energy

We show below the total average radiation energy released (by β^-, β^+, neutrinos, γ rays, atomic electrons, and nuclear recoil) in the electron-capture and β^- decay of ^{152}Eu, as well as the total decay energies from mass differences, Q-values, and decay branchings (1995Au04).

	Total Average Radiation Energy* (keV)	Total Decay Energy& (Q x branching) (keV)
^{152}Eu EC decay	1345 (18)	1351 (6)
^{152}Eu β^- decay	508 (2)	507 (5)

* Calculated with the computer program RADLST [3], and using the recommended radiation data given in this evaluation.

& Q-values (Q(EC) and Q(β^-)) are from 1995Au04. Branchings are from this evaluation.

The agreement between these values confirms the quality, completeness, and self-consistency of the ^{152}Eu decay scheme presented in this evaluation.

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Table 1. Relative g-Ray Emission Probabilities Evaluated in this Revision (Uncertainty given below the value)

E(keV)	1970NO06	1970RI19	1971BA63	1972BA05	1977GE12	1980SH15	1984IW03	1986ME10	1989DA12	1990ME15	1990ST02	1992YA12	1993KA30	1998HW07*
121.8	145.0 4.1	138.5 6.4	132.9 4.0	144.6 4.7	141.0 4.0	140.6 2.8	136.9 1.3	136.7 0.7	139.0 1.0	136.2 1.6	136.6 1.8		133.5 1.8	136.9 3.9
125.7										0.057 0.009	0.115 0.013			
148.0			0.077 0.026			0.154 0.013				0.190 0.040	0.218 0.026		0.231 0.026	
166.9											0.051 0.013		0.010 0.004	
173.1										0.002 0.001	0.038 0.013		0.081 0.003	
192.6										0.033 0.001	0.023 0.006	0.031 0.008	0.029 0.005	
202.6										0.018 0.009	0.028 0.006			
207.6			0.064 0.038	0.035 0.012		0.038 0.013				0.021 0.006	0.031 0.006	0.022 0.003	0.035 0.003	
209.4			0.077 0.038	0.038 0.026		0.026 0.013				0.021 0.006	0.038 0.013	0.027 0.003	0.026 0.013	
212.6		0.086 0.037	0.103 0.026	0.097 0.029		0.103 0.026				0.094 0.003	0.115 0.026		0.077 0.026	
237.3			0.051 0.026							0.045 0.004	0.064 0.026		0.012 0.004	
239.4				0.321 0.154							0.051 0.013		0.019 0.004	
244.7	39.4 1.3	36.2 1.8	35.8 1.0	36.4 1.2	36.6 1.1	35.8 0.6	36.2 0.3	36.5 0.4	36.5 0.3	35.9 0.6	38.0 0.5			36.8 0.9
251.6		0.333 0.051	0.372 0.064	0.359 0.051		0.359 0.013				0.300 0.010	0.321 0.026		0.308 0.026	
269.9				0.015 0.006						0.039 0.004				

E_g(keV)	1970NO06	1970RI19	1971BA63	1972BA05	1977GE12	1980SH15	1984IW03	1986ME10	1989DA12	1990ME15	1990ST02	1992YA12	1993KA30	1998HW07*
271.1#		0.359	0.359	0.374		0.410				0.389	0.372		0.436	
		0.051	0.064	0.038		0.026				0.011	0.026		0.013	
275.5		0.141	0.154	0.154		0.218				0.161	0.205		0.128	
		0.038	0.038	0.013		0.026				0.050	0.026		0.013	
286.0										0.053	0.064		0.044	
										0.005	0.026		0.004	
295.9	2.37	1.94	2.09	2.04		2.06	2.13	2.22	2.12	2.11	2.21		2.08	
	0.19	0.12	0.14	0.06		0.05	0.04	0.04	0.02	0.05	0.06		0.05	
315.2#		0.218	0.237	0.228		0.308				0.253	0.231		0.231	
		0.038	0.043	0.040		0.026				0.008	0.038		0.038	
316.2			0.045	0.023						0.010				
			0.019	0.012						0.006				
320.0										0.008				
										0.003				
324.8		0.333	0.385	0.346		0.359				0.360	0.346			
		0.038	0.064	0.051		0.026				0.010	0.013			
329.4		0.564	0.615	0.577		0.628	0.707			0.590	0.603		0.410	
		0.051	0.103	0.064		0.038	0.015			0.010	0.026		0.038	
330.5				0.029						0.360				
				0.008						0.050				
340.4			0.103	0.117						0.130	0.141		0.182	
			0.051	0.012						0.030	0.038		0.010	
344.3	128.2	128.2	128.2	128.2	127.2	128.2	127.1	126.9	128.2	127.5	128.2		128.2	128.2
	3.6	5.9	3.8	4.2	1.3	2.6	0.7	0.9	0.8	0.9	1.7		1.8	2.9
351.7			0.077	0.086		0.103				0.043	0.090		0.103	
			0.026	0.018		0.026				0.003	0.026		0.026	
357.3										0.023			0.013	
										0.003			0.004	
367.8	3.78	4.04	4.14	4.08	4.19	4.15	4.13	4.14	4.18	4.05	4.05		4.04	4.13
	0.32	0.23	0.15	0.14	0.04	0.09	0.04	0.07	0.04	0.08	0.06		0.08	0.10
379.4										0.004	0.051			
										0.001	0.013			

Eg(keV)	1970NO06	1970RI19	1971BA63	1972BA05	1977GE12	1980SH15	1984IW03	1986ME10	1989DA12	1990ME15	1990ST02	1992YA12	1993KA30	1998HW07*
385.7				0.109						0.024	0.269		0.167	
				0.049						0.003	0.026		0.026	
387.9										0.014	0.017		0.018	
										0.001	0.006		0.005	
391.3										0.006				
										0.001				
395.0											0.038		0.026	
											0.013		0.013	
406.7										0.004				
										0.001				
411.0	10.14	10.32	10.77	10.59	10.71	10.55	10.84	10.73	10.80	10.70	10.82		10.72	10.70
	0.54	0.51	0.38	0.27	0.11	0.22	0.07	0.10	0.10	0.10	0.15		0.23	0.29
416.0		0.487	0.513	0.500		0.513				0.530	0.526		0.500	
		0.051	0.064	0.051		0.026				0.010	0.026		0.026	
423.5										0.013	0.027	0.022	0.013	
										0.003	0.006	0.010	0.005	
440.9										0.052			0.069	
										0.009			0.006	
444.0		13.2	13.5	13.6										
		0.8	0.5	0.8										
444.0		1.15	1.67	1.28										
		0.38	0.26	0.26										
444.0@	15.47	14.36	15.13	14.87	15.00	14.95	15.01	14.81	14.90	14.80	15.06		15.18	13.78
	0.33	0.86	0.57	0.81	0.15	0.13	0.11	0.13	0.20	0.20	0.22		0.22	0.39
482.3		0.141	0.115	0.128		0.167				0.130	0.154			
		0.026	0.026	0.026		0.013				0.010	0.026			
488.7		1.90	1.95	1.91	1.98	1.95	2.03		1.95	1.95	2.01		1.95	1.97
		0.12	0.13	0.06	0.02	0.03	0.02		0.04	0.02	0.04		0.05	0.05
493.5		0.115	0.154	0.218		0.179				0.190	0.179		0.103	
		0.051	0.038	0.038		0.026				0.010	0.026		0.026	
496.3				0.038		0.051				0.044	0.064		0.040	
				0.015		0.013				0.003	0.026		0.009	

Eg(keV)	1970NO06	1970RI19	1971BA63	1972BA05	1977GE12	1980SH15	1984IW03	1986ME10	1989DA12	1990ME15	1990ST02	1992YA12	1993KA30	1998HW07*
503.5		0.705	0.718	0.705		0.718	0.768			0.730	0.782		0.474	
		0.038	0.077	0.038		0.026	0.018			0.010	0.051		0.256	
520.2		0.231	0.269	0.256		0.282				0.257	0.231			
		0.051	0.038	0.038		0.026				0.007	0.026			
523.1			0.051	0.031						0.071	0.103		0.096	
			0.026	0.010						0.004	0.038		0.123	
526.9			0.051	0.046		0.064				0.063	0.077		0.060	
			0.026	0.014		0.026				0.003	0.026		0.029	
534.4			0.179	0.179										
			0.051	0.051										
535.4#		0.205	0.218	0.205		0.231				0.206	0.192		0.167	
		0.051	0.053	0.052		0.026				0.005	0.038		0.026	
538.3										0.020				
										0.003				
556.6										0.091	0.077			
										0.005	0.013			
556.5#			0.115	0.090		0.051				0.110	0.128		0.090	
			0.026	0.026		0.026				0.006	0.018		0.013	
557.9										0.019	0.051			
										0.004	0.013			
561.2				0.013						0.005				
				0.006						0.001				
562.9				0.18										
				0.06										
564.0#		2.40	2.46	2.38		2.31	2.43		2.36	2.36	2.32			
		0.19	0.19	0.09		0.06	0.04		0.06	0.05	0.05			
566.4		0.526	0.564	0.577		0.679	0.640			0.620	0.551		0.697	
		0.128	0.128	0.051		0.038	0.060			0.010	0.026		0.022	
571.8										0.023			0.025	
										0.004			0.008	
586.3		2.08	2.28	2.22	2.24	2.27	2.19		2.22	2.20	2.24			2.14
		0.27	0.14	0.09	0.05	0.05	0.08		0.05	0.05	0.05			0.05

Eg(keV)	1970NO06	1970RI19	1971BA63	1972BA05	1977GE12	1980SH15	1984IW03	1986ME10	1989DA12	1990ME15	1990ST02	1992YA12	1993KA30	1998HW07*
595.6											0.154		0.015	
											0.051		0.008	
616.1			0.064	0.049		0.038				0.043	0.051	0.038	0.064	
			0.026	0.015		0.026				0.004	0.013	0.013	0.026	
644.4			0.064	0.029		0.038				0.028	0.051	0.027	0.028	
			0.038	0.009		0.026				0.004	0.013	0.010	0.009	
656.5		0.590	0.744	0.679		0.654	0.710			0.690	0.718		0.692	
		0.064	0.090	0.051		0.038	0.050			0.010	0.038		0.026	
664.8			0.045	0.017		0.038				0.090	0.064		0.051	
			0.019	0.008		0.026				0.010	0.026		0.038	
671.3		0.059	0.090	0.109		0.064				0.110	0.077	0.091	0.051	
		0.027	0.051	0.038		0.026				0.010	0.038	0.009	0.026	
674.7		0.385	0.744	0.615										
		0.103	0.103	0.064										
675.0#		0.846	0.872	0.744		0.949	0.940			0.890	0.936		0.846	
		0.154	0.115	0.082		0.038	0.050			0.030	0.051		0.038	
678.6		2.06	2.31	2.19	2.30	2.31	2.28		2.21	2.21	2.41		2.24	2.22
		0.15	0.14	0.14	0.03	0.06	0.05		0.03	0.04	0.08		0.05	0.07
686.6			0.192	0.128						0.092				
			0.051	0.051						0.008				
688.7		3.88	4.15	4.14	4.12	4.08	4.20		4.12	4.09	4.06		4.17	4.06
		0.22	0.22	0.27	0.04	0.10	0.04		0.05	0.08	0.08		0.08	0.11
696.9											0.077		0.014	
											0.038		0.005	
703.3				0.073						0.025	0.103		0.013	
				0.022						0.004	0.038		0.009	
712.8		0.346	0.462	0.423		0.487				0.460	0.474			
		0.090	0.077	0.090		0.038				0.010	0.038			
719.3#		1.42	1.64	1.53		1.67	1.67		1.51	1.56	1.62		1.58	
		0.13	0.17	0.13		0.05	0.03		0.02	0.03	0.04		0.04	
719.3			0.283	0.282										
			0.077	0.038										

Eg(keV)	1970NO06	1970RI19	1971BA63	1972BA05	1977GE12	1980SH15	1984IW03	1986ME10	1989DA12	1990ME15	1990ST02	1992YA12	1993KA30	1998HW07*
728.0				0.044		0.051				0.054	0.064	0.051	0.064	
				0.009		0.013				0.050	0.026	0.013	0.013	
735.4										0.028				
										0.005				
756.1										0.026			0.301	
										0.004			0.013	
764.9		0.821	0.910	0.885			0.950			0.840	0.962		0.936	
		0.141	0.103	0.115			0.050			0.040	0.051		0.038	
768.9		0.372	0.397	0.346		0.410				0.430	0.500		0.449	
		0.103	0.064	0.038		0.038				0.040	0.038		0.038	
778.9		59.7	62.6	59.9	62.6	62.5	62.16	62.1	62.2	61.9	62.1		62.5	63.7
		2.9	1.4	0.7	0.6	1.2	0.22	0.5	0.4	0.8	0.9		1.3	1.4
794.8		0.192	0.141	0.141		0.192				0.118	0.192		0.136	
		0.051	0.064	0.090		0.026				0.006	0.038		0.014	
805.7				0.077						0.061	0.090		0.050	
				0.026						0.005	0.026		0.009	
810.5		1.38	1.56	1.50		1.55	1.56		1.51	1.52	1.55		1.50	
		0.12	0.10	0.06		0.05	0.04		0.02	0.02	0.04		0.03	
839.4			0.077	0.079						0.079	0.064		0.077	
			0.038	0.045						0.005	0.013		0.013	
841.6			0.769	0.769						0.780	0.769		0.859	
			0.090	0.115						0.010	0.038		0.051	
867.4		19.23	20.09	19.31	20.54	20.29	20.33	20.36	20.40	19.90	20.33		20.45	20.92
		0.90	0.49	0.35	0.21	0.51	0.10	0.17	0.30	0.40	0.27		0.42	0.48
896.6											0.269		0.323	
											0.051		0.010	
901.2		0.295	0.385	0.359		0.346	0.400			0.440	0.397		0.449	
		0.090	0.064	0.077		0.038	0.050			0.030	0.038		0.038	
906.0										0.072			0.087	
										0.006			0.008	
919.3		1.88	2.06	1.91		2.14	2.08		2.09	2.09	2.04		2.05	2.05
		0.14	0.24	0.07		0.06	0.06		0.04	0.05	0.05		0.06	0.12

Eg(keV)	1970NO06	1970RI19	1971BA63	1972BA05	1977GE12	1980SH15	1984IW03	1986ME10	1989DA12	1990ME15	1990ST02	1992YA12	1993KA30	1998HW07*
926.3		1.167	1.308	1.218		1.333	1.380		1.290	1.270	1.346		1.359	1.340
		0.103	0.128	0.115		0.051	0.060		0.040	0.040	0.641		0.051	0.058
930.6		0.308	0.333	0.346		0.359	0.370			0.350	0.385		0.308	
		0.077	0.064	0.051		0.038	0.060			0.010	0.038		0.038	
937.1				0.010						0.015	0.051			
				0.004						0.005	0.026			
958.6			0.064	0.077		0.064				0.110	0.103			
			0.038	0.038		0.026				0.010	0.038			
963.4			0.628	0.487										
			0.103	0.103										
964.1#		67.44	69.86	68.08	70.40	70.45	70.14	71.03	70.50	69.20	69.67		70.50	67.96
		3.33	1.79	1.79	0.70	1.41	0.23	0.40	0.60	0.90	0.95		1.49	1.93
974.1			0.045	0.051		0.064				0.069	0.090		0.065	
			0.019	0.013		0.013				0.005	0.026		0.009	
990.2		0.167	0.128	0.154		0.179				0.148	0.167		0.179	
		0.051	0.064	0.051		0.026				0.006	0.038		0.038	
1001.1										0.019			0.023	
										0.009			0.005	
1005.3		3.04	3.13	3.00	3.57	3.59	3.08		3.35	3.10	3.46		2.73	3.11
		0.31	0.32	0.21	0.07	0.13	0.02		0.04	0.07	0.13		0.12	0.13
1086.0		47.69	50.64	47.59	48.70	49.62	48.15	47.84	49.60	48.70	49.19		49.60	47.96
		2.82	1.54	0.86	0.50	1.28	0.16	0.31	0.40	0.80	0.67		0.94	1.06
1089.7		8.00	8.46	7.90	8.26	8.59	8.35	8.19		8.20	7.97		8.19	8.19
		0.64	0.77	0.37	0.09	0.26	0.04	0.10		0.10	0.51		0.17	0.19
1109.2			0.897	0.808			1.000			0.880				
			0.385	0.179			0.050			0.020				
1112.0#		63.59	65.77	63.99	65.00	65.64	65.67	65.45	65.90	65.80	65.23		62.47	
		3.21	1.85	0.87	0.70	1.28	0.22	0.78	0.50	0.90	0.99		1.12	
1112.0			64.87	63.18			64.67			64.90				
			1.79	0.86			0.21			0.90				
1139.0										0.006			0.006	
										0.002			0.002	

Eg(keV)	1970NO06	1970RI19	1971BA63	1972BA05	1977GE12	1980SH15	1984IW03	1986ME10	1989DA12	1990ME15	1990ST02	1992YA12	1993KA30	1998HW07*
1170.9		0.167	0.167	0.167		0.256				0.171	0.231		0.141	
		0.038	0.038	0.038		0.026				0.006	0.038		0.038	
1206.1			0.064	0.038		0.038				0.072	0.064		0.051	
			0.038	0.013		0.026				0.005	0.026		0.013	
1212.9		6.55	7.05	6.74	6.67	6.72	6.85		6.83	6.70	6.97		6.85	6.70
		0.35	0.26	0.26	0.07	0.14	0.05		0.05	0.08	0.18		0.15	0.19
1249.9		0.795	0.885	0.833		0.962	0.875			0.880	0.923		0.859	0.921
		0.090	0.077	0.064		0.038	0.024			0.050	0.051		0.064	0.039
1261.3		0.154	0.167	0.167		0.192				0.157	0.192		0.162	
		0.038	0.038	0.038		0.026				0.006	0.026		0.060	
1292.8		0.487	0.474	0.474		0.500	0.460			0.490	0.641		0.654	
		0.090	0.077	0.077		0.026	0.030			0.030	0.064		0.077	
1299.1		7.71	8.23	7.88	7.76	7.97	7.80		7.88	7.80	7.94		8.08	
		0.40	0.41	0.44	0.08	0.19	0.05		0.06	0.10	0.19		0.36	
1314.7			0.019	0.018		0.038					0.038	0.024	0.026	
			0.009	0.006		0.013					0.013	0.005	0.013	
1348.1		0.058	0.090	0.081		0.090				0.081	0.090	0.078	0.115	
		0.023	0.013	0.010		0.013				0.006	0.013	0.008	0.013	
1363.8		0.108	0.128	0.126		0.141				0.117	0.128		0.132	
		0.031	0.013	0.015		0.013				0.005	0.013		0.012	
1390.4			0.026	0.019						0.023	0.031	0.024	0.015	
			0.013	0.006						0.006	0.010	0.005	0.010	
1408.0		99.5	103.6	97.7	100.0	99.9	100.0	100.0	100.0	100.0	99.2		102.6	
		5.0	2.7	2.8	1.0	1.9	0.3	0.6	0.5	0.3	1.1		1.4	
1457.6		2.45	2.46	2.40	2.52	2.46	2.39		2.35	2.36	2.38			
		0.13	0.19	0.13	0.09	0.05	0.03		0.03	0.05	0.10			
1486.0											0.027		0.014	
											0.012		0.005	
1528.1		1.67	1.28	1.46		1.27	1.35		1.38	1.27	1.26		1.47	
		0.09	0.08	0.09		0.04	0.01		0.02	0.03	0.10		0.05	
1537.4		0.007		0.010		0.012								
		0.003		0.003		0.004								

Eg(keV)	1970NO06	1970RI19	1971BA63	1972BA05	1977GE12	1980SH15	1984IW03	1986ME10	1989DA12	1990ME15	1990ST02	1992YA12	1993KA30	1998HW07*
1605.6		0.035	0.038	0.037		0.051				0.036	0.038	0.044	0.041	
		0.008	0.008	0.008		0.013				0.003	0.013	0.004	0.009	
1608.4		0.029	0.023	0.027						0.024	0.027	0.029		
		0.006	0.008	0.006						0.002	0.006	0.004		
1635.2										0.0007				
										0.0002				
1643.6		0.024				0.005							0.009	
		0.005				0.003							0.003	
1647.4		0.033	0.028	0.031		0.038					0.041	0.024	0.031	
		0.006	0.006	0.006		0.013					0.006	0.004	0.003	
1674.3										0.029				
										0.004				
1769.0		0.042	0.041	0.042		0.038				0.042	0.038	0.049	0.046	
		0.004	0.006	0.005		0.013				0.003	0.013	0.003	0.006	

* Evaluators considered unwarranted the precision of the values given by 98Hw07. Their uncertainties have been doubled.

\# Value includes the contribution from the weakest component of the doublet.

@ Value is the sum of the components of the doublet.

Table 1. Relative g-Ray Emission Probabilities Evaluated in this Revision (Uncertainty given below the value), continuation

Eg(keV)	**ICRM01**	**ICRM02**	**ICRM08**	**ICRM10**	**ICRM12**	**ICRM15**	**ICRM16**	**ICRM17**	**ICRM18**	**ICRM20**	**ICRM25**	**ICRM27**	**ICRM28**	**ICRM29**
121.8	135.0	135.7	136.4	131.5	135.8		133.4		139.2	137.0		136.4	132.5	134.8
	1.9	0.8	0.5	4.3	0.9		1.4		2.9	1.0		3.0	2.9	2.0
244.7	35.5	35.5	36.3	36.2	35.9		36.3	36.7		35.7	35.7		36.3	36.4
	0.5	0.3	0.2	1.0	0.5		0.3	1.1		0.4	0.4		0.7	0.4
344.3	128.9	127.2	127.4	123.9	127.6	130.6	130.4	127.1		127.2	126.7	126.2	128.9	128.8
	1.5	0.8	0.6	2.8	0.4	2.9	1.2	1.1		1.0	1.1	3.4	2.4	1.3
411.0	10.46	10.67	10.80	10.27	10.75	10.77	10.90	10.71	10.90	10.72	10.90	10.62	10.72	10.86
	0.16	0.07	0.06	0.22	0.04	0.12	0.12	0.11	0.23	0.10	0.33	0.67	0.26	0.12
444.0@	14.68	14.84	14.96	14.35	15.07	15.25	15.33	14.88	15.3	14.95	14.73	14.64	15.15	15.22
	0.21	0.09	0.07	0.4	0.06	0.12	0.18	0.15	0.26	0.13	0.43	0.89	0.32	0.15
778.9	62.4	62.6	62.25		62.12	62.6	62.4	62.6	61.8	61.9	61.1	61.0	62.0	62.4
	0.8	0.4	0.19		0.23	0.4	1.2	0.6	1.2	0.4	0.9	1.0	1.0	0.5
964.1	69.62	69.82	70.10		70.41	70.40	69.80	70.30	69.90	70.30	70.90	69.30	68.40	70.10
	0.84	0.42	0.23		0.22	0.60	0.90	0.70	1.00	0.40	1.00	1.00	1.10	0.50
1086.0	48.89	48.61	49.13	47.43	48.83	49.10	47.90	48.70	48.90	48.40		48.50		48.59
	0.59	0.29	0.19	0.60	0.14	0.40	0.60	0.50	0.50	0.30		0.90		0.30
1112.0	64.28	64.45	65.25	64.00	65.26	65.70	64.70	64.30	66.70	64.90	67.20	64.50	65.50	65.30
	0.77	0.32	0.27	0.80	0.20	0.70	0.40	0.60	0.80	0.50	0.90	1.10	1.00	0.50
1408.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	1.2	0.5	0.3	1.5	0.3	0.9	0.9	1.0	1.2	0.5	1.2	1.5	2.3	0.7

Eg(keV)	**ICRM30**	**ICRM31**	**ICRM34**	**ICRM35**
121.8	136.8	135.5	138.9	134.9
	4.1	2.0	4.3	1.2
244.7	37.9	35.6		36.4
	1.2	0.5		0.2
344.3	132.7	126.6	133.9	126.4
	4.0	1.3	5.5	0.9
411.0	11.21	10.52	11.18	10.57
	0.39	0.14	0.53	0.08
444.0		14.89	16.15	14.81
		0.19	0.73	0.16

Eg(keV)	**ICRM30**	**ICRM31**	**ICRM34**	**ICRM35**
778.9	61.2	61.3	64.2	62.0
	1.9	0.7	2.1	0.5
964.1	69.80	70.00	71.20	69.90
	2.20	0.80	2.30	0.50
1086.0	50.70	48.00	50.00	
	1.50	0.50	1.20	
1112.0	64.70	65.40	66.50	64.20
	2.00	0.80	1.50	0.70
1408.0	100.0	100.0	100.0	100.0
	3.0	1.0	2.9	1.2

Table 2. Recommended Relative g-Ray Emission Probabilities (Uncertainty given below the value).

Eg(keV)	Recommended	c2/n	Remarks
121.8	136.35 0.25	1.3	
125.7	0.09 0.03	9.9	
148.0	0.166 0.024	5.8	
166.9			[18]
173.1			[18]
192.6	0.0326 0.0010	1.1	
202.6			[18]
207.6	0.0285 0.0019	2.1	
209.4	0.0266 0.0025	0.60	
212.6	0.094 0.003	0.23	
237.3	0.012 0.004		[1]
239.4	0.036 0.016	3.2	
244.7	36.23 0.08	1.5	
251.6	0.322 0.007	2.4	
269.9	0.029 0.012	8.0	
271.1	0.374 0.014	1.9	[2]
275.5	0.155 0.008	2.3	
286.0	0.048 0.003	1.2	
295.9	2.123 0.013	1.6	
315.2	0.238 0.008	1.1	[3]
316.2	0.015 0.005		[3]
320.0	0.008 0.003		[13]
324.8	0.354 0.007	0.27	
329.4	0.62 0.03	11	
330.5	0.029 0.008		[4]
340.4	0.151 0.016	4.6	
344.3	127.53 0.20	0.66	
351.7	0.067 0.011	2.2	
357.3	0.0194 0.0024	4.0	
367.8	4.136 0.018	0.77	
379.4	0.004 0.001		[5]
385.7	0.024 0.003		[6]
387.9	0.0142 0.0010		[5]
391.3	0.006 0.001		[13]
395.0			[18]
406.7	0.004 0.001		[13]
411.0	10.735 0.020	0.95	
416.0	0.523 0.008	0.4	
423.5	0.0155 0.0023	1.7	
440.9	0.064 0.005	2.5	
444.0	13.46 0.09		[7]
444.0	1.53 0.09		[7]
444.0	14.99 0.03	1.2	[7]
482.3	0.141 0.008	1.3	
488.7	1.985 0.008	1.8	

Eg(keV)	Recommended	c2/n	Remarks
493.5	0.178 0.016	2.1	
496.3	0.044 0.004	0.31	
503.5	0.735 0.008	1.0	
520.2	0.257 0.006	0.46	
523.1	0.054 0.010	2.7	
526.9	0.062 0.003	0.39	
534.4	0.176 0.009	0.56	[8]
535.4	0.029 0.010		[8]
538.3	0.020 0.003		
556.6			[18]
556.5	0.085 0.005	1.7	[9]
557.9	0.021 0.003	5.5	[9]
561.2	0.0052 0.0010	1.7	
562.9	0.18 0.06		[4]
564.0	2.19 0.06		[10]
566.4	0.628 0.018	3.2	

Eg(keV)	Recommended	c2/n	Remarks
571.8	0.023 0.004	0.10	
586.3	2.215 0.019	0.57	
595.6	0.015 0.008		[11]
616.1	0.044 0.003	0.32	
644.4	0.030 0.003	0.65	
656.5	0.689 0.008	0.63	
664.8	0.046 0.014	6.6	
671.3	0.093 0.006	1.3	
674.7			[18]
675.0	0.897 0.021	1.3	
678.6	2.256 0.015	1.3	
686.6	0.096 0.008	2.1	
688.7	4.037 0.021	0.60	
696.9	0.014 0.005		[11]
703.3	0.025 0.004	3.6	
712.8	0.461 0.009	0.48	

Eg(keV)	Recommended	c2/n	Remarks
719.3	1.29 0.06	0.33	[12]
719.3	0.282 0.035	0.0	[12]
728.0	0.051 0.006	0.37	
735.4	0.028 0.005		[13]
756.1	0.026 0.004		[13]
764.9	0.912 0.021	0.94	
768.9	0.424 0.016	1.5	
778.9	62.17 0.09	0.8	
794.8	0.126 0.005	2.3	
805.7	0.060 0.004	1.0	
810.5	1.519 0.011	0.57	
839.4	0.077 0.004	0.29	
841.6	0.782 0.009	0.62	
867.4	20.35 0.07	1.3	
896.6	0.321 0.010	1.0	
901.2	0.404 0.016	1.0	

Eg(keV)	Recommended	c2/n	Remarks
906.0	0.077	2.2	
	0.005		
919.3	2.06	1.1	
	0.02		
926.3	1.309	0.73	
	0.019		
930.6	0.350	0.37	
	0.009		
937.1	0.013	1.4	
	0.003		
958.6	0.101	1.10	
	0.009		
963.4	0.644		[14]
	0.009		
964.1	69.55	0.62	[14]
	0.10		
974.1	0.066	0.76	
	0.004		
990.2	0.151	0.39	
	0.006		
1001.1	0.022	0.15	
	0.005		
1005.3	3.19	9.6	
	0.11		
1086.0	48.63	1.9	[17]
	0.20		
1089.7	8.30	0.78	
	0.03		
1109.2	0.892		[15]
	0.018	1.7	
1112.0	64.30		[15]
	0.09		

Eg(keV)	Recommended	c2/n	Remarks
1112.0			[18]
1139	0.006		[13]
	0.002		
1170.9	0.175	2.2	
	0.006		
1206.1	0.065	1.7	
	0.004		
1212.9	6.79	0.95	
	0.03		
1249.9	0.894	0.89	
	0.015		
1261.3	0.161	0.56	
	0.005		
1292.8	0.499	1.6	
	0.015		
1299.1	7.83	0.48	
	0.03		
1314.7	0.023	0.73	
	0.003		
1348.1	0.084	1.2	
	0.004		
1363.8	0.123	0.75	
	0.004		
1390.4	0.023	0.36	
	0.003		
1408.0	100.00	0.22	
	0.12		
1457.6	2.388	0.82	
	0.017		
1486.0			[18]

Eg(keV)	Recommended	c2/n	Remarks
1528.1	1.349	4.4	
	0.021		
1537.4			[18]
1605.6	0.0388	0.54	
	0.0020		
1608.4	0.0255	0.38	
	0.0016		
1635.2	0.0007		[13]
	0.0002		
1643.6	0.0070	0.89	[16]
	0.0020		
1647.4	0.0305	1.1	
	0.0019		
1674.3	0.029		[13]
	0.004		
1769.0	0.0441	0.63	
	0.0016		

REMARKS

- Evaluator's recommended relative γ-ray emission probabilities deduced using the *Limitation of Relative Statistical Weights* method, unless otherwise specified.
- For absolute intensity per 100 disintegrations, multiply by 0.2085 (8).

[1]. From 1993Ka30.
[2]. Iγ = weighted average (Iγ(271) doublet) - Iγ(269) = 0.403 (7) - 0.029 (12) = 0.374 (14). $\chi2/\nu$ = 1.9.
[3]. Iγ = weighted average (Iγ(315) doublet) - Iγ(316) = 0.253 (7) - 0.015 (5) = 0.238 (8). $\chi2/\nu$ = 1.1.
[4]. From 72Ba05.
[5]. From 1990Me15. Value agrees with <0.006 (1990St02).
[6]. From 1990Me15. Author removed double-escape contribution from 1408-keV γ ray.
[7]. Iγ = weighted average (Iγ(444) doublet) - Iγ(444, 810 level) = 14.99 (3) - 1.53 (9) = 13.46 (9).
$\chi2/\nu$ = 1.2. Ig(444, 810 level) is from 152Eu(9.3h) EC decay branching.
[8] I_γ=weighted average (I_γ (535)) – I_γ (534) = 0.205 (5) – 0.176(9)=0.029(10)
[9]. Iγ = weighted average (Iγ(556.5) doublet) - weighted average Iγ(557.8) = 0.106 (5) - 0.021 (4) = 0.085 (6)
[10]. Iγ = weighted average (Ig(563.8) doublet) - Ig(562.9) = 2.37 (2) - 0.18 (6) = 2.19 (6). $\chi2/\nu$ = 0.64.
Iγ(562.9) = 2.37 (2) from transition intensity balance.
[11]. From 1993Ka30, close to upper limit of 92Ya12.
[12]. Iγ = weighted average (Iγ(719) doublet, $\chi2/\nu$ = 3.4) - weighted average Iγ(719.4) = 1.57 (2) - 0.282 (35) = 1.29 (6).
[13]. From 1990Me15.
[14]. Iγ = weighted average (Iγ(964) doublet) - Iγ(963) = 70.19 (10) - 0.644 (9) = 69.55 (10).
Iγ(963) = 0.644 (9) is from 152Eu(9.3h) EC decay branching.
[15]. Iγ = weighted average (Iγ(1112) doublet, $\chi2/\nu$ = 1.5) - weighted average Iγ(1109, $\chi2/\nu$ = 1.7) = 65.19 (9) - 0.895 (18) = 64.30 (9)
[16]. Weighted average of values from 1980Sh15 and 1993Ka30.
[17] Iγ = Iγ (1084)+ Iγ (1086)=1.17 (4) (1990Me15) + 47.46 (20)=48.63 (20)
[18]. Existence is uncertain.

Table 3. Absolute Emission Probabilities of KX Rays

P_{KX}*	70No06	Faerman[†]	72Da23	Bylov[‡]	79De36, 83De11	85Se18	86Me10	93Ka30	P_{KX} (Avg.)[&]	P_{KX}(Cal.)[@]
Sm KA	0.492(35)	0.592(21)	0.501(16)	0.595(9)	0.591(12)	0.595(9)	0.589(9)	0.595(90)	0.584(11)	0.585(7)
Sm KB	0.122(9)	0.173(9)	0.122(8)	0.143(8)	0.149(3)	0.143(8)	0.144(2)	0.137(5)	0.144(3)	0.1482(24)
Gd KA			0.0068(2)	0.00636(14)	0.00648(22)	0.00636(14)	0.00459(11)[#]		0.00645(8)	0.00680(18)
Gd KB			0.00167(50)	0.00163(4)	0.00176(18)	0.00163(4)	0.00171(3)		0.00167(2)	0.00174(5)

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* Absolute emission probabilities renormalized to Pg(121)=0.2841(13), Pg(344)=0.2658(12), or Pg(1408)=0.2084(9).

[&] Weighted average (LWM).

[#] Outlier, not used for calculating the average.

[†] Faermann S, Notea A., Segal Y., Trans. Am. Nuc. Soc. 14, 500 (1971).

[‡] Bylov T., Osipenko B.D., Chunin V.G., EchA Ya no. 9, 1350 (1978) (quoted by 85Se18).

[@] Calculated by evaluators using recommended γ-ray data and K-fluorescence yields.

^{153}Sm - Comments on evaluation of decay data by M.M. Bé, R. G. Helmer and E. Schönfeld

First evaluation was done in 2001 by R.G. Helmer and E. Schönfeld, it has been updated in June 2005, including new half-life and gamma intensity values.

1 Decay Scheme

There are many levels in ^{153}Eu below the decay energy, so other levels may be weakly populated in this decay.

2 Nuclear Data

The Q value is from Audi and Wapstra 2003 (2003Au03). Level energy, spin and parity data are from 1998He06.

The half-life values available are, in hours:

1942Ku03	47	1	as quoted in 1990Le13
1946Mi06	46		as quoted in 1990Le13
1952Ru10	46.5	1	as quoted in 1990Le13
1954Le08	47	0.3	as quoted in 1990Le13
1958Co76	47.1	0.1	
1958Gu09	46.7	1.6	
1960Wi10	45	8	outlier
1961Gr18	46.2	0.1	
1961Wy01	46.8	0.1	
1962Ca24	47.1	0.1	
1963Ho15	46.5	0.5	
1970Ch09	46.75	0.09	
1971Ba28	46.44	0.08	
1987Co04	46.27	0.01	superseded by 1992Un01
1989Ab05	46.70	0.05	
1989Po21	45.6	1.6	outlier
1992Un01	46.2853	0.0014	
1998Bo18	46.285	0.004	
1999Sc12	46.274	0.007	superseded by 2004Sc
2004Sc04	46.281	0.007	*Corrected value and uncertainty*
Adopted	**46.2851**	**0.0013**	**or 1.92855 (5) d**

A mistake appears in the value of the Sm -153 half-life published by 2004Sc04 in Applied Radiation Isotopes 60 (2004) 317 ; after discussion with the author the correct value is 1.92838 (29) d instead of 1.9284 (29) d.

Data are very discrepant, ranging from 46.281 (7) to two values of 47.1 (1), a difference of about 8σ.

The Limitation of Relative Statistical Weight, LRSW, analysis (1985ZiZY, 1992Ra08), with the Lweight 3 program, shows that the values from 1960Wi10 and 1989Po21 are outlier due to Chauvenet's criterion, the reduced-χ^2 is 18.9 and the uncertainty of 1992Un01 value is increased to 0.0034 to reduce its weight to 50 %. The weighted mean is 46.2874 with a σ_{int} of 0.0024 and a σ_{ext} of 0.011. Then, the program recommends the unweighted mean and expands the uncertainty to include the most precise value, this leads to a value of 46.64 (36) h.

The average of the measured values has decreased with time and the last three unreplaced values, which are from metrology laboratories, are among the lowest values and they are consistent. The weighted average of these three values is 46.2851 with a σ_{int} of 0.0013, a reduced-χ^2 of 0.18, and a σ_{ext} of 0.0006. This weighted average and the internal uncertainty are adopted.

2.1 b$^-$ Transitions

The probabilities for the β^- branches are primarily from the intensity balances from the γ-ray transition probabilities for all levels including the ground state. This is possible because one has measurements of the absolute emission probabilities for the 69- and103-keV γ-rays (1987Co04, 1998Bo18, 1999Sc12, 2006Le).

The measured β^- probabilities (in %) from the decomposition of the β^- spectra are:

Level (keV)	Values (%)
0	15 (1952Ba49), 20 (1954Gr19), 21 (1954Le08), 20 (1955Ma62), 22 (1956Du31), 20 (1957Jo24), and 20 (1958Co76) compared to the adopted value of 19.5(15) %.
103	67 (1950Hi17), 35 (1952Ba49), 49 (1954Gr19), 70 (1954Le08), 35 (1955Ma62), 38 (1956Du31), 65 (1957Jo24), and 40 (1958Co76) which have an average of 50(14) compared to the adopted value of 49.2(17)% from the probability balance.
172	50 (1952Ba49), 30 (1954Gr19), 43 (1955Ma62), 40 (1956Du31), 15 (1957Jo24), and 40 (1958Co76) which have an average of 36(11) compared to the adopted value of 30.4(8)% from the probability balance.

2.2 Gamma Transitions

The energies and multipolarities are from theadopted gamma data in Nuclear Data Sheets (1998He06) and they are based on the internal-conversion electron data of 1961Mo07, 1962Su01, 1969Sm04, and 1970PaZI. Gamma transition probabilities are deduced from the gamma emission intensities and the conversion electron coefficients interpolated from the tables of Band *et al.* (2002Ba85).
The 19-keV gamma transition probability is deduced from the probability balance at the 83-keV level.

3 Atomic Data

The fluorescence yields and K x-ray relative intensities are from 1996Sc06.

4 Emissions

4.1 Electron Emission

Data were computed by EMISSION for the Auger electrons and with LOGFT for the average β^- energies.

4.2 Photon Emission

From the evaluation 2000He14, the curved-crystal spectrometer data for the decay of ^{153}Sm and ^{153}Gd give the energies for the γ-rays of 69, 75, 83, 89, 97, 103, and 172 keV on a scale on which the strong line from the decay of ^{198}Au is 411.80205(17). The γ-ray energies from the (n, γ) study of 1970Mu04 have been adjusted to this energy scale to provide values at 54, 68, 96, 118, 151, 166, and 172 keV. The values for 14 and 19 keV are from level energy differences.
The other γ-ray energies are from the data in the following table 1.

Table 1: Gamma-ray energies

1969Un03	1985Ab08	1969Pa03	Adopted	
412.05 (20)	412.26 (30)	411.9 (1)	412.05 (20)	doubly placed
424.38 (20)	424.79 (32)	424.2 (2)	424.4 (3)	
	431.65 (10)			
436.83 (20)	437.10 (30)	436.7 (2)	436.9 (3)	
	443.24 (45)		443.2 (5)	
		462.0 (3)	462.0 (3)	
463.67 (15)	463.93 (35)	463.4 (2)	463.6 (2)	
485.03 (20)	485.12 (40)	484.5 (2)	485.0 (2)	
	487.75 (23)		487.75 (23)	
509.11 (15)	510.36 (35)	509.0 (1)	509.15 (20)	
521.28 (15)	521.62 (26)	521.1 (1)	521.30 (25)	
		523.8 (6)		
531.38 (15)	531.43 (34)	531.6 (3)	531.40 (15)	
533.34 (15)	533.17 (25)	533.1 (1)	533.2 (2)	
539.03 (10)	539.10 (20)	539.2 (3)	539.1 (2)	
542.60 (20)	543.01 (45)	542.7 (6)	542.7 (2)	
545.75 (15)	545.68 (42)		545.75 (15)	
554.94 (10)	554.73 (37)	555.0 (1)	554.94 (10)	
	555.71 (15)			
574.01 (30)	574.32 (51)		574.1 (3)	
578.66 (15)	578.94 (30)	578.8 (1)	578.75 (20)	
584.49 (20)	584.67 (32)	584.8 (5)	584.55 (20)	
587.47 (20)	587.73 (22)	587.7 (6)	587.60 (25)	
	589.3			
590.96 (20)	591.03 (21)	590.7 (6)	590.96 (20)	
596.72 (15)	596.29 (30)	596.9 (2)	596.7 (2)	
598.4 (3)	598.13 (30)		598.3 (3)	doubly placed
603.39 (15)	604.04 (26)	603.5 (2)	603.6 (4)	doubly placed
609.22 (10)	610.21 (42)	609.4 (1)	609.5 (3)	doubly placed
		612 (1)		
615.41 (20)	616.28 (22)	615.5 (6)	615.8 (4)	doubly placed
617.71 (20)	618.07 (24)	618.0 (6)	617.9 (3)	
	623.73 (24)			
630.70 (30)	630.33 (26)	630 (1)	630.5 (4)	
634.61 (30)	634.92 (32)		634.8 (3)	
636.45 (25)	636.73 (30)	636.4 (2)	636.5 (2)	
657.55 (25)	657.68 (25)	657.4 (4)	657.55 (25)	doubly placed
		662.4 (6)	662.4 (6)	
676.9 (5)	677.09 (30)	676 (1)	677.0 (3)	
		682.0 (6)	682.0 (6)	
685.6 (3)	686.64 (21)	685.9 (3)	686.0 (4)	
694.4 (4)	694.02 (25)	694 (1)	694.1 (3)	
701.5 (4)	702.08 (24)	701.7 (10)	701.8 (4)	
706.2 (4)	707.29 (28)	706 (1)	706.8 (5)	
713.6 (3)	713.98 (22)	714.1 (6)	713.9 (3)	
718.5 (4)	719.26 (28)	719.1 (6)	719.0 (4)	
760.2 (3)	760.92 (38)	760.3 (6)	760.5 (4)	
	763.8	763.8 (6)	763.8 (6)	

For the relative γ-ray emission probabilities, the data listed in Table 2 were available. The values of 1969Un03 and 1985Ab08 were not listed since they do not have individual uncertainties and those of 1969Sm04 were not used because the ^{153}Sm was just a background in an (n,γ) study.
Some gamma emissions with weak intensities and reported by only one or two authors are not listed in Table 2, they are : 54.1 ; 68.2 ; 96.8 ; 118.1 ; 166.5 ; 487.7 ; 574.1 ; 630.5 ; 677.0 ; 682.0 ; 694.1 ; 701.8 ; 706.8 ; 719.0 ; 763.8 keV.
The emission intensities assigned to each of the components of the doublets at 598, 603, 609, 615 and 657 keV are equal, as there is no information on how to split the total intensity for the doublet.

For all cases with three or more values, the weighted average is computed by the Limitation of Relative Statistical Weight method. If the reduced-χ^2 is > critical χ^2 and one value has a relative weight > 50%, the uncertainty of this value is increased in order to reduce the relative weight to 50% and this is noted in the table. If the reduced χ^2 is ≤ critical χ^2, no such change is made, but if the relative weight is over 70% this is noted. For all weighted averages the internal uncertainty is given, and if the reduced-χ^2 is > 1.0 the external uncertainty is also given. In some cases the LRSW method expands the uncertainty to include the most precise value; this uncertainty is given as σ_{LRSW}. The adopted values are given in the last row.

The relative γ-ray emission probabilities adopted in Table 2 were normalized to γ's per 100 decays by consideration of the absolute emission probabilities measured by 1987Co04, 1998Bo18, 1999Sc12 and 2006Le. Of the five γ rays that are given in all papers, the three strongest, at 69, 97, and 103 keV, were considered. Since the weighted average of the data for the 97-keV γ-ray gave a reduced-χ^2 value of 20, it was omitted.
For the 69-keV γ-ray, the weighted average of the four values is 4.668 γ's per 100 decays with an internal uncertainty of 0.026, a reduced -χ^2 of 3.1, and an external uncertainty of 0.047. The latter uncertainty was adopted.
For the 103-keV γ ray, the weighted average of the four values is 29.19 γ's per 100 decays with an internal uncertainty of 0.12, a reduced -χ^2 of 1.8, and an external uncertainty of 0.16. The value of 29.19 (16) was adopted and used to convert the relative values into absolute values as listed in the latest line in Table 2.

Table 3. Absolute emission intensities

	103.18 keV		69.6 keV		97.4 keV	
	I %	Uc	I %	Uc	I %	Uc
1987Co04	29.82	0.36	4.85	0.07	0.847	0.011
1998Bo18	28.5	0.5	4.67	0.05	0.794	0.017
1999Sc12	29.23	0.18	4.65	0.05	0.755	0.007
2006Le	29.07	0.2	4.59	0.05	0.738	0.013
chi2	1.8		3.1		19.7	
WM	**29.19**	**0.16**	4.668	0.047	0.778	0.024

X-ray emissions

The measured x-ray emission intensities (in %) are compared with the calculated values deduced from the decay scheme :

XK	$K\alpha_2$		$K\alpha_1$		$K\alpha$		$K\beta'_1$		$K\beta'_2$		$K\beta$	
1992Ch44					44.43	1.31	8.55	0.29	2.23	0.09		
1999Sc12	16.27	0.18	29.4	0.4	45.7	0.5	9.26	0.12	2.444	0.027	11.7	0.13
2006Le	16.03	0.27	28.53	0.20	44.56	0.3	9.03	0.07	2.37	0.06	11.4	0.12
LWM	16.20	0.15	28.70	0.35	44.85	0.35	9.07	0.10	2.417	0.041	11.54	0.15
Calculated	16.6	0.4	30.0	0.7	46.6	1.1	9.45	0.25	2.44	0.08	11.9	0.3

XL	Ll		Lα		Lβ		Lγ	
1992Ch44	0.190	0.018	4.90	0.26	4.20	0.26	0.651	0.044
1999Sc12	0.216	0.011	4.94	0.11	4.26	0.09	0.615	0.01
2006Le	0.245	0.012	5.06	0.15	4.33	0.13	0.0628	0.022
LWM	0.222	0.014	4.97	0.08	4.28	0.07	0.40	0.22
Calculated	0.213	0.007	5.20	0.15	4.63	0.10	0.755	0.017

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Table 2 : gamma relative and absolute emission intensities (1)

keV	**69**		**75**		**83**		**89**		**97**		**151**		**172**		**412(d)**	
1964Al09	1730(O)	100	61	4	75	4	58	3	263	13	3.2	0.5	21(O)	2		
1966Bl06															0.64	0.2
1969Pa03											5.1(O)	1.6	24	5	0.73	0.13
1974HeYW	1620	140	110(O)	12	63	6	32	4	233	20	3	0.5	28	3	0.8	0.1
1987Co04	1626	21	117(O)	5	68	4			284	4			27	0.4		
1992Ch44	1620	50	55	2	63	2	59	2	255	4	3.5	0.1	25	0.4	0.65	0.02
1998Bo18	1639	18	65	4	58	4			279	6			25.3	1.1		
1999Sc12	1591	17	80(O)	7	72	4	53.4	2.4	258.3	2.4	3.93	0.21	24.5	0.24	0.65	0.04
2006Le	1579	17	61	7	69.8	3.4	37	8	253.9	4.5	3.47	0.21	25	0.6	0.38(O)	0.05
Chi2	1.53		2.02		2.55		10.71		8.14		1.34		4.91		0.63	
Chi2 crit	3.02		3.79		2.80		3.32		2.80		3.32		2.80		3.32	
UWM:	1612.5		60.500		66.971		47.880		260.886		3.42		25.543		0.694	
WM:	1606.644		57.839		66.094		53.918		262.783		3.538		25.151		0.656	
Uc (int):	8.865		1.590		1.276		1.277		1.613		0.081		0.175		0.017	
Uc (ext):	10.967		2.258		2.038		4.181		4.603		0.093		0.388		0.014	
LWM :	1607	11	58	2.3	66.1	2	54	5	262.8	4.6	3.54	0.09	25.2	0.7	0.656	0.017
Abs	**4.691**	**0.041**	**0.169**	**0.007**	**0.193**	**0.006**	**0.158**	**0.015**	**0.767**	**0.014**	**0.01033**	**0.00027**	**0.0736**	**0.0021**	**0.00191**	**0.00005**

Table 2 : gamma relative and absolute emission intensities (2)

keV	**424**		**436**		**443**		**462**		**463**		**485**		**509**	
1964Al09														
1966Bl06	0.75	0.2	0.48	0.12					5.1	0.8	0.12	0.06	0.85	0.16
1969Pa03	0.73	0.13	0.5	0.1			0.5	0.1	4.7	0.4	0.12	0.06	0.61	0.2
1974HeYW	0.7	0.1	0.8(O)	0.1					5.3	0.4			1	0.1
1987Co04														
1992Ch44	0.65	0.02	0.53	0.02	0.030	0.005	0.7	0.2	4.3	0.8	0.13	0.01	0.62	0.03(U)
1998Bo18														
1999Sc12	0.62	0.04	0.57	0.03					4.34	0.06	0.12	0.03	0.63	0.06
2006Le	0.758	0.036	0.546	0.038	0.243	0.041			3.93	0.25			0.46	0.10
Chi2	1.80		0.42		13.49		0.80		2.03		0.05		3.61	
Chi2 crit	3.02		3.32		6.63		6.63		3.02		3.79		3.02	
UWM:	0.701		0.525		0.137		0.60		4.612		0.123		0.695	
WM:	0.669		0.541		0.137		0.540		4.349		0.129		0.651	
Uc (int):	0.016		0.015		0.029		0.089		0.057		0.009		0.030	
Uc (ext):	0.021		0.010		0.107		0.080		0.081		0.002		0.058	
LWM :	0.669	0.021	0.541	0.015	0.140	0.11	0.54	0.09	4.35	0.08	0.129	0.009	0.65	0.06
Abs	**0.00195**	**0.00006**	**0.001579**	**0.000045**	**0.00041**	**0.00032**	**0.00158**	**0.00026**	**0.01270**	**0.00024**	**0.000377**	**0.000026**	**0.00190**	**0.00018**

Table 2 : gamma relative and absolute emission intensities (3)

keV	521		531		533		539		542		545		554	
1964Al09														
1966Bl06	$3.5^{(O)}$	0.7	22.3	2	11.6	1	9.1	1.4					1.93	0.3
1969Pa03	2.5	0.9	23	3	8.8	2.5	8.2	2.5	0.6	0.5			1.6	0.13
1974HeYW	$2.8^{(O)}$	0.2	23.8	2	11.9	0.8	8.6	0.6	$1.4^{(O)}$	0.1	0.3	0.1	2	0.2
1987Co04														
1992Ch44	2.3	0.1	18.9	1.3	10.4	0.1	7.2	0.2	0.77	0.08	0.26	$0.01^{(U)}$	1.61	0.04
1998Bo18			19.3	2.1	9.8	2.1								
1999Sc12	2.31	0.04	18.37	0.21	10.02	0.09	7.04	0.09	0.75	0.06	0.41	0.17	1.62	0.03
2006Le	2.281	0.024	18.74	0.17	9.91	0.07	7.09	0.05	0.85	0.048	0.368	0.027	1.484	0.047
Chi2	0.15		2.38		4.04		1.84		0.69		2.91		2.35	
Chi2 crit	3.79		2.80		2.80		3.02		3.79		3.79		3.02	
UWM:	2.348		20.63		10.347		7.872		0.743		0.335		1.707	
WM:	2.289		18.646		10.066		7.094		0.803		0.312		1.595	
Uc (int):	0.020		0.13		0.048		0.043		0.034		0.018		0.021	
Uc (ext):	0.008		0.20		0.097		0.058		0.028		0.031		0.032	
LWM :	2.29	0.02	18.65	0.2	10.07	0.16	7.09	0.06	0.803	0.034	0.312	0.031	1.595	0.032
Abs	**0.00668**	**0.00007**	**0.0544**	**0.0007**	**0.02939**	**0.00049**	**0.02070**	**0.00021**	**0.00234**	**0.00010**	**0.00091**	**0.00009**	**0.00466**	**0.00010**

Table 2 : gamma relative and absolute emission intensities (4)

keV	**578**		**584**		**587**		**590**		**596**		**$598^{(d)}$**		**$603^{(d)}$**	
1964Al09														
1966Bl06	1.38	0.2	$0.54^{(O)}$	0.1					$4.4^{(O)}$	0.7			2	0.4
1969Pa03	1.15	0.23	0.45	0.15	0.1	0.1	0.45	0.15	$4.2^{(O)}$	0.6			1.8	0.3
1974HeYW	1.3	0.2	0.4	0.1	0.2	0.03	0.5	0.1	$4.5^{(O)}$	0.3	0.4	0.1	1.9	0.2
1987Co04														
1992Ch44	1.07	0.03	0.36	0.01	0.16	0.04	0.38	0.01	3.8	0.1	0.61	0.09	1.53	0.05
1998Bo18														
1999Sc12	1.17	0.03	0.352	0.027	0.161	0.027	0.421	0.027	3.56	0.1	0.70	0.03	1.49	0.03
2006Le	1	0.019	0.405	0.02	0.154	0.022	0.448	$0.009^{(U)}$	3.11	$0.05^{(U)}$	0.725	0.032	1.388	0.031
Chi2	5.19		1.20		0.52		6.38		17.69		3.50		3.26	
Chi2 crit	3.02		3.32		3.32		3.32		4.61		3.79		3.02	
UWM:	1.178		0.393		0.155		0.440		3.490		0.609		1.685	
WM:	1.063		0.368		0.165		0.417		3.395		0.693		1.462	
Uc (int):	0.015		0.008		0.014		0.007		0.050		0.021		0.020	
Uc (ext):	0.034		0.009		0.010		0.017		0.210		0.039		0.035	
LWM :	1.18	0.18	0.368	0.009	0.165	0.014	0.417	0.031	3.4	0.29	0.693	0.039	1.68	0.19
Abs	**0.0034**	**0.0005**	**0.001074**	**0.000027**	**0.000482**	**0.000041**	**0.00122**	**0.00009**	**0.0099**	**0.0008**	**0.00202**	**0.00011**	**0.0049**	**0.0006**

Table 2 : gamma relative and absolute emission intensities (5)

keV	**609(d)**		**615(d)**		**618**		**634**		**636**		**657(d)**		**662**	
1964Al09														
1966Bl06	5.5	0.8	0.6(O)	0.12					0.81	0.12	0.13	0.03		
1969Pa03	5.2	0.8	0.21	0.1	0.32	0.14			0.74	0.08	0.12	0.03	0.03	0.01
1974HeYW	5.1	0.4	0.3	0.1	0.3	0.1	0.20	0.03	0.7	0.1	0.1	0.03		
1987Co04														
1992Ch44	4.5	0.1	0.14	0.02	0.2	0.02	0.20	0.05	0.7	0.02	0.14	0.01	0.007	0.002
1998Bo18														
1999Sc12	4.04	0.14	0.233	0.024	0.304	0.027	0.15	0.03	0.595	0.027	0.14	0.024		
2006Le	4.59	0.20	0.159	0.020	0.213	0.022	0.168	0.011	0.65	0.06	0.112	0.009	0.197	0.040
Chi2	2.88		2.80		2.82		0.61		2.45		1.09		11.06	
Chi2 crit	3.02		3.32		3.32		3.79		3.02		3.02		4.61	
UWM:	4.822		0.208		0.267		0.180		0.699		0.124		0.078	
WM:	4.420		0.173		0.230		0.171		0.668		0.125		0.023	
Uc (int):	0.073		0.012		0.013		0.010		0.015		0.006		0.007	
Uc (ext):	0.125		0.020		0.022		0.007		0.023		0.006		0.023	
LWM :	4.42	0.12	0.173	0.020	0.230	0.022	0.171	0.01	0.668	0.023	0.125	0.006	0.023	0.023
Abs	**0.01290**	**0.00036**	**0.00050**	**0.00006**	**0.00067**	**0.00006**	**0.000499**	**0.000029**	**0.00195**	**0.00007**	**0.000365**	**0.000018**	**0.00007**	**0.00007**

Table 2 : gamma relative and absolute emission intensities (6)

keV	**686**		**713**		**760**	
1964Al09						
1966Bl06			0.11	0.03	0.013	0.004
1969Pa03	0.09	0.01	0.066	0.02	0.027	0.015
1974HeYW			0.1	0.03		
1987Co04						
1992Ch44	0.077	0.008	0.077	0.008	0.01	0.002
1998Bo18						
1999Sc12	0.072	0.021	0.09	0.04		
2006Le						
Chi2	0.62		0.53		0.81	
Chi2 crit	4.61		3.32		4.61	
UWM:	0.080		0.089		0.017	
WM:	0.081		0.079		0.011	
Uc (int):	0.006		0.007		0.002	
Uc (ext):	0.005		0.005		0.002	
LWM :	0.081	0.006	0.079	0.007	0.011	0.0018
Abs	**0.000236**	**0.000018**	**0.000231**	**0.000020**	**0.000032**	**0.000005**

(U) Original uncertainty given, was increased in LRSW analysis to reduce the relative weight to 50%.
(O) Omitted or outlier
(d) γ is doubly placed, an undivided intensity is given

^{153}Gd - Comments on evaluation of decay data
by R. G. Helmer and E. Schönfeld

1 Decay Scheme

In addition to the 5 levels populated in the daughter nucleus, there may be a few others with $J \leq 7/2$ in ^{153}Eu, so the completeness of the scheme depends on the failure to observe other γ-rays.

There are some serious discrepancies and ambiguities in the data for some of these five levels.

The recent mass evaluations give the decay energy as 484 keV. However, several measurements of the K-capture probability to the 172-keV level of ^{153}Eu (1962Bl11, 1964Cr08, 1967Bo11, 1980Se01, and 1985Si03) have been interpreted to indicate that the decay energy is 235 to 245 keV. In an attempt to resolve this conflict, 1981Gr19 looked for the 166-keV γ-ray which deexcites the 269-keV level and reported an emission probability of 0.0003(3) per 100 decays; so this result is not definitive since it allows 'no population' within the 1σ uncertainty. The problem with the K-capture probability measurements or their interpretation, if any, has not been resolved.

2 Nuclear Data

Q value is from Audi and Wapstra 1995 (1995Au04).

The half-life values available are, in days:

225	1949Ke01	as quoted in 1990Le13
236 (3)	1950He18	
200	1958An34	as quoted in 1990Le13
242 (1)	1963Ho15	
240.9 (6)	1970LyZZ	superseded by 1972Em01 2nd value
241.6 (2)	1972Em01	
240.9 (6)	1972Em01	
239.63 (4)	1982HoZJ	superseded by 1992Un01 value
226.7 (21)	1989Po21	
239.47 (7)	1992Un01	
240.4 (10)	Adopted value, from LRSW weighted average	

The weighted average of the six remaining values with uncertainties is 239.71 with σ_{int} of 0.07, a reduced-χ^2 of 30.0, and σ_{ext} of 0.36. In the Limitation of Relative Statistical Weight (LRSW) method (1985ZiZY, 1992Ra09), the uncertainty for the 1992Un01 value is increased from 0.07 to 0.185 so that its relative weight is reduced from 88% to 50%. The weighted average is then 240.44 with σ_{int} of 0.13, a reduced-χ^2 of 21.8, and σ_{ext} of 0.61. This method then increases the final uncertainty from 0.61 to 1.0 to include the most precise value, namely, 239.47. In this LRSW analysis, the values of 1972Em01 and 1992Un01 provide 43% and 50% of the relative weight, respectively. The values of 1972Em01, 1989Po21, and 1992Un01 contribute 6.7, 8.6, and 5.5, respectively, to the reduced-χ^2 value.

The value from 1989Po21 differs from this average by about 6σ. The omission of this value would not make a significant difference; in the LRSW analysis without this value the weighted average would only change to 240.49 with a reduced-χ^2 of 16.6. A more aggressive analysis would increase the uncertainties for the extreme values of 226.7(21) and 241.6(2) and thereby drive the result nearer the value of 1992Un01 and give a smaller final uncertainty. However, the evaluator feels that the larger uncertainty of 1.0 is justified by the large spread in the measured values. This large spread is illustrated by the fact that none of the 1σ ranges of the other five values overlap the value from 1992Un01.

2.1 Electron Capture Transitions

The probabilities for the e branches are from the intensity balances from the γ-ray transition probabilities. It is possible to derive the ε intensities because one has a direct measurement of the 97-keV γ-ray emission probability (1987Co04). There is a question as to whether the 151-keV and 269-keV levels are fed in the ^{153}Gd decay; see the discussion in section 4.2. In the decay scheme adopted here, they are omitted.

2.2 Gamma Transitions

The multipolarities and mixing ratios are from the ^{153}Eu Adopted γ data in the Nuclear Data Sheets (1998He06).

3 Atomic Data

The atomic data are from 1996Sc06.

3.1 and 3.2

The relative K x-ray probabilities are from 1996Sc06.

The x-ray emission probabilities (in %) are:

	RADLST	EMISSION	Measured
K$_a$	97.2 (21)	96.6 (23)	94.2 (30)
K$_b$	24.8 (7)	24.6 (7)	24.0 (8)

The EMISSION values were adopted.

The K Auger electron intensities are from RADLST.

4.1 Electron Emission

Data were computed with RADLST for the conversion electrons and for the Auger electrons.

4.2 Photon Emission

From the Helmer and van der Leun evaluation (2000He14), the curved-crystal spectrometer data for the decay of ^{153}Sm and ^{153}Gd give the energies for the γ-rays of 69.6, 75.4, 83.3, 89.4, 97.4, 103.1, and 172.8 keV on a scale on which the strong line from the decay of ^{198}Au is 411.80205 (17) keV. In addition, the values from the ^{152}Eu(n,γ) study of 1970Mu04 have been adjusted to this energy scale and are used for the γ-rays at 54.1, 68.2, 96.8, 118.1, 151.6, 166.5, and 172.3 keV. The remaining two γ-ray energies, 14.0 and 19.8 keV, were computed from the deduced level energies.

The adopted values for the relative γ-ray emission probabilities were generally taken to be the weighted averages of the data in the table below. The values for several γ-rays are very discrepant (e.g., χ_R^2 greater than 3.0) and are discussed below. The uncertainties have been chosen by the evaluator as shown in the table. The relative γ-ray emission probabilities given in 1990GeZZ have not been included since they are the same as those in 1992Ch16.

The 21.2-keV γ-ray has not been placed in the scheme.

The values for the 19-keV γ-ray form two groups, namely, the large values of 0.089 (9), 0.072 (11), and 0.06 (2) and the small values of < 0.03, 0.019 (3), and 0.006 (1); so the weighted average does not give a useful value. If one assumes that there is no electron capture feeding of the 83-keV level, a requirement of an intensity balance at this level gives the transition intensity of the 19-keV γ-ray as 1.55 (14) in the units of the table. Then, with α(19,E2) = 3290, the γ intensity is 1.55/3291 = 0.00047 (5). Also, from conversion electron data of 1963Gr09 (a private communication to the ENSDF system), I_{ce}(LM) =1.17 (in the table units), which, with α(19,E2) = 3290, gives the γ intensity of 0.0004. If these two independent values are correct, then none of the values in the table are correct, except the upper limit.

The measured intensities of the γ-ray which are proposed to depopulate the 151-keV level are not consistent with those from other modes of populating this level (see the 1998He06 for the other modes of population). These values are :

E_γ	Relative I_γ			
	^{153}Sm β^-	(n,γ)	(d,3nγ)	^{153}Gd ε
54	17.1 (18)	26 (4)	25 (3)	330 (130)
68	11 (3)	21.0 (21)	326 (47)	
151	100 (13)	100 (8)	100 (17)	100 (16)

If the ε feeding of the 151-keV level in the ^{153}Gd decay is simply computed from the intensities of the reported intensities of the 54- and 68-keV γ-rays, it is about 0.2%. On the other hand, the log *ft* systematics for 2nd forbidden transitions (1998Si17) give log *ft* >11.0 which corresponds to an upper limit of branch intensity 0.02%. (Also, the intensity data in the table on the next page for the 54- and 151-keV lines are quite discrepant, with reduced-χ^2 values of 121 and 9.1, respectively.) Therefore, no adopted values are given for the 54- and 68-keV γ-rays. [A good new measurement of the intensities of the weak lines is desirable.]

As noted in section 1, it is not known if the level at 269 keV in ^{153}Eu is populated in this decay. If it is, the depopulating γ-rays are at 96.8, 118.1, 166.5, and 172.3 keV as shown from other modes of population. From the reported intensity of the 166-keV γ-ray (1981Gr19), this level would be fed in 0.008 (8) % of the decays. This level is omitted here.

The relative γ-ray intensities were normalized to γ's per 100 decays based on the absolute intensity for the 97-keV line reported by 1990GeZZ; this gives a scaling factor of 0.290 (8), where the published 2σ uncertainty has been divided by 2.

The relative intensities of the K x-rays, on the scale of the table below, are K_α = 333 (8) and K_β = 84.8 (24) as calculated from the decay scheme and 325 (5) and 82.6 (12), respectively, as adopted from the measured values in the table.

Relative Gamma emission Intensities

γ-ray energy (keV)	1974HeYW	1974Se08	1985Si03	1988Su13	1988Ve05	1992Ch16	1992Ch44	1993Eg05	1995Ku34	Weighted average [e] value	σ_{int}	χ_R^2	σ_{ext}	σ_{LRSW}	Adopted value
K α_2						114 (2)[d]		114 (4)[d]							
K α		321 (11)	150 (4)[a]	340 (4)	313 (8)		302 (8)		323 (8)	325	(2)	4.5	(5)	(15)	325 (5)
K α_1						204 (4)[d]		208 (8)[d]							
K ß$_1$'						65.2 (14)[d]		65 (3)[d]	69.2 (19)						
K ß		78 (11)	32.9 (5)[a]	84.9 (8)	78.9 (11)		76.4 (21)			82.6	(5)	5.3	(12)	(23)	82.6 (12)
K ß$_2$'						17.5 (4)[d]		17.5 (7)[d]	16.84 (26)						
14.0			0.054 (9)	0.146 (15)	0.09 (1)		0.11 (3)	0.10 (3)	0.051 (5)[g]	0.068	(4)	9.2	(13)	(17)	0.068 (17)
19.8			0.089 (9)	0.072 (11)	0.006 (1)[g]		0.06 (2)	< 0.03	0.019 (3)	0.018	(2)	27.5	(10)	[f]	0.0004[i]
21.2				0.07 (2)				< 0.03	0.078(16)	0.075	(12)	0.10	(12)	(12)	0.075 (12)[h]
54.1		〈0.01	0.091 (3)	0.058 (8)					0.027 (2)[g]	0.057	(2)	121	(22)	(30)	
68.2		0.04 (1)		0.071 (11)	0.035 (14)		0.064 (17)		0.071(11)	0.056	(5)	2.2	(8)	(16)	
69.6	7.8 (2)	8.4 (3)	8.35 (32)	8.60 (15)	8.31 (13)	8.41 (22)	7.97 (20)		8.20 (26)	8.28	(7)	1.9	(10)	(10)	8.28 (10)
75.4	0.30 (3)	0.26 (8)	0.26 (8)	0.278 (31)	0.27 (1)[g]		0.28 (2)		0.26 (2)	0.272	(8)	0.25	(8)	(8)	0.272 (8)
83.3	0.80 (8)	0.70 (7)	0.69 (7)	0.67 (4)	0.69 (3)		0.66 (2)		0.71 (4)	0.680	(14)	0.68	(14)	(14)	0.680 (14)
89.4	0.30 (3)	0.23 (7)	0.23 (6)	0.218 (26)	0.22 (2)		0.29 (2)		0.22 (2)	0.245	(10)	2.12	(14)	(45)	0.245 (14)
97.4	100 (5)	100.	100.	100.	100.0	100 (3)	100.0 (15)	100.	100.0	100					100
103.1	73.5 (10)	71.0 (15)	71.1 (15)	74.8 (7)	69.6 (10)	73.4 (17)	73.7 (12)		72.1 (14)	72.9	(4)	3.2	(7)	(19)	72.9 (7)
151.6	0.0130 (13)	<0.06	0.31[b]	0.060 (15)	0.02 (1)		<0.010		0.021 (1)	0.0172	(9)	9.1	(27)	(38)	0.017 (4)[h]
172.8	0.130 (13)	0.10 (10)	0.28[c]	0.144 (26)	0.10 (2)		0.13 (1)		0.12 (1)	0.125	(6)	0.56	(6)	(6)	0.125 (6)

[a] Value is uniquely low, omitted from weighted average calculation.

[b] Value is uniquely high, omitted from weighted average calculation.

[c] No uncertainty, omitted from weighted average calculation.

[d] Sum of Kα_1 and Kα_2 and sum of Kβ_1' and Kβ_2' used in weighted average calculation.

[e] Limits are omitted from weighted average calculation.

[f] LRSW method gives unweighted average of 0.049 (43).

[g] LRSW method increased uncertainty in order to reduce relative weight to 50%.

[h] Value is not consistent with one upper limit.

[i] Computed from γ-ray intensity balance at 83-keV level and α(19,E2) and from internal-conversion electron data and α(19,E2).

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^{154}Eu – Comments on evaluation of decay data
by V. P. Chechev and N. K. Kuzmenko

This evaluation was done in June 1999, and revised in January 2003. The literature available by 2003 was included.

1. Decay Scheme

The decay scheme is based on the evaluation of Reich (1998Re22).

The $^{154}Eu \rightarrow ^{154}Gd$ decay scheme has not been completed yet as there are a few unplaced ^{154}Gd gamma transitions. These transitions are weak, so they do not greatly influence the intensity balances.

The 3rd forbidden β^- transitions to the ground states of ^{154}Gd and ^{154}Sm have not been observed. From the log ft systematics (1998Si17), their log *ft* values should be greater than 17,6 and the corresponding upper limits of their intensities would be expected less than $5\cdot10^{-5}$ % and less than $3\cdot10^{-7}$ %, respectively.

In the "Adopted Levels" of 1998Re22, there are several ^{154}Gd levels with energies below Q^- that have not been observed in the ^{154}Eu β^- decay. Their energies are 1900,2; 1911,5; 1912,1; 1943,9; 1948,5 and 1963,8 keV. Their respective spins and parities are not known exactly except those for the 1911,5 keV, which is a 6^+ level. The β^- transition to this 1911,5 keV level is 3 rd forbidden and its intensity is expected to be less than $5\cdot10^{-10}$ % (log ft > 17,6). On the assumption that the remaining levels can be populated by β^- transitions with an order of forbiddenness not lower than 2, their log *ft* values should be greater than 11 and their corresponding branch intensities expected to be less than 0,001%.

Likewise, the intensity of the 3rd forbidden electron-capture transition to the ^{154}Sm 543,7 keV 6^+ level in the decay $^{154}Eu \rightarrow ^{154}Sm$ is expected to be less than 10^{-8} % (from log ft >17,6).

Therefore, all of the above transitions can be neglected, and thus they are not shown in the ^{154}Eu decay scheme.

2. Nuclear Data

Q^+, Q^- values are from 1995Au04.

The evaluated half -life of ^{154}Eu has been obtained by applying the evaluation procedure from 2000Ch01 (Chechev and Egorov). This value is based on the measured results given in Table .

Table 1. Set of experimental data for the evaluation of ^{154}Eu half-life (in days)

Reference	Author	Data set "1" χ^2=22,83 $(\chi^2)_8^{0,05}$=15,51	Data set "2" χ^2=22,79 $(\chi^2)_7^{0,05}$= 14,07	Data set "3" χ^2=22,79 $(\chi^2)_7^{0,05}$=14,07
2002Un02	Unterweger	3145,2(11) [a]	3145,2(11)	3145,2(11)
1998Si12	Siegert et.al	3138,1(16) [b]	3138,1(16)	3138,1(16)
1998Si12	Siegert et.al	3146(11) [c]	3146(11)	3146(11)
1983Th04	Thompson et.al	3170(55)	3170(55)	3170(55)
1992ScZZ	Schötzig et.al	3139,0(20)	3139,0(20)	3139,0(20)
1988RaZM	Rajput et.al	3143(59)	3143(59)	3143(59)
1986Wo05	Woods et.al	3138,0(20)	3138,0(20)	3138,0(20)
1983Wa26	Walz et.al	3136(4)	3136(4)	3136(4)
1972Em01	Emery et.al	3105(180)	Omitted [d]	-

[a] Latest value from this laboratory. Previous measurements at NIST gave 3101(41) – 1982 HoZJ and 3138,2(61) –1992Un01.

[b] Measured with a pressured $4\pi\gamma$ ionization chamber.

[c] Measured with semiconductor detectors.

[d] Omitted on the basis of statistical considerations.

Data set "1" is the original data; set "2" has the discrepant values deleted, and set "3" would have the uncertainty increased for any value having more than 50% of the relative weight. There are none of the latter values, so set "3" is the same as set "2".

It should be noted that there are available the early half-life measurement results which have been omitted because of the very low accuracy: 5,4 years (without uncertainty) – 1949Ha04 and 16(4) years – 1952Ka26. There are also unpublished measurement results of 1978ScZO (7,45 - 10,5 years) and 1978GrZR (8,8(1) years) which have not been included in the set "1".

The weighted mean of data from the final set "3" is 3141,5(14) where the uncertainty has been obtained as an external uncertainty 1,35 multiplied by the Student's coefficient at the confidence level of 0,68 for 7 degrees of freedom (see 2000Ch01). The internal uncertainty is 0,75.

The adopted value of the ^{154}Eu half-life is 3141,5(14) days, or 8,601(4) years (converted to years with 365,24219 d/y).

2.1. b$^-$ **Transition and Electron Capture Transition**

2.1.1. b$^-$ **Transitions**

The energies of β^- transitions have been computed from the Q^- value and the level energies adopted from 1998Re22. The corrections to the level energies taking into account the evaluated values of gamma transition energies from section 2.2 are negligible.

The probabilities of β^- transitions have been obtained from the P(γ+ce) balance for each level of ^{154}Gd based on the P(γ) normalization factor of 0,3489(34) (see section 4.2.). Since 0,018 % (13) of the decays are *via* electron capture, the value of $P_{\beta 1}$=10,3(5), to the first excited level in ^{154}Gd, has been obtained from $P_{\beta 1}$=99,982(13) - $\Sigma P_{\beta i}$, i>1. From the P(γ+ce) balance for this level $P_{\beta 1}$= 10,5(13). The more precise value has been adopted.

The more inaccurate experimental values from 1966Ha36 and 1968Ng01 obtained by direct measurements using magnetic beta-spectrometry and beta-gamma coincidences do not conflict with the calculated ones, as seen from Table 2 (except $\beta_{0,2}$).

Table 2. Comparison of the measured and evaluated (calculated) values of b- transition probabilities.

	E_β, keV	P_β, % 1966Ha36	P_β, % 1968Ng01	Evaluated (calculated) values
$\beta_{0,26}$	248,8(11)		29,1(25)	28,32(22)
$\beta_{0,16}$	570,9(11)		37,8(35)	36,06(35)
$\beta_{0,8}$	840,6(11)		17,0(39)	17,33(18)
$\beta_{0,6}$	972,1(11)		4,6(38)	2,82(18)
$\beta_{0,5}$	1152,9(11)		0,67(49)	0,33(3)
$\beta_{0,2}$	1597,4(11)	0,19(5)		0,31(7)
$\beta_{0,1}$	1845,3(11)	9,2(15)	10,8(12)	10,3(5)

We are listing below the ^{154}Gd levels from the ^{154}Eu β^- decay (see 1998Re22).

Level number	Energy, keV	Spin and parity	Half-life	Probability of β^- transition (× 100)
0	0,0	0^+	Stable	
1	123,071	2^+	1,18 ns	10,3(5)
2	371,00	4^+	45 ps	0,31(7)
3	680,66	0^+	4,0 ps	
4	717,7	6^+	7,8 ps	
5	815,5	2^+	6,4 ps	0,33(3)
6	996,26	2^+	0,95 ps	2,82(18)
7	1047,6	4^+		0,108(18)
8	1127,8	3^+		17,33(18)
9	1136,0	$1,2^+$		
10	1233,2			
11	1241,3	1^-		
12	1251,6	3^-		0,289(6)
13	1263,78	4^+		0,707(7)
14	1277,0			
15	1294,2	$(2)^+$		
16	1397,5	2^-		36,06(35)
17	1414,4	1^-		
18	1418	2^+		0,075(2)
19	1510,1	(1^-)		0,021(2)
20	1531,3	2^+		0,330(13)
21	1560,0	(4^-)		0,100(4)
22	1617,1	3^-		1,78(3)
23	1645,8	4^+		0,148(4)
24	1660,9	3^+		0,849(9)
25	1698,5	(4^+)		0,0100(4)
26	1719,56	2^-		28,32(22)
27	1770,2	5^+		0,0022(4)
28	1790,2	(4^+)		0,022(1)
29	1797,0	3^-		0,060(6)
30	1838,6	2^+		0,017(5)
31	1861,5	4^-		0,034(3)
32	1878,5			0,0042(3)
33	1894,7	2^+		0,0035(6)

2.1.2. Electron Capture Transitions

The energies of the electron capture, ε, transitions have been calculated from the Q^+ value and the level energies from 1998Re22 (see below).

List of ^{154}Sm levels from the ^{154}Eu electron capture decay

Level number	Energy, keV	Spin and parity	Half-life	Probability of electron capture (× 100)
0	0,0	0^+	Stable	
1	81,98	2^+	3,02 ns	0,013(13)
2	266,79	4^+	172 ps	0,0047(8)
3	543,73	6^+	22,7 ps	

The transition probabilities have been obtained from the P(γ+ce) balance for each ^{154}Sm level using a P(γ) normalization factor of 0,3489(34).

Fractional electron capture probabilities P_K, P_L, P_M have been calculated from 1998Sc28 using the program EC-CAPTURE.

2.2. Gamma Transitions and Internal Conversion Coefficients

The evaluated energies of gamma-ray transitions include the recoil energy of $E_\gamma^2/2Mc^2$, where M is mass of the daughter nucleus (^{154}Gd or ^{154}Sm).

The gamma-ray transition probabilities have been deduced from their emission probabilities and total internal conversion coefficients (ICC).

The ICC are theoretical values from 1978Ro22 for the adopted energies and multipolarities. Other values have been taken from the evaluation 1998Re22, based on experimental data from 1957Ke08, 1962Lu03, 1966Za02, 1969An01, 1972Na21, 1977Ya04 and 1996Al31. Total ICC values for $\gamma_{1,0}$(Gd) have been obtained as weighted averages of measured values, 1,200(20) - 1962Lu03 and 1,194(19) - 1995Ma03, and taking into account the rule of “the smallest experimental uncertainty” (see 2000Ch01).

The relative uncertainties of α_K, α_L, α_M for pure multipolarities have been adopted 2%.

3. ATOMIC DATA

3.1. Fluorescence Yields

The fluorescence yield data are from 1996Sc06 (Schönfeld and Janßen).

3.2. X-Radiations

The X-ray energies are based on their wavelengths in the compilation of 1967Be65 (Bearden). The relative KX-ray emission probabilities have been taken from 1996Sc06 and 1999Schönfeld.

3.3. Auger Electrons

The energies of Auger electrons are from 1977La19 (Larkins) and 1987Lagoutine.

The ratios P(KLX)/P(KLL), P(KXY)/P(KLL) are taken from 1996Sc06.

4. PHOTON EMISSIONS

4.1. X-Ray Emissions

The total absolute emission probability of Gd KX-rays has been computed using the adopted value of ω_k (Gd) and the evaluated total absolute emission probability of K conversion electrons in the decay ^{154}Eu→^{154}Gd, namely, P_{ceK} = 27,3(6)%. The emission probability of Sm KX-rays has been computed using the adopted value of ω_K (Sm), the evaluated probability of K electron capture to ^{154}Sm levels $P_{\varepsilon K}$ =0,015(11) % and the evaluated emission probability of K conversion electrons in the decay ^{154}Eu→^{154}Sm, namely, P_{ceK} = 0,007(4) %.

The absolute emission probabilities of the Gd KX-ray components have been computed using the relative probabilities from Section 3.2 and the total value of P_{XK}(Gd) = 25,4(6) % .

4.2. Gamma-Ray Emissions

The energies of prominent gamma-rays $\gamma_{1,0}$(123,1), $\gamma_{2,1}$(247,9), $\gamma_{5,2}$(444,5), $\gamma_{26,8}$(591,7), $\gamma_{6,2}$(625,2), $\gamma_{5,1}$(692,4), $\gamma_{26,6}$(723,3), $\gamma_{8,2}$(756,8), $\gamma_{24,5}$(845,4), $\gamma_{6,1}$(873,2), $\gamma_{13,2}$(892,8), $\gamma_{26,5}$(904,1), $\gamma_{12,1}$(1128,5), $\gamma_{13,1}$(1140,7), $\gamma_{22,2}$(1246,1), $\gamma_{16,1}$(1274,4), $\gamma_{22,1}$(1494,0), $\gamma_{26,1}$(1596,5) have been taken from 2000He14 (Helmer and Van der Leun).

The energies of the gamma rays $\gamma_{26,20}$(188,2), $\gamma_{16,6}$ (401,2), $\gamma_{26,12}$(467,8), $\gamma_{26,11}$(478,3),$\gamma_{3,1}$(557,6), $\gamma_{16,5}$(582,0), $\gamma_{7,2}$(676,6), $\gamma_{20,5}$(715,8), $\gamma_{5,0}$(815,5), $\gamma_{20,3}$(850,6), $\gamma_{12,2}$(880,6), $\gamma_{7,1}$(924,6), $\gamma_{6,0}$(996,3),

$\gamma_{8,1}$(1004,7), $\gamma_{11,1}$(1118,5), $\gamma_{20,2}$(1160,4), $\gamma_{21,2}$(1188,1), $\gamma_{11,0}$(1241,4), $\gamma_{24,2}$(1290,5), $\gamma_{19,1}$(1397,4), $\gamma_{24,1}$(1537,8) have been evaluated using the experimental data of 1990He05, 1992Sm02, 1990Me15 along with taking into account a correction of the gamma -ray energetic scale in 2000He14 (lowering by 5,8 ppm) (Table 3).

Table 3. Measured and evaluated values of some gamma ray energies in the decay of ^{154}Eu (keV)

	1990He05	1990Me05	1992Sm02	Evaluated
$\gamma_{26,20}$	188,252(8)	188,22(4)	188,29(7)	188,24(2)
$\gamma_{16,6}$	401,258(14)	401,30(5)		401,259(14)
$\gamma_{26,12}$	467,84(5)			467,84(5)
$\gamma_{26,11}$		478,26(5)	478,29(7)	478,27(5)
$\gamma_{3,1}$		557,56(5)	557,61(7)	557,58(5)
$\gamma_{16,5}$		582,00(5)	582,03(7)	582,01(5)
$\gamma_{7,2}$	676,600(12)	676,60(5)		676,596(12)
$\gamma_{20,5}$	715,786(18)	715,77(5)	715,75(7)	715,77(3)
$\gamma_{5,0}$		815,57(5)	815,45(7)	815,53(5)
$\gamma_{20,3}$	850,643(12)	850,66(5)	850,61(7)	850,64(3)
$\gamma_{12,2}$	880,61(3)			880,60(3)
$\gamma_{7,1}$	924,64(5)			924,63(5)
$\gamma_{6,0}$	996,262(6)	996,35(4)	996,21(3)	996,25(5)
$\gamma_{8,1}$	1004,725(7)	1004,79(4)	1004,67(3)	1004,718(7)
$\gamma_{11,1}$		1118,53(6)		1118,52(6)
$\gamma_{20,2}$	1160,37(8)			1160,36(8)
$\gamma_{21,2}$	1188,10(4)	1188,60(10)		1188,34(17)
$\gamma_{11,0}$	1241,38(5)	1241,62(9)		1241,43(10)
$\gamma_{24,2}$	1290,51(10)			1290,50(10)
$\gamma_{19,1}$	1397,35(5)			1397,34(5)
$\gamma_{24,1}$	1537,80(4)	1537,84(5)		1537,81(4)

The energies of the gamma rays $\gamma_{15,8}$(165,9), $\gamma_{22,17}$(202,5), $\gamma_{14,7}$(229,0), $\gamma_{22,5}$(801,2) have been taken from 1992El11. The energy of the gamma ray $\gamma_{1,0}$ Sm (82,0) has been adopted from measurements of conversion electrons (1958Ch36). The unplaced gamma ray 197 keV has been reported in 1980Sh15 and 1989Ki10. The energy of the gamma ray $\gamma_{7,4}$(329,9) has been adopted from 1974HeYW. The energy 533,1 keV (twice placed - $\gamma_{24,8}$ and $\gamma_{29,13}$) has been computed from the level energies. The energy and relative emission probability of the gamma ray $\gamma_{3,0}$(680,7) has been taken from 1969An01. The energy of the unplaced gamma-ray γ 1316,4 keV has been adopted from 1970Ri19.

The energies of the remaining weak gamma rays have been taken from 1968Me18.

The measured and evaluated values of relative gamma ray emission probabilities are shown in Table 4.

Table 4. Measured and evaluated values of relative gamma ray emission probabilities in the decay of ^{154}Eu

keV	1968Me18	1969Va09	1970RiZY	1980Ro22	1980Sh15	1984Iw03	1986Wa35	1989Ki10	1989 Schima	1990Me15	1990He05	1992El11	1992Ha02	1992Sm02	1992Sa04	Evaluated value
58,4	0,0113(11)															0,0113(11)
80,4	0,008(4)															0,008(4)
82.0	0,009(6)															0,009(6)
123,1			116(6)		115,4(23)	118,5(13)	111,7(16)	122,1(36)	117,0(11)	114,1(20)	116,5(12)		115,6(15)	113,0(15)	115,4(7)	115,9(8)
125,4	0,0197(56)															0,020(6)
129,5	0,039(6)															0,039(6)
131,6	0,0310(14)				0,037			0,025					0,035(3)			0,0317(13)
134,8	0,0203(11)				0,03			0,024					0,027(6)			0,0205(11)
146,0	0,073(3)		0,085(27)		0,12(1)			0,078(28)					0,075(10)			0,074(3)
156,2	0,0282(12)				0,025			0,019					0,027(3)			0,0280(11)
159,9	<0,003												0,0030(15)			0,0030(15)
162,1	0,0028(14)												0,0035(17)			0,0031(11)
165,9	0,0065(14)				0,021			0,019					0,012(4)			0,0071(14)
180,7	0,0127(28)	0,0058(58)			0,015			<0,001					0,0116(17)			0,0115(17)
184,7	0,0113(28)				0,017			0,003					0,010(3)			0,011(3)
188,2		0,692(17)	0,61(12)		0,70(12)			0,88(10)		0,682(22)			0,658(27)	0,651(15)		0,684(15)
195,5	0,0056(28)															0,006(3)
197					0,005			0,004								0,0045(5)
202,5												0,08(2)				0,08(2)
209,4	0,0068(23)												0,0072(16)			0,0071(16)
219,4	0,0065(25)												0,0067(19)			0,0066(19)
229,0	0,0056(22)												0,0085(25)			0,0069(22)
232,0	0,0677(30)		0,079(43)		0,081(40)			0,059(22)					0,068(6)			0,068(3)
237,0	0,017(11)				0,026			0,024					0,019(9)			0,018(9)
247,9			20,1(10)	20,51(20)	19,34(37)	19,91(14)	19,615(98)	23,04(59)	19,82(16)	19,72(32)	19,8(2)		19,65(44)	19,5(2)	19,857(93)	19,76(9)
260,9	0,0056(25)							0,017					0,0066(20)			0,0062(20)
267,4	0,039(2)				0,023			<0,001					0,037(7)			0,039(2)
269,8	0,0197(28)				0,01			0,017					0,022(4)			0,0205(28)
274,0	0,0113(6)												0,0105(12)			0,0111(6)
279,9	0,0085(4)												0,0092(21)			0,0085(4)
290,0	0,0096(5)												0,010(2)			0,0096(5)
295,7	0,0068(4)												0,0073(15)			0,0068(4)
296,0	0,0039(25)															0,004(3)
301,3	0,0282(12)				0,032			0,03					0,032(2)			0,0292(12)
305,1	0,0496(22)	0,058(12)			0,07			0,078					0,055(7)			0,050(2)
308,2	≤0,005				0,01								0,0068(17)			0,0068(17)
312,3	0,0414(19)	0,055(12)			0,06			0,069					0,059(5)			0,053(4)
315,4	0,0130(7)	0,037(12)			0,03			0,027					0,027(6)			0,021(4)
320	0,0028(20)															0,0028(20)

keV	1968Me18	1969Va09	1970RiZY	1980Ro22	1980Sh15	1984Iw03	1986Wa35	1989Ki10	1989 Schima	1990Me15	1990He05	1992El11	1992Ha02	1992Sm02	1992Sa04	Evaluated value
322,0	0,189(9)	0,193(9)	0,16(4)		0,21(4)			0,168(22)					0,189(10)			0,189(9)
329,9	0,0259(4)		0,036(26)		0,032			0,023					0,031(10)			0,0260(14)
346,7	0,085(3)				0,067								0,075(6)			0,083(3)
368,2	0,0085(4)												0,0081(17)			0,0085(4)
370,7	0,015(4)				0,03			0,007					0,018(6)			0,016(4)
375,2	0,0051(28)												0,0059(23)			0,0056(23)
382,0	0,0285(12)				0,028			0,006					0,027(3)			0,0283(12)
397,1	0,085(3)	0,066(9)	0,12(5)		0,12(4)			0,070(16)					0,076(8)			0,082(3)
401,3		0,55(3)	0,58(10)		0,57(8)	0,49(4)		0,58(6)		0,56(3)	0,543(6)		0,54(3)			0,543(6)
403,5	0,076(3)		0,054(32)		0,042(40)								0,067(8)			0,075(3)
414,3	0,0141(18)												0,015(2)			0,0142(18)
419,4	0,011(6)												0,0094(41)			0,010(6)
422,1	≤0,0034												0,0062(24)			0,0062(24)
435,9	≤0,0073												0,011(3)			0,011(3)
444,5		1,64(4)	1,69(15)	1,53(6)	1,54(3)	1,63(3)	1,87(11)	2,11(6)		1,58(3)	1,600(15)		1,66(7)	1,628(17)	1,564(38)	1,606(15)
463,9	0,0121(7)												0,019(8)			0,0122(7)
467,8	0,161(7)	0,173(17)	0,20(9)		0,16(8)			0,18(3)					0,184(7)			0,173(7)
478,2		0,605(22)	0,69(15)		0,63(10)	0,626(27)		0,64(5)		0,68(3)	0,644(6)		0,63(3)	0,648(12)		0,643(6)
480,6	0,0138(8)															0,0138(8)
483,7	0,0141(8)				0,04			0,045					0,033(12)			0,0142(8)
484,6	0,0113(6)															0,0113(6)
488,3	0,020(9)												0,021(10)			0,020(9)
506,4	0,017(6)							0,017					0,018(4)			0,018(4)
510	0,103(5)		0,17(8)		0,14(8)			0,28(5)					0,19(3)			0,17(2)
512,0	≤0,17	0,092(20)														0,092(20)
518,0	0,132(6)	0,144(26)	0,16(9)		0,18(8)			0,17(5)					0,144(18)			0,135(6)
533,1 $	0,031(6)				0,032			0,04					0,034(8)			0,032(6)
545,6	0,047(6)	0,035(29)											0,036(6)			0,041(6)
557,6		0,75(3)	0,74(10)		0,72(10)	0,758(24)		0,80(10)		0,73(3)	0,778(11)		0,75(3)	0,767(12)		0,767(11)
563,4												0,008(2)				0,008(2)
569,2	0,0282(12)				0,044			0,024					0,0410(64)			0,0286(23)
582,0		2,62(7)	2,53(23)	2,86(11)	2,45(5)	2,61(3)	2,45(5)	2,72(12)		2,51(3)	2,543(2)		2,53(3)	2,53(23)		2,54(2)
591,7		14,44(31)	14,8(8)	13,62(24)	13,57(26)	14,35(6)	14,05(14)	15,84(66)	14,19(11)	14,14(15)	14,21(11)		14,18(31)	14,0(14)	14,338(117)	14,18(7)
597,5	0,0158(9)															0,0158(9)
598,3	0,0172(10)				0,026								0,0280(54)			0,0176(21)
600,0	0,017(11)															0,017(11)
602,8	0,096(4)				0,1			0,15					0,096(8)			0,096(4)
613,3	0,262(11)	0,288(20)	0,22(8)		0,25(8)			0,29(7)					0,265(19)			0,267(11)
620,5	0,0262(14)												0,023(6)			0,0260(14)
625,2		0,922(32)	0,89(12)		0,84(5)	0,927(21)	0,90(4)	0,92(9)		0,90(3)			0,91(2)	0,906(10)		0,909(10)
642,4	0,011(6)							0,040(28)					0,013(5)			0,013(5)

keV	1968Me18	1969Va09	1970RiZY	1980Ro22	1980Sh15	1984Iw03	1986Wa35	1989Ki10	1989 Schima	1990Me15	1990He05	1992El11	1992Ha02	1992Sm02	1992Sa04	Evaluated value
649,4	0,214(9)		0,28(11)		0,25(8)			0,30(10)					0,26(2)			0,223(9)
650,6	0,0282(12)															0,0282(12)
664,7	0,082(3)				0,072			0,03					0,088(15)			0,082(3)
668,9	0,034(8)				0,042			0,031					0,042(7)			0,038(7)
676,6		0,432(30)	0,43(11)		0,52(10)	0,47(5)	0,45(27)	0,53(11)		0,45(3)			0,46(5)			0,45(3)
692,4		5,07(13)	4,97(30)	4,86(8)	4,92(10)	5,182(29)	5,14(5)	5,75(15)		5,10(9)	5,09(4)		5,13(12)	5,04(5)	5,085(59)	5,12(3)
715,8		0,40(6)	0,32(13)		0,61(8)			0,27(12)		0,592(28)			0,52(2)	0,57(3)		0,54(3)
723,3		56,5(12)	60,1(31)	55,40(41)	55,33(106)	58,19(27)	57,23(46)	64,9(21)	57,6(4)	57,2(6)	57,3(4)		57,78(89)	56,9(6)	58,107(276)	57,46(27)
737,6	≤0,024												0,018(7)			0,018(7)
756,8		12,71(23)	12,9(6)	12,51(11)	12,62(24)	13,18(8)	12,89(13)	13,61(20)		12,99(15)	12,9(11)		13,02(24)	12,8(2)	13,035(127)	12,98(8)
774,4	0,028(14)												0,022(11)			0,024(11)
790,1	0,031(8)												0,029(9)			0,030(8)
800,2	0,092(14)							0,09					0,088(30)			0,091(14)
815,6		1,38(6)	1,38(18)	1,45(8)	1,47(10)	1,51(5)	1,48(3)	1,63(12)		1,44(3)	1,455(14)		1,52(4)	1,481(15)		1,467(14)
830,3	≤0,0141				0,02								0,023(8)			0,023(8)
845,4		1,614(62)	1,60(22)		1,58(10)	1,687(22)	1,64(10)	1,61(61)		1,66(3)	1,737(20)		1,69(3)	1,659(17)		1,68(2)
850,7		0,663(30)	0,60(13)		0,67(8)	0,692(23)		0,68(13)		0,68(3)			0,68(2)	0,699(14)		0,692(14)
873,2		33,72(75)	34,8(17)	33,6(25)	34,47(70)	35,18(16)	34,66(21)	35,7(13)	34,95(31)	34,65(30)	34,81(28)		35,01(44)	34,5(4)	34,342(266)	34,87(16)
880,6	0,231(10)	0,14(6)	0,20(8)		0,28(8)			0,22(11)					0,26(4)			0,231(10)
892,8		1,41(4)	1,31(10)	1,38(12)	1,43(3)	1,497(26)	1,55(3)	1,51(10)		1,49(3)			1,48(5)	1,416(16)		1,473(16)
898,4	0,0056(14)															0,0056(14)
904,1		2,45(7)	2,42(17)	2,47(8)	2,49(5)	2,62(3)	2,65(8)	2,74(13)		2,54(6)	2,537(22)		2,58(5)	2,54(3)		2,551(22)
906,1	0,0338(16)															0,0338(16)
919,2	0,0352(16)												0,025(11)			0,0350(16)
924,5	0,166(8)	0,173(29)	0,19(10)		0,18(10)			0,13(6)					0,189(8)			0,177(8)
928,4	≤0,0141												0,013(6)			0,013(6)
981,3	0,023(6)												0,025(5)			0,024(5)
984,5	0,018(11)												0,029(6)			0,027(6)
996,3		29,39(71)	29,4(15)	29,7(21)	30,30(65)	30,09(15)	30,87(12)	31,0(19)	29,9(3)	30,14(30)	29,78(23)		30,29(51)	29,9(3)	29,206(269)	30,1(1)
1004,7		50,4(11)	50,6(25)	50,93(32)	51,40(103)	52,04(25)	52,05(31)	54,84(225)	51,9(5)	51,8(6)	51,55(40)		52,07(89)	51,6(4)	51,233(276)	51,17(25)
1012,8	0,0082(34)															0,008(3)
1023	0,020(8)												0,019(7)			0,019(7)
1033,4	0,0338(16)												0,029(8)			0,0336(16)
1047,4	0,141(7)				0,23(10)			0,17(6)					0,16(5)			0,142(7)
1049,4	0,0493(22)															0,0493(22)
1072,2	≤0,0113												0,010(4)			0,010(4)
1110	0,008(6)															0,008(6)
1118,5		0,403(58)	0,30(8)		0,37(10)			0,04		0,296(25)			0,31(3)			0,31(4)
1124,2	0,0197(28)															0,020(3)
1128,5		0,89(6)	0,79(9)		0,94(8)	0,90(4)		0,88(6)		0,885(25)	0,952(15)		0,89(5)	0,892(10)		0,91(1)
1136,1	0,0211(28)							0,042								0,021(3)

keV	1968Me18	1969Va09	1970RiZY	1980Ro22	1980Sh15	1984Iw03	1986Wa35	1989Ki10	1989 Schima	1990Me15	1990He05	1992El11	1992Ha02	1992Sm02	1992Sa04	Evaluated value
1140,7		0,634(30)	0,69(10)		0,73(8)	0,671(14)		0,75(6)		0,65(3)	0,671(8)		0,68(4)	0,682(11)		0,673(8)
1153,1	0,039(11)												0,024(10)			0,031(10)
1160,3	0,124(6)		0,10(3)		0,13(10)			0,12(4)					0,131(12)			0,125(6)
1170,7	0,012(6)												0,010(3)			0,010(3)
1188,6		0,27(1)	0,23(5)		0,29(8)			0,25(4)		0,25(3)			0,265(20)			0,266(20)
1216,8	≤0,010												0,0096(28)			0,010(3)
1232,1	0,026(17)												0,021(14)			0,023(14)
1241,6		0,43(3)	0,30(7)		0,40(5)	0,38(5)		0,45		0,366(17)			0,38(4)			0,380(17)
1246,1		2,54(7)	2,40(22)	2,35(5)	2,48(10)	2,49(4)	2,52(5)	2,51(12)		2,48(3)	2,449(23)		2,45(8)	2,48(2)	2,403(48)	2,470(23)
1274,4	100	100	100	100	100	100	100	100	100	100	100		100	100	100	100
1290,1	0,0324(15)		0,068(26)		0,086(20)			0,064					0,077(9)			0,071(9)
1292,0	0,0369(17)												0,035(3)			0,0364(15)
1295,5	0,0254(29)				0,026(3)			0,061					0,027(3)			0,026(3)
1316,4			0,074(29)		0,053(10)			0,029(19)								0,050(10)
1387,0	0,056(6)	<0,029											0,055(5)			0,055(5)
1397,4	0,0084(28)							0,012					0,0093(22)			0,0090(22)
1408,5	0,059(8)				0,082(10)								0,063(8)			0,066(8)
1415,0	0,0113(6)				0,004			0,02					0,017(6)			0,0114(6)
1418,6	0,0208(12)		0,027(16)		0,039			0,041(11)					0,037(5)			0,031(5)
1419,0	0,0056(3)															0,0056(3)
1425,9	0,0037(22)												0,0031(19)			0,0034(19)
1489,6	0,0084(14)												0,0081(12)			0,0082(12)
1494,0			1,88(9)	2,10(4)	1,91(8)	2,058(17)	1,99(2)	1,72(8)		1,99(4)	1,979(16)		2,04(8)	2,00(3)		2,00(2)
1510,0	0,0141(28)	<0,012											0,013(4)			0,014(3)
1522	0,0017(8)															0,0017(8)
1531,4	0,0172(12)		0,009(5)		0,018(5)								0,018(2)			0,0171(12)
1537,9			0,15(2)		0,15(1)			0,12(1)		0,155(6)			0,160(13)			0,151(6)
1554	≤0,004												0,0032(15)			0,0032(15)
1596,5			5,15(26)	5,19(8)	4,81(10)	5,247(30)	5,237(84)	4,54(18)	5,08(5)	5,13(8)	5,078(40)		5,12(17)	5,08(5)	5,083(22)	5,11(3)
1667,3	0,0056(8)												0,0053(12)			0,0055(8)
1674,9	0,0039(11)				0,006(1)			0,004					0,0041(16)			0,0049(11)
1716,9	0,0017(11)							0,0017(9)					0,0017(9)			0,0017(9)
1773	0,0008(6)							0,0010(6)					0,0010(6)			0,0010(6)
1838,0	0,0023(6)							0,0027(11)					0,0027(11)			0,0024(6)
1895	0,0017(6)							0,0020(9)					0,0020(9)			0,0018(6)

\$ This energy corresponds to the two gamma-rays: $\gamma_{24,8}$ and $\gamma_{29,13}$. The former one was added in 1998Re22 with a relative emission probability of 0,020(7). Considering the experimental intensity of 0,032(5) as a sum of intensities $\gamma_{24,8}$ and $\gamma_{29,13}$, it leads to the $\gamma_{29,13}$ relative emission probability of 0,012(8)-see section 4.2.

The gamma ray emission probabilities have been computed from their relative evaluated emission probabilities given in Table 3 using the normalization factor K = 0,3489(34). This value has been obtained from the intensity balance for gamma transitions to the ground states of ^{154}Gd and ^{154}Sm assuming that the ground states are not populated directly by beta or electron capture decay. Then, $P_{\gamma+ce}$ ($\gamma_{1,0}$ Sm) + Σ $P_{\gamma+ce}$ ($\gamma_{i,0}$ Gd)=100% where i=1, 3, 5, 6, 9, 11, 17, 18, 19, 20, 30, 33.

There are several measurements of the absolute emission probabilities (P_γ) of some prominent gamma rays in the decay ^{154}Eu→^{154}Gd.

The evaluated (calculated) value of $P_{\gamma1,0}$ (123,07 keV) =40,4(5)% agrees well with the value of 40,6(7)% measured in 1991ZaZZ.

The evaluated value of $P_{\gamma16,1}$ (1274,43 keV)=34,9(3)% agrees well with the value of 34,8(2)% measured in 1994Co02, and it differs somewhat from the value of 35,32(12)% obtained in 1992Ha02.

The values of $P_{\gamma2,1}$ (247,93 keV)=6,96(8) % and $P_{\gamma6,0}$ (996,26keV) = 10,36(18)% measured in 1997Ka47 agree with the evaluated (calculated) values of 6,89(7)% and 10,50(10)%, respectively.

5. Electron Emissions

The energies of the conversion electrons have been calculated from the gamma transition energies given in 2.2 and the electron binding energies.

The emission probabilities of conversion electrons have been deduced from the evaluated P_γ and ICC values.

The absolute total emission probabilities of Gd and Sm K Auger electrons have been computed by using their corresponding evaluated total P(ce_K) for Gd and Sm and their adopted ω_K from section 3.

The absolute total emission probabilities of Gd and Sm L Auger electrons have been computed using their corresponding evaluated total P(ce_K) and P(ce_L) for Gd and Sm and their adopted ϖ_L and n_{KL} from section 3.

Average energies of β^-spectrum components have been calculated using the LOGFT program.

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^{155}Eu – Comments on evaluation of decay data

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1. DECAY SCHEME

The ^{155}Eu decay scheme is complete. The most intense allowed β^--transitions occur to the excited levels with energy of 105.31 keV (46.1%) and 86.55 keV (25.5%).

The 1st forbidden β^--transitions populate the 60.01 keV (9,2%) and 146.07 keV (1.9%) levels.

The ground state in ^{155}Gd is populated by the intense allowed β^--transition (16.6%).

The 2nd forbidden β^--transition to the excited level of 107.58 keV was not observed. From the log ft systematics its log ft should be more than 11.1 and the upper limit on this β^- branch intensity is expected less than 0.01%.

2. NUCLEAR DATA

Q value is from 1995Au04 .

The evaluated value of the ^{155}Eu half-life has been taken from 2000Ch01 (Chechev and Egorov). It is based on the measurement results given in Table 1.

Table 1. Set of experimental data for the evaluation of ^{155}Eu half-life (in days)

Reference	Author	Data set "1" χ^2 =334.9 $(\chi^2)_6^{0.05}$ =14.1	Data set "2" χ^2 =6.14 $(\chi^2)_5^{0.05}$ = 12.6	Data set "3" χ^2 =5.68 $(\chi^2)_5^{0.05}$ =12.6
1998Si12	Siegert *et al.*	1739(8)	1739(8)	1739(8)
1993Th04	Thompson *et al.*	1735(22)	1735(22)	1735(22)
1992Un01	Unterweger *et al.*	1739.0(5)	1739.0(5)	1739(7)[b]
1983Wa26	Walz *et al.*	1737(23)	1737(23)	1737(23)
1974Da24	Daniels *et al.*	1708(18)	1708(18)	1708(18)
1972Em01	Emery *et al.*	1812(4)	Omitted [a]	-
1972Su09	Subba Rao	1653(51)	1653(51)	1653(51)
1970Mo23	Mowatt *et al.*	1698(74)	1698(74)	1698(74)

[a] The value from 1972Em01 has been omitted on the basis of statistical considerations.

[b] The rule of “50% weight”(LRSW) leads to a significant increase of the 1992Un01 uncertainty.

In 2002Un02 the new NIST measurement result was published for the ^{155}Eu half-life: $T_{1/2}$ = 1739.06(45) d. It does not differ practically from 1992Un01 and its use instead of 1992Un01 does not change this evaluation.

The weighted mean of the experimental values from the final data "set 3" is 1736(5) days where the uncertainty is internal. The adopted value of the ^{155}Eu half-life is 1736(5) days, or 4.753(14) years.

2.1. b$^-$-Transitions

The energies of the β^- transitions have been computed from the Q value and the level energies adopted from 1986Sc25, where the reaction ^{154}Gd(n,γ)^{155}Gd was studied. For the level energies see also the evaluation in Nuclear Data Sheets (1994Re10).

The probabilities of the β^- transitions have been obtained from the $P_{\gamma+ce}$ balance for each level based on the P_γ normalization factor of 0.307(3) (see sect.4.2.3). The calculated P($\beta_{0,0}$) agrees with the unweighted mean of 18(4)% of the five measurement results of 1949Ma58, 1954Le08, 1956Du31, 1959Am16, 1960Su04.

2.2. Gamma Transitions and Internal Conversion Coefficients

The evaluated energies of gamma transitions are energies of gamma rays (E_γ) with adding the recoil energy of $E_\gamma^2 / 2Mc^2$ where M – mass of the ^{155}Gd nucleus. The latter changes the energy only for $\gamma_{6,0}$.

The gamma transition probabilities have been calculated from the gamma emission probabilities and the internal conversion coefficients (ICC).

For gamma transitions with energies more than 25 keV the ICC have been evaluated using theoretical values from 1978Ro22 for the adopted multipolarities. For these transitions the following uncertainties for theoretical values have been adopted 1% for α_K and 3% for α_L, α_M, α_{NO}. The ICC interpolated from other tables (1968Ha53, 1978Band) do not differ from the evaluated values within limits of adopted uncertainties.

For low-energy gamma transitions $\gamma_{5,4}$, $\gamma_{3,2}$, $\gamma_{4,2}$ the ICC have been evaluated using theoretical values from 1993Ba60. The ICC values in 1968Ha53 and 1978Ro22 for these energies differ considerably or are absent.

The adopted E2 admixtures for (M1+E2)-transitions $\gamma_{5,4}$, $\gamma_{3,2}$, $\gamma_{5,2}$, $\gamma_{1,0}$ and $\gamma_{2,0}$ have been evaluated using measurement results from 1959De29, 1961Su13, 1962Ha24, 1966As02, 1967Fo11, 1967Ko12, 1975Ch04, 1975Kr04, 1986Sc25 and 1990GoZS. In these works the intensity ratios L_1:L_2:L_3 were measured for conversion electrons in decays of ^{155}Eu and ^{155}Tb and also in the ^{154}Gd(n,γ) reaction. Also $\gamma\gamma(\theta)$-correlations were studied in ^{155}Tb decay and in Coulomb excitation of the ^{155}Gd levels - ^{155}Gd (p, p' γ) (see Table 2).

Table 2. Measured and evaluated E2 admixtures for the (M1+E2) multipolarities of gamma transitions in the decay of ^{155}Eu

E_γ, keV	Measurement result, % E2	NSR code	Method	Evaluated (adopted) value, % E2
10.418	0.11(5) 0.4(3)	1975Ch04 1967Fo11	L_1; L_2; L_3, ^{155}Tb L_1; L_2; L_3, ^{155}Eu	0.11(5)
18.763	7.4(6) 6.3(8) 7.1(4) 5.6(12) 6.3(14)	1990GoZS 1967Fo11 1975Ch04 1962Ha24 1975Kr04	L_1; L_2; L_3, ^{155}Eu L_1; L_2; L_3, ^{155}Eu L_1; L_2; L_3, ^{155}Tb L_1; L_2; L_3, ^{155}Tb $\gamma\gamma$, ^{155}Eu	7.1(4) WM
31.444	17(5)	1986Sc25	L_1; L_2; L_3, ^{154}Gd(n,γ)	17(5)

60.009	4.0(4) 3.3(10) 4.4(4) 3.7(10) 3.5(9) 3.8(10) 4.9(24)	1967Fo11 1967Ko12 1986Sc25 1962Ha24 1975Kr04 1961Su13 1966As62	L$_1$; L$_2$; L$_3$, ^{155}Eu L$_1$; L$_2$; L$_3$, ^{155}Tb L$_1$; L$_2$; L$_3$, ^{154}Gd(n,γ) L$_1$; L$_2$; L$_3$, ^{155}Tb γγ, ^{155}Eu γγ, ^{155}Eu ^{155}Gd (p, p'γ)	4.1(4) WM
86.059	2.5(6) 3.5(10) 4.9(15) 3.5(16)	1986Sc25 1975Kr04 1966As02 1959De29	L$_1$; L$_2$; L$_3$, ^{154}Gd(n,γ) γγ, ^{155}Eu ^{155}Gd (p, p'γ) ^{155}Gd (p, p'γ)	3.0(6) WM

3. ATOMIC DATA

3.1. Fluorescence yields

The fluorescence yields are taken from 1996Sc06 (Schönfeld and Janβen).

3.2. X Radiations

The X-ray energies are based on the wavelengths in the compilation of 1967Be65 (Bearden). The relative KX-ray emission probabilities are taken from 1996Sc06, 1999Schönfeld and 1974Sa28.

3.3. Auger Electrons

The energies of Auger electrons are from 1977La19 (Larkins) and 1987Table.
The ratios P(KLX)/P(KLL) and P(KLY)/P(KLL) are taken from 1996Sc06.

4. PHOTON EMISSIONS

4.1 X-Ray Emissions

The total absolute emission probability of KX -rays (P_{XK}) has been computed using the adopted value of ω_K and the evaluated total absolute emission probability of K conversion electrons Pce_K = 25.17(46) per 100 disintegrations. The absolute emission probabilities of the KX -ray components have been computed from P_{XK} using the relative probabilities from Sect.3.2.

The measured values of the total absolute emission probability of KX -rays given below can be compared to the calculated (adopted) value of $P_{XK}^{eval.}$ = **23.6(5)** per 100 disintegrations:

1967Fo11	1967Bl11	1968Om01	1969Me09	1971Ge11	1994Eg01	WM
22.9(10)	25.2(25)	21.3(23)	21.1(6)	22.5(12)	23.50(19)	23.3(2) [a]

[a] Weighted mean of all 6 values. The value of 1969Me09 gives the 80% contribution to χ^2. With omitting this value the weighted mean of 5 values is 23.5(2).

The total absolute emission probability of LX -rays has been computed using the adopted values of ϖ_L and n_{KL} and the evaluated values of $P(ce_K)$ =25.17(46) and $P(ce_L)$ = 21.2(24)%.

4.2. Gamma–Ray Emissions

4.2.1. Gamma–Ray Energies

The measured and evaluated values of gamma ray energies are given in Table 3.

The evaluated values of Eγ have been obtained as weighted means omitting outliers contradicting to the energies of excited levels measured in 1986Sc25. The values of 1969Me09 have been omitted as the author in 1990Me15 replaces them.

4.2.2. Gamma–Ray Relative Emission Probability

The measured and evaluated values of relative gamma ray emission probabilities ($P'\gamma$) are shown in Table 4.

The evaluated values of $P'\gamma$ have been obtained as weighted means apart from $P'(\gamma_{5,4})$ and $P'(\gamma_{4,2})$. The $P'(\gamma_{5,4})$ has been evaluated from the intensity balance for the 107.58 keV - level. The $P'(\gamma_{4,2})$ has been calculated from data on conversion electrons (1967Fo11) and the adopted ICC using the measured in 1967Fo11 ratio $P(ce_{4,2}\,L3)/P(ce_{3,0}\,K) = 0{,}115(6)$ and the adopted values of $\alpha_{L3}(\gamma_{4,2})$ and $\alpha_K(\gamma_{3,0})$.

The values of 1969Me09 have been omitted as the author in 1990Me15 replaces them. Other values have been omitted due to absence of uncertainties or as statistical outliers.

Our evaluated value $P'(\gamma_{3,0}) = 68.8(14)$ for the intense gamma ray with energy of 105.31 keV is supported by the results of measurements of the intensity ratio $P(ce_{3,0}\,K)/P(ce_{2,0}\,K) = 0.408(8)$ in 1967Fo11 (see Table 5) which leads to the value $P'(\gamma_{3,0}) = 68.7(17)$ if the adopted α_K in sect.2.2 is used.

4.2.3. Gamma-Ray Absolute Emission Probabilities

Two absolute measurements of the emission probability are available for the 86,55 keV gamma ray: 31.1(4)% in 1994Co02 and 30.5(3)% in 1994Eg01. The weighted mean of these values has been adopted as the evaluated $P(\gamma_{2,0}) = 30.7(3)$%. Here the uncertainty is the external one of WM.

The absolute emission probabilities of other gamma rays have been computed from the evaluated emission probabilities (P') given in Table 4 and the evaluated absolute emission probability of $\gamma_{2,0}$ (86.55 keV).

It should be noted that the absolute emission probability of $\gamma_{3,0}$ (105.31 keV) was measured in 1992Sa04: $P(\gamma_{3,0}) = 20.39(13)$ %. This value is considerably less than the evaluated one and measured in 1994Eg01 and 1996Ch27. If it is adopted without changing of the evaluated $P(\gamma_{2,0}) = 30.7(3)$% the relative emission probability of $\gamma_{3,0}$ will be 66.4(9), essentially less than the average of the eight measurement results (Table 4 and comment in sect.4.2.2.). On other hand, if the value of 1992Sa04 is adopted together with the evaluated $P'(\gamma_{3,0}) = 68.8(14)$, the $P(\gamma_{2,0})$ will be obtained as 29.6(6) %, less than both results of direct measurement of the absolute emission probability of this gamma ray (1994Co02 and 1994Eg01).

Therefore we consider the value of 1999Sa04 as too small and do not take it into account.

Table 3. Measured and evaluated values of gamma ray energies in the decay of ^{155}Eu

	1959Ha07	1967Fo11	1969Me09	1970Re08	1970Ra37	1975Ch04[a]	1975Kr04	1986Sc25 [b]	1990Me15	1990GoZS	Evaluated (adopted) value
$\gamma_{5,4}$		10.40(2)*				10.40(2)*		10.4183(13)			10.4183(13)
$\gamma_{3,2}$		18.776(35)*	18.776(35)*			18.749(19)*	18.73(3)*	18.760(4)	18.784(35)*	18.764(2)	18.763(2) [c]
$\gamma_{4,2}$		21.02(2)				21.02(2)		21.030(10)		21.036(4)	21.035(4)
$\gamma_{2,1}$			26.513(21)*				26.49(5)	26.530(23)	26.532(21)		26.531(21)
$\gamma_{5,2}$			31.40(10)*	31.55(12)				31.444(7)	31.40(10)		31.444(7)
$\gamma_{3,1}$	45.29(1)	45.3(2)*	45.299(13)*	45.299(2)	45.2972(13)		45.27(5)*	45.3000(10)	45.295(13)		45.2990(10)
$\gamma_{5,1}$			57.983(30)*	57.970(26)	57.9805(20)		57.99(4)	57.989(1)	57.986(30)		57.989(1)
$\gamma_{1,0}$	60.00(2)		60.019(15)*	60.006(4)	60.0100(18)		60.01(4)	60.008(2)	60.022(15)	60.0086(10)	60.0086(10) [c]
$\gamma_{6,1}$		86.01(20)	86.0(5)	86.062(23)	86.062(5)		86.03(7)	86.0590(10)			86.05910(10)
$\gamma_{2,0}$	86.56(1)	86.82(20)	86.539(15)*	86.541(3)	86.5452(33)		86.53(3)	86.5470(10)	86.554(15)		86.5479(10)
$\gamma_{3,0}$	105.32(3)	105.28(20)	105.315(15)*	105.302(4)	105.308(3)		105.30(3)	105.3090(10)	105.338(15)		105.3083(10)
$\gamma_{3,0}$			146.05(2)*	146.061(5)			146.04(10)	146.0710(10)	146.090(90)		146.0710(10)

[a] Decay of ^{155}Tb

[b] Reaction ^{154}Gd(n,γ)^{155}Gd

[c] The data of 1976Me10 (decay of ^{155}Tb) have been taken into consideration additionally: E($\gamma_{3,2}$)=18.769(15) keV and E($\gamma_{1,0}$)=60.012(3) keV.

* Omitted from averaging. Values of 1969Me09 are superseded by those of 1990Me15.

Table 4. Measured and evaluated values of relative gamma ray emission probabilities in the decay of ^{155}Eu.

	Eγ, keV	1959Ha07	1967Be11	1968Al01	1969Me09	1970Re08	1971Ge11	1975Kr04	1990Me15	1994Eg01	1996Ch27	Evaluated value
$\gamma_{5,4}$	10.418											0.0115(13) [a]
$\gamma_{3,2}$	18.763	≈0,1*			0.16(4)*		0.17(3)	0.13(3)	0.16(4)			0.16(2) [b,c]
$\gamma_{4,2}$	21.035											$1.5(3)\cdot10^{-3}$ [d]
$\gamma_{2,1}$	26.531	≈4*		≈1*	1.03(6)*		1.00(10)	1.10(13)	1.03(6)			1.03(6) [c]
$\gamma_{5,2}$	31.444				0.023(5)*	0.03(2)			0.023(5)			0.023(5) [c]
$\gamma_{3,1}$	45.299	2.3*		2.8(7)*	4.18(17)*	3.6(7)	4.1(3)	3.95(40)	4.21(20)	4.36(12)	4.3(10)	4.27(12) [c]
$\gamma_{5,1}$	51.989			0.20(3)	0.217(18)*	0.22(5)		0.23(3)	0.221(18)	0.213(30)		0.217(18) [c]
$\gamma_{1,0}$	60.009	4,0*	5.1(20)*	3.8(2)	3.60(10)*	4.3(3)	3.9(9)	3.8(4)	3.60(10)	3.99(12)	3.9(9)	3.96(12) [c]
$\gamma_{6,1}$	86.059			0.50(5)		0.49(5)		0.54(11)				0.50(5) [c]
$\gamma_{2,0}$	86.548	100	100	100	100	100	100	100	100	100	100	100
$\gamma_{3,0}$	105.308	64*	65.7(65)	67.9(35)	66.8(27)*	68.3(27)	68(4)	69.9(35)	66.8(27)	68.5(14)	69.5(16)	68.8(14) [c,e]
$\gamma_{6,0}$	146.071		0.16(5)		0.167(10)*	0.19(2)		0.14(2)	0.167(10)			0.166(10) [c]

[a] Evaluated from the intensity balance for the 107.58 keV level

[b] In addition the value of 0.16(2) from 1974HeYW has been taken into account

[c] Weighted mean

[d] Evaluated from the conversion electron intensity and ICC

[e] In addition the value of 69.1(9) from 1982Co05 has been taken into account

* Omitted from averaging. Values of 1969Me09 are superseded by those of 1990Me15.

5. ELECTRON EMISSIONS

The energies of the conversion electrons have been calculated from the gamma -transition energies given in 2.2 and the electron binding energies.

The emission probabilities of the conversion electrons have been calculated using the evaluated Pγ and ICC. In Table 5 the relative intensities of conversion electrons P'ce(exp.) measured in 1967Fo11 are compared to the relative intensity values P'ce(calc.) calculated from the evaluated absolute emission probabilities (in units P'($ce_{3,0}$ K) = 1000).

Table 5. Comparison of experimental and calculated values of relative intensity of conversion electrons in the ^{155}Eu decay.

	Energy, keV	P'ce(exp)	P'ce(calc.)
$ec_{5,4}$ L	2.043-3.175	305(27)	206(30)
$ec_{1,0}$ K	9.770(3)	1870(100)	2000(130)
$ec_{3,2}$ L	10.387-11.520	2730(110)	3080(400)
$ec_{4,2}$ L	12.659-13.792	212(8)	218(30)
$ec_{6,1}$ K	35.820(3)	66(5)	91(12)
$ec_{2,0}$ K	36.309(3)	2450(50)	2440(50)
$ec_{3,1}$ L	36.923-38.053	90(5)	100(5)
$ec_{1,0}$ L	51.633-52.766	420(10)	418(16)
$ec_{3,0}$ K	55.069(3)	1000	1000
$ec_{2,0}$ L	78.172-79.305	380(9)	382(13)
$ec_{3,0}$ L	96.933-98.066	152(6)	152(8)

As seen from Table 5 the experimental and calculated values agree well with the exception of ec $_{5,4}$ L and $ec_{6,1}$ K. The disagreement for ec $_{5,4}$ L can be connected with experimental difficulties of measurement of the 2-3 keV conversion electrons on the background of intense L Auger electrons, and for ec $_{6,1}$ K – of measurement on the background of intense conversion line of $ec_{2,0}$ K.

The total absolute emission probability of K Auger electrons has been computed using the total P(ce_K) = 25.17(46) % and the adopted ω_K in sect.3.

The total absolute emission probability of L Auger electrons has been computed using the evaluated total P(ce_K) and P(ce_L) = 21.2(24) % and the adopted ϖ_L and n_{KL} in sect.3.

The values of β^- average energies have been calculated using the LOGFT program.

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^{159}Gd - Comments on evaluation of decay data
by R. G. Helmer

This evaluation was completed in 2004. The literature available by March 2005 was included.

1 Decay Scheme

^{159}Gd decays by β- emission to levels in ^{159}Tb.

2 Nuclear Data

Q value is 970.5(7) from Audi et al. 2003 mass evaluation (2003Au03).

For the adopted decay scheme, the total radiation energy per decay is calculated to be 970(12) keV which agrees well with the decay energy of 970.5(7) keV from the 2003 mass evaluation (2003Au03), which confirms the internal consistency of this scheme.

The half-life values available are, in hours:

18.0	1948Kr03
18.0(2)	1949Bu01
18.0(3)	1960Wi10
18.56(8)	1966Da19
18.479(4)	1989Ab05
18.479(7)	Adopted value

The weighted average of the last four values in the Limitation of Relative Statistical method, as implemented in the LWEIGHT code, is completely dominated by the value of 1989Ab05 which has 99.7% of the relative weight. The data of 1949Bu01 and 1960Wi10 contribute 2.8 to the reduced-χ^2 value of 3.1, but since this value is less than the critical reduced-χ^2 value of 3.8 used in LWEIGHT for four input values, the relative weight of the dominate input value is not reduced. The internal uncertainty for this average is 0.004 and the external uncertainty is 0.007, which is adopted.

2.1 b$^-$ Transitions

The probabilities for the β^- branches are from the probability balances from the γ-ray transitions for the excited levels and from the measurement of 1975BaXG for the ground state. These values are:

Level (keV)	Value (%)
0	57.8(12)
58	29.6(12)
137	0.012(9)
348	0.315(4)
363	12.19(6)
580	0.0626(8)
617	0.0300(9)
674	0.00388(10)
854	0.0162(5)
891	0.0009(4)

The other measured values from 1975BaXG are 24(4) for the level at 58 keV and 13(2) for the levels at 348 and 363 keV.

2.2 g Transitions

The multipolarities are from the Adopted γ data in the Nuclear Data Sheets (2003He11). See sect. 4.2 for comments on the γ-ray and level energies and the normalization of relative photon emission probabilities to absolute values. The multipolarities are as follows:
( ) indicates a tentative assignment, based on experimental data;
[ ] indicates an assignment based on the spins and parities of the associated levels:

Levels and Jπ's		γ energy (keV)	multipolarity	mixing ratio	%E2
58 5/2+	0 3/2+	58	M1+E2	+0.119(2)	1.40(6)
137 7/2+	58 5/2+	79	M1+E2	+0.126(8)	1.56(20)
	0 3/2+	137	[E2]		
348 5/2+	137 7/2+	210	[M1,E2]		
	58 5/2+	290	[M1,E2]		
	0 3/2+	348	M1+E2	+0.43(+10, -9)	16(6)
363 5/2-	137 7/2+	226	E1		
	58 5/2+	305	E1		
	0 3/2+	363	E1		
580 1/2+	0 3/2+	580	[M1,E2]		
617 3/2+	58 5/2+	559	M1+E2	0.67(+58, -1)	31(+30, -1)
	0 3/2+	617	(M1)		
674 5/2+	137 7/2+	536	(M1)		
	58 5/2+	616	(M1)		
	0 3/2+	674	(M1)		
854 (1/2-)	617 3/2+	237	[E1]		
	580 1/2+	274	[E1]		
	0 3/2+	854	[E1]		
891 (5/2-)	617 3/2+	273	[E1]		
	137 7/2+	753	[E1]		

See section 4.2 for the γ-ray energies and emission probabilities.

3 Atomic Data

3.1 X rays and Auger electrons

The fluorescence yield data are from Schönfeld and Janßen (1996Sc06) and the EMISSION code. These give $\omega_K = 0.935(4)$, the average $\omega_L = 0.186(8)$, and $\eta_{KL} = 0.847(4)$.

The Auger electron emission intensities are from the EMISSION code and based on the adopted γ-ray emission probabilities and conversion coefficients. These values are KLL 0.94(7)%, KLX 0.49(4)%, and KXY 0.063(5)%.

4 Emissions

4.1 K x-rays

The K x-ray electron emission probabilities are from the EMISSIONS code and based on the adopted γ-ray emission probabilities and conversion coefficients.

4.2 Photon Emission

Values for the γ-ray energies are available from 1968Hi03, 1969Br05, and 1995Mo08. Any weighted average would be dominated by the values of 1995Mo08, so the values from the latter reference are adopted.

The γ-ray energies from these references are:

1968Hi03	1969Br05	1995Mo08
58.00(1)	58.00(5)	58.0000(22)
79.45(2)	79.52(2)	79.5132(27)
137.7(3)	137.4(2)	137.515(5)
210.8(3)	210.9(5)	210.783(3)
226.00(4)	226.2(2)	226.0406(18)
236.9(4)	237.5(2)	237.341(5)
		273.62(12)
274.2(6)	274.2(2)	274.163(19)
290.2(3)	290.3(2)	290.2865(25)
305.6(2)	305.5(2)	305.5492(20)
348.17(8)	348.1(2)	348.2807(18)
363.56(3)	363.3(2)	363.5430(18)
		479.84(6)
536.7(4)	536.8(2)	536.730(12)
559.9(3)	559.56(15)	559.623(6)
581.1(3)	580.84(15)	580.808(6)
	616.5(3)	616.233(18)
617.7(3)	617.7(2)	617.615(18)
	674.3(5)	674.26(5)
		753.74(6)
854.5(4)	854.9(2)	854.947(20)

For the relative γ-ray emission probabilities, the following data were used. All the values of 1965Fu14 are omitted since the normalization value of 100 has a 30% uncertainty.

g ray (keV)	1964Pe07	1965Fu14	1968Hi03	1969Br05	1985Da31	1994St05	1995Mo08	2001Ma01	Adopted	Reduced c^2
58			18.0(30)	21(2)	19.1(8)	22.7(4)	18.9(9)	20.7(3)[ae]	21.1(6)	6.2
79		0.44(8)	0.38(7)	0.38(4)	0.37(6)	0.36(2)	0.417(11)	0.388(14)	0.397(9)	1.52
137		0.10(3)	0.042(26)	0.06(1)	0.05(1)	0.05(1)	0.0550(13)[f]		0.0549(13)	0.25
210			0.090(35)	0.165(25)	0.16(3)	0.192(23)	0.178(4)[e]		0.170(12)	1.66
226			1.8(1)	1.96(10)	1.80(4)	1.92(10)	1.89(4)	1.83(1)	1.842(18)	0.99
237			0.055(36)	0.072(11)	0.059(12)	0.064(12)	0.0652(14)[f]		0.0653(14)	0.33
246					0.012(7)		< 0.0008			
269					0.013(9)		< 0.0004			
273		0.065(3)[b]	0.065(40)[b]	0.054(13)[b]	0.056(11)[b]	0.055(12)[b]	0.0065(25)		0.006(3)	
274							0.0478(25)		0.048(3)	
290			0.24(3)	0.28	0.23(5)	0.27(3)	0.275(5)	0.274(8)	0.274(4)	0.43
305			0.54(4)	0.55(4)	0.51(2)	0.52(2)	0.527(10)	0.527(9)	0.526(6)	0.25
348	2.0(3)		2.0(1)	2.00(15)	1.99(8)	2.04(10)	2.05(4)	1.99(1)[ce]	2.031(21)	1.86
363	≡ 100(5)	100(30)	100	100(5)	100	100	100	100	100	
371					0.006(4)		< 0.0003			
429					0.005(4)		< 0.0003			
536	0.07 (4)	< 0.02	0.018(12)	0.010(3)	0.018(9)	0.013(3)	0.0137(4)[f]		0.0136(4)	0.48
559	0.25(10)	0.23(4)	0.17(3)	0.20(2)	0.19(2)	0.19(1)	0.187(6)		0.188(5)	0.20
581	0.70(15)	0.5(2)	0.55(4)	0.57(4)	0.60(4)	0.57(2)	0.578(19)	0.581(5)[f]	0.588(5)	0.24
616	0.20(8)[d]	0.02(1)	0.009(6)	0.020(5)	0.016(6)	0.026(8)	0.0159(7)[f]		0.0160(7)	0.90
617		0.15(5)	0.13(4)	0.13(2)	0.15(3)	0.14(1)	0.134(5)[f]		0.135(4)	0.15
674				0.0034(10)	< 0.008	0.0034(13)	0.00263(20)[f]		0.00268(19)	0.044
753							0.00153(17)		0.00153(17)	
854		0.015(7)	0.014(8)	0.021(3)	0.020(6)	0.021(2)	0.0212(18)		0.0209(12)	0.20

[a] Authors also give value of 20.1(8). The most precise value is adopted.

[b] Value is for sum of 273 and 274 lines.

[c] Authors also give value of 2.11(3), both values are included in the calculation of the average.

[d] Value is for sum of 616 and 617 lines.

[e] This uncertainty was increased in the averaging process to reduce the relative weight to 50%.

[f] Value contributes over 70% of the relative weight in the calculation of the average, but since the input values are consistent this weight is not reduced.

These relative γ-ray emission probabilities have been scaled by 0.1178(5) to obtain absolute values based on the measured emission probability of 11.78(5)% from 2001Ma01.

5. Electron emissions

The internal-conversion electron emission probabilities are from the adopted γ-ray emission probabilities and the associated conversion coefficients. These values for the stronger lines are:

g-ray energy (keV)	shell, energy	emission probability (%)
58	K, 6.004	22.8(9)
	L, 49.292	3.86(16)
	M, 56.032	0.85(4)
	N+, 57.602	0.235(10)
79	K, 27.518	0.17(7)
	L, 70.805	0.0273(11)
	M, 77.546	0.00604(23)
	N+, 70.115	0.00167(5)
137	K, 85.519	0.00307(12)
	L, 128.807	0.00179(7)
210	K, 158.787	0.0036(11)
226	K, 174.045	0.00629(19)
290	K, 238.291	0.0024(8)
348	K, 296.285	0.0134(5)
	L, 339.573	0.00201(6)
363	K, 311.547	0.104(3)
	L, 354.835	0.0145(4)
	M, 361.576	0.00313(9)
581	K, 528.812	0.00084(25)

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^{166}Ho - Comments on evaluation of decay data
by E. Schönfeld and R. Dersch

1 Decay Scheme

Below the Q value of 1854,5 keV there are several other excited levels of ^{166}Er which are populated in the disintegration of ^{166}Ho^{m} ($T_{1/2}$ = 1200 a) and ^{166}Tm ($T_{1/2}$ = 7,70 h). Beta transitions from ^{166}Ho to these levels, if existing, would have high degrees of forbiddeness so that they are not populated in the ^{166}Ho decay (or with extremly low transition probabilities). Thus, the decay scheme, given on page 1, can be considered as complete. Spins, parities and half-lives of the excited levels, and lg *ft* were taken from Ignatochkin et al. (1987).

2 Nuclear Data

Following half-life measurements have been taken into account ($T_{1/2}$ in h):

1	27,5	Inghram and Hayden	1947
2	26,8(4)	Grant and Hill	1949
3	26,9(1)	Cork et al.	1958
4	26,8(2)	Funke et al.	1963
5	26,74(5)	Daniel and Kaschl	1966
6	27,00(4)	Venkata Ramaniah et al.	1976
7	26,827(5)	Abzouzi et al.	1989
8	26,78(1)	Calhoun et al.	1991
9	26,7663(44)	Unterweger et al.	1992
10	26,795(29)	adopted value	1999

Value 1 is only of historical interest. Value 8 is replaced by value 9, value 6 is considered as outlier (or its accuracy is overestimated). The adopted value is the LWM of values 2-5, 7 (with doubled uncertainty to take account for systematical errors) and 9. LWM has used weighted average and expanded the uncertainty so range includes the most precise value 9. The rather large uncertainty reflects the discrepancy between the values 7 and 9.

2.1 ß$^-$ Transitions

The maximum beta energy of the transition to the ground state of ^{166}Er and the transition probability of this transition have been determined as follows:

1	1840	25 %	Sunyar 1954
2	1854(5)	51,6 %	Graham et al. 1955
3	1839(5)	47 %	Cork et al. 1958
4	1844	52 %	Marklund et al. 1960
5	1840	46 %	Cline et al. 1962
6	1859(3)	48,8 %	Funke et al. 1963
7	1857(3)	48,8 %	Daniel and Kaschl 1966
8	1854,7(15)	51,2 %	Grigoriev et al. 1974
9	1845(2)	52 %	Venkata Ramaniah et al. 1976
10	1854,8(17)		weighted average of values 2, 6 - 9 (see text below)
11	1854,5(9)		Audi and Wapstra 1995. Here adopted too

For the calculation of the average value 10, the originally given uncertainty of value 9 has been doubled before inserting it in the averaging procedure because the uncertainty seems to be overestimated. The unweighted average for the transition probability to the ground state (including values 2 to 9) is 49,6 %. This value agrees satisfactorily with the adopted value 48,2(15) % which was derived in the balancing procedure from the gamma transition probabilities.

2.2 Gamma Transitions

The energies of the gamma transitions are calculated from the gamma ray energies (section 4.2) taking the recoil energies into account which can be neglected in most cases. The probabilities P_{g+ce} are calculated from the gamma ray emission probabilities and the total conversion coefficients.

The conversion coefficients are interpolated from the tables of Rösel et al. (1978). Very much work has been spent for the study of the conversion of the 80,57 keV gamma transition. The K conversion coefficient of this transition was found to be

1	1,69(9)	Ramaswamy and Brahmavar	1963
2	1,63(5)	Falkstroem et al.	1968
3	1,72(6)	Nelson and Hatch	1969
4	1,69(6)	Campbell et al.	1971
5	1,66(6)	Campbell et al.	1972
6	1,65(5)	interpolated from Rösel et al.	1978; adopted value

For the K/L ratio the following values were found:

1	0,390(18)	Bogdanovic et al.	1968
2	0,426(11)	Nilsson et al.	1968
3	0,414(13)	Kartashov et al.	1977
4	0,411(12)	interpolated from Rösel et al.	1978; adopted value

Kartashov et al. (1977) have also determined the ratios M/L, N/M and O/N. From their measurements the following set can be derived:
$\alpha_K = 1{,}650(33)$
$\alpha_L = 3{,}983(170)$
$\alpha_M = 0{,}990(50)$
$\alpha_N = 0{,}200(12)$
$\alpha_{OP} = 0{,}048(3)$
$\alpha_t = 6{,}87(18)$

The total conversion coefficient of this transition was determined by Brandtley et al. (1966) to be $\alpha = 6{,}94(48)$. Several other authors have determined L subshell ratios (Hermann et al. (1966), Gelletly et al. (1966, 1967), Karlsson et al. (1966), Zylicz et al. (1966), Arnoux and Gizon (1967), Bogdanovic et al. (1968)). Also M and N subshell ratios were determined (Hoegberg et al. (1968), Dragoun et al. (1972), Bulgakov et al. (1981)).

The conversion coefficients contained in table 2.2 are interpolated from the tables of Rösel et al. (1978).

3 Atomic Data

The atomic data are taken from Schönfeld and Janßen (1996).

3.1 X Radiation

The energies are based on the X ray wave lengths compiled by Bearden (1967). The relative probabilities are calculated using the ratios $P(K_{\alpha_2})/P(K_{\alpha_1})$ and $P(K_\beta)/P(K_\alpha)$ as given by Schönfeld and Janßen (1996). The relative probability of X_L radiation is calculated from the absolute value putting $P(K_{\alpha_1}) = 100$.

3.2 Auger Electrons

The energies are taken mainly from the report of Larkins (1977). The relative probabilities are calculated using the ratios P(KLX)/P(KLL) and P(KXY)/P(KLL) as given in the cited report of Schönfeld and Janßen (1995). The relative probability of e_{AL} electrons is calculated from the absolute value putting P(KLL) = 100.

4 Radiation Emission

4.1 Electron Emission

The numbers of Auger electrons per disintegration are calculated using the program EMISSION and the atomic data as given in Section 3. The numbers of conversion electrons per disintegration are calculated using the conversion coefficients and the probabilities $P_{\gamma+ce}$ as given in 2.2. Spectra of the conversion electrons from the 80,6 keV transition, the 1379,4 keV transition and the $0^+ \rightarrow 0^+$ 1460 keV E0 transition were measured by Grigoriev et al. (1974). The data for the emission of β particles are those already given in 2.1.

4.2 Photon Emission

Most of the gamma-ray energies were taken from Ardisson et al. (1992) ($\gamma_{1,0}$, $\gamma_{4,3}$, $\gamma_{3,1}$, $\gamma_{3,0}$, $\gamma_{4,1}$, $\gamma_{5,0}$, $\gamma_{6,1}$, $\gamma_{6,0}$, $\gamma_{8,1}$, $\gamma_{7,0}$, $\gamma_{8,0}$).

The following measurements of relative photon emission probabilities have been taken into account (the relative emission probability of the 1379,4 keV line was arbitrarily set to 1):

E in keV	1	2	3	4	5	6	7
80,6	6,67(43)	-	7,04(30)	6,72(70)	7,22(8)	6,56(40)	7,02(14)
184,4	-	0,0022(5)	-	0,0013(3)	0,0023(1)	0,0010(1)	0,0016(7)
521,0	-	-	-	0,00032(11)	0,0005(2)	0,00038(1)	0,00038(2)
674,2	0,032(2)	0,022(2)	0,034(2)	0,0176(9)	0,023(1)	0,0201(4)**	0,0212(18)
705,4	0,020(3)	0,016(2)	0,023(1)	0,0137(7)	0,0170(10)	0,0144(3)**	0,0156(13)
785,9	0,016(3)	0,014(2)	0,012(5)	0,0125(7)	0,0140(10)	0,0128(3)**	0,01288(27)
1263,0	-	-	-	0,0015(2)	0,0017(1)	0,0016(3)	0,00166(9)
1379,4	1	1	1	1	1	1	1
1447,5	-	-	-	0,00105(10)	0,0012(1)	0,0014(5)	0,00113(10)
1528,2	-	-	-	0,0002	-	0,00010(1)	0,00015(5)
1581,8	0,206(10)	0,195(10)	0,215(10)*	0,197(7)	0,199(5)	0,197(5)	0,1994(28)
1662,4	0,129(7)	0,125(6)	0,099(5)*	0,130(5)	0,127(4)	0,130(2)**	0,126(5)
1731,5	-	-	-	-	-	0,00005(2)	0,00005(2)
1749,8	0,033(1)*	0,027(2)	0,030(17)	0,028(2)	0,028(1)	0,0285(6)**	0,0292(9)
1812,8	-	-	-	-	-	0,00006(2)	0,00006(2)
1830,5	0,0100(8)*	0,0086(11)	0,0081(5)	0,0089(5)	0,0085(2)	0,0089(3)	0,0087(2)

1 Burson et al. 1967
2 Reich and Cline 1970
3 Venkata Ramaniah et al. 1976
4 Allab et al. 1977
5 Chand et al. 1989
6 Ardisson et al. 1992
7 values adopted in this evaluation (LWM)

* classified as outlier (appearing only in values of references 1 and 3)

** input uncertainty slightly increased (only for some values of reference 6 and one value of reference 5)

Earlier results of Marklund et al. (1960), Hansen et al. (1961), Cline et al. (1962), Funke et al. (1963) and Neumann (1966) were not taken into account because they are less accurate, incomplete and given without uncertainties.

The absolute emission probability for the gamma rays from the transition $\gamma_{1,0}$ (80,6 keV) has been determined as follows (gamma rays per 100 disintegrations):

1	6,55(30)	Venkata Ramaniah et al. 1976
2	6,25(60)	Allab et al. 1977
3	6,60(40)	Sekine and Baba 1981
4	6,55(8)	Calhoun et al. 1991; Coursey et al. 1994

In the present evaluation value 4 is adopted. Combining it with the relative emission probability of the 80,6 keV transition, the normalization factor 0,933(16) is obtained.

5 Main Production Modes

Taken from Firestone (1995).

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Other references can be found in the Tables Part.

^{166}Ho^{m} - Comments on evaluation of decay data
by E. Schönfeld, R. Dersch

1 Decay Scheme

The decay scheme was taken from Ardisson *et al.* 1992. It contains 54 gamma transitions between 17 excited levels of ^{166}Er or to the ground state of this nuclide. This decay scheme is not complete. 12 additional gamma rays have been reported, six of them from branching in Tm-166 EC decay (see 2.2).

The half-lives of the excited level in ^{166}Er indicated in the decay scheme are taken from Shursikow and Timofeeva (1992).

2 Nuclear Data

The half-life was determined by Faler (1965) to be 1200 a. The uncertainty was estimated to be 180 a. New measurements are desirable. The Q-value is 6,0 keV above Q(^{166}Ho). This is the energy difference between the isomer level and the ground state of ^{166}Ho. The Q-value of ^{166}Ho was derived from ß-ray endpoint energies to be 1854,5(9) keV. Thus, the Q-value of ^{166}Ho^{m} is 1860,5(9) keV.

2.1 ß$^{-}$ Transitions

There are seven ß transitions to excited levels of ^{166}Er. The most important transitions are the allowed transitions to levels no. 17 and 16 (17,2(4) % and 74,8(12) %). Weak transitions are feeding the levels 11, 10, 9, 6 and 3. Transitions to the levels 15, 14, 13, 12, 8, 7, 5, 4, 2, 1 and the ground state ($\Delta J_o = 7$) have not been observed. All these transitions are at least second forbidden except a transition to level 8 which is unique first forbidden.

The energies of these transitions were calculated by subtracting the level energy from the Q-value. The transition probabifities P_{β} were calculated from the transition probabifties $P_{\gamma+ce}$ using the relations which correspond to the decay scheme.

2.2 Gamma transitions

The level differences are equal to the gamma-ray energies as the recoil energies are small compared with the uncertainties of the latter. The gamma-ray energy of the 80,6 keV emission has been determined as follows (energy in keV):

1	80,573	Reich and Cline 1970
2	80,589(5)	Morii et al. 1975 .
3	80,572(15)	Souch et al. 1982
4	80,585(15)	Adam et al. 1988
5	80,574(8)	Hardell and Nilsson 1962; cryst.-spektr.
6	80,5725(13)	Helmer and van der Leun 2000; here also adopted

The energies of gamma transitions between the levels 0, 1, 2, 3, 5, 6, 7, 8, 9, 10 and the transitions $\gamma_{16,5}$ and $\gamma_{17,3}$ are taken from Helmer and van der Leun (2000). The energies of all other transitions are either taken from Ardisson *et al.* (1992) or based on values given by these authors.

The probabilities $P_{\gamma+ce}$ were calculated from the gamma -ray emission probabilites P_γ using the values for the total conversion coefficients α_t. The conversion coefficients α_K , α_L and α_t were interpolated from the tables of Rösel *et al.* (1978). The normalization factor which is necessary to convert relative emission probabilities (related to 100 for the 184 keV gamma rays) can be calculated from balancing conditions using cuts between the levels 0 and 1, 1 and 2, 2 and 3. This is possible because the levels 2, 1 and 0 (the ground state) are not populated by β transitions. The cut between the levels 0 and 1 contains the emission probability of the 80,6 keV gamma transition. The conversion coefficient of this transition has a relatively large uncertainty, the calculation of the normalization factor from the cuts 1-2 and 2-3 is therefore preferred here. Moreover, the normalization factor was determined using absolute activity measurements:

1	0,732(37)	Reich and Cline, 1970
2	0,699(14)	Danilenko et al., 1989
3	0,7258(22)	Miyahara et al., 1994
4	0,7021(35)	Morel et al., 1996
5	0,7235(67)	Hino et al., preliminary value, 1999
6	0,7214(72)	from cut between levels 1 and 2, this evaluation 1999
7	0,7298(75)	from cut between levels 2 and 3, this evaluation 1999
8	0,725(3)	adopted value

The value 8 is the LWM between values 1, 3, 5, 6 and 7 where the uncertainty of value 3 has been doubled in order to contribute less than 50 % to the mean. Values 2 and 4 are considered to be significantly too low by the evaluator and were not included in the averaging procedure. The reduced χ^2 of the LWM is 0,2. The adopted value of the normalization factor is in excellent agreement with the value 0,726(9) evaluated by Shursikow and Timofeeva (1992).

The K-conversion coefficients were calculated using the tables of Rösel et al. (1978). The multipolarities of the transitions were determined from the spin and parity assignments as made by Ardisson et al. (1992) and Shursikow and Timofeeva (1992). There is reasonable agreement between measured and calculated conversion coefficient for the 80,6 keV transition:

1	1,76(15)	Marklund et al. 1960
2	1,72(6)	Nelson and Hatch 1969
3	1,69(6)	Campbell et al. 1971
4	1,65(3)	E2 Theory, Rösel et al. 1978

The following gamma rays are not included in the decay scheme and in the tables 2.2 and 4.2:

E_γ in keV	P_{rel} (related to 100 for the 184,4 keV line)	
96,85(5)	0,00307	*
170,31(3)	0,0184(11)	*
255,20(12)	0,0059(13)	
410,80(5)	0,0231(7)	*
520,945(15)	0,00039(7)	*
617,0(5)	0,031(9)	
712,89(13)	0,41(12)	*
736,02(8)	0,19(2)	
1446,72(13)	< 0,01	
1521,99(4)	0,018(5)	
1562,57(4)	0,0040(11)	

* Deduced from branching in Tm-166 EC decay where also the 73 keV transition, contained in Table 2, occurs. These date are taken from Shursikow and Timofeeva (1992), see also Adam et al. (1979).

For several transitions, mixing ratios were determined from γ-γ angular correlation measurements. Most of them are compiled in the following table:

E2-M1 mixing ratios for γ-transitions in ^{166}Er following the decay of ^{166}Ho^{m}

E_r in keV	*d*	*d*(adopted)	% M1
119,0	±1,79(12)[1] 1,75(12)[2]	1,79(12)	24(2)
140,7	±1,43(10)[1] 1,67(11)[2]	1,43(10)	33(3)
160,1	1,45(11)[1]	1,45(11)	32(4)
464,8	-(3,1+1,5-0,9)[3] -80<δ<+30[4] -(32+98-14)[5] -(63+19-12)[6]	-50(20)	(0,04+0,07-0,02)
529,8	-(85+8 -45)[7] -25(3)[4] -5,0(25)[3] -(25+5-4)[5] -(62+40-17)[8] -(60+45-19)[8]	-30(20)	(0,11+0,9-0,07)
594,1	-(9+319-5)[4] (9+8 -5)[5] -(12+29-5)[8] -(8+15-3)[8] -(59+74-21)[2]	-10(5)	(1+3-0,5)
644,5	|δ|>2[4] +1,6+1,0-0,55[3] -0,75(20)[3] <-1or >+4[8] -(13,4+3,3-2,2)[2]	3-2+3	(10+40-7)
670,5	6,3+8 -2,9[3] -(1,15+0,80-0,35)[3] -(20+90-9)[4, 5] (10,0+1,6-1,2)[8] 9,4+2,9-1,6[8] (19+5-3)[2]	12(5)	(0,69+1,31-0,35)
691,3	3,3+3,0-1,2[9] -(10+27-4)[4] -(16+27-4)[5] -(28+7-5)[2] -(16+8 -9)[8] -(16+8 -10)[8]	-16(8)	(0,39-0,22+1,15)
705,2	|δ|=25[10] 38+8 -24[9] 19+38-9[9] -(55+13-9)[2]	50(10)	(0,04+0,02-0,01)
778,8	-(20+8 -13)[3] -(18+8 -9)[4] -(19+8 -10)[5] -(20+4-2)[8] -(18+8-5)[8] -(109+26-17)[2]	18(6)	(0,31+0,35-0,14)
810,3	37+10-7[7] -16,4+3,2-2,3[11] -20(4)[4] -(84+8 -57)[3] -(20+4-3)[5] -(36+11-7)[6] -21(2)[8] -15(1)[8]	25(5)	(0,16+0,09-0,05)
830,6	70+260-30[7] -(42+25-13)[11] -(22+7-5)[4,5] -(37+8 -17)[3] -(18+3-2)[6] -23(4)[8] -(16,6+1,8-1,5)[8] -(15,3+2,3-1,7)[2]	-(18+3-2)	0,31(8)

[1]	Wagner 1992, measured
[2]	Wagner 1992, calculated
[3]	West et al. 1976
[4]	Baker et al. 1975
[5]	Lange et al. 1981
[6]	Alzner et al. 1985
[7]	Reich and Cline 1965
[8]	Krane and Moses 1981
[9]	Domingos et al. 1972
[10]	McGowan et al. 1978
[11]	Miyokawa et al. 1972 as cited in the paper of Krane and Moses 1981

Some of the measurements are discrepant. However, the influence of the results on the conversion coefficients is in most cases small. Gerdau et al. (1963) determined some mixing ratios from γ-γ-angular correlations. Some of them deviate from the results of later publications (411 keV 95 % E1 + 5 % M2; 712 keV 99,6 % E1 + 0,4 % M2; 810 keV 99,1 % E2 + 0,9 % M1; 831 keV 96,1 % E2 + 3,9 % Ml).

If two multipolarities are mentioned in Table 2.2, then the mixing ratio was taken into account when calculating the conversion coefficients. If a second multipolarity is given in brackets, then the conversion coefficients are calculated for the first multipolarity but an admixture of the second multipolarity is not ruled out.

3 Atomic Data

The atomic data are taken from Schönfeld and Janßen (1996).

3.1 X Radiations

The energies are based an the wavelengths of Bearden (1967). The relative probabilities are taken from Schönfeld and Janßen (1996). The relative probability of the L X rays is calculated from the absolute value (Table 4) setting $P(K_{\alpha 1}) = 1$.

3.2 Auger electrons

The energies are taken mainly from Larkins (1977). The relative probabilities are taken from Schönfeld and Janßen (1996). The relative probability of the L Auger electrons is calculated from the absolute value (Table 4) setting P(KLL) = 1

4 Radiation Emissions

4.1 Electron Emissions

The energies of the Auger electrons are the same as in 3.2. The energies of the conversion electrons are calculated from the transition energy (2.2) and the binding energies. The emission probabilities of the Auger electrons are calculated from P_γ's and conversion coefficients using the program EMISSION (PTB, 1997).

The emission probabilities of the conversion electrons are calculated using the conversion coefficients given in Table 2.2, the atomic data given in Section 3, and the emission probabilities of the gamma rays given in Table 4.2.

4.2 Photon Emissions

The energies of the X rays are the same as in Table 3.1. Measured K X-ray emission probabilities (Chand *et al.* 1988, Morel *et al.* 1996) are in good agreement with the calculated values. If the measured values are related to the here adopted emission probability of the
184-keV gamma rays, the following values are obtained (quanta per 100 disintegrations):

	E in keV	P_X (Chand)	P_X(Morel)	P_X(calc)
Er $K_{\alpha 2}$	48,221	10,95(23)	10,63(8)	10,81(21)
Er $K_{\alpha 1}$	49,128	18,4(3)	19,17(13)	19,2(4)
Er $K'_{\beta 1}$	55,624	5,70(9)	6,03(5)	6,24(14)
Er $K'_{\beta 2}$	57,239	1,41(3)	1,594(20)	1,62(5)

The calculated emission probabilities of the X-rays (calculated from $P\gamma$'s and conversion coefficients using the program EMISSION (PTB, 1997)) are compiled in the last column.

The energies of the gamma rays are taken either from Helmer and van der Leun (2000) or from Ardisson *et al.* (1992) (see Sect. 2.2). Their uncertainties are to be considered as standard uncertainties.

The relative emission probabilities of gamma rays (related to 100 for the emission probabilities of the 184,4 keV transition $\gamma_{2,1}$) as measured by 17 authors are compiled in the following table. The last column in this table contains the LWM except of $\gamma_{1,0}$ where balance conditions are taken into account. The transition probability of the transition $\gamma_{1,0}$ is very well known as there is only one other transition to the ground state which is very weak ($\gamma_{4,0}$):

$$f_N\,[P_{rel}(\gamma_{1,0})\,(1+\alpha_t) + P_{rel}(\gamma_{4,0})\,(1+\alpha_t)] = 100$$

The conversion coefficient is, of course, to put for the assigned gamma transition. This yields for the transition $\gamma_{1,0}$

$P_{g\text{+ce}} = 100 - f_{\text{N}}\, P_{\text{rel}}(\gamma_{4,0})\ (1 + \alpha_{\text{t}}\ )$

With $f_{\text{N}} = 0{,}725(3)$, $P_{\text{rel}}(\gamma_{4,0}) = 0{,}026(5)$, $\alpha_{\text{t}}\ (\gamma_{4,0}) = 0{,}00566(12)$

we obtain :

$P_{\gamma\text{+ce}}(\gamma_{1,0})$ = 99,981(4) per 100 disintegrations. With the conversion coefficient of the transition $\gamma_{1,0}$ this yields:

$P_{\gamma}\ (\gamma_{1,0})$ = 12,66(23) per 100 disintegrations, in relative units: 17,46(31).

Gamma relative emission intensities, references 1 to 6 :

$g_{i,f}$	E_g (keV)	1	2	3	4	5	6
$\gamma_{1,0}$	80,577(7)	14,5(29)	14,55(47)	17,1(9)	14,48(48)	16,83(42)	16,7(10)
$\gamma_{16,15}$	94,679(9)	0,16(3)$^{1)}$	-	0,19(1)	0,3	0,21(3)	-
$\gamma_{8,7}$	119,035(10)	-	-	0,24(3)	-	0,23(3)	-
$\gamma_{16,14}$	121,175(10)	0,7(5)$^{1)}$	-	0,36(5)	0,78(18)$^{1)}$	0,54(5)$^{1)}$	-
$\gamma_{17,15}$	135,257(14)	0,1(1)	-	0,14(2)	-	-	-
$\gamma_{9,8}$	140,702(20)	-	-	0,059(14)	-	-	-
$\gamma_{10,9}$	160,077(20)	0,35(10)	-	0,134(16)	0,36(15)$^{1)}$	0,16(3)	-
$\gamma_{17,14}$	161,707(14)	-	-	0,15(2)	-	0,16(3)	-
$\gamma_{3,2}$	184,404(7)	100	100	100	100	100	100
$\gamma_{16,13}$	190,747(16)	-	-	0,30(3)	-	0,31(4)	-
$\gamma_{16,12}$	214,79(3)	-	-	0,75(10)$^{1)}$	-	-	-
$\gamma_{8,5}$	215,871(10)	3,8(4)	4,15(7)	3,6(4)	3,94(9)	3,96(8)	4,1(2)$^{2)}$
$\gamma_{17,12}$	231,32(4)	0,3(2)	0,32(5)	0,33(4)	0,36(3)$^{1)}$	0,31(4)	-
$\gamma_{9,7}$	259,70(3)	1,8(5)$^{1)}$	1,42(10)	1,50(11)	1,77(12)$^{1)}$	1,52(5)	-
$\gamma_{9,2}$	280,468(7)	39,5(28)	43,6(6)$^{1)}$	40,7(29)	38,61(46)	39,63(126)	40,2(18)
$\gamma_{10,9}$	300,731(9)	4,8(4)	5,45(8)	5,12(37)	4,77(9)	4,92(12)	4,97(22)
$\gamma_{9,6}$	305,03(5)	-	-	-	-	-	-
$\gamma_{11,9}$	339,75(5)	-	-	0,23(3)	-	0,23(4)	-
$\gamma_{6,3}$	365,736(9)	2,9(3)$^{1)}$	3,72(8)	3,44(25)	2,93(6)	3,25(10)	3,30(11)
$\gamma_{16,10}$	410,950(8)	15,8(12)	16,8(3)$^{1)}$	15,8(12)	15,50(19)	14,77(30)	15,27(50)
$\gamma_{17,10}$	451,528(9)	3,5(7)	4,30(9)	4,18(30)	3,48(7)$^{1)}$	3,84(13)	3,99(13)
$\gamma_{10,6}$	464,819(12)	2,0(4)	1,66(8)	1,68(14)	2,00(7)	1,50(8)	-
$\gamma_{15,9}$	476,38(6)	0,4(2)$^{1)}$	-	-	-	-	-
$\gamma_{12,8}$	496,86(4)	-	-	-	-	-	-
$\gamma_{4,2}$	520,85(5)	-	-	-	-	-	-
$\gamma_{8,3}$	529,811(10)	10,3(10)$^{1)}$	13,00(42)	13,9(10)	10,16(32)$^{1)}$	12,36(25)	12,78(42)
$\gamma_{16,9}$	570,940(10)	6,8(7)	7,08(16)	7,86(56)	6,77(14)	7,04(14)	7,45(24)
$\gamma_{5,2}$	594,536(24)	1,2(4)$^{1)}$	0,74(10)	0,96(8)$^{1)}$	1,28(18)$^{1)}$	0,70(5)	-
$\gamma_{17,9}$	611,620(17)	1,4(10)	1,59(32)	1,90(15)	1,48(27)	1,67(9)	-
$\gamma_{11,7}$	615,84(9)	-	-	-	-	-	-
$\gamma_{13,7}$	639,97(9)	-	-	0,22(7)$^{1)}$	-	-	-
$\gamma_{11,6}$	644,689(15)	0,27(15)	0,31(105)$^{1)}$	0,25(3)	-	-	-
$\gamma_{9,3}$	670,565(12)	7,0(7)	7,35(30)	7,88(56)	7,01(25)	6,98(16)	7,37(24)
$\gamma_{7,2}$	691,304(12)	1,9(4)	1,62(8)	2,09(15)$^{1)}$	1,85(9)	1,60(10)$^{1)}$	1,800(59)
$\gamma_{4,1}$	705,09(7)	-	-	-	-	-	-
$\gamma_{16,8}$	711,680(8)	72,5(60)	71,5(10)	80,2(57)$^{1)}$	71,65(68)	71,10(142)	74,5(25)
$\gamma_{13,5}$	736,70(7)	0,45(15)	0,50(5)	0,14(5)$^{1)}$	0,46(4)	0,45(5)	-
$\gamma_{17,8}$	752,332(10)	16,1(12)	15,20(34)$^{1)}$	17,9(13)	16,06(40)	15,98(32)	16,57(54)
$\gamma_{8,1}$	778,862(12)	3,8(3)	3,88(7)	4,51(33)	3,72(7)	4,16(12)	4,13(13)
$\gamma_{4,0}$	785,81(7)	-	-	-	-	-	-
$\gamma_{8,2}$	810,325(10)	76(8)	76,40(110)	85,7(61)$^{1)}$	76,38(82)	75,71(151)	78,1(28)
$\gamma_{10,3}$	830,601(15)	12,5(10)	12,90(32)	14,5(11)	12,07(28)	12,83(26)	13,26(44)
$\gamma_{7,1}$	875,63(5)	1,15(15)	0,91(4)	1,08(10)	1,14(7)	1,00(9)	0,979(32)
$\gamma_{9,2}$	950,963(10)	3,6(6)	3,16(13)$^{1)}$	4,15(30)$^{1)}$	3,50(14)$^{1)}$	3,74(16)	3,68(12)
$\gamma_{11,3}$	1010,27(6)	-	0,11(340)	0,12(2)	-	-	-
$\gamma_{14,3}$	1120,35(5)	-	0,26(2)	0,31(3)	0,30	-	-
$\gamma_{15,3}$	1146,81(9)	0,38(6)$^{1)}$	0,26(2)	0,30(3)	0,38(5)$^{1)}$	-	0,274(9)
$\gamma_{16,3}$	1241,52(2)	1,25(25)	1,06(4)	1,37(10)$^{1)}$	1,22(5)	1,17(12)	1,098(37)
$\gamma_{17,3}$	1282,06(6)	0,80(15)$^{1)}$	0,22(2)	0,31(3)	0,38(4)$^{1)}$	0,24(5)	0,241(8)
$\gamma_{12,2}$	1306,60(15)	-	-	-	-	-	-
$\gamma_{13,2}$	1331,04(13)	-	-	-	-	-	-
$\gamma_{14,2}$	1400,79(2)	0,93(9)$^{1)}$	0,72(2)	0,75(6)	0,86(5)$^{1)}$	-	0,670(22)
$\gamma_{15,2}$	1427,24(2)	0,69(7)	0,69(2)	0,81(6)$^{1)}$	0,65(3)	-	0,665(23)
-	1446,7(2)	-	-	-	-	-	-

Gamma relative emission intensities, references 7 to 12 :

$g_{i,f}$	E_g **(keV)**	**7**	**8**	**9**	**10**	**11**	**12**
$\gamma_{1,0}$	80,577(7)	17,51(61)	16,56(8)	17,8(4)	16,97(13)	17,2(8)	16,59(39)
$\gamma_{16,15}$	94,679(9)	0,221(12)	-	0,22(1)	0,20(1)	0,190(26)	-
$\gamma_{8,7}$	119,035(10)	0,222(12)	-	0,27(2)1)	0,24(1)	0,243(13)	-
$\gamma_{16,14}$	121,175(10)	0,337(15)	-	0,45(2)1)	0,35(2)	0,346(14)	-
$\gamma_{17,15}$	135,257(14)	0,126(10)	-	0,14(1)	0,14(1)	0,128(6)	-
$\gamma_{9,8}$	140,702(20)	0,059(9)	-	0,06(1)	0,07(1)	0,060(4)	-
$\gamma_{10,9}$	160,077(20)	0,109(8)	-	0,14(1)	0,14(2)	0,124(4)	-
$\gamma_{17,14}$	161,707(14)	0,135(8)	-	0,15(1)	0,15(2)	0,140(7)	-
$\gamma_{3,2}$	184,404(7)	100	100	100	100	100	100
$\gamma_{16,13}$	190,747(16)	0,304(15)	-	0,31(1)	0,33(2)	0,291(10)	-
$\gamma_{16,12}$	214,79(3)	0,586(23)	-	0,61(2)	0,61(2)	-	0,60(5)
$\gamma_{8,5}$	215,871(10)	3,54(13)	4,04(4)	3,67(9)	3,60(13)	4,14(17)2)	3,61(13)
$\gamma_{17,12}$	231,32(4)	0,284(15)	-	0,30(1)	0,33(3)	0,289(11)	0,263(20)
$\gamma_{9,7}$	259,70(3)	1,446(52)	-	1,53(3)	1,52(3)	1,47(5)	1,50(5)
$\gamma_{9,2}$	280,468(7)	40,79(141)	41,26(28)	41,0(5)	40,6(5)	40,4(15)	40,9(8)
$\gamma_{10,9}$	300,731(9)	5,12(18)	5,22(4)	5,17(8)	5,11(8)	5,04(19)	5,13(10)
$\gamma_{9,6}$	305,03(5)	-	-	-	0,023(3)	0,030(3)	-
$\gamma_{11,9}$	339,75(5)	0,234(16)	-	0,21(1)	0,21(3)	0,222(8)	-
$\gamma_{6,3}$	365,736(9)	3,327(117)	3,30(3)	3,49(6)	3,46(6)	3,33(12)	3,44(7)
$\gamma_{16,10}$	410,950(8)	15,25(53)	15,65(10)	15,9(2)	15,5(4)	15,3(5)	15,93(28)
$\gamma_{17,10}$	451,528(9)	4,02(15)	3,85(5)	4,17(5)	4,04(11)	4,00(14)	4,12(9)
$\gamma_{10,6}$	464,819(12)	1,651(61)	-	1,67(3)	1,73(7)	1,59(5)	1,69(6)
$\gamma_{15,9}$	476,38(6)	-	-	-	0,052(6)	0,050(3)	-
$\gamma_{12,8}$	496,86(4)	-	-	0,18(3)	0,17(1)	0,170(6)	-
$\gamma_{4,2}$	520,85(5)	-	-	0,22(3)	0,21(1)	0,20(3)	0,240(24)1)
$\gamma_{8,3}$	529,811(10)	13,10(45)	12,48(10)	13,3(2)	13,18(34)	12,83(39)	13,46(26)
$\gamma_{16,9}$	570,940(10)	7,53(27)	7,22(6)	7,65(9)	7,64(20)	7,42(24)	7,81(15)
$\gamma_{5,2}$	594,536(24)	0,773(34)	-	0,77(2)	0,80(9)	0,769(24)	0,80(4)
$\gamma_{17,9}$	611,620(17)	1,951(72)	-	1,86(4)	1,86(12)	1,85(7)	1,95(11)
$\gamma_{11,7}$	615,84(9)	-	-	-	0,044(13)	0,163(8)	-
$\gamma_{13,7}$	639,97(9)	0,122(16)	-	0,12(1)	0,11(1)	0,124(6)	-
$\gamma_{11,6}$	644,689(15)	0,213(19)	-	0,19(1)	0,23(6)	0,186(6)	-
$\gamma_{9,3}$	670,565(12)	7,37(26)	7,28(6)	7,53(9)	7,16(20)	7,32(22)	7,60(14)
$\gamma_{7,2}$	691,304(12)	1,871(69)	-	1,87(4)	1,86(9)	1,79(6)	1,84(5)
$\gamma_{4,1}$	705,09(7)	-	-	-	0,011(1)	0,025(15)	-
$\gamma_{16,8}$	711,680(8)	74,48(258)	72,37(39)	75,7(8)	75,33(177)	73,8(32)	76,4(14)
$\gamma_{13,5}$	736,70(7)	0,506(26)	-	0,51(2)	0,50(4)	0,530(18)	0,547(23)
$\gamma_{17,8}$	752,332(10)	16,57(56)	16,26(12)	17,0(2)	17,08(43)	16,5(5)	16,98(33)
$\gamma_{8,1}$	778,862(12)	4,17(15)	4,00(3)	4,25(6)	4,22(14)	4,13(13)	4,27(8)
$\gamma_{4,0}$	785,81(7)	-	-	-	0,019(4)	0,023(3)	-
$\gamma_{8,2}$	810,325(10)	78,66(273)	76,94(44)	80,1(8)	79,31(177)	78,2(26)	80,3(12)
$\gamma_{10,3}$	830,601(15)	13,34(47)	12,99(10)	13,5(2)	13,51(35)	13,3(4)	13,62(26)
$\gamma_{7,1}$	875,63(5)	0,993(35)	-	0,99(4)	1,00(5)	0,987(31)	1,002(25)
$\gamma_{9,2}$	950,963(10)	3,71(14)	3,65(4)	3,89(6)	3,87(12)	3,74(12)	3,85(8)
$\gamma_{11,3}$	1010,27(6)	0,096(8)1)	-	0,11(1)	0,13(3)1)	0,107(4)	-
$\gamma_{14,3}$	1120,35(5)	0,327(15)1)	-	0,35(1)1)	0,28(5)	0,268(8)	-
$\gamma_{15,3}$	1146,81(9)	0,271(14)	-	0,30(1)	0,29(4)	0,279(9)	0,281(26)
$\gamma_{16,3}$	1241,52(2)	1,142(41)	-	1,21(4)	1,21(6)	1,118(34)	1,12(4)
$\gamma_{17,3}$	1282,06(6)	0,246(13)	-	0,29(1)	0,28(4)	0,240(11)	0,271(19)
$\gamma_{12,2}$	1306,60(15)	-	-	-	0,010(2)	0,0044(4)	-
$\gamma_{13,2}$	1331,04(13)	-	-	-	0,010(1)	0,0051(6)	-
$\gamma_{14,2}$	1400,79(2)	0,686(25)	-	0,74(2)	0,76(4)	0,672(21)	0,720(27)
$\gamma_{15,2}$	1427,24(2)	0,667(25)	-	0,72(2)	0,77(4)1)	0,673(22)	0,708(21)
-	1446,7(2)	-	-	-	<0,01	<0,0006	-

Gamma relative emission intensities, references 13 to 17 :

$g_{i,f}$	E_g(keV)	13	14	15	16	17	18
$\gamma_{1,0}$	80,577(7)	17,00(22)	16,7(5)	17;6(4)	16,050(120)	17,18(15)	17,46(31)
$\gamma_{16,15}$	94,679(9)	0,208(10	0,198(5)	0,23(3)	-	0,1977(50)	0,202(5)
$\gamma_{8,7}$	119,035(10)	-	0,236(7)	0,23(3)	-	0,2384(72)	0,238(4)
$\gamma_{16,14}$	121,175(10)	0,307(11)	0,326(9)	0,38(3)	-	0,343(9)	0,333(9)
$\gamma_{17,15}$	135,257(14)	-	0,1358(35)	0,15(3)	-	0,142(9)	0,1350(25
$\gamma_{9,8}$	140,702(20)	-	0,0584(19)	0,07(1)	-	0,051(7)	0,059(3)
$\gamma_{10,9}$	160,077(20)	0,153(7)	0,139(3)	0,14(3)	-	0,140(11)	0,134(5)
$\gamma_{17,14}$	161,707(14)	-	0,160(5)	0,15(3)	-	0,1580(80)	0,151(5)
$\gamma_{3,2}$	184,404(7)	100	100	100	100	100	100
$\gamma_{16,13}$	190,747(16)	-	0,273(8)$^{1)}$	0,31(3)	-	0,3010(62)	0,296(6)
$\gamma_{16,12}$	214,79(3)	-	0,671(17)	0,61(4)	-	0,600(10)	0,614(14)
$\gamma_{8,5}$	215,871(10)	3,594(37)	3,60(9)	3,49(14)	3,447(26)	3,566(85)	3,67(24)
$\gamma_{17,12}$	231,32(4)	0,283(6)	0,260(7)	0,30(4)	-	0,2933(55)	0,302(8)
$\gamma_{9,7}$	259,70(3)	1,529(34)	1,507(34)	1,45(5)	1,434(25)	1,480(12)	1,487(9)
$\gamma_{9,2}$	280,468(7)	41,41(51)	41,8(9)	39,8(9)	40,634(167)	40,66(29)	40,75(21)
$\gamma_{10,9}$	300,731(9)	5,339(58)	5,29(12)	4,98(13)	5,079(39)	5,118(36)	5,15(4)
$\gamma_{9,6}$	305,03(5)	-	0,020(10)	0,023(3)	-	0,026(6)	0,0252(16)
$\gamma_{11,9}$	339,75(5)	-	0,221(6)	0,22(3)	-	0,2250(36)	0,2229(27)
$\gamma_{6,3}$	365,736(9)	3,589(45)	3,51(9)	3,34(9)	3,439(47)	3,404(24)	3,39(4)
$\gamma_{16,10}$	410,950(8)	16,49(19)	16,02(36)	15,0(4)	15,424(74)	15,81(11)	15,65(22)
$\gamma_{17,10}$	451,528(9)	4,235(60)	4,11(10)	3,89(13)	4,023(30)	4,062(42)	4,02(5)
$\gamma_{10,6}$	464,819(12)	1,729(35)	1,73(4)	1,66(7)	2,027(31)	1,665(19)	1,73(6)
$\gamma_{15,9}$	476,38(6)	-	0,0494(26)	0,052(7)	-	-	0,0500(18)
$\gamma_{12,8}$	496,86(4)	-	0,175(4)	0,17(3)	-	0,174(16)	0,173(4)
$\gamma_{4,2}$	520,85(5)	-	0,276(14)$^{1)}$	0,21(3)	-	0,212(13)	0,211(8)
$\gamma_{8,3}$	529,811(10)	13,19(15)	-	12,6(4)	13,380(126)	13,33(10)	13,0(6)
$\gamma_{16,9}$	570,940(10)	7,964(91)	-	7,27(23)	7,505(71)	7,71(6)	7,49(27)
$\gamma_{5,2}$	594,536(24)	0,761(22)	-	0,78(7)	-	0,880(20)	0,80(8)
$\gamma_{17,9}$	611,620(17)	2,097(26)	-	1,86(11)	1,952(60)	1,911(36)	1,81(29)
$\gamma_{11,7}$	615,84(9)	-	0,138(11)	0,044(13)	-	0,160(10)	0,13(4)
$\gamma_{13,7}$	639,97(9)	-	0,137(4)	0,11(2)	-	0,138(9)	0,130(4)
$\gamma_{11,6}$	644,689(15)	-	0,206(5)	0,21(4)	-	0,189(12)	0,198(5)
$\gamma_{9,3}$	670,565(12)	7,718(84)	-	6,98(22)	7,618(45)	7,56(6)	7,36(28)
$\gamma_{7,2}$	691,304(12)	1,872(40)	-	1,78(9)	1,914(17)	1,862(21)	1,82(10)
$\gamma_{4,1}$	705,09(7)	-	0,0272(7)	0,011(2)	-	-	0,019(9)
$\gamma_{16,8}$	711,680(8)	77,51(62)	-	72,0(19)	76,30(35)	76,3(6)	75,7(16)
$\gamma_{13,5}$	736,70(7)	0,510(12)	-	0,49(4)	-	0,524(16)	0,514(7)
$\gamma_{17,8}$	752,332(10)	17,16(14)	-	16,2(5)	16,973(84)	16,98(12)	16,8(4)
$\gamma_{8,1}$	778,862(12)	4,279(56)	-	4,04(14)	4,257(28)	4,242(33)	4,15(11)
$\gamma_{4,0}$	785,81(7)	-	0,0312(11)	0,019(4)	-	-	0,026(5)
$\gamma_{8,2}$	810,325(10)	80,81(59)	-	76,1(20)	80,52(38)	80,3(6)	79,1(14)
$\gamma_{10,3}$	830,601(15)	13,87(18)	-	12,9(4)	13,639(79)	13,64(10)	13,41(23)
$\gamma_{7,1}$	875,63(5)	1,003(21)	-	0,97(6)	-	0,501(9)$^{1)}$	0,994(11)
$\gamma_{9,2}$	950,963(10)	3,898(48)	-	3,68(12)	3,789(25)	3,793(30)	3,785(21)
$\gamma_{11,3}$	1010,27(6)	-	0,1113(28)	0,11(2)	-	0,107(6)	0,1095(21)
$\gamma_{14,3}$	1120,35(5)	-	0,281(8)	0,28(3)	-	0,278(10)	0,275(5)
$\gamma_{15,3}$	1146,81(9)	0,290(6)	0,289(8)	0,27(3)	-	0,279(6)	0,284(3)
$\gamma_{16,3}$	1241,52(2)	1,211(10)	-	1,14(5)	-	1,121(14)	1,17(4)
$\gamma_{17,3}$	1282,06(6)	0,268(12)	0,263(7)	0,27(3)	-	0,2434(30)	0,252(9)
$\gamma_{12,2}$	1306,60(15)	-	0,00610(3)	0,010(2)	-	-	0,0076(15)
$\gamma_{13,2}$	1331,04(13)	-	0,0025(10)	0,010(2)	-	-	0,0059(16)
$\gamma_{14,2}$	1400,79(2)	0,707(17)	-	0,70(3)	-	0,689(7)	0,700(7)
$\gamma_{15,2}$	1427,24(2)	0,705(28)	-	0,68(3)	-	0,696(12)	0,687(7)
$\gamma_{15,2}$	1427,24(2)	-	-		<0,01	-	-

[1] Outlier

[2] 214, 8 + 215, 8 keV doublet

Upper limits for a possible 1446,7 keV transition have been determined by authors 10, 11, 16.

1	Burson et al. 1967
2	Gunther and Parsignault 1967
3	Reich and Cline 1970
4	Lavi 1973
5	Lingeman et al. 1974
6	Gehrke et al. 1977
7	Sampson 1978
8	Blagojevic and Wood 1982
9	Sooch et al. 1982
10	Ogandaga et al. 1986
11	Adam et al. 1988 (give also values for six additional very weak transitions)
12	Danilenko et al. 1989
13	Wang Xin Lin 1992
14	Wagner 1992 (gives additionally four weak transitions)
15	Ardisson 1992
16	Miyahara et al. 1994
17	Morel et al. 1996
18	Adopted value

The final values of Hino et al. (2000) were not available when this evaluation was carried out. The absolute emission probabilities (Table 4.2) are calculated by multiplying the relative values by the normalization factor f_N = 0,725 (3).
The transition probabilities (Table 2.2) are calculated by multiplying the emission probabilities by $(1 + \alpha_t)$.

5 Main Production Mode

Taken from Firestone (1996).

6 References

References are given only in those cases where the reference is not already included in the list of references in the Tables Part.

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^{169}Yb - Comments on evaluation of decay data
by M. M. Bé and E. Schönfeld

1. Decay Scheme

The decay scheme tries to be complete : the confirmed gamma rays (even the weakest, are placed), the questionable gamma transitions are mentioned but not placed.

The J^{π} values and the level half-lives are taken from NDS 64,2 (1991).

2. Nuclear Data

- To determine the half-life of ^{169}Yb the following values have been taken in account ($T_{1/2}$ in d):

1	31,83(21)	Walker 1949 (49Wa23)
2	31,97(5)	Lagoutine et al. 1975 (75La16)
3	32,022(8)	Houtermans et al. 1980 (80Ho17)
4	32,015(9)	Rutledge et al. 1980 (80RuZY)
5	32,032(20)	Funck et al. 1983 (83Fu12)
6	32,07(8)	Kits et al. 1988 (88Ki12)
7	31,88(12)	Parker 1990 (90Pa08)
8	32,0147(93)	Unterweger et al. 1992 (92Un01)
9	32,001(34)	Iwahara et al. 1999
10	32,018(5)	weighted mean, adopted value

Value 1 was measured with a Geiger counter, value 2 with a proportional counter, value 7 with a Ge(Li) detector. For all the other measurements an ionisation chamber was used.

This set is a consistent one with a reduced -χ^2 of 0,59. The largest weights are those of values 3 (36 %), 4 (28 %) and 8 (27 %).

Several others values with greater or without uncertainty can be found: 33,0(15) d (Bothe 1946); 32,4 d (Cork 1954), 33,0(15) d (Don Martin 1951), 32 d (Michel, 1954), 30,6(2) d (Cork 1956).

- The Q value is from Audi and Wapstra (1995).

2.1 Electron Capture Transitions

The probabilities and uncertainties are deduced from the gamma transition probability balance on each level.

The balance on level 13 (570 keV) introduces the possible existence of a second forbidden transition to populate this level. This solution is preferred to those of a possible gamma transition from level 19 (878 keV) with energy 307,5 keV, this gamma line being not mentioned in any publication. The existence of gamma rays from levels 14, 16, 17 has not been pointed out in any process.

From spin and parity it follows that a transition to the ground state ($\Delta J^{\pi} = 3^{+}$) would be unique second forbidden and an EC transition to the 8,4 keV ($\Delta J^{\pi} = 2^{+}$) level would be non-unique second forbidden. If theses transitions exit, the limits of their probabilities, which are based on lg *ft* systematics, are 0,001% and 0,1% respectively.

EC transitions to the 118 keV ($J^{\pi} = 5/2^{+}$) and 139 keV ($J^{\pi} = 7/2^{+}$) levels of the rotational band ($K^{\pi} = 1/2^{+}$) could also be possible and would both be allowed. Nevertheless the projection of the angular momentum J on the rotational symmetry axis K, is ½, this involves a transfer of 3 units of angular momentum rather than the 0 or 1 unit indicated by the J value. Due to the fact that this nucleus is a deformed nucleus and from lg *ft* > 9, it results that the intensities of the EC transitions, if exist, are very low.

In the proposed decay scheme the sum of the electron capture transition probabilities is 100,0 (19)

From experimental emission probabilities and balancing conditions, and taking into account the uncertainties of the gamma transitions feeding and leaving these levels, it seems not necessary to introduce the EC transitions mentioned to the 118 keV and 139 keV levels.

The fractional capture probabilities given in section 2.1 have been calculated on the basis of the table of Schönfeld (1998) and the Q value of Audi and Wapstra (1995). Sahota *et al.* (1982) have determined experimental values of P_K with a relative uncertainty of 3 to 5 % [$P_K(472) = 0{,}812(29)$; $P_K(379) = 0{,}823(34)$; $P_K(316) = 0{,}825(43)$]; their values agree within the uncertainties with the more accurate theoretical values.

The lg *ft* values were calculated from the half-life, the evaluated EC transition probabilities and the transition energies using the log-*f* tables for beta decay of Gove and Martin (1971).

2.2 Gamma Transitions

Precise γ-ray energies of the main γ-rays have been determined by Borchert *et al.* 1975 and Kessler *et al.* 1979. The values of nine lines (i. e., 63, 93, 109, 118, 130, 177, 197, 261, and 307) given in the table in Section 4.2 are taken from Helmer (2000He14). They are based on a value of 411,80205(17) keV for the 412 keV line following the ^{198}Au decay. The energies of the weaker γ-rays are taken from Vagner (1990). The remaining energies (316, 328, 425, 614 keV) were computed from these energies and the relationships in the decay scheme. In order to calculate the level differences which are given in section 2.2 the recoil energies have been taken in account. The γ-ray energies can be found in section 4.2.

The transition probabilities $P_{\gamma+ce}$ were calculated from the measured relative γ-ray emission probabilities (see section 4.2), the total conversion coefficients and from the absolute intensity value of the 198 keV line 35,93(12) which was derived from statistical treatment of measured values (see section 4.2).

The conversion coefficients were interpolated from the table of Rösel *et al.* 1978. Mixing ratios are taken from angular correlation measurements and from $L_1/L_2/L_3$ ratios respectively $M_1/M_2/M_3/M_4/M_5$ ratios (Günther *et al.* 1969, Agnihotry *et al.* 1972, Krane *et al.* 1972, Akhmetov *et al.* 1985, Davaa *et al.*. 1987, Kracikova *et al.* 1987, Wagner *et al.* 1990). The mixing ratio were derived by comparing the subshell ratios from theory and experiment.

The uncertainties of the conversion coefficients are assumed to be 1,5 % for the three well studied transitions 2,1; 4,3; 4,2; 10 % for the less accurate measured transitions 6,3; 7,3; 7,4 and those above 330 keV, and 3 % for all other transitions.

Recently Dey *et al.* (1997) found from angular correlation measurements evidence for a pure M1 character of the 94 keV transition, almost pure E2 character for the 198 keV transition and only 4 % E2 admixture in the 177 keV transition. The corresponding change in $\alpha_t(94)$ from 3,89 to 3,88 is negligible, the change in $\alpha_t(177)$ from 0,59 to 0,62 is small, but $\alpha_t(198)$ would become markedly lower and lead to disagreement when determining the normalisation factor from different cuts through the decay scheme. Also, considering the recent measurements carried out by Baratova *et al.* (1993) who found a E2 admixture of : 3,4 % in the 94 keV; 16 % in the 177 keV and, 11 % in the 198 keV transition these results being in agreement with the other experiments; the values of Dey *et al.* (1997) were not used for the present evaluation.

Comparison between measured α_k and theoretical value from Rösel and from new tables of Band *et al.*(1993) for some important lines which are M1+E2 or E2 :

Eg	**93,6**	**109,8**	**130**	**177,2**	**198**	**307,8**
Adopted admixture %E2	3,25 (25)	2,17 (4)	100	15,8 (3)	9,0 (6)	100
Grabowski (1962)	3,3 (3)	2,15 (20)		0,52 (4)	0,41 (3)	0,048 (5)
Agnihotry (1972)				0,445 (35)	0,30 (2)	0,049
Zheltonozhsky (1995)		2,04 (2)	0,545 (5)	0,515 (5)	0,388 (4)	
α_K theoretical Rösel	3,18 (10)	2,03 (3)	0,538 (17)	0,484 (7)	0,370 (6)	0,0482 (15)
α_K theoretical Band	3,06 (10)	1,95 (3)	0,529 (16)	0,467 (6)	0,358 (5)	0,0477 (14)

3. Atomic data

- The values of ω_K, ϖ_L, n_{KL} are taken from Schönfeld and Janßen 1996.
- The energies of the X rays are based on the wavelengths given by Bearden (1967).

4.1 X-ray emissions

The emission intensities of the L- and K- X-rays are calculated with the EMISSION program (version 102) from the data set evaluated in this study : electron capture transition probabilities, gamma emission probabilities and from the internal conversion coefficients (α_K, α_{L1}, α_{L2}, α_{L3}) from Rösel *et al.* and the partial capture coefficients P_K , P_L taken from the PTB EC-CAPTURE program with the ratio P_{L2} / P_{L1} = 0,0527.

These values are compared with experimental values (see table enclosed), they are generally in good agreement within the uncertainty limits. The measurements were performed with a Si-Li detector for Reference 1-E, an HP-Ge for References 7-E, 10-E1,10-E2 and 3, a Si-Li and HP-Ge for References 1 and 2 and a low energy photon spectrometer for Reference 4.

4.2 Gamma Emissions

The gamma emission probabilities taken in consideration are from the EUROMET exercise 410 (Morel *et al.*) and from several other authors.

List of laboratories which took part in the EUROMET exercise (all details can be found in the report- 1999MoZV) :
- Institute for Physics and Nuclear Engineering (Romania)
- Institut de Radiophysique Appliquée (Switzerland)
- Institute for Reference Materials and Measurements (Belgium)
- V.G. Khlopin Radium Institute (Russia)
- Laboratorio Nacional de Metrologia das Radiações Ionizantes (Brazil- Iwahara *et al.*)
- Laboratoire Primaire des Rayonnements Ionisants (France)
- National Physical Laboratory (U.K.)
- National Office of Measures (Hungary)
- Radioisotope Centre POLATOM (Poland)
- Physikalish-Technische Bundesanstalt (Germany – Schönfeld *et al.*)
- D.I.Mendeleyev Institute for Metrology (Russia – Sazonova *et al.*)

An arbitrary code number was assigned to each participant. The same code number is used here to reference the results.

The recent references : Schönfeld *et al.* (1999), Sazonova *et al.*(2000), Iwahara *et al.* (2000) have not been included as independent reference because they were participants in the EUROMET exercise and then, their results are *de facto* included.

In the EUROMET exercise 410, references 1-E to 11-E, the values were given in absolute value, they have been converted relatively to the 198 keV line.

The other references used are :

1: Artomonova *et al.* 1976 (below 308 keV) and Balalaev *et al.* 1972 (above 308 keV), in this reference the values are given relatively to the 307 keV gamma-ray. As described, from V.S Aleksandrov the absolute intensity for this ray was taken as 10,1(5) % and those of the 198 keV gamma -ray is 34,34 (264). For this study the values given by Balalaev were converted relatively to the 198 keV ray taken as 100, with respect to the above absolute values used in the quoted paper.

2: Gehrke *et al.* 1977

3: Funck *et al.* 1983 (below 308 keV), Georgieva and Tumbev 1976 (above 308 keV)

4: Mehta *et al.* 1986 (uncertainties above 130 keV multiplied by a factor 2 to be compatible with the results of other authors)

5: Vagner et al. 1990, this work is supposed to be the continuation of the work of I. Adam, V. Vagner *et al.* (1986).

6: Bhattacharya *et al.* 1996

7: Miyahara 1998

The less accurate values of the following references were not taken into account for the present evaluation:

Alexander and Boehm 1963
Brown and Hatch 1967
Sen *et al.* 1972
Agnihotry *et al.* 1972
Potnis *et al.* 1972
Lavy *et al.* 1973
Aleksandrov *et al.* 1973
Verma *et al.* 1976

- Other remarks :

- The gamma given at the 205,99 energy by Vagner and at the 206,2 energy by Mehta are processed together in the same line.
- The intensity of the 51 keV is from the imbalance of level 7.
- Some weak gamma transitions were seen in only one spectrum :

105,2 ; 193,1 ; 213,9 ; 226,3 ; 291,2 ; 294,5 ; 316,2 ; 328,0 ; 356,7 ; 425,0 ; 500,3 ; 507,8 ; 546,1 ; 614,1 ; 633,3 ; 693,5 ; 710,3 ; 739,4 ; 760,2 and 781,6 lines.

The 616,2 and the 614,1 lines can not be placed in the decay scheme.

- Four EUROMET participants and Funck made the measurement of the resulting gamma emission of the 8,4 keV transition with the $L_{\beta 2}$ and $L_{\beta 15}$ X-rays emission. The LWEIGHT program running on these 5 values gives for this line (γ8,4 + $L_{\beta 2,15}$) = 4,68(14)%

On the other hand, we obtain with the EMISSION program : $L_{\beta 2,15}$ = 3,93(10)% for the X-ray emission.

The gamma emission absolute intensity can be deduced : 4,68 - 3,93 = 0,75(17)%

From the balance on the levels 1 and 0 of the decay scheme, a probability of 95,1 % for the 8,4 keV transition is deduced. As the decay scheme is quite consistent in every part, this value is certainly good.

The consequence is that the deduced ICC total is : 125(16)
This is not consistent with the theoretical ICC obtained from the Rosel table for a M1+0,108%E2 transition which is = 273(13)
It can be noted that with a pure M1 transition the Rosel ICC is 177(8)

The E2 admixture to the M1 multipolarity is deduced from the M1/M2/M3/M4/M5 ratio measured by T.A.Carlsson, *et al.* They compared their measured ratio with those from the Tables of Hager and Seltzer. Their calculations, taking the Rösel *et al.* conversion coefficients, were repeated and confirmed their result of 0,108(5) % E2 admixture. There are also some older less accurate values giving 0,10(2) %.

It also exists an old measurement of α_{MN} = 106(6) from G. Charpak and F. Suzor (1959).

Without other confirmation of this value, we will stay with the theoretical ICC for a M1+0,108%E2 transition calculated from Rösel *et al.*
This leads to the **adopted absolute value of 0,347(17)%** for the emission intensity.
This approach was also followed by Artomonova who gave a value of 0,33(4)% for the 8,4 keV gamma line emission intensity.

- Determination of the absolute emission intensity of the 198 keV line

During the EUROMET exercise the absolute activity measurement of Yb -169 sources was carried out by several methods and the absolute intensity of the 198 gamma-ray line deduced. This gives 8 measurements made by independent laboratories (references from 1-E to 11 -E), moreover 3 others absolute measurements are available (references 3, 7, 8). In these conditions a statistical treatment by using the program LWEIGHT has been done to determine the absolute emission intensity of the 198 keV line.
Absolute values of the 198 keV line from EUROMET exercise and others :

1-E	(36,26 ± 0,18)	EUROMET, 1999
3-E	(37,3 ± 0,5)	EUROMET, 1999
4-E	(35,7 ± 0,6)	EUROMET, 1999
7-E	(36,3 ± 1,1)	EUROMET, 1999
8-E	(35,9 ± 0,8)	EUROMET, 1999
9-E	(35,49 ± 0,39)	EUROMET, 1999
10-E1	(36,06 ± 0,15)	EUROMET, 1999
11-E	(35,9 ± 0,5)	EUROMET, 1999
3	(36,0 ± 0,5)	Funck et al. 1983
7	(35,14 ± 0,28)	Miyahara et al. 1999
8	(35,5 ± 0,4)	Coursey et al. 1994

The reference 3-E is rejected due to deviation from the weighted average (Chauvenet criteria), this leads to process 10 values. No value contributes more than 50%, the reduce-χ^2 is 1,64 ; the weighted mean and external uncertainty is chosen. Then **the adopted value is *35,93(12)%*.**
This value is quite close to those obtained by Schönfeld et al. (35,91(13)) by considering the balance of the decay scheme.

5. Electron Emissions

Auger Electrons

The energies of the KLL Auger electrons are taken from Larkins (1977), the others are calculated from the binding energies using approximations. The probabilities of L - and K-Auger electrons are calculated with the PTB program Emission (version 102).

Conversion Electron Emissions

The energies were calculated from the gamma transition energies and from the binding electron energies on the electronic shells.

The emission probabilities were calculated using the adopted gamma emission probabilities and conversion coefficients.

The comparison between measured internal conversion electron intensities and calculated values gives a good agreement which confirms the consistency of the evaluated data set.

E gamma	Agnihotry (1972)	Artamonova (1976)	Calculated
8,4 keV - Ie M		71 (7)	76 (5)
20,7 keV - Ie L		7,5 (4)	8,6 (3)
Ie M		1,7 (1)	1,93 (7)
63 keV - Ie K		36 (7)	39,6 (12)
- Ie L		7,16 (15)	7,2 (3)
93 keV - Ie K		7,5 (7)	8,18 (27)
- Ie L		1,5 (1)	1,4 (5)
109 keV - Ie K		34,9 (11)	35,2 (6)
- Ie L		5,7 (1)	5,68 (9)
118 keV - Ie K		1,28 (6)	1,30 (4)
- Ie L			1,37 (4)
130 keV - Ie K		6,2 (3)	6,1 (2)
- Ie L		5,4 (2)	5,3 (2)
177 keV - Ie K	10,1 (5)	10,7 (7)	10,8 (2)
- Ie L		2,1 (1)	1,94 (3)
198 keV - Ie K	10,8 (5)	13,5 (5)	13,29 (22)
- Ie L		2,16 (5)	2,17 (3)
240 keV - Ie K	0,0043 (4)	0,0045 (5)	0,0042 (5)
- Ie L		0,0010 (5)	0,00075 (8)
261 keV - Ie K	0,047 17)	0,040 (4)	0,040 (1)
- Ie L			0,0060 (2)
307 keV - Ie K	0,53	0,50 (2)	0,484 (15)
- Ie L		0,15 (2)	0,142 (4)

6. Main Production Modes

From Firestone (1996) and Shirley (1991)

References of the programs used

LWEIGHT : A computer program to calculate averages, D. MacMahon, E. Browne
EC-CAPTURE : Calculation of electron capture probabilities. PTB
EMISSION-102 : Calculation of X-rays and Auger electrons emission probabilities. PTB
ICC Database : ICC computer code, CEA-BNM/LNHB technical note LPRI/98/002

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Other quoted references can be found in the Tables Part.

^{170}Tm - Comments on evaluation of decay data
by V. P. Chechev and N. K. Kuzmenko

1. Decay Scheme

Since ^{170}Tm has spin and parity 1^-, it decays with detectable probability to the 0^+ ground states and 2^+ first excited levels in both ^{170}Yb and ^{170}Er. The only other levels below the decay energies are at 277 keV (4^+) and 573 keV (6^+) in ^{170}Yb and 260 keV in ^{170}Er. From the log *ft* systematics of 1998Si17, one expects the log *ft*'s of the 3rd forbidden decays to the 4^+ levels to be greater than 16, which corresponds to a β branch of less than 0,000 002% to the 4^+ level of ^{170}Yb and weaker branch to 4^+ in ^{170}Er. Since the branch to the 6^+ level will be a 5th forbidden decay, it will be even much weaker. Therefore, all of these unobserved β branches will be negligible.
For decay scheme see also Baglin (1996Ba01).

2. Nuclear Data

Q value is from Audi and Wapstra (1995Au04).
The ^{170}Tm half-life values are available, in days

125 (2)	1962Bo12	
134,2 (8)	1965Fl02	Omitted as outlier
128 (1)	1967Ke13	
128,6 (3)	1968Re04	
127,1 (3)	1969La34	(the original value of uncertainty is 3σ =0,9)
127,8 (6)	Average	

The outlier value of 1965Fl02 was omitted on the statistical considerations of its large deviation from the mean.
For statistical processing one third of the total 3σ-uncertainty, 0,9 days, stated in 1969La34, was used. Then, the weighted average is 127,8 d with an internal uncertainty of 0,21 d, a reduced-χ^2 of 4,85 and an external uncertainty of 0,45 d. In this case the different statistical procedures using the weighted average give the following values for a final uncertainty, in days: UINF - 0,45; PINF - 0,45; BAYS - 0,79; MBAYS - 0,56; LWM - 0,77; tS- 0,54. The LWEIGHT program using the LWM method has expanded the uncertainty to 0,77 d to include the accurate value of the 1968Re04. The EV1NEW program chooses the tS or MBAYS procedure for this case and gives 0,6 d. The latter value was adopted for the final uncertainty of the average.
It should be noted that without rejecting 1965Fl02 the Normalised Residuals technique leads almost to the same average of 127,9(6) days. It inflates the uncertainty of the 1965Fl02 value to 2,7 days and of each of the 1968Re04 and 1969La34 to 0,5 days.
A considerable discrepancy of few available experimental data on the ^{170}Tm half-life, all obtained before 1970, requires new ^{170}Tm half-life measurements.

2.1 b$^-$ - Transitions

The β^--decay probabilities have been computed from the $P_{\gamma+ce}$(Yb) of section 2.3 and balance correlations.

2.2. Electron Capture Transitions

The values of the electron capture probabilities to the ^{170}Er ground state and the level of 78,6 keV have been obtained from the balance correlations including the X K- and gamma emission probabilities. Indeed, we can write:

$$P_{XK}(Yb) = \omega_K(Yb)\,\alpha_K(84)\,P\gamma(84)$$

$$P_{XK}(Er) = \omega_K(Er)\;[\,P_K^{0,0}\,P(\varepsilon_{0,0}) + P_K^{0,1}\,P(\varepsilon_{0,1}) + \alpha_K(79)\,P\gamma(79)]$$

From here:

$$S \equiv \frac{P_{XK}(Er)}{P_{XK}(Yb)} = \frac{\omega_K(Er)}{\omega_K(Yb)} \cdot \frac{1}{\alpha_K(84)\cdot P\gamma(84)}[P_K^{0,0}\cdot P(\varepsilon_{0,0}) + P_K^{0,1}\cdot P(\varepsilon_{0,1}) + \alpha_K(79)\cdot P\gamma(79)]$$

Finally, for $P(\varepsilon_{0,0})$ and $P(\varepsilon_{0,1})$ the following expressions are obtained (see also 1988Kuzmenko):

$$P(\varepsilon_{0,0}) = \frac{P\gamma(84)}{P_K^{0,0}}\{\alpha_K(84)\cdot S\cdot\frac{\omega_K(Yb)}{\omega_K(Er)} - \frac{P\gamma(79)}{P\gamma(84)}[\alpha_K(79) + P_K^{0,1}(1+\alpha_T(79))]\}$$

$$P(\varepsilon 0,1) = P\gamma(79)\,.\,(1+\alpha_T(79))$$

In this calculation, the adopted values of ICC, P_K, ω_K, P_γ and the ratio of S = 0,035(1) measured in 1986Ve05 were used.

The fractional electron capture probabilities to the specific atomic shells (P_K, P_L, P_M ...) have been deduced from the tables of Schönfeld (1998Sc28).

2.3. Gamma Transitions and Internal Conversion Coefficients

The energies of gamma transitions are the energies of gamma rays with the recoil energy added. The probabilities of gamma transitions $P_{\gamma+ce}$ have been computed using the gamma-ray emission probabilities and the total internal conversion coefficients (ICC).

The theoretical values of ICC from Rosel et al. (1978Ro21) have been adopted for the gamma transitions which have the same multipolarity E2. The evaluated α_{NO} values have been computed from α_M(theoretical) using the ratio α_M/α_{NO} = 3,77 (9) (1968Ni06).

The weighted mean of the eight measurement results for $\alpha_K(\gamma 84)$ [1,48 (5) (1966Di02), 1,41 (4) (1969Ne02), 1,37 (4) (1970Mo07), 1,41 (5) (1971Ca08), 1,46 (7) (1973Pl08), 1,39 (3) (1985Me18), 1,41 (3) (1986Ve01), and 1,43 (4) (1990Ke01)] is 1,41 with an internal uncertainty of 0,014 ; a reduced χ^2 of 0,6 and an external uncertainty of 0,011. Taking into account that a systematic error of the measurement method can contribute mainly to the measurement uncertainties, the smallest of the input uncertainties has been chosen as a final uncertainty of the weighted mean. The average value of $\alpha_K(\gamma 84)$ (experimental), equal 1,41 (3), agrees well with the theoretical value of 1,39(2). The relative uncertainty of the theoretical ICC has been adopted of 1,5%. This value of uncertainty provides overlapping $\alpha_K(\gamma 84)$ (theoretical) and $\alpha_K(\gamma 84)$ (experimental).

3. Atomic Data

The fluorescence yields are taken from 1996Sc06 (Schönfeld and Janβen). The X-ray energies are based on the wavelengths in the compilation of 1967Be65 (Bearden). The relative KX-ray emission Kβ/Kα, $K\alpha_2/K\alpha_1$, $K'\beta_2/K'\beta_1$ probabilities and the ratios P(KLX)/P(KLL), P(KLY)/P(KLL) are taken from 1996Sc06. The energies of Auger electrons are from 1977La19 (Larkins).

4. Photon Emissions

4.1. X-Ray Emissions

The absolute XK(Er), XK(Yb), XL(Yb) emission probabilities have been computed on the basis of the relative intensities $P_X/P_\gamma(84)$ measured in 1985Me18 and 1986Ve05. The absolute measurement results of 1989Egorov for XK(Yb) [$K\alpha_2 = 1{,}00(2)$, $K\alpha_1 = 1{,}69(4)$, $K'\beta_1 = 0{,}54(2)$, $K'\beta_2 = 0{,}14(1)$] agree well with our evaluated values. The total absolute XK(Er) emission probability of 0,089(5) measured in 1990EgZY disagrees with the evaluated value of section "X Radiations".

The weighted mean of the two measurement results for the Yb $K\alpha_1$-ray, 0,675(17), was adopted as the evaluated value and the values on $K\alpha_2$, $K'\beta_1$, $K'\beta_2$ were computed from the relative probabilities from 1996Sc06. The analogous procedure was made for the Er with the $K\alpha_1$ value from the measurements of 1986Ve05 and the other values from the relative probabilities from 1996Sc06.

$P_{XK}/P_\gamma(84)$ for Er

Er	1985Me18	1986Ve05	adopted
$K\alpha_2$	} 0,0248 (6)	0,0133 (4)	0,0134 (4)
$K\alpha_1$	}	0,0238 (4)	0,0238 (4)
$K'\beta_1$	$6{,}3\ (2) \cdot 10^{-3}$	$7{,}7\ (3) \cdot 10^{-3}$	0,0077 (3)
$K'\beta_2$	$1{,}45\ (6) \cdot 10^{-3}$	$2{,}2\ (1) \cdot 10^{-3}$	0,0020 (1)

$P_{XK}/P_\gamma(84)$ for Yb

Yb	1985Me18	1986Ve05	average (EV1NEW)	adopted
$K\alpha_2$	0,377 (9)	0,381 (11)	0,379 (9)	0,383 (9)
$K\alpha_1$	0,680 (17)	0,668 (20)	0,675 (17)	0,675 (17)
$K'\beta_1$	0,2145 (32)	0,228 (7)	0,221 (12)	0,222 (7)
$K'\beta_2$	0,0533 (9)	0,0604 (19)	0,057(1)	0,058 (2)

$P_{XL}/P_\gamma(84)$ for Yb

Yb	adopted (1985Me18)
Ll	0,0238 (8)
$L\alpha+L\eta$	0,573 (18)
$L\beta$	0,603 (19)
$L\gamma$	0,0974 (31)
ΣXL	1,297 (27)

The total absolute Er LX emission probability has been computed using the adopted values of ω_K, ϖ_L, n_{KL}, the evaluated total KX absolute emission probability and the evaluated total absolute emission probabilities of L conversion electrons and electron capture.

It should be noticed that the absolute XK - emission probabilities of $P_{XK}(\mathrm{Er})=0{,}113(6)$ and $P_{XK}(\mathrm{Yb})=3{,}27\ (12)$ per 100 disintegrations, calculated from the adopted values of ω_K, the evaluated total absolute emission probabilities of K conversion electrons (P_{ceK}) and the electron capture ($P_{\varepsilon K}$), agree well with the evaluated, 0,116 (3) and 3,31 (8), respectively.

For $P_{XL}(\mathrm{Yb})$ such a calculation gives 2,93 (15) per 100 disintegrations - in comparison with the value of 3,22 (13), adopted from experimental data on $P_{XL}/P_\gamma(84)$.

The evaluated values of $P_{XK}(Er) = 0{,}116\ (3)\%$, $P_{XK}(Yb) = 3{,}31\ (8)\%$ and $P_{XL}(Yb) = 3{,}22\ (13)\%$ have been obtained directly from relative measurements of the intensity of peaks in the ^{170}Tm photon spectrum ($P_X/P_\gamma(84)$) with use of the $P_\gamma(84)$ value evaluated from independent experimental data. Unlike that the calculated value of $P_{XK}(Er) = 0{,}113(6)$ has been founded on the adopted semiempirical and theoretical values ω_K, $P_K(\varepsilon_{0,1})$, and $\alpha_K(\gamma 79)$ as well as the evaluated $P_\gamma(79)$. In the calculation of $P_{XK}(Yb) = 3{,}27\ (12)\%$ the same value of $P_\gamma(84)$ is used as in the evaluation of 3,31 (8)%. However, the adopted $\omega_K(Yb)$ and theoretical value of $\alpha_K(\gamma 84)$ have been used instead of the experimental relative intensity $P_{XK}/P_\gamma(84)$.

Above agreement of the evaluated and calculated values shows a concordance of the obtained decay characteristics for ^{170}Tm.

4.2. Gamma Emissions

The energy of 78,6 keV γ-ray has been obtained as the weighted mean of the following three measurements results: 78,59 (2) keV (1958Ch36), 78,7 (5) keV (1969Ha20) and 78,6 (4) keV (1970Mo07).

The 84,25 keV γ-ray energy has been adopted from 2000He14.

The absolute emission probability for the γ-ray of 84,25 keV (per 100 disintegrations) has been obtained with use of the weighted mean of the three measurement results: 2,54 (6) (1973Pl08), 2,56 (4) (1987GeZU, 1988GeZS) and 2,37 (4) (1990Ke01). This weighted average is 2,48 with an internal uncertainty of 0,03, a reduced $-\chi^2$ of 6,3 and an external uncertainty of 0,06. In this case the different statistical procedures using the weighted average give the following values for a final uncertainty: UINF - 0,064; PINF - 0,064; BAYS - 0,091; MBAYS - 0,091; LWM - 0,109; tS - 0,084. The EVINEW program has chosen MBAYS for this case and hence the uncertainty of 0,09. This value was adopted as the uncertainty of the evaluated $P\gamma(84)$. It should be noted that the Rajeval technique leads to the same result of 2,48(9). The normalised Residuals technique gives only sligttly greater value of 2,51(4).

The absolute emission probability for the γ-ray of 78,6 keV has been obtained with use of the weighted mean of the results of measurements of the ratio of $P_\gamma(79)/P_\gamma(84)$: 0,00122 (24) (1970Mo07), 0,0015 (2)(1985Me18) and 0,00140 (8) (1986Ve01). The LRSW method has expanded the uncertainty of the 1986Ve01 from 0,00008 to 0,00015 in order to reduce its relative weight from 79% to 50%. Then, the weighted mean is 0,00139 with an internal uncertainty of 0,00011, a reduced $-\chi^2$ value of 0,4 and an external uncertainty of 0,00007. The adopted value of $P_\gamma(79)/P_\gamma(84)$ is 0,00139 (11).

5. Electron Emissions

The energies of the conversion electrons have been calculated from the gamma-transition energies given in 2.3 and the electron binding energies. The energies of the Auger electrons are taken from 1977La19 (Larkins).

The emission probabilities of the conversion electrons have been calculated using the conversion coefficients given in 2.3. The values of the emission probabilities of K-Auger electrons have been calculated using the transition probabilities given in 2.1 and 2.2, the atomic data given in 3. and the conversion coefficients given in 2.3.

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^{177}Lu - Comments on Evaluation of Decay Data for b^{-} Decay

F. G. Kondev

Evaluation Procedures

The *Limitation of Relative Statistical Weight* (LWM) [1] method for averaging numbers has been applied throughout this evaluation.

1. Decay Scheme

The decay scheme for ^{177}Lu is taken from the recent evaluations of Kondev (2002KoXX) and Browne (1993Br06). The ground state has been assigned $J^{\pi} = 7/2^{+}$ and the $7/2^{+}[404]$ ($g_{7/2}$) Nilsson configuration. It decays via β^{-} emission ($P_{\beta-}$= 100%) to levels of the stable ^{177}Hf daughter isotope. While the decay branches to the ^{177}Hf ground state ($J^{\pi} = 7/2^{-}$) and to the 112.9499 keV ($J^{\pi} = 9/2^{-}$), and 321.3162 keV ($J^{\pi} = 9/2^{+}$) levels are well established, there is some ambiguity in the literature regarding the direct β^{-}-decay feeding into the $J^{\pi} = 11/2^{-}$ level at 249.6744 keV.

2. Nuclear Data

Half-life

The half-life of the ^{177}Lu ground state has been measured by several authors and the results are summarized in Table 1. In all cases the source was prepared using the ^{176}Lu(n,γ) reaction, where a three-quasiparticle isomer ($K^{\pi} = 23/2^{-}$ and excitation energy of 970 keV), with a half-life that is significantly longer ($T_{1/2}$ = 160.44(6) d), when compared to that for the ^{177}Lu ground state, is also produced. Since the isomer de-excites partially via gamma emission (P_{γ}= 21.4%(8)), its half-life and relative population should be taken into account when determining the $T_{1/2}$ for the ground state. The recommended value for the ^{177}Lu ground state half-life is $T_{1/2}$ = 6.647(4) d. It is the weighted average of the 6.645(30) d (1982La25), 6.65(1) d (2001Zi01) and 6.646(5) d (2001Sc23) values. The half-lives reported by 1958Be41, 1960Sc19, 1972Em01 and 1990Ab02 were excluded from this analysis since authors did not consider the effect of the ^{177}Lu^{m} isomer ($T_{1/2}$ = 160.44 d) was not taken into account. Although the relative statistical weight of the 2001Sc23 value was 78.3%, its uncertainty was not increased since the set is consistent. It should be noted that there are may be a systematic uncertainty in the recommended $T_{1/2}$ value for the ^{177}Lu ground state, due to possible differences in the half-life values of ^{177}Lu^{m} and its population intensity that were used in 1982La25, 2001Zi01 and 2001Sc23.

Table 1 Measured and recommended values for the ^{177}Lu ground state half-life.

Reference	$T_{1/2}$, d	Comment
1958Be41	6.75 (5) #	
1960Sc19	6.74 (4) #	
1972Em01	6.71 (1) #	
1990Ab02	6.7479 (7) #	
1982La25	6.645 (30)	$T_{1/2}$(^{177m}Lu) = 159.5 d (7) was used in the fitting procedure.
2001Zi01	6.65 (1)	Corrections for $T_{1/2}$(^{177m}Lu) have been applied, but the value has not been reported.
2001Sc23	6.646 (5)	$T_{1/2}$(^{177m}Lu) = 160.4 d was used in the fitting procedure.
Adopted	**6.647 (4)**	c2/(N-1) = **0.07**

Contributions from the decay of the ^{177}Lu^{m} ($T_{1/2}$ = 160.44 d) isomer have not been taken into account. The value is not used in the analysis.

Q value

The Q(β^-) = 498.3(8) keV is from 1995Au04. It is in agreement with that of 496.8(17) keV (1962El02), deduced from the β^-–decay endpoint energy to the ^{177}Hf ground state. The total average decay energy released in the β^--decay of the ^{177}Lu ground state is calculated using RADLST [2] as 497.4(25) keV. It agrees very well with the Q(β^-) value that is reported by Audi (1995Au04), thus suggesting that the decay scheme is complete.

2.1 b - **Decay Transitions**

The β^- transition endpoint energies were determined from Q(β^-) = 498.3(8) keV (1995Au04) and the individual level energies. The latter were deduced from a least-squares fit to the adopted gamma-ray energies that are given in Table 3. The β^- transition endpoint energies are in agreement with values measured by 1962El02 and 1955Ma12. The adopted values for the β^- transition probabilities per 100 disintegrations were determined from the total (photons + conversion electrons) transition probability balances at each level. In general, values deduced in the present evaluation are consistent with those from 2001Sc23, 1975El07 and 1993Br06, albeit in 2001Sc23 there is no report on a direct β^- -decay feeding into the $J^\pi = 11/2^-$ level.

Table 2 Measured and adopted values for the ^{177}Lu b$^-$-decay transition probabilities

Reference	P_β– to $J^\pi = 7/2^-$	P_β– to $J^\pi = 9/2^-$	P_β– to $J^\pi = 11/2^-$	P_β– to $J^\pi = 9/2^+$
2001Sc23	79.3 (5)	9.1 (5)		11.58 (12)
1975El07 1993Br06	78.6 (10)	9.1 (10)	0.05 (2)	12.2 (7)
1967Ha09	87.2 (11)	6.0 (8)	0.07 (2)	6.7 (3)
1964Al04	86.3 (13)	7 (1)	0.03 (3)	6.7 (3)
1962El02	90 (4)	2.95 (3)	0.31 (6)	6.72 (25)
1956Wi39	96	1.3	0.2	2.6
1955Ma12	90	3		7
1949Do05	65	17		
Adopted	**79.3 (5)**	**9.1 (5)**	**0.012 (8)**	**11.64 (10)**

There are, however, significant differences with the 1967Ha09, 1964Al04, 1962El02, 1956Wi39, 1955Ma12 and 1949Do05 work, as summarized in Table 2. The log *ft* values were calculated using the program LOGFT [3] using the adopted β^- transition probabilities.

2.2 Gamma Transitions and Internal Conversion Coefficients

The measured values for gamma-ray transition energies that follow the decay of the ^{177}Lu ground state are presented in Table 3. The gamma-ray energies reported by Matsui et al. (1989Ma56) were adopted in the present evaluation. These were measured with a high precision using a germanium spectrometer. The total (photon + conversion electrons) transition probabilities were deduced by multiplying the adopted values for the relative gamma-ray intensities (Table 10) by a normalization factor that was deduced from the values for the absolute intensity per 100 disintegrations of the 208.3662 keV gamma ray (Table 11). The total electron conversion coefficients were interpolated from the tables of Rösel (1978Ro22). Transition multipolarities are taken from 2002KoXX and 1996Br06. They are based on comparisons between the measured electron conversion coefficients with theoretical values (1978Ro22), as well as on available angular correlation data.

Table 3 Measured and adopted values for gamma ray transition energies following b$^-$ **decay of** ^{177}**Lu**

Reference	$\gamma_{1,0}$	$\gamma_{2,1}$	$\gamma_{2,0}$	$\gamma_{3,2}$	$\gamma_{3,1}$	$\gamma_{3,0}$
1989Ma56	112.9498 (4)	136.7245 (5)	249.6742 (6)	71.6418 (6)	208.3662 (4)	321.3159 (6)
1981Hn03	112.95 (2)	136.72 (2)	249.7 (5)	71.646	208.35 (2)	321.27 (5)
1967Ha09	112.95 (2)	136.72 (5)	249.65 (6)	71.66 (6)	208.34 (6)	321.32 (12)
1965Ma18	112.952 (2)	136.730 (6)	249.868 (25)	71.646 (2)	208.359 (10)	321.330 (40)
1964Al04	112.97 (2)	136.68 (2)	249.69 (10)	71.64 (2)	208.36 (6)	321.36 (20)
1961We11	112.97 (2)	136.70 (10)	249.70 (10)	71.60 (10)	208.38 (2)	321.34 (3)
1955Ma12	112.965 (20)		250.0 (5)	71.644 (20)	208.362 (20)	321.36 (10)
Adopted	**112.9498 (4)**	**136.7245 (5)**	**249.6742 (6)**	**71.6418 (6)**	**208.3662 (4)**	**321.3159 (6)**

Details about the mixing ratios values for E1+M2 and M1+E2 transitions are given below. The electron conversion coefficients are interpolated values from the tables of Rösel (1978Ro22). The quoted uncertainties reflect the corresponding uncertainties in the mixing ratios values. Adopted α_K, α_{L1}, α_{L2}, α_{L3}, and α_M values were also used as an input for the RADLST [2] and EMISSION (2001Sc08) programs.

2.2.1 112.9498 keV ($g_{1,0}$)

Values used in the analysis of the mixing ratios are summarized in Table 4. The unweighted average value is adopted, but its uncertainty was increased to 0.4, so that the range includes the most precise value of $\delta(\gamma_{1,0})$ = –4.85(5) (1992De53). During the analysis, the uncertainty of the 1992De53 value was also increased to 0.056, so that its relative statistical weight is scaled down from 55.8% to 50%.

Table 4 Measured and adopted mixing ratios values for the 112.9498 keV transition

Reference	$\delta(\gamma_{1,0})$	Comment
1974Kr12	-4.7 (2)	From $\gamma(\theta)$ in ^{177m}Lu ($T_{1/2}$ = 160.44 d) decay.
1974Ag01	-3.99 (25)	From $\gamma\gamma(\theta)$ in ^{177}Lu ($T_{1/2}$ = 6.647 d) β^- decay.
1970Hr01	-3.7 (3)	From $\gamma\gamma(\theta)$ in ^{177}Lu ($T_{1/2}$ = 6.647 d) β^- decay.
1961We11	-4.0 (2)	From $\gamma\gamma(\theta)$ in ^{177}Lu ($T_{1/2}$ = 6.647 d) β^- decay.
1972Ho54	-4.75 (7)	From $\gamma\gamma(\theta)$ in ^{177}Lu ($T_{1/2}$ = 6.647 d) β^- decay.
1972Ho39	-4.5 (3)	From ICC ratios in ^{177}Lu ($T_{1/2}$ = 6.647 d) β^- decay.
1977Ke12	-4.8 (2)	From $\gamma(\theta)$ in ^{177}Lu ($T_{1/2}$ = 6.647 d) β^- decay.
1992De53	-4.85 (5)	From $\gamma\gamma(\theta)$ in ^{177}Lu ($T_{1/2}$ = 6.647 d) β^- decay.
Adopted	**-4.4 (4)**	**c2/(N-1) = 5.61**

2.2.2 136.7245 keV ($g_{2,1}$)

The adopted mixing ratios values of $\delta(\gamma_{2,1})$ = –3.0 (7) is from 1974Kr12.

2.2.3 321.3159 keV ($g_{3,0}$)

Values used in the analysis of the mixing ratios are summarized in Table 5. The unweighted average value is adopted, but the uncertainty was expanded so that the range includes the most precise value of $\delta(\gamma_{1,0})$ = + 0.17(1) (1974Kr12). The sign of $\delta(\gamma_{3,0})$ was determined to be positive by 1974Kr12.

Table 5 Measured and adopted mixing ratios values for the 321.3159 keV transition

Reference	$\vert\delta(\gamma_{3,0})\vert$	Comment
1974Kr12	0.17 (1)	From $\gamma(\theta)$ in ^{177m}Lu ($T_{1/2}$ = 160.44 d) decay
	0.42 (1)	From comparison between experimental α_K = 0.087(3), weighted average from values reported by 1972Gr35, 1974Ag01, 1974Je02 and 1961We11, and theoretical α_K(E1), and α_K(M2) values from 1978Ro22.
	0.42 (1)	From comparison between experimental α_L = 0.0169(8), weighted average from values reported by 1972Gr35, 1974Ag01, 1974Je02 and 1961We11, and theoretical α_L(E1), and α_L(M2) values from 1978Ro22.
Adopted	**0.34 (17)**	**c2/(N - 1) = 208.33**

2.2.4 208.3662 keV ($g_{3,1}$)

Values used in the analysis of the mixing ratios are given in Table 6. The weighted average and the internal uncertainty were adopted. The sign of $\delta(\gamma_{3,1})$ is uncertain. It has been reported to be positive by 1974Kr12, but negative by 1977Ke12 and 1961We11.

Table 6 Measured and adopted mixing ratios values for the 208.3662 keV transition

Reference	$\vert\delta(\gamma_{3,1})\vert$	Comment
1974Kr12	0.07 (2)	From $\gamma(\theta)$ in ^{177m}Lu ($T_{1/2}$ =160.44 d) decay
1977Ke12	0.08 (2)	From $\gamma(\theta)$ in ^{177}Lu ($T_{1/2}$ = 6.647 d) β^- decay
1961We11	0.07 (3)	From $\gamma\gamma(\theta)$ in ^{177}Lu ($T_{1/2}$ = 6.647 d) β^- decay
Adopted	**0.074 (13)**	**$c^2/(N - 1) = 0.07$**

2.2.5 71.6418 keV ($g_{3,2}$)

Values used in the analysis of the mixing ratios are shown in Table 7. None of them has a relative statistical weight greater than 50%, and hence the weighted average value was adopted. The sign of $\delta(\gamma_{3,2})$ is negative as determined by 1974Kr12 and 1970Hr01.

Table 7 Measured and adopted mixing ratios values for the 71.6418 keV transition

Reference	$\vert\delta(\gamma_{3,2})\vert$	Comment
1974Kr12	0.051(37)	From $\gamma(\theta)$ in ^{177m}Lu ($T_{1/2}$ = 160.44 d) decay.
1974Ag01	0.049 (15)	From comparison between experimental α_K = 0.90(11) from 1974Ag01 and theoretical α_K(E1), and α_K(M2) values from 1978Ro22.
1970Hr01	0.017 (7)	From $\gamma\gamma(\theta)$.
	0.016 (6)	From comparison between experimental α_{L1} = 0.076(5), weighted average from values reported by 1972Gr35 and 1974Ag01, and theoretical α_{L1}(E1), and α_{L1}(M2) values from 1978Ro22.
	0.034 (14)	From comparison between experimental α_{L2} = 0.029(3), weighted average from values reported by 1972Gr35 and 1974Ag01, and theoretical α_{L2}(E1), and α_{L2}(M2) values from 1978Ro22.
Adopted	**0.018 (4)**	**$c^2/(N - 1) = 0.37$**

3. Atomic Data

3.1 Hf

The data are from Schönfeld and Janssen (1996Sc06).

3.1.1 X Radiation

While the energies for XKα_2 (Hf) and XKα_1 (Hf) are from Schönfeld and Rodloff (1999ScZX), the X-Kβ and XL energies are from Firestone (1996FiZX). Relative emission probabilities were calculated using the program EMISSION (2001Sc08).

3.1.2 Auger Electrons

The energies for KLL (Hf), KLX (Hf) and KXY (Hf) are from Schönfeld and Rodloff (1998ScZM). Relative emission probabilities were calculated using the program EMISSION (2001Sc08).

4.Photon Emission

4.1 X-Ray Emission

While the energies for X-Kα2 (Hf) and X-Kα1 (Hf) are from Schönfeld and Rodloff (1999 ScZX), the X-Kβ and XL energies are from Firestone (1996FiZX). The adopted absolute intensities per 100 disintegrations were calculated using the program EMISSION (2001Sc08). Comparisons between calculated values and the experimental data in 2001Sc23 and 1987Me17, as well as values calculated using the program RADLST [2], are presented in Table 8. In general the agreement between various entries is fairly good, thus suggesting that the ^{177}Lu ground state decay scheme is complete.

Table 8 comparison between various X-ray emission intensities per 100 disintegration

	Energy KeV	2001Sc23	1987Me17	RADLST	EMISSION
XLl (Hf)	6.960	0.0735 (25)	0.087 (5)		0.0613 (16)
XLα2 (Hf)	7.844				0.137 (4)
XLα1 (Hf)	7.899	1.51 (3)	1.59 (6)		1.21 (3)
XLη (Hf)	8.139				0.0313 (9)
XLβ4 (Hf)	8.905				0.0335 (12)
XLβ1 (Hf)	9.023	1.34 (3)			1.15 (4)
XLβ6 (Hf)	9.023		1.76 (7)		0.0147 (4)
XLβ3 (Hf)	9.163				0.0435 (15)
XLβ2,15 (Hf)	9.342	0.274 (7)			0.248 (7)
XLγ1 (Hf)	10.516	0.231 (6)			0.222 (6)
XLγ6 (Hf)	10.733				0
			0.292 (12)		
XLγ2 (Hf)	10.834	0.0223 (14)			0.00835 (19)
XLγ3 (Hf)	10.890				0.0115 (4)
XL				3.08 (7)	3.18 (6)
XKα2 (Hf)	54.6120 (7)	1.55 (3)	1.65 (3)	1.59 (5)	1.59 (3)
XKα1 (Hf)	55.7909 (8)	2.73 (6)	2.84 (5)	2.78 (9)	2.78 (6)
XK'β1 (Hf)	62.985-63.662	0.885 (15)	0.919 (16)		0.917 (23)
XK'β2 (Hf)	64.942-65.316	0.238 (5)	0.252 (5)		0.245 (8)
XKβ (Hf)				1.16 (4)	1.16 (3)

4.2 Gamma Emission

The measured relative intensities for transitions following the β– decay of ^{177}Lu and their adopted values are presented in Table 9. The original values were normalized to I_γ = 100.0 for the 208.3662 keV ($\gamma_{3,1}$) gamma ray. The uncertainty in I_γ for the 321.3159 keV ($\gamma_{3,0}$) gamma ray was increased 1.86 times so that its statistical weight was lowered from 77.6% to 50%.

The measured absolute intensities for the 208.3662 keV ($\gamma_{3,1}$) gamma ray and its corresponding adopted value are presented in Table 10. The latter was used to normalize the relative intensities (Table 9) to absolute values per 100 disintegrations.

Table 9 - Relative gamma-ray intensities for transitions following b$^-$ decay of ^{177}Lu

	$\gamma_{1,0}$	$\gamma_{2,1}$	$\gamma_{2,0}$	$\gamma_{3,2}$	$\gamma_{3,1}$	$\gamma_{3,0}$
2001Sc23	59.6 (6)	0.448 (8)	1.918 (17)	1.674 (21)	100.0	2.002 (19) *
1987Me17	59.6 (11)	0.457 (8)	2.00 (3)	1.71 (5)	100.0	2.17 (4)
1974Ag01	60 (5)	0.52 (5)	1.90 (20)	1.50 (10)	100.0	2.00 (20)
1964Al04	58 (4)	0.43 (3)	1.93 (14)	1.40 (10)	100.0	1.99 (14)
1961We11	62 (2)	0.47 (15)	2.00 (20)	0.30 (10) #	100.0	2.28 (10)
1955Ma12	45.5 #		1.36 #	0.91 #	100.0	1.45 (29) #
Adopted	**59.7 (5)**	**0.453 (6)**	**1.938 (15)**	**1.663 (19)**	**100.0**	**2.08 (8)**
c^2/(N-1)	**0.38**	**0.76**	**1.45**	**3.58**		**3.62**

* The uncertainty was increased 1.86 times in order to reduce its statistical weight from 77.6% to 50%.
\# Value not used in the analysis.

Table 10 - Absolute emission probabilities per 100 disintegrations for the 208.3662 keV gamma ray

	Absolute Intensity for $\gamma_{3,1}$ per 100 disintegrations, %
2001Sc23	10.36 (7)
1964Cr02	10.7 (5)
1961We11	11.4 (6)
Adopted	**10.38 (7)**
c^2/(N-1)	**1.69**

5. Electron Emission

The electron energies and emission probabilities were calculated using the RADLST [2] program. The average β^- energies were calculated using the LOGFT [3] program. The β^- transition endpoint energies were determined using Q(β^-) = 498.3(8) keV (1995Au04) and the individual level energies that were deduced from a least-squares fit to the recommended gamma-ray energies. The adopted values for the β^- transition emission probabilities were determined from the total (photons + electrons) gamma-ray emission probability balances at each level.

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^{182}Ta - Comments on evaluation of decay data
by V. Chisté and M. M. Bé

This evaluation was completed in September 2010, including all publications by this date.

1 Decay Scheme

^{182}Ta disintegrates 100 % by beta minus emissions to excited levels of ^{182}W.

A good agreement was found between the effective Q value (1821 (19) keV) calculated from the decay scheme data and the adopted and recommended value from the mass adjustment of Audi (2003Au03).

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).

Experimental ^{182}Ta half-life values (in days) are given in Table 1:

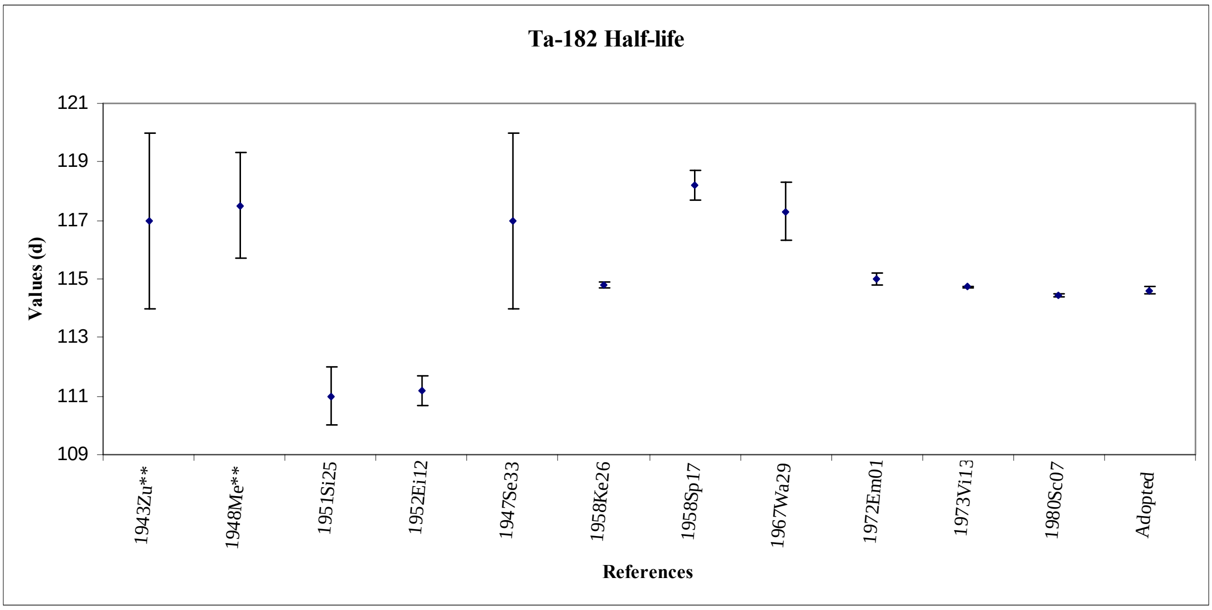
Table 1: Experimental values of ^{182}Ta half-life

Reference	Experimental value (d)	Comments
R. V. Zumstein (1943Zu**)	117 (3)	
L. Seren (1947Se33)	117 (3)	
L. Meitner (1948Me**)	117.5 (18)	
W. K. Sinclair (1951Si25)	111 (1)	
G. G. Eichholz(1952Ei02)	111.2 (5)	
H. W. Wright (1957Wr37)	115.05 (25)	Superseded by 1972Em01
J. P. Keene (1958Ke26)	114.80 (12)	
A. Speecke (1958Sp17)	118.2 (5)	
D. A. Walker (1967Wa29)	117.3 (10)	
J. F. Emery (1972Em01)	115.0 (2)	
C. J. Visser (1973Vi13)	114.740 (24)	Original uncertainty is 3σ (0.08)
U. Schötzig (1980Sc07)	114.43 (4)	
Recommended value	**114.61 (13)**	χ^2 = 16

For the data of L. Meitner (1948Me**), the evaluators have chosen to use the average value of 117.5 (18), calculated from two experimental values given in the paper to produce a single DDEP value for each laboratory. A weighted average has been calculated using LWEIGHT computer program (version 3). Originally, the largest contributions to the weighted average come from the values of U. Schötzig (1980Sc07) and C. J. Visser (1973Vi13), amounting to 43 % and 70 %, respectively. LWEIGHT increased the uncertainty of 1973Vi13 value from 0.024 to 0.037 in order to reduce its relative weight from 70 % to 50 %.

The adopted value is the weighted average of 114.61 d with an uncertainty of 0.13 d (expanded so range to include the most precise value of C. J. Visser (1973Vi13)). The reduced-χ^2 value is 16, that reflects the high discrepancy of the set of data. See Graphic 1.

Graphic 1: ^{182}Ta half-life values



2.1 β- Transitions

The maximum energies of the β^- transitions in the decay of ^{182}Ta → ^{182}W have been obtained from the Q^- value (2003Au03) and the level energies given in Table 2 from B. Singh (2010Si13).

Table 2: ^{182}W levels populated in the decay of ^{182}Ta and the adopted β^- transition probabilities

Level Number	Level energy, (keV)	Spin and parity	Half-life	Adopted $P_{\beta-}$ (%)
0	0	0^+		
1	100.10598 (7)	2^+	1.40 (2) ns	~ 0*
2	329.4268 (6)	4^+	62 (3) ps	~ 0*
5	1221.4001 (10)	2^+	0.434 (11) ps	1.6 (22)
6	1257.4121 (11)	2^+	1.71 (13) ps	0.22 (21)
7	1289.1498 (10)	2^-	1.12 (4) ns	45.1 (23)
8	1331.1153 (10)	3^+	< 0.6 ns	2.39 (15)
9	1373.8301 (10)	3^-	78 (10) ps	19.9 (7)
10	1442.836 (9)	4^+	0.32 (3) ps	0.563 (10)
11	1487.5018 (10)	4^-	< 49 ps	1.5 (7)
12	1510.25 (7)	4^+		0.1414 (39)
13	1553.2240 (10)	4^-	1.27 (4) ns	29.0 (7)

* Measured values by 1967Ba01 are 0.058 (6) and 0.096 (10), respectively. These values are inconsistent with intensity balance at each level of the decay scheme.

The adopted β^- transition probabilities and the associated uncertainties (Table 2) were deduced from the γ transition probability balance at each level of the decay scheme.

The values of log ft and average β^- energies have been calculated with the program LOGFT for the allowed and 1st forbidden β^- transitions.

2.2 γ Transitions

The γ-ray transition probabilities were calculated using the γ-ray emission intensities and the relevant internal conversion coefficients (see **5.2 γ Emissions**).

For all γ transitions, the internal conversion coefficients (ICC) and the associated uncertainties were interpolated from the theoretical values of I. M. Band et al. (2002Ba85) using the BrIcc computer program (2008Ki07) for the “frozen orbital” approximation.

For multipolarities and mixing ratios, the evaluators used:

1) Multipolarities and mixing ratios of the γ-ray transitions listed in the Table 3 are from B. Singh (2010Si13).

Table 3: Multipolarities of γ-ray transitions

	Multipolarity	E_γ (keV)
^{182}W	[E2]	(121.50 (14)), 829.80 (12)
	[E1]	110.388 (9)
	E3	1373.824 (3)
	E2	100.10595 (7), 198.35187 (29), 229.3207 (6), 264.0740 (3), 351.06 (6), 891.9710 (12), 927.9828 (13), 1035.80 (14), 1221.395 (3), 1257.407 (3), 1410.14 (7)
	E1	31.7377 (15), 42.7148 (14), 116.4179 (6), 152.42991 (26), 156.3864 (3), 222.1085 (3), 1158.0711 (12),
	E0	1135.91 (14)
	M1 + E2	1231.004 (3) δ = - 33 (+6, -9) 1180.82 (7) δ = - 2.8 (10) 1001.6856 (12) δ = - 8.9 (+18, -21)
^{182}W	M2	1289.145 (3)
	M2 + E3	1387.390 (3) δ = 2.6 (3)
	E1 + M2 + E3	1273.719 (3) δ(M2/E1) = 0.36 (10), δ(E3/E1) = - 0.28 (12)

2) For the 84-,113- and 179-keV γ-ray transitions (M1 + E2), the adopted mixing ratios (δ) are the weighted means of the δ values found in the literature and shown in Table 4. A good agreement has been found between the experimental values of K and L internal coefficients and the calculated ones obtained by using the evaluated δ values and the BrIcc program.

Table 4: Experimental and recommended conversion coefficients and mixing ratios for 84-, 113- and 179-keV γ-ray transitions

E_γ (keV)	δ experimental (mixing ratio)	α experimental	α theoretical (given by BRICC)
84.68024 (26)	0.30 (9) (1964Ba12) 0.33 (17) (1966Gr21) 0.35 (7) (1967Ni03) 0.352 (45) (1972He10) 0.30 (2) (1972Kr05) 0.31 (5) (1975Qu01) 0.30 (2) (1980Sp01) 0.32 (3) (1983Ri05)	α_K = 5.2 (10) α_L = 1.44 (10) (1963Ni07)	α_K = 5.88 (9) α_L = 1.36 (4)
Recommended value	**0.309 (12)**	χ^2 = 0.26	

E_γ (keV)	δ experimental (mixing ratio)	α experimental	α theoretical (given by BRICC)
113. 67170 (22)	0.21 (6) (1964Ba12) 0.32 (17) (1966Gr21) 0.30 (14) (1967Ni03) 0.36 (8) (1972He10) 0.31 (2) (1972Kr05) 0.31 (5) (1975Qu01) 0.36 (3) (1980Sp01) 0.36 (2) (1983Ri05)	α_K = 2.4 (10) α_L = 0.50 (5) (1963Ni07)	α_K = 2.52 (4) α_L = 0.519 (10)
Recommended value	**0.338 (12)**	χ^2 = 0.70	
179.39381 (25)	2.8 (8) (1964Ba12) 0.72 (26) (1966Gr21) 0.84 (32) (1967Ni03) 0.92 (10) (1972Kr05) 1.26 (15) (1981Ka22) 2.1 (3) (1983Ri05) 2.2 (2) (1992Ch26)	α_K = 0.49 (5) α_L = 0.15 (2) (1963Ni07)	α_K = 0.44 (8) α_L = 0.148 (7)
Recommended value	**1.21 (29)**	χ^2 = 7	

3) For the eleven remaining γ-ray transitions, the mixing ratios (δ) were deduced by comparison between the weighted mean of the experimental values of internal coefficients and the theoretical ICC calculated using the BrIcc computer code (2008Ki07), shown in the Table 5.

Table 5: Experimental and recommended conversion coefficients and mixing ratios

E_γ (keV)	α experimental	δ (mixing ratio)	α theoretical (given by BRICC)	Multipolarities
65.72215 (15)	α_L = 2.5 (1) (1963Ni07)	0.094 (43)	α_L = 2.3 (1)	M1 + E2
67.74970 (10)	α_L = 0.18 (2) (1963Ni07)	0.018 (9)	α_L = 0.17 (2)	E1 + M2
959.7203 (12)	α_K = 7 (5) 10^{-3} (1961Gr21) α_K = 9.2 (24) 10^{-3} (1966Dz01) α_K = 9.08 (20) 10^{-3} (1976He18) α_K (LWM) = 9.08 (20) 10^{-3}	- 5.48 (44)	α_K = 9.01 (15) 10^{-3}	M2 + E3
1044.4001 (12)	α_K = 2.4 (6) 10^{-3} (1966Dz01) α_K = 4.4 (20) 10^{-3} (1969Ga23) α_K = 4.35 (10) 10^{-3} (1976He18) α_K (LWM) = 4.36 (10) 10^{-3}	0.48 (1)	α_K = 4.44 (12) 10^{-3}	E1 + M2
1113.406 (9)	α_K = 4.8 (8) 10^{-3} (1972Ga23) α_K = 3.59 (13) 10^{-3} (1975We22) α_K = 3.02 (6) 10^{-3} (1976He18) α_K (LWM) = 3.32 (30) 10^{-3}	5.6 (+13,-10) (from 1983Ri05)	α_K = 3.11 (8) 10^{-3}	M1 + E2
1121.290 (3)	α_K = 3.9 (2) 10^{-3} (1960Gr**) α_K = 3.2 (2) 10^{-3} (1964Da15) α_K = 2.9 (3) 10^{-3} (1966Dz01) α_K = 3.28 (15) 10^{-3} (1966Ko12) α_K = 3.15 (19) 10^{-3} (1972Ga23) α_K = 3.16 (10) 10^{-3} (1975We22) α_K = 2.99 (4) 10^{-3} (1976He18) α_K (LWM) = 3.036 (40) 10^{-3}	30 (+6,-4) (from 1983Ri05)	α_K = 2.97 (5) 10^{-3}	M1 + E2

E_γ (keV)	α experimental	δ (mixing ratio)	α theoretical (given by BRICC)	Multipolarities
1157.3022 (11)	α_K = 2.7 (3) 10^{-3} (1960Gr**) α_K = 3.5 (5) 10^{-3} (1964Da15) α_K = 3.5 (8) 10^{-3} (1966Dz01) α_K = 6.3 (4) 10^{-3} (1966Ko12) α_K = 6.8 (7) 10^{-3} (1972Ga23) α_K (LWM) = 4.1 (14) 10^{-3}	1.3 (7)	α_K = 3.9 (11) 10^{-3}	M1 + E2
1189.040 (3)	α_K = 4.3 (2) 10^{-3} (1960Gr**) α_K = 4.6 (3) 10^{-3} (1964Da15) α_K = 3.6 (4) 10^{-3} (1966Dz01) α_K = 4.22 (40) 10^{-3} (1966Ko12) α_K = 4.10 (21) 10^{-3} (1972Ga23) α_K = 4.18 (14) 10^{-3} (1975We22) α_K = 3.88 (4) 10^{-3} (1976He18) α_K (LWM) = 3.93 (6) 10^{-3}	δ(M2/E1) = 0.470 (17), δ(E3/E1) = - 0.662 (32)	α_K = 3.732 (33) 10^{-3}	E1 + M2 + E3
1223.7928 (12)	α_K = 2.4 (4) 10^{-3} (1976He18)	0.38 (7)	α_K = 2.4 (5) 10^{-3}	E1 + M2
1342.72(5)	α_K = 1.9 (10) 10^{-3} (1966Dz01) α_K = 2.20 (85) 10^{-3} (1966Ko12) α_K = 2.28 (6) 10^{-3} (1976He18) α_K (LWM) = 2.28 (6) 10^{-3}	- 0.11 (11)	α_K = 2.3 (5) 10^{-3}	E2 + M3
1453.1118 (10)	α_K = 3.7 (6) 10^{-3} (1966Dz01) α_K = 2.4 (16) 10^{-3} (1966Ko12) α_K = 4.38 (30) 10^{-3} (1976He18) α_K (LWM) = 4.28 (29) 10^{-3}	2.1 (4)	α_K = 4.3 (3) 10^{-3}	M2 + E3

For the 1113-, 1121- and 1157-keV γ-ray transitions, from comparison between measured and calculated ICCs, the introduction of a third E0 component appears not to be necessary. This was proposed for:

1. 1113-keV by 1975We22, but not by 1972Ga23 and 1976He18;
2. 1121-keV by 1966Ko12 and 1975We22, but not by 1960Gr**, 1964Da15, 1966Dz01 and 1972Ga23;
3. 1157-keV by 1966Ko12 and 1972Ga23, but not by 1960Gr**, 1964Da15 and 1966Dz01.

3 Atomic Data

Atomic values, ω_K, ϖ_L, ϖ_M, n_{KL} and the X-ray and Auger electron relative probabilities are from Schönfeld and Janβen (1996Sc06).

4 Electron emissions

The conversion electron emission probabilities were deduced from the ICC values and the γ-ray emission intensities.

5 Photon emissions

5.1 X-ray emissions

The X-ray absolute intensities were deduced from the decay data using the EMISSION computer code and are compared in Table 6 with measured values found in the literature. A good agreement has been found between the experimental and calculated values, supporting the overall consistency of the decay scheme data.

Table 6: Experimental and recommended (calculated) values of X-ray absolute intensities (%)

	U. Schötzig (1980Sc07)	B. Chand (1992Ch26)@	**Recommended values**
Kα x-ray	28.02 (52)	27.82 (39)	**27.54 (34)**
K β_1 x-ray		6.01 (12)	**5.79 (13)**
K β_2 x-ray		1.51 (5)	**1.59 (5)**
L x-ray		21.84 (44)	**24.4 (4)**

@Using a normalization factor of 0.3517 (33) (see **5.2 Gamma Emissions**)

5.2 Photon emissions

The energies of the γ-rays in Table 7 are from R. G. Helmer (2000He14). For other γ-rays, the energy values come from B. Singh (2010Si13).

Table 7: γ-ray energies given by R. G. Helmer (2000He14).

E_γ (keV)	65.722 15 (15), 67.749 70 (10), 84.680 24 (26), 100.105 95 (7), 113.671 70 (22), 116.417 9 (6), 152.429 91 (26), 156.386 4 (3), 179.393 81 (25), 198.351 87 (29), 222.108 5 (3), 229.320 7 (6), 264.074 0 (3), 1121.290 (3), 1189.040 (3), 1221.395 (3), 1231.004 (3), 1257.407 (3), 1273.719 (3), 1289.145 (3), 1373.824 (3), 1387.390 (3)

The experimental relative γ-ray emission intensities from ^{182}Ta were obtained from all the available relative values (Table 8).

The normalization factor to convert the relative emission intensities to absolute emission intensities was calculated using the formula:

$$N = \left(\frac{100}{(\sum(1 + \alpha_T)P_{rel})} \right) = 0.3517\ (33),$$

where the sum is over all the γ transitions to the ground state (100-, 1135-, 1221-, 1257-, 1289- and 1373-keV) and α_T is the relevant coefficient. The uncertainty was calculated through its propagation on the formula given above.

The experimental γ-ray emission probabilities relative to 100 for the 1121-keV γ-ray are given in Table 8, except for the Edwards's values (1965Ed01) who measured only the low energy γ-rays until 264-keV relatively to the 100 keV line.

Our recommended relative and absolute γ-ray emission probabilities are given in Table 9.

The adopted values are the weighted means calculated by the LWEIGHT program (version 3).

Were omitted from analysis:

* : N. A. Voinova (1959Vo27), V. D. Vitman (1961Vi07) and N. A. Voinova (1961Vo05), because these values come from the same laboratory that B. S. Dzhelepov (1966Dz01);

$: Idem for 1976He18 superseded by 1977Ge12 only for high energy γ-rays (1121-keV to 1453-keV), where both measured the same energies. For other energies (891-keV to 1113-keV), the evaluators used the values given by 1976He18;

£ : Idem to 1983El02, superseded by 1990Ja02;

§ : Idem to 1989Ka20, superseded by 1992Ch26;

¤ : 1969Wh03 - superseded by 1970Wh03;

µ : the set of value from H. Daniel (1964Da15), because of a lack of information on the γ-ray reference line more generally, on γ spectrometry part of the experiment;

& : the set of value from W. F. Edwards (1965Ed01), because of a lack of information in the article about the experimental measurements carried out and, therefore on the results.

Table 8: Experimental data sets of the relative γ-ray emission intensities (%) (cont'd. next pages)

Energy (keV) **Reference**	**31**	**42 65**		**67**	**84**	**100**	**110**	**113**	**116**	**152**
1959Vo27*										
1961Ry03						67.2 (47)£				33.2 (29)£
1961Vi07*										
1961Vo05*						15 (7)				18 (4)
1964Da15µ			8.6 (5)	128 (6)	9.0 (6)	43.2 (25)		5.6 (3)	1.41 (12)	19.4 (8)
1965Ed01&		1.73 (9)	20.0 (10)	293 (15)	18.8 (9)	100		13.6 (7)	3.16 (19)	51.0 (20)
1965He07										
1966Dz01										
1966Ko12										
1969Sa25					7.0 (7)	40.7 (41)		5.2 (5)	1.2 (2)	19.5 (20)
1969Wh03¤										
1970Wh03										21.3 (10)
1971Ja21						40.2 (10)				20.5 (5)
197Ml01					6.70 (22)*	38.0 (23)		4.90 (29)	1.00 (8)*	19.7 (12)
1972Ga23					7.6 (8)	40.3 (40)		5.28 (40)	1.27 (13)	19.3 (14)
1974La15				121.0 (52)	7.82 (16)	37.43 (80)*		6.15 (14)*		18.70 (60)
1976He18$										
1977Ge12				122 (7)	7.80 (41)	40.8 (35)		5.43 (18)	1.260 (42)	20.5 (6)
1978MeZK/1990Me15	2.75 (6)	0.86 (7)	8.75 (17)	130 (10)	7.19 (14)	40.4 (5)	0.330 (20)	5.34 (5)	1.260 (20)	19.95 (19)
1980Ro22						40.6 (26)		4.95 (40)	1.18 (18)	19.59 (80)
1980Sc07	2.53 (6)	0.750 (21)	161.7 (36)		7.45 (17)	40.3 (10)		5.29 (19)	1.26 (5)	19.69 (28)
1981Is08	1.18 (12)*	0.82 (10)	13.5 (14)*		7.6 (6)	41.6 (14)*	0.25 (4)	5.87 (40)*	1.14 (8)*	23.15 (50)*
1983Ji01						40.3 (6)	0.25 (6)	5.36 (7)	1.260 (30)	19.94 (19)
1983El02£	1.40 (2)	0.80 (1)	8.45 (14)	118.3 (20)	6.81 (26)	40.50 (64)	0.25 (1)	5.47 (8)	1.22 (2)	19.52 (32)
1986Wa35					7.30 (22)	39.03 (64)*		4.44 (16)*		21.19 (39)
1989Ka20§					7.87 (14)	41.50 (51)		5.47 (8)	1.24 (4)	20.30 (25)
1990Ja02	2.21 (2)	0.82 (3)	8.55 (7)	120.0 (11)	7.31 (5)	40.45 (51)	0.30 (4)	5.31 (8)	1.28 (6)	19.86 (17)
1992Su09	1.80 (6)*	0.827 (24)	7.61 (16)	126.2 (24)	7.80 (16)	42.6 (9)*	0.37 (3)	5.64 (11)	1.33 (3)	20.94 (24)
1992Ch26	2.44 (7)	0.710 (21)	8.40 (21)	131.8 (24)	7.65 (10)	41.4 (5)*	0.300 (10)	5.27 (10)	1.230 (22)	20.40 (26)
1992Ke02	2.46 (5)	0.754 (18)	9.02 (22)		7.43 (12)	40.5 (5)	0.320 (20)	5.34 (6)	1.270 (21)	19.81 (22)
1998Mi17					7.58 (7)	38.50 (23)*		5.21 (5)		19.60 (11)
Evaluated	**2.38 (17)**	**0.765 (18)**	**8.45 (20)**	**124.0 (40)**	**7.45 (14)**	**40.42(24)**	**0.305 (9)**	**5.315 (29)**	**1.264 (10)**	**19.93 (33)**
χ^2	**20**	**3.3**	**9.7**	**3.8**	**2.6**	**0.025**	**1.4**	**1.5**	**0.8**	**3.2**

* Outliers values, based on the Chauvenet's criterion and thus were omitted in the final calculation.

£ Data rejection parameters for deviation from weighted mean (3σ).

Energy (keV) Reference	156	179	198	222	229	264	351	829	891	927	959
1959Vo27*									< 1.4	3 (2)	2.5 (15)
1961Ry03	13.7 (35)£	19.5 (39)£	7.7 (13)£	29.2 (18)£	14.2 (11)£	13.4 (41)£					
1961Vi07*									< 0.5		
1961Vo05*	18 (3)	3 (1)		19 (3)		8 (1)					
1964Da15µ	7.3 (4)	10.0 (5)	4.5 (3)	23.4 (7)	10.3 (5)	10.6 (7)					
1965Ed01&	20.0 (9)	22.9 (10)	10.7 (6)	56.1 (22)	27.7 (12)	26.9 (12)					
1965He07									1	1	2
1966Dz01									~ 0.3	1.74 (26)	0.94 (24)
1966Ko12											
1969Sa25	7.5 (8)	8.7 (9)	4.3 (4)	21.2 (21)	10.5 (11)	10.3 (10)			0.20 (7)	1.6 (2)*	1.3 (2)£
1969Wh03¤									0.15 (2)	1.79 (9)	1.02 (6)
1970Wh03	8.07 (40)*	9.57 (5)£	4.40 (25)*	22.6 (12)*	10.9 (5)*	10.6 (4)			0.15 (2)	1.79 (9)	1.02 (6)
1971Ja21	7.6 (2)	8.8 (3)		21.30 (55)	10.3 (3)	10.1 (3)					
1971Ml01	7.5 (7)	8.70 (48)	4.20 (24)	21.5 (12)	10.3 (7)	10.0 (6)				1.50 (30)*	1.00 (10)
1972Ga23	7.13 (48)*	8.7 (6)	4.15 (28)	21.5 (15)	10.3 (7)	10.4 (7)				1.75 (20)	0.95 (11)
1974La15	7.78 (20)	8.57 (25)	3.75 (12)£	21.26 (62)	9.24 (26)£	9.46 (29)*				2.10 (8)*	1.12 (6)*
1976He18$									0.164 (19)	1.779 (27)	0.998 (18)
1977Ge12	7.77 (24)	9.10 (29)	4.31 (14)	21.9 (7)	10.60 (32)	10.50 (32)					
1978MeZK/1990Me15	7.59 (10)	8.82 (10)	4.19 (9)	21.60 (31)	10.39 (18)	10.26 (18)	0.034 (8)			1.730 (30)	0.980 (30)
1980Ro22	7.43 (40)	8.88 (66)	4.13 (28)	21.75 (56)	10.39 (34)	10.36 (52)				1.53 (45)*	0.92 (47)
1980Sc07	7.46 (12)	8.75 (11)	4.09 (6)	21.27 (28)	10.32 (13)	10.26 (16)					
1981Is08	7.6 (8)	9.1 (7)	4.2 (2)	21.3 (8)	10.2 (6)	9.98 (50)			0.21 (5)	1.64 (10)*	0.87 (8)*
1983Ji01	7.60 (7)	8.84 (9)	4.22 (6)	21.61 (20)	10.49 (10)	10.37 (7)	0.033 (19)	0.038 (15)	0.16 (5)	1.760 (40)	0.98 (5)
1983El02£	7.26 (11)	8.38 (9)	3.91 (4)	21.12 (22)	10.33 (13)	9.81 (12)	0.24 (1)		0.14 (4)	1.85 (3)	1.06 (3)
1986Wa35	7.26 (18)*	8.85 (24)	4.14 (7)	21.62 (51)	10.24 (22)	9.9 (8)					
1989Ka20§	7.51 (15)	8.92 (10)	4.23 (4)	21.90 (24)	10.59 (13)	10.32 (12)				1.71 (4)	0.93 (2)
1990Ja02	7.59 (12)	8.83 (8)	4.12 (5)	21.80 (20)	10.38 (11)	10.14 (9)			0.15 (4)	1.77 (6)	1.01 (3)
1992Su09	7.89 (16)*	9.04 (18)	4.21 (10)	21.6 (5)	10.5 (2)	10.26 (22)	0.03 (1)	0.05 (2)	0.20 (6)	1.72 (8)	0.99 (8)
1992Ch26	7.54 (10)	8.93 (12)	4.19 (5)	21.90 (27)	10.43 (13)	10.37 (15)	0.0330 (10)	0.039 (8)	0.160 (10)	1.720 (24)	0.970 (21)
1992Ke02	7.51 (9)	8.81 (9)	4.12 (6)	21.43 (24)	10.43 (12)	10.43 (14)	0.028 (6)		0.174 (22)	1.75 (7)	0.99 (8)
1998Mi17	7.570 (46)	8.770 (48)	4.150 (24)	21.17 (12)	10.20 (6)	10.13 (6)					
Evaluated	7.570 (29)	8.811 (29)	4.155 (16)	21.45 (7)	10.334 (36)	10.243 (35)	0.0329 (10)	0.040 (7)	0.162 (7)	1.746 (13)	0.989 (11)
χ^2	0.3	0.4	0.4	0.9	0.7	0.8	0.2	0.1	0.3	0.4	0.2

* Outliers values, based on the Chauvenet's criterion and thus were omitted in the final calculation.

£ Data rejection parameters for deviation from weighted mean (3σ).

Energy (keV) Reference	1001	1035	1044	1113	1121	1135	1157	1158 1180		1189	1221
1959Vo27*	9 (3)				100			< 4		45 (8)	84 (8)
1961Ry03					100			4.2 (9)		47.5 (27)	81 (6)*
1961Vi07*	5 (2)		0.9 (8)		100			3.6 (10)		44 (3)	80 (6)
1961Vo05*					100					43	118
1964Da15µ											
1965Ed01&											
1965He07	6 (2)		2 (1)£		100			3		44	72
1966Dz01	5.4 (3)		1.2 (2)*		100			4.1 (12)		44.3 (15)*	77 (6)
1966Ko12	7.9 (26)£		< 1		100		2.67 (15)			48.1 (20)	85.1 (31)£
1969Sa25	5.6 (6)		0.8 (1)	1.2 (2)	100		2.0 (3)	0.76 (16)	0.25 (4)	46.3 (32)	77.3 (54)
1969Wh03¤	5.98 (30)		0.69 (8)	1.13 (10)	100		1.84 (35)	0.99 (28)		47.7 (7)	79.3 (12)
1970Wh03	5.98 (30)		0.69 (8)	1.13 (10)	100		1.84 (35)	0.99 (28)		47.7 (7)	79.3 (12)*
1971Ja21					100					46.5 (7)	77.3 (12)
1971Ml01	5.4 (10)		0.60 (10)		100		2.60 (21)			47.2 (21)	78.0 (34)
1972Ga23	5.66 (40)		0.69 (10)	1.44 (20)	100		2.90 (20)		0.28 (4)	46.7 (23)	80.3 (41)*
1974La15	6.43 (11)*			1.11 (7)	100		2.96 (9)			46.1 (15)	78.4 (12)
1976He18$	5.90 (8)		0.678 (14)	1.276 (19)	100		2.838 (39)		0.249 (15)	46.64 (46)	77.3 (6)
1977Ge12					100		2.850 (49)			46.5 (7)	77.0 (11)
1978MeZK/1990Me15	5.87 (6)			1.320 (30)	100		2.920 (31)			47.1 (8)	77.80 (38)
1980Ro22	5.99 (35)			1.18 (7)	100					47.61 (53)	78.1 (9)
1980Sc07					100					46.59 (46)	77.0 (8)
1981Is08	5.36 (11)		0.58 (10)	2.21 (20)£	100			2.65 (20)	0.56 (7)*	48.8 (17)*	77.9 (27)
1983Ji01	5.85 (10)		0.72 (7)	1.30 (3)	100		1.66 (24)	1.22 (21)	0.210 (40)	46.40 (20)	76.8 (6)
1983El02£	5.99 (6)		0.68 (3)	0.95 (4)	100		2.72 (6)		0.10 (3)	46.90 (45)	78.31 (79)
1986Wa35	5.89 (34)				100		2.92 (34			47.02 (48)	77.3 (13)
1989Ka20§	5.92 (7)		0.66 (2)	1.15 (3)	100					47.18 (67)	78.38 (81)
1990Ja02	6.01 (5)		0.70 (8)	1.35 (15)	100		2.71 (20)		0.23 (9)	47.37 (9)	77.48 (34)
1992Su09	5.87 (13)	0.017 (6)	0.68 (5)	1.08 (5)	100		2.01 (7)	0.82 (5)	0.23 (4)	46.3 (19)	76.2 (15)
1992Ch26	5.86 (10)		0.660 (21)	1.240 (22)	100		2.830 (46)		0.250 (10)	46.6 (8)	
1992Ke02	5.89 (13)		0.72 (5)	1.19 (7)	100		2.87 (5)		0.22 (6)	47.0 (6)	78.0 (10)^{a}
1998Mi17					100		2.930 (22)			46.70 (24)	
Evaluated	**5.88 (13)**	**0.017 (6)**	**0.677 (10)**	**1.257 (19)**	**100**		**2.37 (36)**	**0.84 (5)**	**0.248 (8)**	**47.13 (9)**	**77.53 (20)**
χ^2	**2.2**		**0.5**	**2.7**			**12**	**1.3**	**0.3**	**1.7**	**0.3**

* Outliers values, based on the Chauvenet's criterion and thus were omitted in the final calculation.

£ Data rejection parameters for deviation from weighted mean (3σ).

a Doublet with 1223 keV gamma-ray.

Energy (keV) Reference	1223	1231	1257	1273	1289	1342 1373 1387			1410	1453
1959Vo27*		35 (10)	6 (2)	3 (2)	5 (2)		< 1.4			
1961Ry03		29.1 (22)*	5.1 (9)£		< 2.9					
1961Vi07*		25 (5)	4 (1)							
1961Vo05*		118		~ 4	~ 4		~ 2			~ 0.4
1964Da15µ										
1965Ed01&										
1965He07		36	4.5	2	4	0.80 (16)	0.70 (14)			
1966Dz01		26 (5)£	3.8 (3)*	1.5 (3)*	3.7 (2)	0.60 (9)*	0.52 (9)	0.25 (6)	0.115 (17)	0.094 (12)
1966Ko12		28.6 (10)*	3.91 (15)£	1.64 (15)	3.67 (15)	0.79 (5)	0.70 (14)	0.184 (41)	0.13 (6)	0.14 (6)
1969Sa25	0.6 (1)	32.7 (23)	4.3 (3)	1.8 (1)	3.8 (3)	0.7 (1)	0.6 (1)	0.18 (2)	0.11 (2)	0.12 (2)
1969Wh03¤		33.4 (5)	4.33 (7)	1.90 (4)	4.05 (7)	0.75 (2)	0.66 (2)	0.217 (10)	0.117 (8)	0.123 (10)
1970Wh03		33.4 (5)	4.33 (7)	1.90 (4)	4.05 (7)	0.75 (2)	0.66 (2)	0.217 (10)	0.117 (8)	0.123 (10)
1971Ja21		32.8 (5)								
1971Ml01		32.3 (14)	4.27 (19)	1.92 (10)	4.06 (19)	0.750 (38)	0.690 (36)	0.240 (21)	0.140 (30)	0.120 (30)
1972Ga23		34.5 (25)*	4.46 (45)*	1.96 (19)	4.10 (40)	0.80 (9)	0.70 (8)	0.225 (23)	0.130 (25)	0.10 (2)
1974La15		32.60 (52)	4.31 (8)	1.83 (5)	3.96 (8)	0.74 (3)	0.65 (3)	0.21 (1)		
1976He18$		32.92 (30)	4.269 (46)	1.864 (28)	3.87 (5)	0.720 (11)	0.628 (9)	0.2019 (39)	0.1152 (46)	0.0804 (32)
1977Ge12	0.778 (11)	32.96 (47)	4.26 (6)	1.860 (27)	3.86 (6)	0.718 (12)	0.628 (11)	0.202 (5)	0.112 (6)	0.0790 (31)
1978MeZK/1990Me15	0.30 (10)*	33.1 (5)	4.36 (8)	1.950 (31)	4.29 (8)	0.740 (10)	0.680 (10)	0.270 (10)*	0.1170 (40)	0.123 (8)
1980Ro22		32.32 (56)	4.33 (15)	1.66 (18)	4.06 (22)					
1980Sc07		32.81 (33)	4.250 (36)		3.860 (34)					
1981Is08		32.3 (11)	4.07 (30)*	1.67 (15)	3.65 (20)	0.66 (8)	0.58 (8)	0.20 (5)	0.10 (4)	0.10 (4)
1983Ji01	0.53 (24)	32.72 (14)	4.276 (24)	1.871 (13)	3.800 (32)	0.723 (7)	0.626 (6)	0.2040 (40)	0.111 (5)	0.0872 (24)
1983El02£		33.20 (22)	4.27 (2)	1.87 (1)	3.89 (4)	0.72 (1)	0.60 (1)	0.20 (1)	0.10 (1)	0.09
1986Wa35		33.42 (31)	4.36 (16)	1.73 (12)	4.17 (30)					
1989Ka20§		33.28 (45)	4.40 (6)	1.92 (3)	4.01 (5)	0.75 (1)	0.68 (2)			
1990Ja02	0.55 (12)	33.85 (22)	4.35 (6)	1.90 (4)	3.90 (5)	0.76 (4)	0.65 (2)	0.24 (3)	0.14 (2)	0.11 (2)
1992Su09	0.58 (10)	32.2 (7)	4.22 (9)	1.84 (5)	3.80 (8)	0.69 (3)	0.55 (2)	0.19 (2)	0.083 (10)*	0.11 (1)
1992Ch26		32.80 (48)	4.31 (7)	1.850 (33)	3.91 (6)	0.720 (12)	0.610 (11)	0.205 (6)	0.1090 (41)	0.0830 (31)
1992Ke02	78.0 (10)[a]	33.17 (37)	4.34 (7)	1.860 (31)	4.03 (7)	0.748 (21)	0.628 (13)	0.220 (11)	0.117 (8)	0.097 (7)
1998Mi17		33.18 (19)	4.320 (24)		3.940 (23)					
Evaluated	0.58 (6)	33.04 (10)	4.296 (13)	1.872 (9)	3.907 (33)	0.7284 (43)	0.633 (7)	0.2060 (24)	0.1136 (21)	0.106 (19)
χ^2	0.05	1.7	0.5	1.1	3.0	0.8	3.2	0.9	0.5	4.3

* Outliers values, based on the Chauvenet’s criterion and thus were omitted in the final calculation.

£ Data rejection parameters for deviation from weighted mean (3σ).

a Doublet with 1221 keV gamma-ray.

Table 9: Recommended relative and absolute γ-ray intensities (%)

Eγ (keV)	Relative γ-ray intensity (%)	Absolute γ-ray intensity (%)	Eγ (keV)	Relative γ-ray intensity (%)	Absolute γ-ray intensity (%)	Eγ (keV)	Relative γ-ray intensity (%)	Absolute γ-ray intensity (%)
31	2.38 (17)	0.84 (6)	**229**	10.334 (36)	3.634 (36)	**1180**	0.247 (8)	0.0869 (29)
42	0.765 (18)	0.269 (7)	**264**	10.243 (35)	3.602 (36)	**1189**	47.13 (9)	16.58 (16)
65	8.45 (20)	2.97 (8)	**351**	0.0329 (10)	0.01157 (37)	**1221**	77.53 (20)	27.27 (27)
67	124.0 (40)	43.6 (15)	**829**	0.040 (7)	0.0141 (25)	**1223**	0.58 (6)	0.204 (21)
84	7.45 (14)	2.62 (6)	**891**	0.162 (7)	0.0570 (25)	**1231**	33.04 (11)	11.62 (12)
100	40.42 (24)	14.22 (16)	**927**	1.746 (13)	0.614 (7)	**1257**	4.296 (13)	1.511 (15)
110	0.305 (9)	0.1073 (33)	**959**	0.989 (11)	0.348 (5)	**1273**	1.872 (9)	0.658 (7)
113	5.315 (29)	1.869 (20)	**1001**	5.88 (13)	2.07 (5)	**1289**	3.906 (33)	1.374 (17)
116	1.264 (10)	0.445 (5)	**1035**	0.017 (6)	0.0060 (21)	**1342**	0.7284 (43)	0.2562 (28)
(121)*		0.0021 (7)	**1044**	0.677 (10)	0.2381 (42)	**1373**	0.633 (7)	0.2226 (32)
152	19.93 (33)	7.01 (13)	**1113**	1.257 (19)	0.442 (8)	**1387**	0.2060 (24)	0.0725 (11)
156	7.570 (29)	2.662 (27)	**1121**	100	35.17 (33)	**1410**	0.1136 (21)	0.0400 (8)
179	8.811 (29)	3.099 (31)	**1135**			**1453**	0.106 (19)	0.037 (7)
198	4.155 (16)	1.461 (15)	**1157**	2.37 (36)	0.83 (13)			
222	21.45 (7)	7.54 (7)	**1158**	0.84 (5)	0.295 (18)			

*Deduced from gamma-ray probability imbalance at level 4 (1135 keV) of the decay scheme.

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^{186}Re - Comments on evaluation of decay data by E. Schönfeld and R. Dersch

This evaluation was completed in November 1998 and the half-life value has been updated in May 2004.

1 Decay Scheme

The decay scheme is taken from Baglin (1997). It is based mainly on the work of Fogelberg (1972), Seegmiller et al. (1972) and Maly et al. (1964). The latter two authors did not only study gammas, but also conversion electrons. There are EC branches to the 122 keV level and the ground state of ^{186}W (together 7,53 %) and beta branches to the ground state (70,9 %) and the excited states (21,5 %) in ^{186}Os. Spins and parities of the levels are taken from Baglin (1997), also the half-lives of the excited levels in ^{186}Os. The splitting into the EC and the beta part was calculated from the measured total W K-X ray emission probability. Beside the four excited levels of ^{186}Os given in the decay scheme, there is a level at 868,94(4) keV (6+). A direct beta transition to this level would be fifth forbidden and, therefore, would be too weak to be observed. The next higher level in ^{186}Os is at 1070,5 keV which is already above the adopted $Q_{\beta-}$ value if the latter is correct.

^{186}W has below the Q_{EC} value a further level at 396,26 keV (4+; 36 ps). An EC transition to this level would be third forbidden, so this branch will be very weak, thus the decay scheme given on page 1 can be considered to be complete.

2 Nuclear Data

The following values of the half-life have been considered ($T_{1/2}$ in d):

1	3,750	Sinma et al. (1939); Fajans et al. (1940); Chu (1950)
2	3,792	Cork et al. (1940); Grant *et al.* (1945); Dybvig *et al.* (1950)
3	3,867(8)	Yamasaki et al. (1940)
4	3,867(8)	Goodman and Pool (1947)
5	3,704(8)	Porter et al. (1956)
6	3,775(13)	Gueben and Govaerts (1958)
7	3,777(4)	Michel and Herpers (1971)
8	3,775(1)	Abzouzi et al. (1989)
9	3,7187(29)	Unterweger et al. (1992)
10	3,7183(11)	Schönfeld et al. (1994) ; superseded by 11
11	3,7186(5)	Schrader (2004)
12	3,7186(17)	by the present evaluator adopted value

The adopted value is mainly based on values 9 and 11. The values 1 to 4 are considered to be only of historical interest. The remaining six values are discrepant: there is a group of three low values (5, 9, 11) and three high values (6, 7, 8). If values 6, 7 and 8 would be included in an averaging procedure, the mean value would be larger than value 12 and also its uncertainty. The present evaluator has not included values 6, 7 and 8 into the averaging procedure because of the well agreeing values 9, 10 and 11 which were measured in well equiped national instituts by experienced scientists whereas the consideration of radioactive impurities and other systematical uncertainties is not convincing in the papers 7 and 8. The value 10 is superseded by value 11 and was then not used for the mean.

Both Q values are taken from Audi and Wapstra (1995).

2.1 b^{-} Transitions

The maximum beta energy of the transition to the 137 keV level have been measured to be (values in keV)

1	934,3(13)	Porter et al. (1956)
2	927(2)	Johns et al. (1956)
3	937(14)	Bashandi and El Nesr (1963)
4	939(3)	Maly et al. (1964)
5	927(3)	Andre and Liaut (1968)
6	945(5)	Trudel et al. (1970)
7	932,8(21)	weighted mean

By adding the level energy of 137,1 keV to the weighted mean we obtain 1069,9 keV for the Q value which is in good agreement with the value given for $Q_{\beta-}$ by Audi and Wapstra: 1069,5(9) keV.

The energy of the $\beta_{0,1}$ transition in table 2.1 is deduced from the adopted Q_β value and the gamma ray energy. The spectra of the β transitions to the ground state and to the 137 keV level which are both non-unique first forbidden were found to have an almost allowed shapes. The total beta emission probability is calculated by subtracting the total EC probability (Section 2.2) from 1.

2.2 Electron Capture Transitions

The fractional capture probabilities of the transitions $\varepsilon_{0,1}$ and $\varepsilon_{0,0}$ were calculated using the data of Schönfeld (1998). The energies are derived from the Q values and the level energies. From the emission probability of the 122 keV γ ray (which was found to be 0,00603(6); original value of Schönfeld et al., 1994) and the conversion coefficient of this transition, the transition probability $P_{\gamma+\mathrm{ce}}$ (which is also the transition probability of the electron capture branch to the 122 keV level) is obtained to be $P_{\gamma+\mathrm{ce}} = P_{\mathrm{EC}}(0,1) = 0,0169(3)$.

The transition probability of the electron capture transition feeding the ground state of ^{186}W can be calculated from the total emission probability of W KX rays. This emission probability is given by

$$P(\mathrm{W\ KX}) = \left\{ P_{EC}(0,1)\left[P_K(0,1) + a_K / \left(1 + a_t\right)\right] + P_{EC}(0,0)\, P_K(0,0) \right\} w_K .$$

Using the known values for P_K (Table 2.2), the conversion coefficients a_K and a_t (Table 2.3), and the fluorescence yield w_K for tungsten, the transition probability $P_{\mathrm{EC}}(0,0)$ can be extracted from the above expression. Using $P(\mathrm{W\ KX}) = 0,0602(8)$ as determined by Schönfeld et al. (1994), one obtains $P_{\mathrm{EC}}(0,0) = 0,0584(12)$.

Thus, the total electron capture probability amounts to $P_{\mathrm{EC}}(0,1) + P_{\mathrm{EC}}(0,0) = 0,0169(3) + 0,0584(12) = 0,0753(12)$.

2.3 Gamma Transitions

Concerning the energies see Sect. 4.2. The transition probabilities $P\gamma$+ce are calculated from the emission probabilities (Sect.4.2) and the total conversion coefficients. The conversion coefficients were interpolated from the tables of Rösel et al. (1978). Maly et al. have determined the K conversion coefficients as follows: α_K (122 keV) = 0,53(5), α_K (137 keV) = 0,44(2). Both are pure E2 transitions.

These values are in agreement with the theoretical ones. Maly et al. have also determined the ratios K/L/M/N for these two transitions. Mixing ratios for the transitions $\gamma_{4,3}$, $\gamma_{4,2}$, $\gamma_{3,1}$ and $\gamma_{4,1}$ were taken from Baglin (1997).

3 Atomic Data

The atomic data are taken from Schönfeld and Janßen (1996).

3.1 X Radiation

The energy values are calculated from the wave lengths in Å* as given by Bearden (1967). The relative emission probabilities of K X rays are taken from Schönfeld and Janßen (1996). The relative emission probabilities of L X rays is calculated from the absolute emission probability given in Table 4.2 setting $P(\mathrm{K}_{a_1}) = 1$.

3.2 Auger Electrons

The energy values are taken from Larkins (1977) (KLL) and the Table de Radionucléides (LMRI 1982) (KLX, KXY). The relative emission probabilities of K Auger electrons are taken from Schönfeld and Janßen (1996). The relative emission probabilities of the L Auger electrons is calculated from the value in the table 4.1 putting *P*(KLL) = 1.

4 Radiation Emission

4.1 Electron Emission

The energies of the Auger electrons are the same as in 3.2. The energies of the conversion electrons are calculated from the transition energy (2.2) and the binding energies.

The emission probabilities of the conversion electrons are calculated using the conversion coefficients given in 2.2. The values of the emission probabilities of the Auger electrons are calculated using the transition probabilities given in 2.1 and 2.2, the atomic data given in 3, and the conversion coefficients given in 2.2 using the Programm EMISSION.

4.2 Photon Emission

The energy of the X rays are from 3.1. The energy of the 137 keV gamma rays was determined by Marklund and Lindström (1963) using a curved-crystal spectrometer. The energies of the other γ rays are taken from Baglin (1997) who took into account also coulomb excitation and n,γ reactions.

The emission probability (photons per disintegration) of the 137 keV γ rays in ^{186}Os has been determined to be 0,0945(16) by Coursey et al. (1991) and 0,0939(9) by Schönfeld et al. (1994). Together with Baglin (1997) we take the unweighted mean 0,0942(6) as adopted value in the present evaluation in order to compare the results of different authors who carried out relative measurements. Then we have (normalized to this value) the following emission probabilities:

	1	2	3	4	5
W L X	0,0308(?)	-	-	0,0192(2)	0,0166(4)
W K_{a_2}	0,0178(4)	-	0,0172(5)	0,0176(4)	0,01736(30)
W K_{a_1}	0,0312(4)	-	0,0297(8)	0,0303(6)	0,0302(5)
W K_{a}	0,0490(6)	0,0445(13)	0,0469(10)	0,0479(8)	0,0475(8)
W K'_{b_1}	0,0109(2)	-	0,0099(4)	0,00989(20)	0,01000(23)
W K'_{b_2}	0,0034(2)	-	0,0026(2)	0,00269(6)	0,00274(8)
W K_{b}	0,0143(3)	-	0,0125(4)	0,01258(21)	0,1273(29)
W K X	0,0633(7)	-	0,0594(11)	0,0605(8)	0,0603(10)
Os L X	0,0300(3)	-	-	0,0306(34)	0,0299(7)
Os K_{a_2}	0,0114(2)	-	0,0113(4)	0,0112(3)	0,01128(26)
Os K_{a_1}	0,0199(4)	-	0,0193(6)	0,0196(4)	0,0194(5)
Os K_{a}	0,0313(5)	0,0286(6)	0,0306(7)	0,0308(5)	0,0307(7)
Os K'_{b_1}	0,0067(2)	-	0,0066(3)	0,00635(14)	0,00650(18)
Os K'_{b_2}	0,00198(20)	-	0,00170(6)	0,00186(4)	0,00182(6)
Os K_{b}	0,0087(2)	-	0,0083(3)	0,00821(15)	0,00833(23)
Os K X	0,0400(6)	-	0,0389(7)	0,0390(5)	0,0390(9)
W γ 122	0,00603(20)	0,00598(10)	0,00604(23)	0,00605(6)	0,00603(6)
Os γ 137	≡0,0942(6)	≡0,0942(6)	≡0,0942(6)	≡0,0942(6)	≡0,0942(6)
Os γ 630	-	0,00032(3)	0,000292(6)	0,000294(6)	0,000293(6)
Os γ 767	-	0,00037(4)	0,000324(7)	0,000328(6)	0,000327(6)

1 Seegmiller et al. (1972)
2 Coursey et al. (1991)
3 Goswamy et al. (1991)
4 Schönfeld et al. (1994)
5 calculated with EMISSION (X rays); values adopted by the present evaluator (gammas)

In all cases there is excellent agreement. Relative values for the emission probabilities of the gamma rays were also determined by Johns et al. (1956), Maly et al. (1964) and Rao et al. (1969). These values are less accurate and were not taken into account in the present evaluation. The emission probabilities and the energies of the gamma rays of the very weak gamma transitions in ^{186}Os (not contained in the above table) were determined by Fogelberg (1972) which is the only one to report these values.

Multiplying the adopted value for $P_{\gamma}(122)$ by 1 + $a_{t}(122)$ we obtain, in agreement with table 2.2 , $P_{EC}(122) = 0,0169$.

Values, recently measured by Miyahara *et al.* (2000) and Woods *et al.* (2000) are also in good agreement with the here adopted values.

5 Main Production Modes

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For additional references see also § References in the Tables Part.

^{195}Au - Comments on evaluation of decay data
by V. Chisté and M. M. Bé

This evaluation was completed in June 2012, including all publications by this date.

1 Decay Scheme

^{195}Au disintegrates 100 % by electron-capture transitions to the ground state level and excited levels of ^{195}Pt. Good agreement is found between the effective $Q^{\pm}$ value (227 (5) keV) calculated from the decay scheme data and that recommended (226.8 (10) keV) from the atomic mass evaluation of Audi and Meng (2012Au06).

2 Nuclear Data

The Q^{+} value is from the atomic mass evaluation of Audi *et al.* (2011AuZZ).

The recommended ^{195}Au half-life has been deduced from the experimental values (in days) given in Table 1:

Table 1: Experimental values of ^{195}Au half-life.

Reference	Experimental value (d)	Comments
R. M. Steffen (1949St17)	180 (15)	
G. Wilkinson (1949Wi08)	185 (3)	
A. Bisi (1959Bi07)	192 (5)	Omitted, outlier.
M. Bresesti (1960Br11)	199 (3)	Omitted, outlier.
N. A. Bonner (1962Bo12)	185 (1)	
G. Harbottle (1963Ha17)	182.9 (5)	
D. D. Hoppes (1982HoZJ)	186.09 (4)	Omitted, superseded by 2002Un02.
M. P. Unterweger (2002Un02)	186.098 (47)	
Recommended value	**184.7 (14)**	**$\chi^2 = 6$**

A weighted average was calculated by using LWEIGHT computer program (version 3). The Bisi (1959Bi07) and Bresesti (1960Br11) values were showed to be outliers, based on the Chauvenet's criterion, and thus were omitted in the final calculation. The largest contribution to the weighted average comes from the value of Unterweger (2002Un02), with a relative statistical weight of 99 %. The LWEIGHT program increased the uncertainty of the 2002Un02 value from 0.047 to 0.44 in order to reduce its relative statistical weight to 50 %.

The recommended value of ^{195}Au half-life is the weighted average of 184.7 d with a final uncertainty of 1.4 d, expanded to include the most precise value of M. P. Unterweger. The reduced-χ^2 value is 6.

2.1 Electron capture transition

The energies of the electron-capture transitions in the decay of ^{195}Au → ^{195}Pt have been obtained from the Q^{+} value (2011AuZZ) and the level energies given in Table 2 from C. Zhou (1999Zh11).

Table 2: ^{195}Pt levels populated in the decay of ^{195}Au and the evaluated electron-capture transition probabilities.

Level Number	Level energy, (keV)	Spin and Parity [a]	Evaluated $P_{\varepsilon c}$ (%)
0	0	$1/2^-$	9.5 (4)
1	98.882 (4)	$3/2^-$	57.6 (35)
2	129.777 (5)	$5/2^-$	32.8 (30)
3	199.526 (12)	$3/2^-$	0.0149 (14)
4	211.398 (6)	$3/2^-$	0.0210 (18)

[a] Given by C. Zhou (1999Zh11).

For the ^{195}Pt ground state, the adopted electron-capture transition probability of 9.5 (4) % is from S. C. Goverse (1973Go05).

The electron-capture transition probabilities to the ^{195}Pt excited levels and the associated uncertainties (Table 2) were deduced from the γ transition probability balance at each level of the decay scheme.

The partial electron-capture transition probabilities P_K, P_L, P_{MNO} and log ft values were calculated for the 1st forbidden and 1st forbidden unique electron-capture transitions using the LOGFT computer code.

2.2 γ Transitions

The γ transition probabilities were obtained using the γ-ray emission intensities and the relevant internal conversion coefficients (see **5.2 Gamma Emissions**).

For all γ transitions, the internal conversion coefficients (ICC) and the associated uncertainties were interpolated from theoretical values of I. M. Band *et al.* (2002Ba85) using the BrIcc computer program (2008Ki07) for the “frozen orbital” approximation.

For multipolarity and mixing ratio of the γ-ray transitions, the evaluators used:
1) The multipolarities of the 129-, 199- and 211-keV γ transitions are from C. Zhou (1999Zh11):

129-keV γ-ray: E2;
199-keV γ-ray: M1 + E2, $|\delta| = 1.2$ (2);
211-keV γ-ray: M1 + E2, $|\delta| = 0.38$ (3).

2) For the 30- and 98-keV γ transitions (M1 + E2), the mixing ratios (δ) were calculated from experimental ICC’s (α), using BriccMixing program, version 2.2a (the same package of BrIcc computer program, http://bricc.anu.edu.au/index.php) and the adopted values of δ are shown in the table 3.

Table 3: Experimental ICC’s (α) and adopted mixing ratios (δ).

E_γ (keV)	Experimental α	Adopted mixing ratio (δ)
30.895 (7)	$\alpha_L = 30.2$ (39); $\alpha_M = 6.9$ (9) (1969Fi08) $\alpha_{L1} = 17.9$ (46); $\alpha_{L2} = 1.40$ (64); $\alpha_{L3} = 0.25$ (8) (1970To19) $\alpha_{L1} = 23.0$ (28); $\alpha_{L2} = 2.50$ (30); $\alpha_{L3} = 0.43$ (5) (1970Ah05)	- 0.013 (7), $\chi^2 = 1.7$
98.882 (4)	$\alpha_K = 8.4$ (5) (1959Bi07) $\alpha_K = 5.8$ (15) (1959Mc69) $\alpha_K = 6.01$ (15) (1964Go19) $\alpha_K = 5.8$ (5); $\alpha_L = 0.82$ (7); $\alpha_M = 0.186$ (15) (1969Fi08) $\alpha_K = 6.9$ (15); $\alpha_{L1} = 0.92$ (20); $\alpha_{L2} = 0.088$ (17); $\alpha_{L3} = 0.027$ (6) (1970To19) $\alpha_K = 5.6$ (7); $\alpha_{L1} = 0.870$ (36); $\alpha_{L2} = 0.119$ (8); $\alpha_{L3} = 0.033$ (3) (1970Ah05)	-0.122 (+14,-13), $\chi^2 = 3.3$

3 Atomic Data

Atomic values, ω_K, ϖ_L and n_{KL} are from Schönfeld and Janβen (1996Sc06).
The X-ray and Auger electron emission probabilities were calculated from the data set values using the computer program EMISSION.

4 Electron emissions

The conversion electron emission probabilities were deduced from the ICC values and the γ-ray emission intensities.

5 Photon Emissions

5.1 X-rays

The X-ray absolute intensities were deduced from the decay data using the EMISSION computer code and are compared in Table 4 with measured values found in the literature. A reasonable agreement has been found between the experimental and calculated values.

Table 4: Experimental and recommended (calculated) values of the total K X-ray absolute intensities.

	1964Go19 *	1967Sc18 *	1968Ja11*	1970Ah05 *	1972Ha21	Recommended
K X-rays	92.5	99 (13)	87.2	98 (7)	99 (5)	94.6 (35)

*Using normalization factor of 0.1121 (15) (see **5.2 Gamma Emissions**)

5.2 Gamma emissions

The γ-ray energies given in section 5.2 were deduced from the decay scheme using the ^{195}Pt level energies adopted by C. Zhou (1999Zh11).

The experimental relative γ-ray emission probabilities in ^{195}Au decay were obtained by averaging all the available measured values. The normalization factor to convert relative γ-ray emission probabilities to absolute values was calculated with the formula:

$$\text{Normalization} = \frac{100 - P_{\varepsilon c}(g.s.)}{\sum(1 + \alpha_T)P_{rel}} = 0.1121\ (15)$$

where the sum is to be done over all the gamma transitions populated the ground state, P_{rel} is a relative γ-ray emission probability and $P_{\varepsilon c}$ (g.s.) = 9.5 (4) %, given by S. C. Goverse (1973Go05)**.** From the theoretical total ICC α_T and the evaluated relative γ-ray emission probabilities (Table 5), the calculated normalization factor is 0.1121 (15).

The experimental γ-ray emission probabilities relative to the 98-keV γ-ray taken equal to 100 are given in Table 5.

The evaluated relative γ-ray emission probability values are the weighted means calculated with the LWEIGHT computer program (version 3).

Our recommended relative and absolute γ-ray emission probabilities are given in Table 6.

Table 5: Experimental and evaluated relative γ-ray emission probabilities (%).

Reference	1965Ha13	1967Sc18	1970Ah05	1972Ha21	1974HeYW	Evaluated	Reduced χ^2
Energy (keV)							
30.895 (7)	12.3 (18)		6.8 (5)	7.08 (41)		7.1 (7)	4.3
98.882 (4)	100	100	100	100	100	100	
129.777 (5)	7.7 (8)	7.2 (8)	7.4 (5)	7.64 (44)	8.0 (6)	7.62 (26)	0.2
199.526 (12)		0.093 (10)			0.078 (9)	0.083 (7)	0.9
211.398 (6)	0.25 (3)*	0.119 (11)			0.102 (11)	0.108 (9)	0.8

* the experimental value has been shown to be an outlier value according to Lweight computer program.

Table 6: Recommended relative and absolute γ-ray emission probabilities (%).

Eγ (keV)	Relative γ-ray emission probability (%)	Absolute γ-ray emission probability (%)
30.895 (7)	7.1 (7)	0.80 (8)
98.882 (4)	100	11.21 (15)
129.777 (5)	7.62 (26)	0.854 (29)
199.526 (12)	0.083 (7)	0.0093 (8)
211.398 (6)	0.108 (9)	0.0121 (10)

6 References

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^{198}Au - Comments on evaluation of decay data
by E. Schönfeld and R. Dersch

1 Decay Scheme

In addition to the 411,8 keV level (2+) and the 1087,7 keV level (2+), ^{198}Hg has an excited level at 1048,5 keV (4+, half-life 1,80(8) ps) which is below the Q value. Its spin 4 was deduced from $\gamma\gamma$ angular correlation in ^{198}Tl EC decay and its positive parity from the E2 character of the γ transition to the 2+ level. A β transition from the ^{198}Au (2-) ground state to this level (ΔJ = 2 and parity change, $E_b^{\max}$ = 323,7 keV) would be unique 1st forbidden and was not observed. From lg ft systematics (lg $ft \geq 8{,}5$) an upper limit of 0,004 for the transition probability to this level was derived.

Iwata and Yoshizawa (1980) estimated the probability of a possible EC transition leading to the ground state of ^{198}Pt (unique first forbidden) to be less than 0,0017 % from lg ft systematics, i. e. negligible for most purposes.

2 Nuclear Data

The following values of the half-life have been considered ($T_{1/2}$ in d):

1	2,7	Mc Millan et al. (1937)
2	2,73(2)	Diemer and Groendijk (1946)
3	2,69(1)	Silver (1949)
4	2,69	Saxon and Heller (1949)
5	2,73(2)	Sinclair and Holloway (1951)
6	2,66(1)	Cavanagh et al. (1951)
7	2,697(3)	Lockett and Thomas (1953)
8	2,699(3)	Bell and Yaffe (1954)
9	2,686(5)	Tobailem (1955)
10	2,697(3)	Johansson (1956)
11	2,694(6)	Sastre and Price (1956)
12	2,704(4)	Keene et al. (1958)
13	2,699(4)	Robert (1960)
14	2,687(5)	Starodubtsev (1964)
15	2,694(4)	Anspach et al. (1965)
16	2,693(5)	Reynolds et al. (1966)
17	2,697(5)	Lagoutine et al. (1968)
18	2,695(7)	Goodier (1968)
19	2,695(2)	Vuorinen and Kaloinen (1969)
20	2,696(4)	Costa Paiva and Martinho (1970)
21	2,6946(10)	Cabell and Wilkins (1970)
22	2,693(3)	Debertin (1971)
23	2,6937(2)	Merritt and Gibson (1977)
24	2,6935(4)	Rutledge et al. (1980)
25	2,695(2)	Hoppes et al. (1982)
26	2,6966(7)	Abzouzi et al. (1990)
27	2,69517(21)	Unterweger et al. (1992)
28	2,6837(50)	Mignonsin (1994)
29	2,6944(8)	LWM, adopted value

Values 1 - 6 are only of historical interest. Value 25 is not used because it is replaced by value 27. Value 28 was rejected because identified as outlier by LWM. The adopted value 29 is a weighted average of 20 values with expanded uncertainty so range includes the most precise value 23 which contributes 43 % to the mean. The reduced

χ^2 is 2,9. The adopted value 29 is very close to the value recommended in the IAEA -TECDOC 619 (2,6943(8)) - based on 16, 17, 18, 19 - 22, 24, 25.

Nyikos et al. (1973) studied the influence of the chemical surrounding on the half-life of ^{198}Au and found $\lambda(Au) - \lambda(Au_2O_3)/\lambda(Au) = (1,0 \pm 0,3) \cdot 10^{-4}$. If this result is correct, it would need to be taken into account if any additional very precise values are reported. This chemical shift is comparable to the uncertainties for values 23 and 27.
The *Q* value was calculated by adding the level difference $\gamma_{1,0}$ (411,8 keV) to the evaluated maximum beta energy of the beta transition $\beta_{0,1}$ (960,4 keV). This value is 1372,2(10) compaired to the Audi and Wapstra (1995) value of 1372,4(5) keV.

2.1 b^{-} Transitions

For the evaluation of the maximum energy of the beta transition $\beta_{0,1}$ the following values were considered:

1	958,8(16)	weighted mean of eight results 1948 - 1954 cited by Dzhelepov et al. 1955
2	959,0(25)	Elliott et al. 1954
3	960(2)	Porter 1956
4	962(1)	Depommier and Chabre 1961, as recalculated by Beekhuis and de Waard
5	964(3)	Graham 1961, as recalculated by Beekhuis and de Waard
6	960(3)	Hamilton et al. 1962
7	957(5)	Sharma et al. 1962
8	959(2)	Lewin et al. 1963
9	965(2)	Lehmann 1964
10	960,5(8)	Keeler and Connor 1965
11	961,0(12)	Paul 1965
12	962(1)	Lewin 1965
13	959,4(5)	Beekhuis and de Waard 1965, value which is cited in their text
14	960,4(5)	LWM with external uncertainty; reduced $\chi^2 = 1.54$
15	960,4(10)	adopted value with an uncertainty enlarged to cover the most precise value 13

The values of Wapstra et al. (1958) and de Vries (1960) were not used; they are replaced by value 8. The values 4 and 5 are recalculated by Beekhuis and de Waard (1965). The most precise values are 4 and 10 to 13. The maximum beta energies of the other beta transitions were calculated from the maximum beta energy of the transition $\beta_{0,1}$ and level differences taken from γ ray measurements.

2.2 Gamma Transitions

The energies of the level differences are calculated from the γ ray energies (section 4.2) and the recoil energies.

The probabilities $P_{\gamma+ce}$ were calculated from the γ ray emission probabilities (see section 4.2) and the conversion coefficients.

For the conversion coefficients of the 411,8 keV γ transition the following values were considered:

	a_K	a_L	a_M	a_t	
1	0,0301(5)				Lewin et al. 1963
2	0,0302(4)				Bergkvist and Hultberg 1964
3	0,0299(4)	-	-	0,0444(5)	Keeler and Connor 1964
4	0,0308(9)				Petterson et al. 1965
5	0,0299(2)				Paul 1965
6	0,0302(4)	-	-	0,0447(6)	Bosch and Szichman 1967
7	0,0301(3)				Nagarajan et al. 1972
8	0,03035(45)				El-Nesr and Mousa 1973
9	0,0300(3)	-	-	0,043(4)	Reddy 1976

10	0,03005(12)			0,0445(4)	LWM of the exp. values
11	0,03016	0,01073	0,00268	0,04439	interpol. from Rösel et al. 1978 (theory)
12	0,0301(2)	-	-	0,044(2)	Hansen 1985 evaluated
13	0,0301(2)	0,01091(25)	0,0027(2)	0,0447(5)	adopted in the present eval.

For α_{K} there is good agreement between measured values and the theory (value 10 and value 11). The arithmetic mean between 10 and 11 is taken as finally adopted value. It coincides with the value 12 evaluated by Hansen (1985). The uncertainty is estimated from the difference between theory and experiment and the spread of the experimental values. The values given for α_{L} and α_{M} are calculated from the adopted value for α_{K} and the adopted ratios (see below). A value for α_{t} is calculated as the sum of α_{K}, α_{L} and α_{MNO}, where α_{MNO} is calculated from the ratio MNO/L = 0,347(6) according to Kel'man and Metskhvarishvili. The result is 0,0448(4). With respect to the experimental value 10 the finally adopted value for α_{t} was taken to be 0,447(5).

For the ratios of the conversion coefficients the following values were found:

	K/L	K/LM	K/LMN	
1	2,69(2)	2,15(4)	2,00(4)	Kel'man and Metskhvarishvili 1959
2	-	-	2,08(6)	Bosch and Szichman 1967
3	-	2,06	-	Keeler and Connor 1964
4	2,79(4)	-	-	Herrlander and Graham 1964
5	-	2,17(8)	-	Kurey and Roy 1963
6	2,54(6)	-	1,98(5)	Parsignault 1966
7	2,75(10)	-	-	Bogdanovich et al. 1968
8	-	-	2,36(60)	Reddy 1976
9	2,70(5)	2,16(4)	2,01(3)	LWM of exp. values
10	2,81	2,25	2,12	Theory (Rösel et al., 1978)
11	2,76(6)	2,21(6)	2,06(6)	In this evaluation adopted values

Herrlander and Graham (1964) cited for K/L taken from theory 2,72 (Sliv and Band, 1958) and 2,75 (Rose, 1958). These values are slightly lower than the value which was interpolated from the tables of Rösel (value 10). The adopted values are in all cases the unweighted mean between experiment (values 9) and theory (value 10). The uncertainties of the adopted values were taken with a look to the differences experiment - theory and the spread of the experimental values. The one value without uncertainty in the above table was not included in the averaging procedure. L and M subshell ratios were determined by Kel'man and Metskhvarishvili 1959, Herrlander and Graham 1964 and Dragoun et al. 1972.

Values for the K conversion coefficients of the two other γ transitions are:

	1	2	3	4
676 keV	0,0224(19)	0,019(5)	0,03(1)	0,0211(15)
1088 keV	0,00450(31)	0,0046(6)	0,0046(6)	0,00419(12)

1 Elliot et al. 1954 based on $\alpha_{\mathrm{K}}(412) = 0{,}0317$; K/L = 5,7(5) and 6,3(5)
2 Volpe and Hinman 1956
3 Bosch and Szichman 1967
4 Theory, Rösel et al. 1978; the value for the 676 keV transition is based on a mixing ratio of 44(5) % M1 + 56(5) % E2.

There is agreement between experiment and theory within the quoted uncertainties.

From the conversion electron ratio measured by Elliot et al. (1954) a value for the emission probability of the 676 keV gamma quanta can be derived:

$$P_g(676) = \frac{ce_K(676)}{ce_K(412)} \cdot \frac{a_K(412)}{a_K(676)} \cdot P_g(412)$$

The three factors on the right hand side are 0,0059(2) (from Elliot et al.), 1,43(5) (from theory) and 0,9554(7) (from the present evaluation). This gives $P_\gamma(676) = 0{,}00806(39)$ in excellent agreement with the present evaluation but with a greater uncertainty.

The M1 admixture to the 676 keV E2 + M1 transition was determined to be:

	% M1	δ	
1	52(5)	- 0,96(10)	Schrader et al. 1953
2	40(10)	- 1,22(22)	Schiff and Metzger 1953
3	32(6)		Elliot et al. 1954
4	36(23)		Volpe and Hinmann 1956
5	33(4)	- 1,43(14)	Sakai et al. 1964
6	45(5)	- 1,1	Béraud et al. 1965
7	39(4)	- 1,26(8)	Uhl and Wahanek 1966
8	36(4)	- 1,34(9)	Koch et al. 1967
9	43(6)	- 1,14(16)	Pakkanen 1971
10	54(2)		Venkata Ramana 1972
11	39,4(25)		Kawamura and Tomiyama 1974
12	44,3(25)		weighted mean of 1 - 11
13	44(5)		adopted value with an uncertainty enlarged to cover the most precise value, value 11

Values 1, 2 and 4 - 11 were derived from γγ angular correlation measurements of the 676-412 keV cascade.
For the 1088 keV transition we assumed pure E2 character and assigned an uncertainty of 3 % to the conversion coefficients interpolated from the tables of Rösel et al. (1978).

3 Atomic Data

The atomic data are taken from Schönfeld and Janßen (1996).

3.1 X Radiation

The energy values are calculated from the wave lengths in Å* as given by Bearden (1967).
The relative emission probabilities of K X rays are taken from Schönfeld and Janßen (1996).
The relative emission probability of L X rays is calculated from the value in table 4.2 putting $P(\mathrm{K}_{a_1}) = 1$.

3.2 Auger Electrons

The energy values are taken from Larkins (1977) (KLL) and the Table de Radionucléides (LMRI 1982) (KLX, KXY). The relative emission probabilities of K Auger electrons are taken from Schönfeld and Janßen (1996).

The relative emission probabilities of the L Auger electrons is calculated from the value in table 4.1 putting $P(\mathrm{KLL}) = 1$.

4 Radiation Emission

4.1 Electron Emission

The energies of the Auger electrons are the same as in 3.2. The energies of the conversion electrons are calculated from the transition energy (2.2) and the binding energies.

The emission probabilities of the conversion electrons are calculated using the conversion coefficients given in 2.2. The values of the emission probabilities of the Auger electrons are calculated using the transition probabilities given in 2.1 and 2.2, the atomic data given in 3 and the conversion coefficients given in 2.2. and the program EMISSION.

4.2 Photon Emission

The energy of the X rays are the same as in 3.1. The energies of the gamma rays were taken from Helmer (2000). They are mainly based on measurements of Deslattes et al. (1980).

The emission probabilities of the K X rays were determined with the program EMISSION using the evaluated atomic data, transition probabilities and conversion coefficients. The total emission probabilities of L X rays was also calculated with the help of the program EMISSION.

For the relative γ-ray emission probabilities the following values were taken into account:

	411,8 keV	675,9 keV	1087,7 keV
1	100	1,5	0,4
2	100	1,4(1)	0,25(5)
3	100	1	0,2
4	100	1,3	0,25
5	100	0,842(56)	0,170(12)
6	100	1,11(5)	0,26(2)
7	100	1,0	0,28
8	100	0,75	0,15
9	100	0,841(5)	0,1664(22)
10	100	0,846(11)	0,165(4)
11	100	0,844(7)	0,166(3)

1 Cavanagh et al. 1951
2 Hubert 1951
3 Brosi et al. 1951
4 Maeder et al. 1954
5 Elliott et al. 1954
6 Dzhelepov et al. 1955
7 Keeler and Connor 1965
8 Bosch and Szichman 1967
9 Iwata and Yoshizawa 1980, recalculated from 100,0(4) to 100 for the 411,8 keV line
10 Chand et al. 1989, recalculated from 100,0(8) to 100 for the 411,8 keV line

11 Adopted values (LRSW of 5, 9 and 10)

The normalization factor f_N was calculated from

$$\left[P_g\,(412)\left(1+a_t(412)\right)+P_g\,(1088)\left(1+a_t(1088)\right)\right]\cdot f_N=1-P_b\left(1372\right)$$

With the evaluated values of the total conversion coefficients and $P_\beta(1372) = 0,00025(5)$ as measured by Elliot et al. 1954, we obtained $f_N = P_\gamma(412) = 0,9554(7)$.

Concerning KX/γ ratios there is excellent agreement between the values recommended by Campbell and Mc Nelles (1975) and the values evaluated in the present paper:

	Campbell	calculated
$P(\mathrm{K}_\alpha)/P_\gamma(412)$	0,0229(5)	0,0228(2)
$P(\mathrm{K}_\beta)/P_\gamma(412)$	0,00635(15)	0,00630(10)

For the emission probabilities of X rays the following values were considered:

	Energy in keV	1	2	3
L_ℓ	8,7213(6)	0,00027(3)	0,00020(16)	-
L_α	9,90-9,99	0,00592(17)	0,00440(30)	-
L_β	10,6514(9)	0,000105(15)	0,00008(1)	-
L_η	11,36-12,56	0,00643(19)	0,00483(35)	-
L_γ	13,41-14,47	0,00124(5)	0,00130(10)	-
$\mathrm{L}_{\mathrm{total}}$	8,72-14,47	0,01397	0,01081	0,0121(2)
K_{a_2}	68,8952(12)	0,00816(24)	-	0,00809(8)
K_{a_1}	70,8196(12	0,0141(4)	-	0,01372(12)
K'_{b_1}	79,82-80,75	0,00485(12)	-	0,00466(8)
K'_{b_2}	82,44-83,04	0,00137(7)	-	0,00136(4)
$\mathrm{K}_{\mathrm{total}}$	68,89-83,04	0,0285(5)	-	0,02784(22)

1 Chand et al. 1989
2 Beghzanov et al. 1987
3 calculated values = adopted values in this evaluation

In he case of the K X rays there is agreement between measured and calculated values within the quoted uncertainties.

5 Main Production Modes

Taken from Zhou Chunmei (1995).

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[ω_K, ϖ_L, n_{KL}, K_β/K_α,, KLX/KLL, KXY/KLL]

^{201}Tl - Comments on evaluation of decay data
by E. Schönfeld

This evaluation was completes in May 1997 and the half life value has been updated in May 2004.

1 Decay Scheme

Above the 167 keV level and below available energy there are three levels of ^{201}Hg: 384,601(18) keV (5/2-), 414,522(17) keV (7/2-) ; 21,3 ps, and 464,41(3) keV (5/2 -); 2,6 ps. EC transitions to these levels would be (in the above order) unique first forbidden / nonunique third forbidden and unique first forbidden. But, these transitions have not been observed in the decay of ^{201}Tl. If these transitions do not exist, then the decay scheme on page 1 is complete.

2 Nuclear Data

The following values of the half-life have been considered ($T_{1/2}$ in d):

1	3,00(13)	Neumann and Perlman (1950)
2	3,063(33)	Herrlander et al. (1960)
3	3,0380(7)	Debertin et al. (1979) ; superseded by 6
4	3,0408(14)	Lagoutine and Legrand (1982); originally given 3 σ = 0,0040 d
5	3,0447(9)	Hoppes et al. (1982) ; superseded by 7
6	3,043(3)	Schrader (1989) ; superseded by 10
7	3,0456(15)	Unterweger et al. (1992)
8	3,0400(28)	Simpson and Meyer (1994)
9	3,038(17)	de Souza (2004)
10	3,0486(30)	Schrader (2004)
11	3,0421(17)	adopted value with external uncertainty, present evaluation

Values 1 and 2 are only of historical interest. Value 5 is superseded by value 7 and value 3 by value 6 and then by value 10. The LWM of values 4, 7, 8, 9 and 10 is given as value 11, the reduced χ^2 is 4,3.

The Q_{EC} value 483(15) keV is taken from Audi and Wapstra (1995).

2.1 Electron Capture Transitions

The adopted values P_K, P_L, P_M, P_N were calculated from the table of Schönfeld (1995) using the Q_{EC} value of Audi and Wapstra (1995) and the binding energies of Hg. These values are:

ΔE keV	P_K	P_L	P_M	P_{NO}
316(15)	0,724(7)	0,206(7)	0,054(2)	0,016(2)
451(15)	0,758(3)	0,181(3)	0,0461(12)	0,025(2)
483(15)	0,763(3)	0,178(3)	0,0451(12)	0,014(2)

The above values are in excellent agreement with the values calculated by Funck and Nylandstedt Larsen (1983) although the latter have no assigned uncertainties:

to level keV	P_K	P_L	P_M
167	0,7230	0,2016	0,0549
32	0,7567	0,1813	0,0474
1,6 and 0	0,7613	0,1779	0,0464

They are also in agreement with the values given by Lagoutine in the Table des Radionucléides (1984). It has to be mentioned that Lagoutine used different transition energies. His values are:

ΔE keV	P_K	P_L	P_{MN}
321(15)	0,730(5)	0,206(3)	0,064(2)
456(15)	0,762(5)	0,182(3)	0,056(2)
488(15)	0,767(5)	0,178(3)	0,055(2)

The transition probabilities of the EC transitions were calculated by

$$P_{e_{0,4}} = P_{g+ce_{4,0}} + P_{g+ce_{4,1}} + P_{g+ce_{4,2}} + P_{g+ce_{4,3}}$$

$$P_{e_{0,3}} = P_{g+ce_{3,0}} + P_{g+ce_{3,1}} + P_{g+ce_{3,2}} - P_{g+ce_{4,3}}$$

$$P_{e_{0,1}} + P_{e_{0,0}} = 1 - (P_{e_{0,4}} + P_{e_{0,3}})$$

2.2 Gamma Transitions

The energies of the main transitions are measured by Herrlander et al. (1960) via the conversion energies. The present values are taken from S. Rab (1994).
Herrlander et al. (1960) have measured the $L_1/L_2/L_3$ ratios of the 30,6 keV, 32,19 keV, 135,34 keV and 167,43 keV. By comparing the experimental values with theoretical ones the multipolarity of all this transitions were prooved to be M1. For the 165,88 keV an E 2 mixture of up to 7 % could not be excluded. The present multipolarities and conversion coefficients are taken from Rab (1994). The transition probabilities are calculated from the gamma-ray emission probabilities (4.2) and the total conversion coefficients.

3 Atomic data

The atomic data are taken from Schönfeld and Janßen (1996).

3.1 X Radiation

The energy values are calculated from the wavelengths in Å* as given by Bearden (1967).
The relative emission probabilities of K X rays are taken from Schönfeld and Janßen (1996).

3.2 Auger Electrons

The energy values are taken from Larkins (1977) (KLL) and the Table de Radionucléides (LMRI 1982) (KLX, KXY). The relative emission probabilities of K Auger electrons are taken from Schönfeld and Janßen (1996). The relative emission probabilities of the L Auger electrons is calculated from the value in the table 4.1 putting P(KLL) = 1.

4 Radiation Emission

4.1 Electron Emission

The energies of the Auger are the same as in 3.2. The energies of the conversion electrons are calculated from the transition energy (2.2) and the binding energies.

The emission probabilities of the conversion electrons are calculated using the conversion coefficients given in 2.2. The values of the emission probabilities of the Auger electrons are calculated using the transition probabilities given in 2.1 and 2.2, the atomic data given in 3 and the conversion coefficients given in 2.2.

4.2 Photon Emission

The energy of the X rays are the same as in 3.1. For the relative K X ray emission probabilities and the relative γ ray emission probabilities it has been found

E_γ in keV		1	2	3	4	5	6	7	8	9
30,60		2,2(2)	3,10(13)	2,35(25)	2,57(6)	2,60(8)	2,60(8)	2,53(5)	2,58(5)	-
32,19		2,2(2)	2,85(12)	2,69(34)	2,60(9)	2,60(7)	2,72(6)	2,58(5)	2,63(5)	-
68,90	K_{a_2}		274(9)	243(15)	261(7)		270(4)		268(4)	273(5)
70,82	K_{a_1}		466(14)	412(25)	446(12)		442(6)		446(6)	464(7)
	K_a		740(23)	655(29)	707(14)	722(13)	712(7)		715(7)	737(11)
80,2	K'_{b_1}				153(4)				153(4)	157(4)
82,5	K'_{b_2}				45,9(15)				45,9(15)	46,1(13)
	K_b		205(7)	182(11)	199(16)	205(4)	195(5)		202(5)	203(5)
135,34		26,5(13)	26,5(10)	31(4)	26,4(3)	26,5(4)	27,2(5)	25,65(18)	26,04(22)	-
165,88		1,6(1)	1,80(20)	1,6(3)	1,5(2)	1,46(20)	1,45(2)	1,55(5)	1,47(2)	-
167,43		100	100,0(17)	100(8)	100,0(11)	100,0(10)	100,0(12)	100	100,0(10)	-

1: Hofmann and Walcher (1975)
2: Nass (1977)
3: Martin (1976)
4: Debertin et al. (1978)
5: Funck et al. (1983)
6: Kawada et al. (1990)
7: Coursey et al. (1990)
8: LWM (without 3)
9: Calculated from atomic data, EC data and conversion coefficients. Adopted and recommended values for the X rays.

The values in column 8 are the LWM from 1, 2, 4 - 7 (the values 3 are less reliable). The uncertainties were taken not smaller than the minimum of a single value. Between values 8 and 9 there is not in all cases 1 σ overlapping. The transformation from relative emission probabilities to absolute emission probabilities was made using the absolute transition probability for the 167 keV transition $P_\gamma(167) = 0,1000(10)$ as determinated by Coursey et al. (1990) from absolute activity measurements..

5 Main Production Modes

Taken from the "Table de Radionucléides", LMRI, 1982.

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[$T_{1/2}$]

And also see the Tables Part.

^{203}Hg – Comments on evaluation of decay data
by A.L. Nichols

Evaluated: April 2001
Re-evaluated: January 2004

Evaluation Procedures

Limitation of Relative Statistical Weight Method (LWM) was applied to average numbers throughout the evaluation. The uncertainty assigned to the average value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

The simple and consistent decay scheme is dominated by beta decay to the first excited state of ^{203}Tl, followed by a single gamma transition to the ground state.

Nuclear Data

The single well-characterised gamma ray at 279.1952(10) keV and the 46.6-day half-life of ^{203}Hg make this radionuclide of some value as a standard in the calibration of γ-ray detectors.

Half-life

Half-life adopted from the evaluation of Woods et al (2004) for the IAEA-CRP: Update of X- and Gamma-ray Decay Data Standards for Detector Calibration. The measurements of 1968La10, 1972Em01, 1980Ho17, 1980RuZY, 1983Wa26 and 1992Un01 were considered.

Reference	Half-life (days)
1968La10	47.000(30)*
1972Em01	46.760(80)*
1980Ho17	46.582(2)#
1980RuZY	46.600(10)
1983Wa26	46.612(19)
1992Un01	46.619(27)
Recommended value	46.593(7)

* Removed from evaluated data set due to large deviation from mean.
\# Uncertainty adjusted to ± 0.008 to reduce weighting below 0.5.

Woods evaluation for IAEA-CRP (2004WoZZ): recommended half-life of 46.594(12) days (using above dataset).

Gamma Rays

Energy
The gamma-ray energy and uncertainty recommended by 2000He14 were adopted. This energy is in good agreement with the nuclear level energy of the first excited state of ^{203}Tl as specified by 1985Sc23 and 1993Ra11.

Emission Probability

The 279.1952 keV gamma transition is of mixed M1 + E2 multipolari ty, and α_{tot} of 0.2271(12) and α_K of 0.1640(10) have been adopted from the evaluation of 1985HaZA, in good agreement with various measurements (1962Ta06, 1964He19, 1974Ha29, 2000Sc05). A small uncertainty was assigned to these two parameters because of the high degree of confidence in the data. The gamma transition probability of 0.9999(1) was deduced as described below, and used in conjunction with α_{tot} to calculate an absolute emission probability of 0.8148(8).

Multipolarity and Internal Conversion Coefficients of 279.1952 keV Gamma Ray

The comprehensive assessment of 1985HaZA provides accurate estimates for α_{tot} of 0.2271(12) and α_K of 0.1640(10), and a multipolarity of close to 25%M1 + 75%E2. These values have been adopted, and used to calculate the other α components in terms of the recommended value of α_{tot}. The selected data set used by 1985HaZA to determine α_{tot} and α_K is included in the table below (see footnotes); not all measurements are listed (see 1985HaZA for further details).

Internal conversion coefficients for 279.1952 keV gamma ray – selected measurements

	1956Wa30	1958Ni28	1960Pe22	1961Su10	1962Ta06*	1963Bu09*
α_{tot}	-	-	0.227(8)	-	0.2273(24)#	-
α_K	0.164(5)#	0.163(3)#	0.164(6)#	0.164(4)#	0.1642(21)#	0.165(9)#
α_L	0.049(2)	0.0487(12)	-	-	-	
α_{M+}	-	-	-	-	-	

	1963Cr14	1964He19	1972Sa34	1972WaYL*	1974Ha29	2000Sc05
α_{tot}	-	-	0.149(9) 0.156(9)	0.2267(16)#	0.2279(24)#	0.2250(12)
α_K	0.162(3)#	0.163(3)#	-		0.1653(17)#	-
α_L	-	0.0484(6)	-		0.0475(13)	-
α_{M+}	-	0.0153(4)	-		-	-

* Data adjusted by 1985HaZA from the published values.
\# Values adopted in an evaluation by 1985HaZA.

Internal conversion coefficients of 279.1952 keV gamma ray – theoretical values and 1985HaZA evaluation

	1978Ro22*	1985HaZA‡	Recommended Values
α_{tot}	0.231(7)	0.2271(12)	0.2271(12)
α_K	0.161(5)	0.1640(10)	0.1640(10)
α_L	0.053(2)	-	0.0476(2)
α_{M+}	0.017(5)	-	0.0155(2)

* Interpolated values for 25%M1 + 75%E2, with 3% uncertainty.
‡ Hansen used three α_{tot} and nine α_K values (see previous table) to derive recommended values, which were originally selected from six α_{tot} and twenty-eight α_K values respectively.

Beta-particle Emissions

Energies

The beta-particle energies were calculated from the proposed decay scheme. The nuclear level energies of 1993Ra11 and the Q-value were used to determine the energies and uncertainties of the beta -particle transitions to the first excited state (dominant) and ground level.

Emission Probabilities

The beta-particle emission probabilities were calculated from the limits set on the beta transition to the ground state by 1955Ma40 and 1956Wo09. Beta-decay branch to ½$^+$ Ground State of ^{203}Tl:

	1955Ma40	1956Wo09	Recommended Values
P_β ($5/2^- \dashrightarrow 1/2^+$)	<0.00004	<0.0003	0.0001(1)
log $f^{1u}t$	-	>11.3	11.6(4)

A value of 0.0001(1) was recommended from these studies. Hence, the beta-particle emission probability was defined as 0.9999(1) for the transition to the first excited state of ^{203}Tl ($5/2^- \rightarrow 3/2^+$).

Beta-particle Emission Probabilities

E_b(keV)	**P_b**
	Recommended Values*
212.6(12)	0.9999(1)
491.8(12)	0.0001(1)

* Recommended emission probabilities derived from the postulated limit of the beta branch to the ^{203}Tl ground state.

Atomic Data

The X-ray data have been calculated using the evaluated gamma -ray data, and the atomic data from 1996Sc06, 1998ScZM and 1999ScZX.

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^{203}Pb - Comments on evaluation of decay data
by V. Chisté and M. M. Bé

1 Decay Scheme

^{203}Pb disintegrates by electron capture to ^{203}Tl via excited levels. Spin and half-life of the 680-keV level are from the mass-chain evaluation of F. G. Kondev (2005Ko20).

2 Nuclear Data

The Q(EC) value is from the atomic mass adjustment of Audi et al. (2003Au03).

Experimental ^{203}Pb half-life values (in hours) are given in Table 1:

Table 1: Experimental values of ^{203}Pb half-life.

Reference	Experimental value (h)	Comments
K. Fajans (1941Fa04)	52,0 (5)	
J. R. Prescott (1954Pr04)	52 (1)	
A. A. Barlett (1958Bart)	52,1 (2)	
L. Persson (1961Pe12)	52,1 (2)	
G. A. Chackett (1971Ch54)	52,02 (10)	Original uncertainty increased (x 2) for missing details (systematic uncertainty).
H. Houtermans (1979Ho17)	51,88 (2)	
D. D. Hoppes (1982HoZJ)	51,92 (4)	Superseded by 2002Un02.
K. Lindenberg (2001Li17)	51,94 (1)	
M. P. Unterweger (2002Un02)	51,923 (37)	
Recommended value	**51,929 (10)**	χ^2 = 1,37

The evaluators have chosen to take into account the eight values with associated uncertainty for the calculation. The original uncertainty given by Chackett (1971Ch54) has been multiplied by 2, in order to take into account the systematic uncertainties not considered by 1971Ch54.Then a weighted average of the eight values above has been calculated using LWEIGHT computer program (version 3). The largest contribution comes from the value of Lindenberg (2001Li17), amounting to 75 %.

The recommended value is the weighted average of *51,929 h*, with an external uncertainty of *0,010* and a reduced χ^2 of 1,37.

Experimental 279-keV level half-life values (in ps) are given in Table 2.

Table 2: Experimental 279-keV level half-life.

Reference	Experimental value (ps)
R.E. Azuma (1955Az33)	300 (100)
E. E. Berlovich (1957Be57)	290 (30)
E. Bashandy (1960Ba16)	290 (20)
S. Gorodetzky (1960Go15)	283 (17)
B. Johansson (1960Jo15)	220 (30)
E.C. Pederson (1960Pe16)	282 (8)
A. Schwarzschild (1961Sc04)	281 (6)
J. de Boer (1962De14)	340 (3)
R. Rougny (1964Ro19)	283 (7)
J.C. Palathingal (1967Pa09)	280 (40)
Recommended value	282,3 (37)

The half-life weighted average has been calculated by the LWEIGHT program (version 3).

The evaluators have chosen to take into account for the calculation the ten experimental values shown in Table 2. The Azuma (1955Az33), Johansson (1960Jo15) and de Boer (1962De14)values were rejected by the LWEIGHT program, based on the Chauvenet's criterion, thus they were not used for averaging.

The recommended value is the weighted average of*282,3 ps*, with an internal uncertaintyof *3,7* and a reduced χ^2 of 0,05.

2.1 Electron Capture Transitions

The electron capture probabilities have been deduced from gamma -ray transition intensity imbalance for each level of the decay scheme.

P_K, P_L, P_M values have been calculated for 1st forbidden and 1st forbidden unique electron-capture transitions in the decay of ^{203}Pb to the excited states in ^{203}Tl using the LOGFT computer program.

2.2 g Transitions

Probabilities

The absolute transition probabilities have been deduced from the relative γ-ray emission intensities (see **5.2 Gamma ray emission**), the internal conversion coefficients and the normalization of the decay scheme to an absolute radiation intensity scale.

Multipolarity and internal conversion coefficients

Multipolarities of γ-ray transitions in decay of ^{203}Tl are from 2005Ko20:
279-keV γ-ray : M1 + E2, with $\delta = +1,17$ (6)
401-keV γ-ray : M1 + E2, with $\delta = 0,030$ (3) (1965Ka02)
680-keV γ-ray : E2

The internal conversion coefficients (ICC's) for these γ-ray transitions have been calculated using the BRICC computer program, which interpolates the new values in 2006Ra03.

For the 279-keV γ-ray, the evaluators have chosen to follow the recommendations of H. H. Hansen (1985HaZA). The 279-keV γ-ray transition is M1(l -forbidden) + E2. It takes place between the $d_{3/2}$ and $s_{1/2}$ shell model proton configurations. Thus nuclear penetration is significant (see 1979Ha21). The forbidness applies only to the M1 component. Therefore, the evaluators have chosen to use experimental values for α. The experimental data set given by 1985HaZA to determine α_T and α_K are included in Tables 3 and 4, respectively.

Table 3: Experimental values of α_T used by 1985HaZA.

Reference	Original value	Revised by Hansen (1985HaZA) and used value.	Comments
1960Pe22	0,227 (8)		**Not used.**
1962Ta06	0,2262 (19)	0,2273 (24)	The authors revised their values.
1965Ra12	0,210 (30)		**Not used.**
1965Wa13	0,222 (15)		**Not used.**
1971WaYL	0,2267 (7) 0,2240 (9)	0,2267 (16)	The author gives 2 results without explaining the reason of the discrepancy. Hansen has chosen the higher one, with the sum of their uncertainties quoted for both results.
1974Ha29	0,2279 (24)	0,2279 (24)	
2000Sc05	0,2250 (12)	0,2250 (12)	
Recommended value		**0,2261 (8)**	$\chi^2 = 0,60$.

Hansen's study provides, together with three experimental values, an α_T average of 0,2271 (12). The evaluators have included the most recent measurement of 2000Sc05 (0,2250 (12)) in their evaluation and, with four experimental values (1962Ta06, 1972WaYL, 1974Ha29, 2000Sc05), a weighted average has been calculated using the LWEIGHT computer program (version 3).The recommended value is the weighted average of *0,2261*, with an internal uncertainty of *0,0008* and a reduced χ^2 of 0,60.

Table 4: Experimental values of α_K and α_L.

Reference	Original value of α_K	Revised by Hansen (1985HaZA) and used value.	Original value of α_L (10^{-2})	Comments
1952He18	0,23 (10)			**Not used.**
1954Th17	0,154 (15)			**Not used.**
1954Wa12	0,15 (1) 0,141 (15)			**Not used.**
1955Do12	0,147 (2)			**Not used.**
1955Ma40	0,205 (20)			**Not used.**
1956No26	0,159 (4)			**Not used.**
1956Of03	0,150 (10)		4,8 (3)	**Not used.**
1956Wa30	0,164 (5)	0,164 (5)	4,90 (17)	
1956Wo09	0,130 (10)			**Not used.**
1958Ni28	0,163 (3)	0,163 (3)	4,87 (12)	
1960Pe22	0,163 (6)	0,163 (6)		
1960Ra04	0,195 (14)			**Not used.**
1960St21	0,160 (15)			**Not used.**
1961Hu15	0,1750 (36)			**Not used.**
1961Su10	0,164 (4)	0,164 (4)	4,49 (34)	
1962Ta06	0,1633 (17)	0,1642 (21)		The authors revised their values.
1963Bu09	0,168 (8)	0,165 (9)		Result had to be corrected for ω_K.
1963Cr14	0,162 (3)	0,162 (3)		
1964He19	0,163 (3)	0,163 (3)	4,84 (6)	
1965Ra12	0,158 (24)			**Not used.**
1967Bo47	0,14 (3)			**Not used.**
1968Ra26	0,179 (13)			**Not used.**
1968Sa22	0,156 (7)			**Not used.**
1974Ha29	0,1653 (17)	0,1653 (17)	4,75 (13)	
Recommended values		0,1640 (10)	4,837 (48)	χ^2 = 0,16 ; χ^2 = 0,22

For the α_K recommended value, the evaluators, following the recommendations of H. H. Hansen (1985HaZA), used only nine experimental values with their associated uncertainties in the weighted average calculation, using the LWEIGHT computer program (version 3). A recommended value of *0,1640* for α_K(279-keV γ-ray) is a weighted average, with an internal uncertainty of *0,0010* and a reduced χ^2 of 0,16.

Evaluators' recommended α_L is 4,837 (48) 10^{-2} (reduced χ^2 = 0,22), weighted average of values from: A. H. Wapstra (1956Wa30), G. J. Nijgh (1958Ni28), Z. Sujkowski (1961Su10), C. J. Herrlander (1964He19) and H. H. Hansen (1974Ha29).

3 Atomic Data

Atomic values, ω_K, ϖ_L and n_{KL}, are from Schönfeld and Janssen (1996Sc06).

3.1 X rays and Auger electrons

The X-ray and Auger electrons relative probabilities have been calculated from γ-ray data by using the EMISSION computer program.

4 Electron Emissions

The Auger electrons emission probabilities have been calculated from γ-ray data using the EMISSION computer program.

5 Photon emissions

5.1 K x-rays

X-ray emissions probabilities have been calculated from γ-ray data using the EMISSION computer program.

5.2 Gamma-ray emissions

The measured energies of γ-ray emissions are given in Table 6.

Table 6 : The measured energies of γ-ray emissions, in keV.

γ-ray	1954Pr04	1954Wa12	1958Ni28	1964He19	1969Cl11	1978He21	2000He14 (evaluated)	Recommended values (keV)
$\gamma_{1,0}$	280 (5)	279 (1)	279,12 (5)	279,16 (2)	279,16 (2)	279,1967 (12)	279,1952 (10)	279,1952 (10)
$\gamma_{2,1}$	400 (7)	400 (2)	403,8 (3)	401,27 (5)	401,28 (40)	401,325 (10)	401,320 (3)	401,320 (3)
$\gamma_{2,0}$	685 (10)	678 (3)			680,7 (6)	680,514 (10)	680,515 (3)	680,515 (3)

The evaluators have adopted the recommended values of R. G. Helmer (2000He14).

The measured relative emission intensities listed in Table 7 are given in values relative to 100 for the 279-keV γ ray.

Table 7: Measured relative γ emission intensity in %.

Energie (keV)	1954Pr04	1954Wa12	1989Ne05	Recommended value
279	100	100	100	100
401	4,7 (3)	4,30 (8)	4,14 (8)	4,24 (8)
680	0,87 (10)	0,80 (1)	0,932 (22)	0,932 (22)

For the 401-keV γ-ray, the recommended value is a weighted average (with an external uncertainty) calculated using the LWEIGHT computer program with these three experimental values. For the 680-keV γ-ray, the calculation using the LWEIGHT computer program showed that the data are discrepant, so the evaluators have chosen to use the most recent and precise result of Zs. Németh (1989Ne05).

The normalization factor to convert the relative emission intensities to absolute emission intensities is calculated using the formula:

$$N = \left(\frac{100}{(\Sigma(1 + a_T)P_{rel})} \right) \times 100$$

where the sum is over all the γ transitions to the ground state and α_T is the relevant coefficient. In this case, the contributions are from the 279- and 680-keV γ transitions. The uncertainty was calculated through the propagation on the formula given above.

From the recommended α_T (Table 5) and the evaluated relative emission intensities (Table 7), the deduced normalization factor is ***80,94 (5)***.

The evaluated relative and absolute γ-ray emission intensities are given in Table 8.

Table 8 : Evaluated relative and absolute γ-ray emission intensities, in %.

Energy (keV)	Relative emission intensity	Absolute emission intensity
279	100	80,94 (5)
401	4,24 (8)	3,43 (6)
680	0,932 (22)	0,754 (18)

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^{204}Tl – Comments on evaluation
by M. M. Bé and V. Chisté

The electron capture transition to the Hg-204 ground state is first forbidden unique, so the P_K/P_L ratio strongly depends on the decay energy. In this evaluation the Q^+ value from Audi and Wapstra has been adopted. However, if this value changes, P_K and P_L, as well as the decay branching ratios, must be reevaluated.

Nuclear Data

Spin and parity assignments are from Schmorak (1994Sc24).

Experimental Q^+ *values*

The following experimental values have been noted from publications :

Reference	Value in keV	Uc	
Biavati(1962Bi04)	310	10	393 quoted in Klein
Leutz (1962Le05)	410	+30 – 23	As quoted by Christmas
Christmas (1964Ch17)	313	+17 – 14	
Klein (1966Kl02)	324	+21 – 16	
Lancman (1973La17)	385	20	
Zide (1979Zi02)	357	15	
Audi (1995Au04)	347,5	15	
Audi (2002)	**345,0**	**13**	**Adopted**

In the 1995Au04 publication, Audi recommended 347,5(15) keV for the Q^+ energy, but a new mass determination of Hg-204 (2002Be) leads to the value of 345,0(13) keV (Audi on the AMDC web site) from the atomic mass differences. As these mass measurements were performed with Penning trap facility, the resulting Q value is considered to be more reliable than the other values quoted in the above table.

Adopted Q values

Q^- value is from Audi and Wapstra (1995Au04)
Q^- = 763,72 (18) keV
Q^+ = 345,0 (13) keV

Half-life

Reference	Value (years)	Uc	Comments
Anspach (1965An07)	3,754	0,004	
Horroks (1968Ho07)	3,825	0,003	
Bortels (1969Bo24)	3,774	0,008	Uc for 1 σ
Jordan (1969Jo02)	3,7730	0,0028	Uc for 1 $\sigma \times 1,5$
Harbottle (1970Ha32)	3,793	0,005	
Adopted	**3,788**	**0,015**	

The uncertainty for one standard deviation given by Jordan has been multiply by 1,5. The set of five values quoted above is quite discrepant with a reduced -χ^2 of 64,3. The Lweight program has calculated a weighted average of *3,788 years* with an external uncertainty of 0,013, which was increased to *0,015* to include the most precise value.

Electron capture sub shell probabilities

The adopted values have been calculated with the LOGFT program for a unique 1st forbidden transition and Q = 345,0 (13) keV.
P_K = 0,5843(14) ; P_L = 0,3024(10) ; P_{M+} = 0,1133(5)

Several measurements of the P_L / P_K ratio were carried out :

Reference	P_L/P_K	P_K/P_{b-}	Branching ratio %
Christmas (1964Ch17)	0,600 (55)	0,01590 (36)	2,54 (12)
Joshi (1961JO12)	0,42 (5)	0,0155 (10)	
Leutz (1962Le05)	0,41 (3)		
Klein (1966Kl02)	0,55 (5)	0,0153 (5)	2,15 (6)
Weighted mean	0,47 (3)		
Adopted values	0,518 (2)		2,92 (13)

Branching ratios

From the Xk emissions intensities measured by Schötzig (1990Sc08), I_{XK} = 1,64(7), and using P_K = 0,5843(14) and ω_K = 0,962(4), the electron capture branching ratio Pε becomes:
$P\varepsilon = I_{XK} / (P_K \times \omega_K) = 2,92(13)$ %

And then $P\beta^-$ = 97,08(13) %

Atomic data

All the atomic data : ω_K = 0,962(4) etc. and ratio K_β/K_α etc. are from Schönfeld (1996Sc06).

Photons emissions

X-ray emissions

The X_K emission intensities are those measured by Schötzig.

Reference		I(%)	Uc
Schotzig (1990Sc08)	Hg- $K_{\alpha2}$	0,474	0,020
	Hg- $K_{\alpha1}$	0,812	0,034
	Hg- K_{β} 1	0,273	0,010
	Hg- K_{β} 2	0,081	0,003
	Pb- $K_{\alpha2}$	4,4 10^{-3}	0,3
	Pb- $K_{\alpha1}$	6,1 10^{-3}	0,3
	Pb-K_{β} 1	2,7 10^{-3}	0,2
	Pb- K_{β} 2	7,3 10^{-4}	0,2

The X_L emission intensities have been calculated by using the Emission program after addition of the PL1, etc. values.

The ratio K–Auger / β- = 6,7(8) 10^{-4} , deduced from the evaluated data, can be compared with the measured value, K–Auger /β– = 4,9(28) 10^{-4} given by Park and Christmas (1967Pa08).

Internal bremsstrahlung

Internal bremsstrahlung accompanying capture of orbital electrons is about (3×10^{-5}) photons per K capture.

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^{206}Hg - Comments on evaluation of decay data
by F. G. Kondev

This evaluation was completed in May 2011 with a literature cut off by the same date. The Saisinuc software (2008DuZX) and associated supporting programs were used in assembling the data following the established protocol within the DDEP collaboration.

1 Decay Scheme

The nuclide ^{206}Hg disintegrates 100 % by β^- emissions. The strongest β^--decay branch of 62 (7) % populates the $J^\pi = 0^-$ ground state of the daughter nuclide ^{206}Tl. The level schemes of ^{206}Hg and ^{206}Tl are based on the ENSDF evaluations of Browne (1999Br39) and Kondev (2008Ko21).

2 Nuclear Data

$Q(\beta^-)$ value is taken from the evaluation of Audi *et al.* (2003Au03).

The experimental half-life data for the ^{206}Hg ground state are presented in Table 1. These data were evaluated using different techniques (see for example 1992Ra08, 1994Ka08 and 2004Mb11 and references therein) and the results are presented in Table 2. The LRSW value of $T_{1/2}$ = 8.32 (7) min is recommended here with $\chi^2_\nu = 3.22$ ($\chi^2_\nu = \chi^2$/N-1) which is smaller than the critical value of $\chi^2_{\nu\,crit} = 4.61$ (99 % confidence level). The lifetimes assigned to the excited states of the daughter nuclide ^{206}Tl are taken from the ENSDF evaluation of Browne (1999Br39).

Table 1. Experimental data for the half-life of ^{206}Hg.

Author	**$T_{1/2}$ (min)**	**Used in the evaluation**
1961Nu01	7.5 (10)	No
1962Ka27	8.5 (1)	Yes
1964Wo05	8.1 (4)	Yes
1968Wo08	8.15 (10)	Yes

Table 2. Evaluated values for the half-life of ^{206}Hg.

Method/Author [a)]	**Evaluated $T_{1/2}$ (min)**	**χ^2/N-1**
UWM	8.25 (13)	3.70
WM	8.32 (7)	3.22
LRSW	8.32 (7)	3.22
NRM	8.27 (8)	2.30
RM	8.18 (9)	0.38
1999Br39	8.15 (10)	

[a)] UWM – Unweighted Mean; WM – Weighted Mean; LRSW – Limitation of Relative Statistical Weight; NRM – Normalized Residual; RM – Rajeval.

2.1 β- Transitions

Information of level and maximum β^--decay energies, $E_{\beta\ max}$, and β^--decay transition probabilities, P_β, and log *ft* values is presented in Table 3. The $E_{\beta\ max}$ values for the $\beta_{0,2}$ and $\beta_{0,3}$ transitions were determined from Q(β^-) (2003Au03) and the excitation energies for the 1^- states, deduced from the corresponding γ–ray transition energies (see section 2.2 and Table 4 for details). The $P_{\beta0,2}$ and $P_{\beta0,3}$ values were deduced from the decay scheme and the corresponding absolute γ–ray transition probabilities, as detailed in section 2.2 and Table 4. It was assumed that no direct β^--decay feeding takes places to the first excited state at 265.8 keV (J^π = 2-), since such a transition is a second-fold forbidden non-unique, and hence, the $\beta_{0,0}$ transition probability was determined as:

$$P_{\beta0,0} = 100 - P_{\beta0,2} - P_{\beta0,3} \qquad (1)$$

The log *ft* values were calculated using the LOGFT program from the ENSDF evaluation package.

Table 3. Level energies, $E_{\beta\ max}$, P_β and log *ft* values in decay of ^{206}Hg.

	Level energy (keV)	**$E_{\beta-\ max}$ (keV)**	**P_β (%)**	**Nature**	**log *ft***
$\beta_{0,0}$	0.0	1308 (20)	62 (7)	First forbidden non-unique	5.67 (10)
$\beta_{0,2}$	304.896 (6)	1003 (20)	35 (7)	First forbidden non-unique	5.24 (10)
$\beta_{0,3}$	649.42 (5)	659 (20)	3.0 (4)	First forbidden non-unique	5.41 (6)

2.2 γ Transitions

The γ–ray transition energies, multipolarities, absolute transition probabilities and electron internal conversion coefficients are presented in Table 4.

Table 4. Energies, multipolarities, absolute transition probabilities and electron internal conversion coefficients for γ–ray transitions following β^-–decay of ^{206}Hg.

	Energy (keV)	Pγ+ce (%)	Multi-polarity	α_K	α_L	α_M	α_T
$\gamma_{1,0}$	265.832 (5)	0.014 (7)	E2	0.0855 (12)	0.0561 (8)	0.01440 (21)	0.1603 (23)
$\gamma_{2,0}$	304.896 (6)	36 (7)	M1	0.308 (5)	0.0519 (8)	0.01211 (17)	0.375 (6)
$\gamma_{3,0}$	649.42 (5)	2.3 (3)	M1	0.0412 (6)	0.00681 (10)	0.001585 (23)	0.0501 (7)
$\gamma_{3,2}$	344.52 (17)	0.70 (14)	M1	0.221 (4)	0.0371 (6)	0.00866 (13)	0.269 (4)
$\gamma_{3,1}$	383.59 (6)	0.014 (7)	M1(+E2)	0.10 (7)	0.021 (7)	0.0050 (15)	0.13 (8)

The γ–ray transition energies and multipolarities are taken from the ENSDF evaluation of Browne (1999Br39). The γ(3,1) energy is deduced from the adopted level energies difference. The electron internal conversion coefficients were calculated using a program supplied by the Saisinuc software (2008DuZX) which uses interpolated values of Band et al (2002Ba85) with the hole being taken into account. These are consistent with values given by the BrIcc program (2008Ki07). The $P_{\beta0,2}$ value was deduced from the reported in 1968Wo08 absolute γ–ray transition probabilities for the 304.9 keV transition of $P_{\gamma2,0+ce}$(304.9γ) = 36 (7) % and by taking into account a small feeding from the 1^- level at 649.4 keV via the 344.5 keV γ–ray transition. The $P_{\gamma+ce}$ values for the γ(1,0) and γ(2,1) transitions were determined from the absolute γ–ray emission probabilities, P_γ, shown in Table 5, and the total electron internal conversion coefficients as:

Table 5

	Relative Intensity				**Abs. Total Int. (%)**
E level (keV)	**Eγ (keV)**	**1970As05**	**1969La18**	**1976TuZY**	**1968Wo08**
265.832	265.832 (5)				
304.896	304.896 (6)	100 (1)			36 (7)
649.42	344.52 (17)	2.4 (1)	1.4	1.4	
	383.59 (6)			0.011	
	649.42 (5)	8.4 (17)	5.6	7.7	5 (2)

3 Atomic Data

The atomic data (fluorescence yields, X-ray energies and relative probabilities, and Auger electrons energies and relative probabilities) were provided by the Saisinuc software (2008DuZX). Details regarding the origin of these data can be found in 1996Sc06, 1998ScZM, 1999ScZX, 2000Sc47 and 2003De44.

4 Emissions

4.1 Photon emissions

The number of γ rays per 100 disintegrations was evaluated from the available experimental data, as described in section 2.2 (see also Table 5).

5 Electron emissions

The energies of the conversion electrons were calculated from the γ–ray transition energies presented in Table 4 and the corresponding electron shell binding energies (1977La19). The number of conversion electrons of type x=T,K and L where T stands for total, K and L for K- and L-shell electrons, per 100 disintegrations was calculated from the recommended in the present evaluation (see Table 5) numbers of photons per 100 disintegrations, $P_{\gamma1,0}$, and the corresponding electron internal conversion coefficients (see Table 4), $\alpha_{x1,0}$: $ec_{1,0x} = P_{\gamma1,0} \times \alpha_{x1,0}$.

The number of K and L Auger electrons per 100 disintegrations, $P(e_{AK(L)})$ was calculated from the number of vacancies in the K and L shells and the corresponding $P_{XK(L)}$ yield: $P(e_{AK}) = N_K - P_{XK}$ and $P(e_{AL}) = N_L - P_{XL}$.

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^{206}Tl - Comments on Decay Data Evaluation

by F.G. Kondev

This evaluation was completed in September 2006 with a literature cut off by the same date. The Saisinuc software (2002BeXX) and associated supporting programs were used in assembling the data following the established protocol within the DDEP collaboration.

1. Decay Scheme

The nuclide ^{206}Tl ($J^{\pi}=0^{-}$) disintegrates 100 % by β^{-} emissions. The strongest β^{-}-decay branch of 99.885 (14) % populates the $J^{\pi}=0^{+}$ ground state of the daughter nuclide ^{206}Pb. The level schemes of ^{206}Tl and ^{206}Pb are based on the ENSDF evaluation of Browne (1999Br39).

2. Nuclear Data

$Q(\beta^{-})$ value is taken from the evaluation of Audi *et al.* (2003Au03).

The experimental half-life data for the ^{206}Tl ground state are presented in Table 1. These data were evaluated using different techniques (see for example 1992Ra08, 1994Ka08 and 2004MaXX and references therein) and the results are presented in Table 2. The value of 1961Nu01 was excluded from the data analysis, since no uncertainty was quoted in the original publication. The LRSW value of $T_{1/2}$=4.202 (11) min is recommended here with $\chi^2_\nu = 1.54$ ($\chi^2_\nu = \chi^2/N\text{-}1$) which is smaller than the critical value of $\chi^2_{\nu\ crit} = 2.64$ (99 % confidence level). The lifetimes of the excited states of the daughter nuclide ^{206}Pb are taken from the ENSDF evaluation of Browne (1999Br39).

Table 1. Experimental data for the half-life of ^{206}Tl

Author	$T_{1/2}$, min	Used in the evaluation
1941Fa04	4.23 (3)	Yes
1953Sa11	4.19 (2)	Yes
1959Po64	4.29 (5)	Yes
1961Nu01	4.2	No
1970Fl12	4.27 (5)	Yes
1971Pe03	4.183 (17)	Yes
1972CoYX	4.14 (5)	Yes
1972Gr01	4.2 (2)	Yes
1972Wi18	4.27 (5)	Yes

Table 2. Evaluated values for the half-life of ^{206}Tl

Method/Author $^{a)}$	**Evaluated $T_{1/2}$, min**	**c^2/N-1**
UWM	4.222 (19)	2.02
WM	4.202 (11)	1.54
LRSW	4.202 (11)	1.54
NRM	4.202 (11)	1.54
RM	4.202 (11)	1.41
1999Br39	4.200 (17)	

$^{a)}$ UWM – Unweighted Mean; WM – Weighted Mean; LRSW – Limitation of Relative Statistical Weight; NRM – Normalized Residual; RM – Rajeval.

2.1. b$^-$ Transitions

The experimental data for the maximum $\beta_{0,0}$ energy, $E_{\beta 0,0\ \max}$, are presented in Table 3. The LRSW value of 1527 (3) keV (χ^2_ν = 1.48 is smaller than $\chi^2_{\nu\ \mathrm{crit}}$ = 4.61 (99 % confidence level)) is comparable with Q(β^-) = 1532.4 (6) keV (2003Au03). The $E_{\beta\,\max}$ values for the $\beta_{0,1}$ and $\beta_{0,2}$ transitions were determined from Q(β^-) (2003Au03) and the 2^+ and 0^+ level energies that were deduced from the corresponding transition energies (see section 2.2 and Table 4 for details). The $\beta_{0,1}$ and $\beta_{0,2}$ transition probabilities, P_β, were deduced from the decay scheme and the corresponding absolute γ–ray transition probabilities, $P_{\gamma+ce}$, as detailed in section 2.2 and Table 5. The P_β value for the $\beta_{0,1}$ transition is an upper limit, since the possible feeding from the 1166.4 keV level ($J^\pi=0^+$) via the yet unobserved 363.3 keV γ–ray transition ($\gamma_{2,1}$) was not taken into account. It should be noted that only a limit for $P_{\gamma 2,1}$ is reported in the literature (see section 2.2 for details). The $\beta_{0,0}$ transition probability was determined as:

$$P_{b\,0,0} = 100 - P_{b\,0,1} - P_{b\,0,2}\,.$$

The lg *ft* values were calculated using the LOGFT program from the ENSDF evaluation package. The lg *f* values are based on the work of Gove and Martin (1971Go40). For the first forbidden $\beta_{0,0}$ transition (0^- ->0^+) the shape factor was measured by several authors, as shown in Table 3. The fit to the experimental data using the expression $S(W) = 1 + aW + b/W$, where W is the electron energy, yields the shape factor coefficients, *a* and *b*, which are also presented in Table 3. The value of $a = -\ 0.020$ (2) (with b = 0.000) (1972Wi18) is recommended in the present evaluation. It should be noted that using this parameterization of the shape factor, a lg *f* value of 2.85 for the $\beta_{0,0}$ transition (0^- ->0^+) can be obtained. It is in a good agreement with lg *f* = 2.78, deduced using the LOGFT program (1971Go40).

Table 3. Measured $E_{\beta 0,0\ max}$ values and shape factor parameters *a* and *b* (S(W)=1+*a*W+*b*/W) for the first forbidden $0^- \rightarrow 0^+$ decay of ^{206}Tl

Author	*a*	*b*	$E_{b0,0\ max}$, keV	Used in the evaluation
1951Al14			1510 (10)	No
1961Ho17	-0.154	-0.484	1571 (10)	No
1970Fl12	-0.017 (5)	0.030 (9)	1523 (4)	Yes
1971Pe03	0.00 (1)	0.00	1534 (5)	Yes
1972Wi18	-0.020 (2)	0.000	1527 (4)	Yes
Adopted	**-0.020 (2)**	**0.000**	**1532.4 (6)**	

Table 4. Level energies, $E_{\beta\ max}$, P_β and log *ft* values in decay of ^{206}Tl

	Level energy, keV	$E_{b-\ max}$, keV	P_b ´ 100	Nature	log *ft*
$\beta_{0,0}$	0.0	1532.4 (6)	99.885 (14)	First forbidden	5.1775 (13)
$\beta_{0,1}$	803.06 (3)	729.3 (6)	0.0051 (3)	First forbidden Unique	8.60^{1U} (3)
$\beta_{0,2}$	1166.4 (5)	366.0 (8)	0.110 (14)	First forbidden	5.99 (6)

2.2 Gamma Transitions and Electron Internal Conversion Coefficients

The γ–ray transition energies, multipolarities, absolute transition probabilities and electron internal conversion coefficients are presented in Table 5.

The γ–ray transition multipolarities are taken from the ENSDF evaluation of Browne (1999Br39). The recommended γ1,0 transition energy of 803.06 (3) keV is determined as the weighted mean of 803.10 (5) keV (1972Ma63) and 803.04 (3) keV (1996Ra16), the two most precise values reported in the literature. The γ2,0 transition between the excited 0^+ level and the 0^+ ground state is a pure E0, and hence, there is no γ–ray component associated with the decay of the former level. The transition energy is taken from the work of Draper *et al.* (1977Dr08) where the K-shell conversion electron energy was measured with a Si(Li) detector. The γ2,1 transition was not observed and its energy is inferred from the energy difference between the excited 0^+ and 2^+ levels. The electron internal conversion coefficients were calculated using a program supplied by the Saisinuc software (2002BeXX) which uses interpolated values of Band *et al.* (2002Ba85) with the hole being taken into account. The $P_{\gamma+ce}$ values for the γ1,0 and γ2,1 transitions were determined from the absolute γ–ray emission probabilities, P_γ, shown in Table 6, and the total electron internal conversion coefficients as: $P_{g+ce} = P_g \times (1 + a_T)$.

Experimental and evaluated P_γ values are shown in Table 6. The LRSW value of $P_{\gamma1,0}$= 0.0050 (3) % (χ^2_ν = 2.40 is smaller than $\chi^2_{\nu\ cryt}$ = 4.61 (99 % confidence level)) is recommended for the γ1,0 transition. As stated above, the $\gamma_{2,1}$ transition was not observed experimentally and only a limit for its absolute emission probability was given in 1972CoYX and 1972Gr01. The value of $P_{\gamma2,1} < 0.00026$ % (1972CoYX) is adopted in the present evaluation. The $\gamma2,0$ transition is a pure E0 ($0^+ \rightarrow 0^+$) and hence $P_{\gamma2,0}$ is zero. The recommended $P_{\gamma+ce}(\gamma_{2,0})$ value here is deduced from the measured absolute KX-ray yield, $P_{XK}(\gamma_{2,0})$, the corresponding fluorescence yield, ω_K, and the K/T conversion electrons ratio. The value of $P_{XK}(\gamma_{2,0})$ = 0.09 (1) %, deduced as a weighted mean of 0.08 (2) % (1972CoYX) and 0.10 (2) % (1972Gr01) (see Table 6), is adopted in the present work. It should be noted that an electron shake-off component of 0.02 % has been taken into account in these values. The K-shell to total conversion electrons ratio of K/T = 0.85 (6) was deduced from K/L = 5.7 (4), a weighted mean of the measured K/L = 5.61 (38) and 6 (1) in 1990Tr01 and 1977Dr08, respectively. This value is in very good agreement with that of K/T = 0.855, calculated using the electronic factors of Ω_K(E0) and Ω_L(E0) that are given by the BRICC program (2005KiZW). Using a K-fluorescence yield value of ω_K = 0.963 (4) (1996Sc06) one then obtains:

$$P_{g+ce}(g\,2{,}0) = P_{ce}(g\,2{,}0) = \left(P_{KX}(g\,2{,}0)/w_K\right)/(K/T) = 0.110\ (14)\ \%$$

Table 5. Energies, multipolarities, absolute transition probabilities and electron internal conversion coefficients for γ–ray transitions following β^-–decay of ^{206}Tl

	Energy, keV	$P_{\gamma+ce}$ × 100	Multi-polarity	α_K	α_L	α_M	α_N	α_T
$\gamma_{1,0}$	803.06 (3)	0.0051 (3)	E2	0.00801 (24)	0.00174 (5)	4.19 (13)10^{-4}	1.06 (3)10^{-4}	0.0103 (3)
$\gamma_{2,1}$	363.3 (5)	0.00015 (15)	(E2)	0.0414 (12)	0.0187 (6)	0.00476 (14)	0.00120 (4)	0.066 (2)
$\gamma_{2,0}$	1166.4 (5)	0.110 (14)	E0					

Table 6 Experimental and evaluated γ–ray emission probabilities.

Authors	**$P_{g1,0}$, %**	**$P_{XK}(g_{2,0})$ %$^{a)}$**	**$P_{g2,1}$, %**	**Comment $^{b)}$**
1968Zo02	0.0055 (5)			Not used
1970Zo02	0.0055 (4)			Expt.
1972CoYX	0.0041 (6)	0.08 (2)	<0.00026	Expt.
1972Gr01	0.004 (1)	0.10 (2)	<0.001	Expt.
Adopted	**0.0050 (3)**	**0.09 (1)**	**<0.00026**	**Evaluated**

$^{a)}$ Absolute KX-ray yield
$^{b)}$ Expt. – experimental value used in the present evaluation. The 1968Zo02 value is superseded by 1970Zo02

3. Atomic Data

The Atomic data (Fluorescence yields, X-Ray energies and Relative probabilities, and Auger electrons energies and Relative probabilities) were provided by the Saisinuc software (2002BeXX). Details regarding the origin of these data can be found in 1996Sc06, 1998ScZM, 1999ScZX, 2000ScXX and 2003DeXX.

4. Photon Emissions

4.1 X-Ray Emissions

The X-ray yield in β^- decay of ^{206}Tl is produced entirely in the decay of the 1166.4 keV (E0, $0^+ \rightarrow 0^+$) transition. Contributions from the much weaker 803.06 and 363.3 keV transitions can be neglected, since their X-ray yields are several orders of magnitude smaller than that of the 1166.4 keV transition.

For the 1166.4 keV E0 $(0^+ \rightarrow 0^+)$ transition, the number of vacancies in the K-shell per 100 disintegrations was determined as:

$$N_K = P_{ceK} = P_{XK} / w_K = 0.090\ (10) / 0.963\ (4) = 0.093\ (11).$$

The corresponding number of vacancies in the L shell per 100 disintegrations was then determined as:

$$N_L = P_{ceL} + n_{KL} \times N_K = 0.0163\ (22) + 0.811\ (5) \times 0.093\ (11) = 0.092\ (11)\ \%$$

where $P_{ceL} = P_{ceK} / (K/L) = 0.0163\ (22)\ \%$ with K/L= 5.7 (4), a weighted mean of 5.61 (38) (1990Tr01) and 6 (1) (1977Dr08). The number of X-rays per 100 disintegrations was then calculated as:

$$P_{XK} = w_K \times N_K \text{ and } P_{XL} = \overline{w}_L \times N_L$$

4.2 Gamma Emissions

The number of γ rays per 100 disintegrations was evaluated from the available experimental data, as described in section 2.2 (see also Table 6).

5. Electron Emissions

The energies of the conversion electrons were calculated from the γ–ray transition energies presented in Table 5 and the corresponding electron shell binding energies (1977La19). For the γ1,0 transition, the number of conversion electrons of type x = T,L,M,N and O, where T stands for total, L for L-shell electrons, etc., per 100 disintegrations was calculated from the absolute photon intensity ($P_{\gamma 1,0}$ per 100 disintegrations) recommended in the present evaluation (see Table 6), and the corresponding electron internal conversion coefficients (see Table 5), $\alpha_{x1,0}$: $ec_{1,0x} = P_{g1,0} \times a_{x1,0}$. For the γ2,0 transition, the number of K and L conversion electrons per 100 disintegrations was determined from the measured P_{XK} yield, w_K value and the K/L sub-shell ratio, as detailed in section 4.1.

The number of K and L Auger electrons per 100 disintegrations, $P(e_{AK(L)})$ was calculated from the number of vacancies in the K and L shells and the corresponding $P_{XK(L)}$ yield: $P(e_{AK}) = N_K - P_{XK}$ and $P(e_{AL}) = N_L - P_{XL}$.

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^{207}Tl - Comments on evaluation of decay data
by F. G. Kondev

This evaluation was completed in September 2010, with a literature cut off by the same date, as a part of ANL commitment to the IAEA-CRP on "Updated Decay Data Library for Actinides".

1 Decay Scheme

The nuclide ^{207}Tl (J^{π} = 1/2^{+}) disintegrates 100 % by β^{-} emission. The strongest β^{-}-decay branch of 99.729 (10) % populates the J^{π} = 1/2^{-} ground state of the daughter nuclide ^{207}Pb. The level schemes of ^{207}Tl and ^{207}Pb, including level energies and J^{π} values, are based on the ENSDF evaluation of Kondev and Lalkovski (2011Ko04).

2 Nuclear Data

Adopted Q(β^{-}) value of 1418 (5) keV is taken from the evaluation of Audi *et al.* (2003Au03).

The experimental half-life data for the ^{207}Tl ground state are listed in Table 1. The LRSW value of $T_{1/2}$ = 4.774 (12) min was adopted (χ^2_{ν} = 0.38, which is smaller than the critical value of $\chi^2_{\nu\,crit}$= 3.78 (99 % confidence level)).

Table 1. Experimental data for the half-life of ^{207}Tl.

Author	$T_{1/2}$ (min)	Used in evaluation
1931Cu01	4.76 (2)	Yes
1940Fa04	4.77 (5)	Yes
1953Sa11	4.79 (2)	Yes
1967Tr01	4.77 (3)	Yes

2.1 β- Transitions

The values for the maximum β^{-}-decay energies, $E_{\beta-,max}$, presented in Table 2, were deduced from Q(β^{-}) = 1418 (5) keV (2003Au03) and the adopted level energies of ENSDF (2011Ko04). The β^{-}-decay transition probabilities (P_{β}) were deduced from the decay scheme and the corresponding absolute γ transition probabilities. Comparisons with other measured values are given in Table 3. The log*ft* values were calculated using the LOGFT program from the ENSDF evaluation package, based on the work of Gove and Martin (1971Go40).

Table 2. Level energies, quantum numbers, $E_{\beta0,\iota\,max}$, P_{β} and log *ft* values in decay of ^{207}Tl.

	Level energy (keV)	J^{π}	$E_{\beta-\,max}$ (keV)	P_{β} (%)	Nature	log *ft*
$\beta_{0,2}$	897.698 (17)	3/2-	520 (5)	0.271 (10)	First forbidden non-unique	6.15
$\beta_{0,1}$	569.6982 (20)	5/2-	848 (5)	$< 8\times10^{-5}$	First forbidden unique	$> 10.8^{1U}$
$\beta_{0,0}$	0.0	1/2-	1418 (5)	99.729 (10)	First forbidden non-unique	5.11

Table 3. Beta-decay transition probabilities (P_β) in decay of ^{207}Tl.

	Present work (%)	**1967Da10 (%)**	**1963Ch09 (%)**	**1988Hi14 (%)**
$\beta_{0,2}$	0.271 (10)	0.24	0.155 (20)	
$\beta_{0,1}$	$< 8\times10^{-5}$	$< 1\times10^{-2}$		$< 8\times10^{-5}$
$\beta_{0,0}$	99.729 (10)	99.76	99.845 (20)	

2.2 γ Transitions

The γ–ray energies, multipolarities, absolute transition probabilities and electron internal conversion coefficients are listed in Table 4.γ transition multipolarities are taken from the ENSDF evaluation of Kondev and Lalkovski (2011Ko04), while the electron conversion coefficients were calculated using the BrIcc code (2008Ki07).

The P_γ(897.77 γ) value of 0.263 (9) % was deduced from the intensity ratio of $I_\gamma(898\gamma)/I_\gamma(351\gamma)$ = 0.0202 (7) (1988Hi14) and P_γ(351γ in ^{211}Bi α decay) = 13.02 (12) %. A P_γ(328.10γ) value of 0.00142 (14) % was deduced from the intensity ratio of $I_\gamma(328.10\gamma)/I_\gamma(898\gamma)$ = 0.0054 (5) (1988Hi14) and P_γ(897.77γ) = 0.263 (9) %, as described above. The absolute emission probability for the 569.698 γ of 0.00185 (19) %was deduced from the intensity balance at the 569-keV level and by neglecting the small β^- decay feeding contribution of < 8×10^{-5} reported in 1988Hi14. The mixing ratio of + 0.091 (9) for the569.698-keV transition was deduced as a weighted average of + 0.096 (11) (1970Kl03), + 0.075 (25) (1972Ha59), + 0.075 (25) (1976Av01), and + 0.11 (6) (1973Ba38).

Table 4. Energies, multipolarities, mixing ratios, absolute emission probabilities and electron internal conversion coefficients for γ transitions following the β^-–decay of ^{207}Tl.

	Energy (keV)	Multi-polarity	δ	P_γ (%)	α_K $\times10^{-2}$	α_L $\times10^{-3}$	α_M $\times10^{-4}$	α_{N+} $\times10^{-4}$	α_T
$\gamma_{2,0}$	897.77 (12)	M1+E2	+0.091 (9)	0.263 (9)	1.92 (3)	3.18 (5)	7.41 (11)	2.30 (4)	0.0233 (4)
$\gamma_{2,1}$	328.10 (12)	[M1]		0.00142 (14)	27.3 (4)	46.6 (7)	109.0 (16)	33.8 (5)	0.334 (5)
$\gamma_{1,0}$	569.698 (2)	E2		0.00185 (19)	1.584 (23)	4.39 (7)	10.81 (16)	3.30 (5)	0.0216 (3)

3 Atomic Data

The atomic data (fluorescence yields, X-ray energies and relative probabilities, and Auger electrons energies and relative probabilities) were provided by the SAISINUC software (2008DuZX). Details regarding the origin of these data can be found in 1996Sc06, 1998ScZM, 1999ScZX, 2000Sc47 and 2003De44.

4 Emissions

4.1 K x-rays

The X-ray data have been calculated using the evaluated gamma-ray data, and the atomic data from 1996Sc06, 1998ScZM and 1999ScZX. Both the X-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program. This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

5 Electron emissions

Electron energies were determined from electron binding energies tabulated by Larkins (1977La19) and the evaluated gamma-ray energies. Absolute electron emission probabilities were calculated from the evaluated absolute gamma-ray emission probabilities and associated internal conversion coefficients.

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2011Ko04 F. G. Kondev, S. Lalkovski. Nucl. Data Sheets 112(2011)707 (Nuclear levels)

^{207}Bi - Comments on evaluation of decay data
by M.M. Bé and V. Chisté

This evaluation was completed in November 1997 and reviewed in December 2009.

1) Decay scheme

The J^{π} values are from **NDS 70,2** (1993).
The level energies are deduced from the γ-ray energies.

2) **Nuclear Data**

- The Q value is from **Audi *et al.* 2003**
- The measured half-life values are, in years:

28 (3)	**J. Sosniak et al.**, Can. J. Phys 37,1 (1959) 1
30,2 (5)	**G. Harbottle**, J. Inorg. Nucl. Chem. 12 (1959) 6
38 (3)	**E.H. Appelman**, Phys. Rev. 121,1 (1961) --- uncertainty divided
38 (4)	**T. Rupnik**, Phys. Rev. C6,4 (1972) 1433
33,4 (8)	**M. Yanokura et al.**, Nuclear Physics A299 (1978) 92 --- omitted from analysis
	Hoppes et al (1982)
34,9 (4)	**D.E. Alburger et al.**, Phys. Rev. C 41,5 (1990) 2320 --- uncertainty divided
32,7 (8)	**W.J. Lin et al.**, J. Radioanal. Nucl. Chem. Letters 153,1 (1991) 51
31,55 (5)	**M.P. Unterwegger et al.**, NIM A312 (1992) 349 --- replaces [82HoZJ], Hoppes et al.
31,549 (41)	**M.P. Unterwegger,** Applied Rad. Isot. 56 (2002) 125 – replaces the previous one

1. The value from **M. Yanokura et al.** has been omitted because it is dependent on:
   - the EC/α branching ratio of At-211,
   - the probability for the 6868 keV α-transition from Po-211 to the 569,7 keV level in Pb-207,
   - the half-life of At-211,
   - the decay probability of Bi-207 feeding the 569,7 keV level in Pb-207.

All these data were updated since 1978, it should be necessary to re-calculate the value taking into account all these parameters. So, this value is not included in the data set.

2. The uncertainty on the **Appelman**'s value is given for 3σ, it has been divided by 3 to give 38 (1).

3. The uncertainty on the **Alburger**'s value is given for 2σ, it has been divided by 2 to give 34,9 (2).

Conclusion: **The adopted value of *32,9 (14) a*** is from the LRSW analysis of the seven accepted values. The uncertainty on the Unterwegger (2002) value has been increased to (0,177) in order to reduce its relative weight to 50 %. Then σ_{int} = 0,13; σ_{ext} = 0,75 and, reduced-χ^2 = 36,2. The final value is the weighted average and the uncertainty is expanded to include the most precise value.
New measurements would be desirable.

2.1) Electron-Capture Transitions

- The EC transition energies are deduced from Q(EC) = 2397,2 (21) keV and from the individual level energies.
- The transition probabilities are deduced from the total gamma-ray transition probability balance at each level.
- The electron-capture sub shell ratios were calculated by using the LOGFT program.

LOGFT calculated values

level	P_K	P_L	P_{M+}	(L+M+...)/K
570	0,797(8)	0,150 (3)	0,049 (1)	0,25
1633	0,733(7)	0,199 (4)	0,069 (1)	0,365
2340		0,651 (6)	0,349 (6)	

Experimental values from **Mandal et al.** for the transitions to the 570-keV and 1633-keV levels:

level	P_K	(L+M+...)/K
570	0,59 (6)	0,68 (16)
1633	0,73 (6)	0,37 (12)

The P_K value for the transition to the 570 keV level is the weighted average of two values (0,62 (8) and 0,59 (6)) obtained by two different coincidence method measurements. These values are dependant on: ω_K, $K\alpha/(K\alpha + K\beta)$, α_K, α_T and on the EC branching ratios. By using, for these parameters, the values evaluated in this work the re-calculated value for the first P_K is = 0,73 instead of 0,62, in agreement, within the uncertainty limits, with the theoretical values from the LOGFT program.

Experimental values from **A De Beer et al.** and **M. Tan et al.** for the transition to the 2340-keV level:

A. De Beer, P_L = 0,663 (14), this measurement does not depend on any other data.
M. Tan, P_L = 0,57 (3), this measurement depends on α_K and α_T for the 570 keV γ-transition. In this case α_K = 0,0159 and α_T = 0,0218.

2.2) β^+ transitions

A weak β^+ transition to the 570-keV level was reported by **Rupnik** (1972) to be (1,2 (2)) 10^{-2} %.

2.3) Gamma transitions

- Internal Conversion coefficients

The adopted values are from the LRSW analysis of all the values published after 1963. An earlier value from **R.A. Ricci** (1957) was not used due to its large uncertainty. The values from **E. Baldinger et al.** (1967) have been replaced by those of **E. Baldinger et al.** (1969). Two set of values were published by **Sen and Rizvi**, [1967Ri00, 1967Se15], one in a B.A.P.S. abstract (June), the other one in N.I.M. (July); only the last one was used because it gave a detailed description.

Internal Conversion coefficients measured values (**All values are multiplied by 10^2**) :

- 570 keV gamma transition

	α_K - 570 keV	u_c	
1967KL02	1,56	0,07	1969Ba53 and 1974Mu16 are rejected due to the Chauvenet criterion Internal uncertainty = 0,009; external uncertainty = 0,24 Reduced-χ^2 = 0,15 No value has a relative weight greater than 50 %. LRSW has used the weighted average and the external uncertainty. The evaluated value is = 1,574 (24)
1967VA25	1,59	0,06	
1967SE15	1,60	0,10	
1968AN04	1,56	0,05	
1969HE19	1,55	0,05	
1969AnZU	1,60	0,05	
1969BA53	1,50	0,15	
1974MU16	2,30	0,03	

	α_L - 570 keV	u_c	
1967SE15	0,49	0,03	Reduced-χ^2 = 1,1 Internal uncertainty = 0,0060 External uncertainty = 0,0064 1988Fu05 amounts for 74 % LRSW has used the weighted average and the external uncertainty The evaluated value is = 0,452 (6)
1968AN04	0,452	0,047	
1969HE19	0,444	0,021	
1969BA53	0,50	0,10	
1974AV03	0,483	0,018	
1988FU05	0,446	0,007	

	α_M - 570 keV	u_c	
1967SE15	0,10	0,05	Reduced-χ^2 = 3 Internal uncertainty = 0,003; external uncertainty = 0,005 weighted average and external uncertainty = 0,114 (5)
1974AV03	0,138	0,010	
1988FU05	0,112	0,003	

	α_{NOP} - 570 keV	u_c	
1974AV03	0,0288	0,0032	
1988FU05	0,0341	0,0017	

	α_{M+} - 570 keV	u_c	
1968AN04	0,172	0,047	Reduced-χ^2 = 1,5 Internal uncertainty = 0,003; external uncertainty = 0,004 evaluated: weighted average = 0,1485 (39)
1969BA53	0,168	0,035	
1974AV03	0,167	0,010	
1988FU05	0,1461	0,0034	

- 897 keV gamma transition

	α_K - 897 keV	u_c	
1970AhZX	1,90	0,30	No value has a relative weight greater than 50 %.
1974AV03	1,81	0,25	Internal uncertainty = 0,13; external uncertainty = 0,07 reduced-χ^2 = 0,24
1975JA04	1,60	0,30	LRSW has used the weighted average.
1988FU05	1,90	0,23	The evaluated value is = 1,82 (13)

- 1064 keV gamma transition

	α_K - 1064 keV	u_c	
1967SE15	8,5	0,5	1967Se15, 1967Kl02 and 1988Fu05 are rejected due to Chauvenet criterion Reduced-χ^2 = 0,03 Internal uncertainty = 0,23; external uncertainty = 0,04 Adopted: weighted average = 9,53 (23)
1967KL02	9,0	0,9	
1969ANZU	9,4	0,9	
1969HE19	9,6	0,3	
1969AN00	9,4	0,9	
1969BA53	9,5	1,3	
1974AV03	9,43	0,47	
1974MU16	9,5	1,1	
1988FU05	9,86	0,35	

	α_L - 1064 keV	u_c	
1967SE15	2,33	0,15	Reduced-χ^2 = 1,3 Internal uncertainty = 0,06; external uncertainty = 0,07 Adopted: weighted average = 2,47 (7)
1969BA53	2,97	0,46	
1974AV03	2,23	0,16	
1988FU05	2,51	0,10	

	α_M - 1064 keV	u_c	
1967SE15	0,44	0,09	Reduced-χ^2 = 2,2 ; Critical-χ^2 = 4,6 Internal uncertainty = 0,022; external uncertainty = 0,033 Adopted: weighted average = 0,591 (33)
1974AV03	0,55	0,05	
1988FU05	0,615	0,026	
	α_{M+} - 1064 keV	u_c	
1969BA53	1,05	0,17	

	α_{NOP} - 1064 keV		
1974AV03	0,17	0,03	Internal uncertainty = 0,012; external uncertainty = 0,010 Adopted: weighted average = 0,194 (12)
1988FU05	0,198	0,013	

- 1442 keV gamma transition

	α_K - 1442 keV	u$_c$	
1974AV03	0,27	0,04	
	α_L - 1442 keV		
1974AV03	0,042	0,008	

- 1770 keV gamma transition

	α_K **- 1770 keV**	u_c	
1971Al03	0,34	0,03	Reduced-χ^2 = 0,65
1974AV03	0,30	0,05	Internal uncertainty = 0,018; external uncertainty = 0,014
1988FU05	0,362	0,019	Uncertainty increased to 0,025 to reduce weight to 50 %
			evaluated: weighted average = 0,346 (18)

	α_L **- 1770 keV**	u_c	
1974AV03	0,041	0,009	Mean = 0,0049 (8), WM = 0,053
1988FU05	0,0569	0,0048	Internal uncertainty = 0,04; external uncertainty = 0,07
			evaluated: simple mean = 0,049 (8)

	α_{M+} **- 1770 keV**		Mean = 0,0126 (31), WM = 0,0136
1974AV03	0,0095	0,0024	Internal uncertainty = 0,0029; external uncertainty = 0,0017
1988FU05	0,0157	0,0017	evaluated: simple mean = 0,0126 (31)

Comparison of experimental results and theoretical values : ($\alpha \times 10^2$)

Theoretical ICC values were derived from the Band *et al.* tables with the program BrIcc for the “frozen orbital” approximation (Kibédi *et al.*).
Multipolarities and mixing ratios were deduced from comparison between measured and theoretical ICC values and by comparison with δ values obtained by angular correlation measurements.

	α_K	α_L	α_M	α_{M+}	α_T	δ	**Multipolarity**
570 keV							
Exper.	1,574 (24)	0,452 (6)	0,114 (5)	0,1485 (39)	2,174 (9)		
BrIccFO	1,583 (23)	0,439 (7)	0,1081 (16)		2,16 (3)		E2
Adopted	1,583 (23)	0,439 (7)	0,1081 (16)		2,16 (3)		E2
897 keV	α_K						
Exper.	1,82 (13)						
BrIccFO	1,82 (8)					0,3 (3)	M1+8,3%E2
Adopted	1,82 (8)	0,304 (12)	0,071 (13)		2,22 (9)		
1064 keV	α_K	α_L	α_M	α_{NOP}	α_T		
Exper.	9,53 (23)	2,47 (7)	0,591 (3)	0,194 (12)	12,78 (24)		
BrIccFO	9,43 (14)	2,38 (4)	0,589 (9)	0,1833 (25)	12,57 (18)	0,01 (1)	M4+0,01%E5
Adopted	9,53 (23)	2,47 (7)	0,591 (33)	0,194 (12)	12,78 (24)		
1442 keV	α_K	α_L					
Exper.	0,27 (4)	0,042 (8)					
BrIccFO	0,271 (4)	0,0468 (7)					E2
Adopted	0,271 (4)	0,0468 (7)					
1770 keV	α_K	α_L	α_M	α_{M+}	α_T		
Exper.	0,346 (18)	0,049 (8)		0,0126 (31)	0,408 (20)		
BrIccFO	0,342 (5)	0,0555 (8)			0,442 (7)	0,05 (5)	M1+0,0025%E2
Adopted	0,342 (5)	0,0556 (8)			0,442 (7)	0,05 (5)	
Measured internal-pair formation coefficient, α_π = 0,025 (5) 10^{-2} (**Allan 1971**)							

- Gamma transition probabilities

The transition probabilities were calculated from the adopted values of the ICC and the absolute emission intensities.

4.1) X-ray emissions

- ω_K is from **Bambynek**, ϖ_L η_{KL} η_{LM} from **Schönfeld et al.**, ϖ_M from **Hubbell et al**.

A value of ω_K = 0,972 (8) was measured by **Hansen et al.** (1972) and is in good agreement.

- X-ray energy: the wavelengths are from **Bearden** and converted into energy with

1 Å = 1,000 014 81 (92) 10^{-10} m.

- The emission intensities are calculated with the EMISSION program from PTB.

The ratios used are in good agreement with the measured values from **Dasmahapatra et al.**

	EMISSION	Measured
$K\alpha_2/ K\alpha_1$ =	0,5950 (25)	0,5984 (42)
$K\beta/K\alpha$ =	0,279 (4)	0,283 (9)
$K\beta_2'/K\beta_1'$ =	0,302 (5)	0,302 (30)

- Some others measurements were made by **Campbell et al.**:

$K\beta_1/ K\alpha_1$ = 0,2215 (30)

$K\beta_2/ K\alpha_1$ = 0,083 (1)

4.2) Gamma emissions

The γ-ray energies are from **Helmer *et al.*** for those of 569, 1063 and 1770 keV. Those at 897 and 1442 keV are from **Jardine** and 368 keV is from level energies.

All the experimental emission intensities were done relatively to that of the 570 keV gamma-ray, except **Lin et al.** where the absolute intensity is assumed to be 97,75.

The adopted values are from the LRSW analysis of all the known values, except Aubin et al. because no uncertainties were given.

897 keV	I_{rel}	u_c	
1969Ra13	0,150	0,015	
1975Ja04	0,14	0,02	Reduced-χ^2 = 1,23; critical-χ^2 = 3,3 Internal uncertainty = 0,0043; external uncertainty = 0,0048 LRSW has used the weighted average and the external uncertainty. The adopted value is = 0,1313 (48)
1980Yo05	0,122	0,013	
1989Sc**	0,1274	0,0052	
1991Li10	0,153	0,015	

1064 keV	I_{rel}	u_c	
1967Do09	78,4	2,40	
1969Ra13	78,7	4,00	
1972Ro03	75,6	0,50	
1968He00	74,0	2,00	
1975JA04	75,5	2,3	
1973Wi10	77,7	0,45	
1980Yo05	75,79	0,25	
1989De**	76,5	0,50	Reduced-χ^2 = 2; critical-χ^2 = 2,3 Internal uncertainty = 0,15; external uncertainty = 0,22 LRSW has used the weighted average. The adopted value is = 76,29 (22)
1989Sc**	76,584	0,367	
1990He16	76,4	0,50	
1991Li10	77,7	1,4	

1442 keV	I_{rel}	u_c	
1969Ra13	0,150	0,015	Internal uncertainty = 0,0025; external uncertainty = 0,0018 Reduced-χ^2 = 0,65; critical-χ^2 = 3 LRSW has used the weighted average and the internal uncertainty. The adopted value is = 0,1345 (23)
1975JA04	0,15	0,02	
1980Yo05	0,132	0,005	
1979Si17	0,144	0,024	
1989Sc**	0,1337	0,0027	
1991Li10	0,147	0,012	

1770 keV	I_{rel}	u_c	
1967Do09	7,07	0,35	
1969Ra13	7,5	0,4	<--- This value is rejected due to the Chauvenet criterion
1975JA04	6,95	0,20	Reduced-χ^2 = 0,14; critical -χ^2 = 3,3 Internal uncertainty = 0,026; external uncertainty = 0,01 The adopted value is = 7,028 (26)
1980Yo05	7,026	0,029	
1989Sc**	7,023	0,068	
1991Li10	7,11	0,13	

Gamma - 328 keV
A weak gamma emission was reported by **Schima**, with a relative intensity of 0,0045 (36).

Gamma - 1460 keV
A transition with Eγ = 1460 keV was reported by **Singh et al.**, nevertheless in spite of its relatively great intensity (= 1,65 (6)), it has never been confirmed by other authors.

Absolute emission intensities:

Considering the decay scheme, the absolute emission intensity of the 570 keV gamma ray is calculated by:
$\Sigma P(\gamma + ce)(570 + 897) = 100$
The α_T coefficients are those determined above.

Eγ	Absolute γ-ray intensity
328	0,0044 (35)
570	97,76 (3)
897	0,1284 (47)
1064	74,58 (22)
1442	0,1315 (22)
1770	6,871 (26)

5) Electron emissions

- The intensities of Auger electrons emitted were deduced from the decay scheme data by using the EMISSION program.
- The intensities of conversion electrons were calculated from the conversion coefficients and the gamma emission intensities.

6) Main production modes

From CEA/LMRI

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^{208}Tl – Comments on evaluation of decay data
by A. L. Nichols

Evaluated: July/August 2001
Re-evaluated: January 2004 and July 2010

Evaluation Procedures

Limitation of Relative Statistical Weight Method (LWM) was applied to average numbers throughout the evaluation. The uncertainty assigned to the average value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

The ground state of ^{208}Tl ($J^{\pi} = 5^{+}$) decays by beta minus emission to various excited levels of ^{208}Pb. A consistent decay scheme has been derived, assuming no direct beta decay to both the 2614.55-keV nuclear level and ground state of ^{208}Pb (based on spin-parity considerations). This decay scheme is primarily based on the gamma-ray measurements of 1960Em01, 1960Sc07, 1961Si11, 1969Au10, 1969La23, 1969Pa02, 1972DaZA/1973Da38, 1972Ja25, 1975Ko02, 1977Ge12, 1978Av01, 1982Sa36, 1983Sc13, 1983Va22, 1984Ge07, 1992Li05 and 1993El08.

Nuclear Data

^{228}Th decay chain is important in quantifying the environmental impact of the decay of naturally-occurring ^{232}Th. Specific radionuclides in this decay chain are noteworthy because of their decay characteristics (^{224}Ra alpha decay to ^{220}Rn; ^{212}Bi and ^{208}Tl gamma-ray emissions).

Half-life

The half-life is the weighted mean of the measurements of 1957Ba05, 1967La20, 1970Mu21 and 1971Ac02, with the uncertainty increased artificially to encompass the most precise study.

Reference	Half-life (min)
1957Ba05	3.100 (15)
1967La20	3.055 (6)
1970Mu21	3.17 (5)
1971Ac02	3.0527 (33)*
Recommended value	3.058 (6)#

* Uncertainty adjusted to ± 0.0055 to reduce weighting to no more than 0.50.
\# Weighted mean adopted, with uncertainty increased to include most precise value.

Gamma Rays

Energies

Both the 583.187 (2)- and 2614.511 (10)-keV gamma-ray energies were taken from 2000He14. All other gamma-ray transition energies were calculated from the structural details of the proposed decay scheme; the nuclear level energies of 2007Ma45 were adopted, and used to determine the energies and associated uncertainties of the gamma-ray transitions between the various populated-depopulated levels.

Adopted nuclear levels of ^{208}Pb: Energy, J$^{\pi}$ and origins (2007Ma45).

Nuclear level	Nuclear level energy (keV)*	J$^{\pi}$	Origins
0	0.0	0 +	^{208}Bi EC decay, **^{208}Tl β^{-} decay**, ^{212}Po α decay, ^{206}Pb(t,x), ^{207}Pb(n,γ), ^{207}Pb(d,x), ^{208}Pb(γ, x), ^{208}Pb(e,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{210}Pb(p,x), ^{209}Bi(d,x), ^{209}Bi(t,x), Coulomb excitation, etc.
1	2614.552 ± 0.010	3 –	^{208}Bi EC decay, **^{208}Tl β^{-} decay**, ^{212}Po α decay, ^{206}Pb(t,x), ^{207}Pb(n,γ), ^{207}Pb(d,x), ^{208}Pb(e,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{210}Pb(p,x), ^{209}Bi(d,x), ^{209}Bi(t,x), Coulomb excitation, etc.
2	3197.711 ± 0.010	5 –	**^{208}Tl β^{-} decay**, ^{212}Po α decay, ^{206}Pb(t,x), ^{207}Pb(d,x), ^{208}Pb(e,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{210}Pb(p,x), ^{209}Bi(d,x), ^{209}Bi(t,x), Coulomb excitation, etc.
3	3475.078 ± 0.011	4 –	**^{208}Tl β^{-} decay**, ^{207}Pb(d,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{209}Bi(d,x), etc.
4	3708.451 ± 0.012	5 –	**^{208}Tl β^{-} decay**, ^{206}Pb(t,x), ^{207}Pb(d,x), ^{208}Pb(e,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{209}Bi(d,x), ^{209}Bi(t,x), etc.
5	3919.966 ± 0.013	6 –	**^{208}Tl β^{-} decay**, ^{207}Pb(d,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), etc.
6	3946.578 ± 0.014	4 –	**^{208}Tl β^{-} decay**, ^{207}Pb(d,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{209}Bi(d,x), etc.
7	3961.162 ± 0.013	5 –	**^{208}Tl β^{-} decay**, ^{206}Pb(t,x), ^{207}Pb(d,x), ^{208}Pb(e,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{210}Pb(p,x), ^{209}Bi(d,x), ^{209}Bi(t,x), etc.
8	3995.438 ± 0.013	4 –	**^{208}Tl β^{-} decay**, ^{207}Pb(n,γ), ^{207}Pb(d,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{209}Bi(d,x), etc.
9	4037.443 ± 0.014	7 –	^{206}Pb(t,x), ^{207}Pb(d,x), ^{208}Pb(e,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{210}Pb(p,x), etc.
10	4051.134 ± 0.013	3 –	^{207}Pb(n,γ), ^{207}Pb(d,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{209}Bi(d,x), etc.
11	4085.52 ± 0.04	2 +	^{206}Pb(t,x), ^{207}Pb(n,γ), ^{207}Pb(d,x), ^{208}Pb(γ, x), ^{208}Pb(e,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{210}Pb(p,x), ^{209}Bi(d,x), Coulomb excitation, etc.
12	4125.347 ± 0.012	5 –	**^{208}Tl β^{-} decay**, ^{207}Pb(d,x), ^{208}Pb(e,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{209}Bi(d,x), ^{209}Bi(t,x), etc.
13	4180.414 ± 0.014	5 –	**^{208}Tl β^{-} decay**, ^{206}Pb(t,x), ^{207}Pb(d,x), ^{208}Pb(e,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{210}Pb(p,x), ^{209}Bi(d,x), etc.
14	4206.277 ± 0.004	6 –	^{207}Pb(d,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{209}Bi(d,x), etc.
15	4229.590 ± 0.017	2 –	^{207}Pb(n,γ), ^{207}Pb(d,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x)
16	4254.795 ± 0.017	3 –	^{206}Pb(t,x), ^{207}Pb(n,γ), ^{207}Pb(d,x), ^{208}Pb(e,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{210}Pb(p,x), ^{209}Bi(d,x)
17	4261.871 ± 0.013	4 –	**^{208}Tl β^{-} decay**, ^{207}Pb(d,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{209}Bi(d,x), etc.
18	4296.560 ± 0.013	5 –	**^{208}Tl β^{-} decay**, ^{206}Pb(t,x), ^{207}Pb(d,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{210}Pb(p,x), ^{209}Bi(d,x), etc.
19	4323.946 ± 0.014	4 +	**^{208}Tl β^{-} decay**, ^{206}Pb(t,x), ^{207}Pb(d,x), ^{208}Pb(e,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{210}Pb(p,x), ^{209}Bi(d,x), etc.
20	4358.670 ± 0.013	4 –	**^{208}Tl β^{-} decay**, ^{207}Pb(d,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{209}Bi(d,x), etc.
21	4383.285 ± 0.017	6 –	**^{208}Tl β^{-} decay**, ^{207}Pb(d,x), ^{208}Pb(e,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{209}Bi(d,x), etc.
22	4423.647 ± 0.015	6 +	^{207}Pb(d,x), ^{208}Pb(e,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{210}Pb(p,x), ^{209}Bi(d,x), etc.
23	4480.746 ± 0.016	6 –	**^{208}Tl β^{-} decay**, ^{207}Pb(d,x), ^{208}Pb(e,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{209}Bi(d,x), etc.

* Nuclear levels at 4144 (5) and 4447 (5) keV not included, although proposed in studies of the ^{209}Bi(d,^{3}He) reaction.

Placements of gamma-ray transitions (2007Ma45).

	Adopted E_γ* (keV)	Proposed location in decay scheme (^{208}Pb nuclear levels)		Adopted E_γ* (keV)	Proposed location in decay scheme (^{208}Pb nuclear levels)
$\gamma_{5,4}$	211.52 (2)	3919.966 (13) – 3708.451 (12)	–	835.90 (11)	not placed in decay scheme
$\gamma_{4,3}$	233.37 (2)	3708.451 (12) – 3475.078 (11)	$\gamma_{3,1}$	860.53 (2)	3475.078 (11) – 2614.552 (10)
$\gamma_{7,4}$	252.71 (2)	3961.162 (13) – 3708.451 (12)	$\gamma_{20,3}$	883.59 (2)	4358.670 (13) – 3475.078 (11)
$\gamma_{3,2}$	277.37 (2)	3475.078 (11) – 3197.711 (10)	$\gamma_{12,2}$	927.64 (2)	4125.347 (12) – 3197.711 (10)
$\gamma_{7,3}$	486.08 (2)	3961.162 (13) – 3475.078 (11)	$\gamma_{13,2}$	982.70 (2)	4180.414 (14) – 3197.711 (10)
$\gamma_{4,2}$	510.74 (2)	3708.451 (12) – 3197.711 (10)	$\gamma_{4,1}$	1093.90 (2)	3708.451 (12) – 2614.552 (10)
$\gamma_{2,1}$	583.187 (2)	3197.711 (10) – 2614.552 (10)	$\gamma_{19,2}$	1126.24 (2)	4323.946 (14) – 3197.711 (10)
$\gamma_{18,4}$	588.11 (2)	4296.560 (13) – 3708.451 (12)	$\gamma_{20,2}$	1160.96 (2)	4358.670 (13) – 3197.711 (10)
$\gamma_{12,3}$	650.27 (2)	4125.347 (12) – 3475.078 (11)	$\gamma_{21,2}$	1185.57 (2)	4383.285 (17) – 3197.711 (10)
$\gamma_{13,3}$	705.34 (2)	4180.414 (14) – 3475.078 (11)	$\gamma_{23,2}$	1283.04 (2)	4480.746 (16) – 3197.711 (10)
$\gamma_{5,2}$	722.26 (2)	3919.966 (13) – 3197.711 (10)	$\gamma_{8,1}$	1380.89 (2)	3995.438 (13) – 2614.552 (10)
$\gamma_{6,2}$	748.87 (2)	3946.578 (14) – 3197.711 (10)	$\gamma_{17,1}$	1647.32 (2)	4261.871 (13) – 2614.552 (10)
$\gamma_{7,2}$	763.45 (2)	3961.162 (13) – 3197.711 (10)	$\gamma_{20,12}$	1744.12 (2)	4358.670 (13) – 2614.552 (10)
–	808.32 (13)	not placed in decay scheme	$\gamma_{1,0}$	2614.511 (10)	2614.552 (10) – 0
$\gamma_{18,3}$	821.48 (2)	4296.560 (13) – 3475.078 (11)			

* Values derived from the adopted energies of the ^{208}Pb nuclear levels as specified in columns 3 and 6, with the uncertainties rounded upwards on the basis of the recommended uncertainties of the nuclear level energies (2007Ma45).

Emission Probabilities

A consistent decay scheme has been constructed from the gamma-ray measurements of 1960Em01, 1960Sc07, 1961Si11, 1969Au10, 1969Pa02, 1969La23, 1972Ja25, 1972DaZA/1973Da38, 1975Ko02, 1977Ge12, 1978Av01, 1982Sa36, 1983Sc13, 1983Va22, 1984Ge07, 1992Li05 and 1993El08. The study of 1975Ko02 is particularly comprehensive, along with the gamma-ray measurements of 1993El08 below 1000 keV. Gamma-ray emission probabilities have been expressed relative to the 2614.511-keV transition, and specific sets of data were adjusted accordingly (some of the original measurements were quantified relative to the 583.187-keV gamma ray or as absolute emission probabilities, while minor modifications were made to the relevant emission probabilities for the partially resolved 277.37-, 510.74- and 583.187-keV gamma rays as reported by 1983Sc13). 1993El08 observed additional gamma rays (808.32 and 835.90 keV) that have not been successfully placed in the proposed decay scheme – all nuclear levels of ^{208}Pb below an energy of 4611 keV have been assessed in terms of shell-model calculations and particle-gamma coincidence measurements by 1997Sc21, arguing against the possible existence of additional nuclear levels below this energy that might accommodate either of these two gamma transitions.

Experimental studies have been made of weak crossover gamma transitions by Vasil'ev et al. (2006Va23) to provide upper limits for the emission probabilities of three such emissions:

E_γ (keV)	P_γ (%), expressed per 100 decays of ^{208}Tl
3197.7	≤ 0.0007
3475.0	≤ 0.0003
3708.5	≤ 0.0004

Other high-energy gamma emissions were identified as summation peaks. These crossover gamma transitions have not been included in the proposed decay scheme because of their somewhat ill-defined, low emission probabilities and tentative nature.

Published gamma-ray emission probabilities.

E_γ (keV)	P_γ						
	1960Em01	**1960Sc07**	**1961Si11**		**1969Au10***	**1969La23**	**1969Pa02**
211.52 (2)	-	-	-	-	-	0.20 (5)	0.17 (8)
233.37 (2)	-	0.3	-	-	-	0.30 (5)	0.33 (17)
252.71 (2)	1.5 (7)	1.1	-	-		0.8 (1)	0.70 (11)
277.37 (2)	6.9 (8)	8.6	-	7.2 (7)	-	6.9 (5)	6.5 (4)
486.08 (2)	-	0.1 (1)	-	-	-	0.07 (4)	0.05 (2)
510.74 (2)	23 (2)	25.3 (12)	24 (3)	22.5 (25)	-	23 (1)	22.5 (12)
583.187 (2)	86.4 (56)	85.1 (40)	81 (5)	84 (5)	100	85 (4)	86 (4)
588.11 (2)	-	-	-	-	-	-	-
650.27 (2)	-	-	-	-	-	-	-
705.34 (2)	-	-	-	-	-	-	-
722.26 (2)	-	-	)	-	-	0.3 (1)	0.27 (8)
748.87 (2)	-	-	) 22.5 (20)	-	-	-	-
763.45 (2)	1.9 (5)	3.4 (2)	)	3.6 (7)	-	2.0 (2)	1.68 (8)
808.32 (13)	-	-	-	-	-	-	-
821.48 (2)	-	-	-	-	-	-	0.09 (4)
835.90 (11)	-	-	-	-	-	-	-
860.53 (2)	11.4 (12)	14.2 (6)	15.3 (20)	15.2 (15)	-	13 (1)	12.0 (8)
883.59 (2)	-	-	-	-	-	-	-
927.64 (2)	-	-	-	-	-	0.15 (5)	0.13 (3)
982.70 (2)	-	-	-	-	-	0.20 (5)	0.20 (3)
1004 (2)	-	-	-	-	-	-	~ 0.01
1093.90 (2)	-	0.7 (1)	~ 2	-	-	0.5 (1)	0.38 (5)
1126.24 (2)	-	-	-	-	-	-	-
1160.96 (2)	-	-	-	-	-	-	-
1185.57 (2)	-	-	-	-	-	-	-
1283.04 (2)	-	-	-	-	-	-	0.05 (2)
1380.89 (2)	-	-	-	-	-	-	0.02 (1)
1647.32 (2)	-	-	~ 3	-	-	-	~ 0.01
1744.12 (2)	-	-	-	-	-	-	-
2614.511 (10)	100	(100)	100	100	116.7 (24)	100	100

Published gamma-ray emission probabilities (cont.).

E_γ (keV)	**P_γ** (cont.)					
	1973Da38	**1972Ja25**	**1975Ko02**	**1977Ge12**[*]	**1978Av01**	**1982Sa36**[†]
211.52 (2)	0.16 (4)	-	0.17 (2)	-	-	-
233.37 (2)	~ 0.2	-	0.31 (3)	-	-	-
252.71 (2)	0.8 (2)	-	0.80 (5)	-	0.62 (4)	0.28 (3)
277.37 (2)	6.6 (13)	6.2 (7)	6.8 (3)	-	6.1 (2)	2.4 (1)
486.08 (2)	0.04 (1)	-	0.050 (5)	-	-	-
510.74 (2)	22.9 (23)	21.9 (7)	21.6 (9)	-	22.8 (7)	7.8 (4)
583.187 (2)	85.0 (85)	86.0 (4)	86 (3)	100	85	30.0 (14)
588.11 (2)	~ 0.04	-	0.04 (2)	-	-	-
650.27 (2)	-	-	0.036 (5)	-	-	-
705.34 (2)	~ 0.02	-	0.022 (4)	-	-	-
722.26 (2)	0.21 (6)	-	0.203 (14)	-	0.27 (2)	-
748.87 (2)	0.05 (1)	-	0.043 (4)	-	-	-
763.45 (2)	1.7 (3)	-	1.64 (9)	-	1.82 (9)	0.7 (1)
808.32 (13)	-	-	-	-	-	-
821.48 (2)	0.04 (1)	-	0.040 (4)	-	-	-
835.90 (11)	-	-	-	-	-	-
860.53 (2)	11.8 (12)	11.5 (10)	12.0 (4)	14.79 (15)	13.9 (6)	4.2 (2)
883.59 (2)	~ 0.025	-	0.031 (3)	-	-	-
927.64 (2)	0.13 (4)	-	0.125 (11)	-	-	-
982.70 (2)	0.20 (6)	-	0.197 (15)	-	-	-
1004 (2)	-	-	< 0.005	-	-	-
1093.90 (2)	0.37 (7)	-	0.37 (4)	-	-	-
1126.24 (2)	-	-	0.005 (2)	-	-	-
1160.96 (2)	-	-	0.011 (3)	-	-	-
1185.57 (2)	-	-	0.017 (5)	-	-	-
1283.04 (2)	~ 0.05	-	0.052 (5)	-	-	-
1380.89 (2)	-	-	0.007 (3)	-	-	-
1647.32 (2)	-	-	0.002 (1)	-	-	-
1744.12 (2)	-	-	0.002 (1)	-	-	-
2614.511 (10)	100	(100)	100	118.5 (16)	(100)	-

Published gamma-ray emission probabilities (cont.).

E_γ (keV)	**P_γ** (cont.)				
	1983Sc13[‡]	**1983Va22**[#]	**1984Ge07**[*]	**1992Li05**	**1993El08**[¶]
211.52 (2)	-	-	0.228 (20)	-	0.18 (1)
233.37 (2)	-	-	0.31 (4)	-	0.30 (1)
252.71 (2)	-	-	0.955 (13)	-	0.77 (2)
277.37 (2)	2.33 (7)	2.29 (4)	7.55 (6)	2.54 (7)[§]	6.88 (12)
486.08 (2)	-	-	-	-	0.055 (11)
510.74 (2)	7.90 (23)	8.31 (14)	26.9 (9)	-	22 (1)
583.187 (2)	30.7 (8)	30.8 (6)	100.0 (6)	29.4 (7)[§]	86 (3)
588.11 (2)	-	-	-	-	0.07 (1)
650.27 (2)	-	-	-	-	0.065 (11)
705.34 (2)	-	-	-	-	-
722.26 (2)	-	-	0.31 (6)	-	0.27 (2)
748.87 (2)	-	-	-	-	0.054 (9)
763.45 (2)	0.73 (5)	-	2.15 (2)	0.651 (40)	1.72 (8)
808.32 (13)	-	-	-	-	0.029 (7)
821.48 (2)	-	-	-	-	0.041 (17)
835.90 (11)	-	-	-	-	0.075 (11)
860.53 (2)	4.55 (12)	-	14.78 (9)	4.32 (15)	12.6 (7)
883.59 (2)	-	-	-	-	-
927.64 (2)	-	-	-	-	0.13 (1)
982.70 (2)	-	-	-	-	0.21 (1)
1004 (2)	-	-	-	-	-
1093.90 (2)	-	-	0.525 (8)	-	0.47 (4)
1126.24 (2)	-	-	-	-	-
1160.96 (2)	-	-	-	-	-
1185.57 (2)	-	-	-	-	-
1283.04 (2)	-	-	-	-	0.049 (13)
1380.89 (2)	-	-	-	-	-
1647.32 (2)	-	-	-	-	-
1744.12 (2)	-	-	-	-	-
2614.511 (10)	35.6 (11)	-	119.1 (21)	-	98.1 (13)

[*] Emission probabilities relative to P_γ(583.187 keV) of 100.
[†] Emission probabilities relative to P_γ(583.187 keV) of 30.0.
[‡] Emission probabilities relative to P_γ(583.187 keV) of 30.7.
[#] Emission probabilities relative to P_γ(583.187 keV) of 30.8.
[¶] Absolute emission probabilities.
[§] Unresolved overlap with another gamma-ray emission.

Equivalent measurements of specific emission probabilities deviate significantly between laboratories:

252.71-keV gamma ray: 1960Em01 and 1978Av01;
486.08-keV gamma ray: 1960Sc07;
510.74-keV gamma ray: 1960Sc07;
583.187-keV gamma ray: 1961Si11;
763.45-keV gamma ray: 1960Sc07 and 1961Si11;
860.53-keV gamma ray: 1960Sc07, 1961Si11 and 1978Av01;
927.64-keV gamma ray: 1969La23;
1093.90-keV gamma ray: 1960Sc07.

These particular values were judged to be outliers, and were not included in the weighted-mean analyses. Other gamma-ray emission probabilities were not reported with uncertainties within 1960Sc07, along with the 583.187-keV gamma-ray emission in 1978Av01; these data were also not included in the weighted-mean analyses. 1982Sa36, 1983Va22 and 1992Li05 reported measurements that did not include the main 2614.511-keV gamma-ray transition: the evaluated relative emission probability of the 583.187-keV gamma ray was adopted to create data sets comparable with the other studies, and therefore the assumed Pγ(583.187 keV) in these particular calculations were not included in the subsequent analysis.

While an uncertainty of 0.8 % can be derived for the relative emission probability of the 2614.511-keV gamma ray from the emission probabilities and uncertainties determined experimentally by 1969Au10, 1977Ge12, 1983Sc13, 1984Ge07 and 1993El08, the precise nature of this transition in such a well-defined area of the decay scheme permits the establishment of a recommended value of 100 % with no assigned uncertainty:

Reference	**P_γ(2614.511 keV)**
1969Au10	100 (2)
1977Ge12	100.0 (14)
1983Sc13	100 (3)
1984Ge07	100 (2)
1993El08	100.0 (13)
Weighted-mean value (LRSW)	100.0 (8) → 100 (1)
Recommended value	100

Gamma-ray emission probabilities: Relative to P_γ(2614.511 keV) of 100 %.

E_γ (keV)	**P_γ^{rel}**						
	1960Em01	**1960Sc07**	**1961Si11**		**1969Au10**	**1969La23**	**1969Pa02**
211.52 (2)	-	-	-	-	-	0.20 (5)	0.17 (8)
233.37 (2)	-	0.3[§]	-	-	-	0.30 (5)	0.33 (17)
252.71 (2)	1.5 (7)[†]	1.1[§]	-	-		0.8 (1)	0.70 (11)
277.37 (2)	6.9 (8)	8.6[§]	-	7.2 (7)	-	6.9 (5)	6.5 (4)
486.08 (2)	-	0.1 (1)[†]	-	-	-	0.07 (4)	0.05 (2)
510.74 (2)	23 (2)	25.3 (12)[†]	24 (3)	22.5 (25)	-	23 (1)	22.5 (12)
583.187 (2)	86.4 (56)	85.1 (40)	81 (5)[†]	84 (5)	85.7 (18)	85 (4)	86 (4)
588.11 (2)	-	-	-	-	-	-	-
650.27 (2)	-	-	-	-	-	-	-
705.34 (2)	-	-	-	-	-	-	-
722.26 (2)	-	-	)	-	-	0.3 (1)	0.27 (8)
748.87 (2)	-	-	) 22.5 (20)[‡]	-	-	-	-
763.45 (2)	1.9 (5)	3.4 (2)[†]	)	3.6 (7)[†]	-	2.0 (2)	1.68 (8)
808.32 (13)	-	-	-	-	-	-	-
821.48 (2)	-	-	-	-	-	-	0.09 (4)
835.90 (11)	-	-	-	-	-	-	-
860.53 (2)	11.4 (12)	14.2 (6)[†]	15.3 (20)[†]	15.2 (15)[†]	-	13 (1)	12.0 (8)
883.59 (2)	-	-	-	-	-	-	-
927.64 (2)	-	-	-	-	-	0.15 (5)[†]	0.13 (3)
982.70 (2)	-	-	-	-	-	0.20 (5)	0.20 (3)
1004 (2)	-	-	-	-	-	-	~ 0.01
1093.90 (2)	-	0.7 (1)[†]	~ 2	-	-	0.5 (1)	0.38 (5)
1126.24 (2)	-	-	-	-	-	-	-
1160.96 (2)	-	-	-	-	-	-	-
1185.57 (2)	-	-	-	-	-	-	-
1283.04 (2)	-	-	-	-	-	-	0.05 (2)
1380.89 (2)	-	-	-	-	-	-	0.02 (1)
1647.32 (2)	-	-	~ 3	-	-	-	~ 0.01
1744.12 (2)	-	-	-	-	-	-	-
2614.511 (10)	100	(100)	100	100	100 (2)	100	100

Gamma-ray emission probabilities: Relative to P$_{\gamma}$(2614.511 keV) of 100 % (cont.).

E$_{\gamma}$ (keV)	**P$_{\gamma}^{rel}$** (cont.)					
	1973Da38	**1972Ja25**	**1975Ko02**	**1977Ge12**	**1978Av01**	**1982Sa36**
211.52 (2)	0.16 (4)	-	0.17 (2)	-	-	-
233.37 (2)	~ 0.2	-	0.31 (3)	-	-	-
252.71 (2)	0.8 (2)	-	0.80 (5)	-	0.62 (4)[†]	0.80 (9)
277.37 (2)	6.6 (13)	6.2 (7)	6.8 (3)	-	6.1 (2)	6.8 (3)
486.08 (2)	0.04 (1)	-	0.050 (5)	-	-	-
510.74 (2)	22.9 (23)	21.9 (7)	21.6 (9)	-	22.8 (7)	22.2 (11)
583.187 (2)	85.0 (85)	86.0 (4)	86 (3)	84.4 (11)	85[§]	[85.2 (3)][#]
588.11 (2)	~ 0.04	-	0.04 (2)	-	-	-
650.27 (2)	-	-	0.036 (5)	-	-	-
705.34 (2)	~ 0.02	-	0.022 (4)	-	-	-
722.26 (2)	0.21 (6)	-	0.203 (14)	-	0.27 (2)	-
748.87 (2)	0.05 (1)	-	0.043 (4)	-	-	-
763.45 (2)	1.7 (3)	-	1.64 (9)	-	1.82 (9)	2.0 (3)
808.32 (13)	-	-	-	-	-	-
821.48 (2)	0.04 (1)	-	0.040 (4)	-	-	-
835.90 (11)	-	-	-	-	-	-
860.53 (2)	11.8 (12)	11.5 (10)	12.0 (4)	12.48 (13)	13.9 (6)[†]	11.9 (6)
883.59 (2)	~ 0.025	-	0.031 (3)	-	-	-
927.64 (2)	0.13 (4)	-	0.125 (11)	-	-	-
982.70 (2)	0.20 (6)	-	0.197 (15)	-	-	-
1004 (2)	-	-	< 0.005	-	-	-
1093.90 (2)	0.37 (7)	-	0.37 (4)	-	-	-
1126.24 (2)	-	-	0.005 (2)	-	-	-
1160.96 (2)	-	-	0.011 (3)	-	-	-
1185.57 (2)	-	-	0.017 (5)	-	-	-
1283.04 (2)	~ 0.05	-	0.052 (5)	-	-	-
1380.89 (2)	-	-	0.007 (3)	-	-	-
1647.32 (2)	-	-	0.002 (1)	-	-	-
1744.12 (2)	-	-	0.002 (1)	-	-	-
2614.511 (10)	100	(100)	100	100.0 (14)	(100)	-

Gamma-ray emission probabilities: Relative to P_γ(2614.511 keV) of 100 % (cont.).

E_γ (keV)	P_γ^{rel} (cont.)					
	1983Sc13	**1983Va22**	**1984Ge07**	**1992Li05**	**1993El08**	**Recommended value**[*]
211.52 (2)	-	-	0.19 (2)	-	0.18 (1)	0.18 (1)
233.37 (2)	-	-	0.26 (3)	-	0.31 (1)	0.31 (1)
252.71 (2)	-	-	0.80 (1)	-	0.78 (2)	0.78 (2)
277.37 (2)	6.5 (2)	6.3 (1)	6.34 (5)	7.36 (20)[ψ]	7.01 (12)	6.6 (3)
486.08 (2)	-	-	-	-	0.056 (11)	0.049 (4)
510.74 (2)	22.2 (6)	23.0 (4)	22.6 (8)	-	22 (1)	22.6 (2)
583.187 (2)	85.8 (22)	[85.2 (3)][#]	84.0 (5)	[85.2 (3)][ψ]	88 (3)	85.2 (3)
588.11 (2)	-	-	-	-	0.07 (1)	0.06 (1)
650.27 (2)	-	-	-	-	0.066 (11)	0.041 (5)
705.34 (2)	-	-	-	-	-	0.022 (4)
722.26 (2)	-	-	0.26 (5)	-	0.28 (2)	0.24 (4)
748.87 (2)	-	-	-	-	0.055 (9)	0.046 (3)
763.45 (2)	2.05 (14)	-	1.81 (2)	1.89 (12)	1.75 (8)	1.80 (2)
808.32 (13)	-	-	-	-	0.030 (7)	0.030 (7)
821.48 (2)	-	-	-	-	0.042 (17)	0.041 (4)
835.90 (11)	-	-	-	-	0.076 (11)	0.076 (11)
860.53 (2)	12.8 (3)	-	12.41 (8)	12.5 (4)	12.8 (7)	12.4 (1)
883.59 (2)	-	-	-	-	-	0.031 (3)
927.64 (2)	-	-	-	-	0.13 (1)	0.128 (7)
982.70 (2)	-	-	-	-	0.21 (1)	0.205 (8)
1004 (2)	-	-	-	-	-	-
1093.90 (2)	-	-	0.441 (7)	-	0.48 (4)	0.44 (1)
1126.24 (2)	-	-	-	-	-	0.005 (2)
1160.96 (2)	-	-	-	-	-	0.011 (3)
1185.57 (2)	-	-	-	-	-	0.017 (5)
1283.04 (2)	-	-	-	-	0.050 (13)	0.052 (5)
1380.89 (2)	-	-	-	-	-	0.007 (3)
1647.32 (2)	-	-	-	-	-	0.002 (1)
1744.12 (2)	-	-	-	-	-	0.002 (1)
2614.511 (10)	100 (3)	-	100 (2)	-	100.0 (13)	100

[*] Weighted mean values adopted when appropriate; remainder derived from proposed decay scheme; normalisation factor of 0.997 55 (4) calculated from total theoretical internal conversion coefficient of 2614.511-keV (0.002 46 (4)) gamma transition and transition probability of 100 % (1.00), with no direct β^- decay to the 2614.552-keV nuclear level and ground state of ^{208}Pb.

[†] Rejected as outlier, and not included in weighted-mean analysis.

[§] No uncertainty quoted; data not included in the weighted-mean analysis.

[‡] Unresolved data not included in the weighted-mean analysis.

[#] Measurements did not include determination of the 2614.511-keV gamma ray; therefore, relative emission probability of 85.2 (3) for the 583.187-keV gamma ray was used to convert all other data in this study to comparable relative values – under these circumstances, P_γ(583.187 keV) was not included in the weighted-mean analysis.

[ψ] unresolved overlap with another gamma-ray emission, and measurement did not include 2614.511-keV γ ray; therefore relative emission probability of 85.2 (3) was used for the 583.187-keV γ ray to convert other data in this study to comparable relative values – under these circumstances, P_γ(277.37 keV) and P_γ(583.187 keV) were not included in the weighted-mean analyses.

Multipolarities and Internal Conversion Coefficients

The major 583.187- and 2614.511-keV gamma rays were identified as E2 and E3 transitions, respectively. Many other gamma rays have mixed M1 + E2 multipolarities; these transitions were generally assumed to be 100 % M1, although estimated mixing ratios derived from the studies of 1954El07, 1957Kr56, 1957Vo22, 1963Da11, 1972Ja25, 1976Av03, 1978Av01 and 1990Go33 were used to determine specific multipolarities and theoretical internal conversion coefficients: ((97 % M1 + 3 % E2) for the 211.52-keV gamma transition, (67 % M1 + 33 % E2) for the 233.37-keV gamma transition, (86 % M1 + 14 % E2) for the 252.71-keV gamma transition, (99.96 % M1 + 0.04 % E2) for the 277.37-keV gamma transition, (99.75 % M1 + 0.25 % E2) for the 510.74-keV gamma transition, (91.2 % M1 + 8.8 % E2) for the 722.26-keV gamma transition, (99.0 % M1 + 1.0 % E2) for the 763.45-keV gamma transition, and (99.98 % M1 + 0.02 % E2) for the 860.53-keV gamma transition). The assigned multipolarity of the 860.53-keV gamma ray is particularly important in achieving the desired population-depopulation balance for the 2614.552-keV nuclear level. Recommended internal conversion coefficients have been determined from the frozen orbital approximation of Kibédi *et al.* (2008Ki07), based on the theoretical model of Band *et al.* (2002Ba85, 2002Ra45). Ion-pair formation coefficients were calculated by means of the methodology described by Kibédi *et al.* (2008Ki07). Uncertainties of ± 1.5 % were adopted for the E1 and E2 gamma transitions.

A normalisation factor (NF) of 0.997 55 (4) was calculated for the relative emission probabilities of the gamma rays, assuming no direct beta decay to the ground state of ^{208}Pb:

absolute transition probability of 2614.511-keV gamma ray = 100 %,
relative emission probability of 2614.511-keV gamma ray = 100 %, and
total theoretical internal conversion coefficient (2614.511-keV E3 transition) = 0.002 46 (4) (2002Ba85, 2002Ra45, 2008Ki07) →

$$P_\gamma^{abs} = P_\gamma^{rel} \ x \ NF = \frac{TP_\gamma^{abs}}{[1+\alpha_{total}]}$$

and, therefore:

$$NF = \frac{TP_\gamma^{abs}}{[1+\alpha_{total}] \ x \ P_\gamma^{rel}} = \frac{100}{[1+0.00246(4)] x \ 100}$$

$$NF = 0.99755(4)$$

Gamma-ray emissions: multipolarities, theoretical internal conversion coefficients (frozen orbital approximation) and ion-pair formation coefficients.

E_γ (keV)	Multipolarity	α_K	α_L	α_{M+}	α_{IPF}	α_{total}
211.52 (2)	97%M1 + 3%E2 δ = 0.18(2) 1957Kr56, 1957Vo22	0.890 (14)	0.1570 (22)	0.049	–	1.096 (17)
233.37 (2)	67%M1 + 33%E2 δ = 0.70(7) 1957Kr56, 1957Vo22	0.51 (3)	0.1136 (18)	0.0364	–	0.66 (3)
252.71 (2)	86%M1 + 14%E2 δ = -0.40(4) 1957Vo22, 1963Da11, 1978Av01	0.495 (14)	0.0926 (14)	0.0284	–	0.616 (15)
277.37 (2)	99.96%M1 + 0.04%E2 δ = 0.02(1) 1957Vo22, 1963Da11, 1976Av03, 1978Av01, 1990Go33	0.432 (6)	0.0739 (11)	0.0231	–	0.529 (8)
486.08 (2)	[M1] 1957Vo22	0.0954 (14)	0.01608 (23)	0.00492	–	0.1164 (17)
510.74 (2)	99.75%M1 + 0.25%E2 δ = -0.05(5) 1957Vo22, 1963Da11, 1976Av03, 1978Av01	0.0835 (13)	0.01406 (21)	0.00434	–	0.1019 (16)
583.187 (2)	E2 1954El07, 1957Kr56, 1963Da11, 1972Ja25, 1978Av01	0.01509 (22)	0.00410 (6)	0.00131	–	0.0205 (3)
588.11 (2)	[M1]	0.0577 (8)	0.00968 (14)	0.00302	–	0.0704 (10)
650.27 (2)	[M1]	0.0444 (7)	0.00742 (11)	0.00228	–	0.0541 (8)
705.34 (2)	[M1]	0.0360 (5)	0.00599 (9)	0.00181	–	0.0438 (7)
722.26 (2)	91.2%M1 + 8.8%E2 δ = 0.31(3) 1976Av03, 1978Av01	0.0317 (6)	0.00534 (10)	0.00166	–	0.0387 (7)
748.87 (2)	[M1]	0.0308 (5)	0.00512 (8)	0.00158	–	0.0375 (6)
763.45 (2)	99.0%M1 + 1.0%E2 δ = -0.10(1) 1957Vo22, 1963Da11, 1978Av01, 1990Go33	0.0291 (4)	0.00484 (7)	0.00146	–	0.0354 (5)
808.32 (13)	–	–	–	–	–	–
821.48 (2)	[M1]	0.0242 (4)	0.00402 (6)	0.00128	–	0.0295(5)
835.90 (11)	–	–	–	–	–	–
860.53 (2)	99.98%M1 + 0.02%E2 δ = 0.015 1957Vo22, 1963Da11, 1972Ja25, 1976Av03, 1978Av01, 1990Go33	0.0215 (3)	0.00356 (5)	0.00114	–	0.0262 (4)
883.59 (2)	[M1]	0.0201 (3)	0.00333 (5)	0.00097	–	0.0244 (4)
927.64 (2)	[M1]	0.01774 (25)	0.00293 (5)	0.00093	–	0.0216 (3)
982.70 (2)	[M1]	0.01530 (22)	0.00253 (4)	0.00077	–	0.0186 (3)
1093.90 (2)	E2	0.00449 (7)	0.000844 (12)	0.000266	–	0.00560 (8)
1126.24 (2)	E1	0.001691 (24)	0.000256 (4)	0.000081	0.00000206 (3)	0.00203 (3)
1160.96 (2)	[M1]	0.01000 (14)	0.001641 (23)	0.000496	0.00000259 (4)	0.01214 (17)
1185.57 (2)	[M1]	0.00947 (14)	0.001555 (22)	0.000480	0.00000501 (7)	0.01151 (17)
1283.04 (2)	[M1]	0.00775 (11)	0.001269 (18)	0.000388	0.0000232 (4)	0.00943 (14)
1380.89 (2)	[M1]	0.00643 (9)	0.001050 (15)	0.000315	0.0000546 (8)	0.00785 (11)
1647.32 (2)	[M1]	0.00411 (6)	0.000669 (10)	0.000207	0.000194 (3)	0.00518 (8)
1744.12 (2)	[M1]	0.00356 (5)	0.000578 (8)	0.000177	0.000255 (4)	0.00457 (7)
2614.511 (10)	E3	0.001708 (24)	0.000292 (4)	0.000089	0.000371 (6)	0.00246 (4)

Beta Particles

Energies

All beta-particle energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 2007Ma45 and the $Q_{\beta-}$ value of 4999.0 (17) keV adopted from 2003Au03 were used to determine the energies and uncertainties of the beta-particle transitions to the various levels.

Emission Probabilities

The beta-particle emission probabilities were calculated from gamma-ray probability balances, through the recommended gamma-ray emission intensities, and adopted multipolarities and theoretical internal conversion coefficients. A significant majority of the beta-particle transitions were defined as first forbidden non-unique.

Beta-particle emission probabilities per 100 disintegrations of ^{208}Tl.

	E_β(keV)	**P_β**				**Transition type**	**log ft**
		1960Em01	**1960Sc07**	**1967Os01**	**Recommended value***		
$\beta_{0,23}$	518.3 (17)	–	–	–	0.052 (5)	1st forbidden non-unique	6.67
$\beta_{0,21}$	615.7 (17)	–	–	–	0.017 (5)	1st forbidden non-unique	7.41
$\beta_{0,20}$	640.3 (17)	–	–	4.15 (15)	0.045 (4)	1st forbidden non-unique	7.04
$\beta_{0,19}$	675.1 (17)	–	–	–	0.005 (2)	allowed	8.1
$\beta_{0,18}$	702.4 (17)	–	–	–	0.102 11)	1st forbidden non-unique	6.82
$\beta_{0,17}$	737.1(17)	–	–	–	0.002 (1)	1st forbidden non-unique	8.6
$\beta_{0,13}$	818.6 (17)	–	–	–	0.231 (9)	1st forbidden non-unique	6.70
$\beta_{0,12}$	873.7 (17)	–	–	–	0.174 (9)	1st forbidden non-unique	6.92
$\beta_{0,8}$	1003.6 (17)	–	–	–	0.007 (3)	1st forbidden non-unique	8.5
$\beta_{0,7}$	1037.8 (17)	3.6	4.6 (2)	< 0.6	3.17 (4)	1st forbidden non-unique	5.92
$\beta_{0,6}$	1052.4 (17)	–	–	–	0.048 (3)	1st forbidden non-unique	7.76
$\beta_{0,5}$	1079.0 (17)	–	–	–	0.63 (4)	1st forbidden non-unique	6.68
$\beta_{0,4}$	1290.5 (17)	24.3	23.9 (8)	21 (2)	24.1 (2)	1st forbidden non-unique	5.38
$\beta_{0,3}$	1523.9 (17)	20.6	22.7 (7)	22 (2)	22.1 (5)	1st forbidden non-unique	5.69
$\beta_{0,2}$	1801.3 (17)	51.3	48.8 (27)	52 (1)	49.2 (6)	1st forbidden non-unique	5.61
					Σ 99.9 (8)		

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[*] Recommended emission probabilities derived from evaluated gamma-ray emission probabilities and theoretical internal conversion coefficients.

Atomic Data

The x-ray and Auger-electron data have been calculated using the evaluated gamma-ray data, and atomic data from 1996Sc06, 1998ScZM and 1999ScZX. Both the x-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.01, 28 January 2003). This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

K and L X-ray emission probabilities per 100 disintegrations of ^{208}Tl.

			Energy (keV)	**Photons per 100 disint.**
XL		(Pb)	9.184 – 15.216	2.75 (12)
	XL$_l$	(Pb)	9.184	0.0671 (19)
	XL$_\alpha$	(Pb)	10.450 – 10.551	1.27 (4)
	XL$_\eta$	(Pb)	11.349	0.0209 (7)
	XL$_\beta$	(Pb)	12.142 – 13.015	1.155 (25)
	XL$_\gamma$	(Pb)	14.765 – 15.216	0.220 (5)
XK$_\alpha$	XK$_{\alpha2}$	(Pb)	72.8049 (8)	2.03 (5)
	XK$_{\alpha1}$	(Pb)	74.9700 (9)	3.42 (7)
XK$'_{\beta1}$	XK$_{\beta3}$	(Pb)	84.451	1.17 (3)
	XK$_{\beta1}$	(Pb)	84.937	
	XK$''_{\beta5}$	(Pb)	85.470	
XK$'_{\beta2}$	XK$_{\beta2}$	(Pb)	87.238	0.353 (11)
	XK$_{\beta4}$	(Pb)	87.580	
	XKO$_{2,3}$	(Pb)	87.911	

Electron energies were determined from electron binding energies tabulated by Larkins (1977La19) and the evaluated gamma-ray energies. Absolute electron emission probabilities were calculated from the evaluated absolute gamma-ray emission probabilities and associated internal conversion coefficients.

Data Consistency

A Q$_\beta$-value of 4999.0 (17) keV has been adopted from the atomic mass evaluation of Audi *et al.* (2003Au03) while in the course of formulating the decay scheme of ^{208}Tl. This value has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{208}Tl beta-decay process (i.e. β^-, conversion electrons, γ, etc.):

$$\text{calculated Q-value} \quad = \quad \sum (E_i \times P_i) \quad = \quad 4989\ (14)\ \text{keV}$$

Percentage deviation from the Q-value of Audi *et al.* is (0.2 ± 0.3) %, which supports the derivation of a highly consistent decay scheme.

Acknowledgement

ALN would like to thank M.J. Martin (ORNL, USA) for an exchange of information in November 2006 with respect to an earlier DDEP evaluation of the β^- decay of ^{208}Tl undertaken in January 2004. This further re-evaluation of July 2010 to May 2011 includes a number of adjustments and corrections based on this welcome communication.

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^{209}Tl- Comments on Evaluation of Decay Data

By F.G. Kondev

This evaluation was completed in May 2011, with a literature cut off by the same date, as a part of ANL commitment to the IAEA-CRP on "Updated Decay Data Library for Actinides".

1. Decay Scheme

The nuclide ^{209}Tl (J^{π}=1/2^{+}) disintegrates 100 % by β^{-} emissions. The strongest β^{-}-decay branch of 97.70 (15) % populates the J^{π}=1/2^{-} excited state at 2149.29 keV of the daughter nuclide ^{209}Pb. The decay scheme of ^{209}Tl was constructed by the evaluator, based on the work of Gromov (2000Gr35) and Ardisson (1998Ar03). The ENSDF evaluation of Martin (1991Ma16) was consulted for J^{π} and mutipolarity assignments to levels in ^{209}Pb.

2. Nuclear Data

Adopted Q(β^{-}) value of 3976 (8) keV is taken from the evaluation of Audi *et al.* (2003Au03).

The experimental data for the half-life of the ^{209}Tl ground state are very scarce. The value of 2.161 (7) min (1998Ar03) is adopted in the present evaluation. It is in agreement with the other known, but less precise, value of 2.20 (17) min (1950Ha64).

2.1. β^{-} Transitions

The values for the maximum β^{-}-decay energies, $E_{\beta-,max}$, presented in Table 1, were deduced from Q(β^{-}) = 3976 (8) keV (2003Au03) and the level energies deduced in the present evaluation, as detailed in section 2.2. The β^{-}-decay transition probabilities, P_{β}, were deduced from the decay scheme and the corresponding absolute γ–ray transition probabilities. The sum of the β- intensities to levels above 2149 keV is 2.30 (15) %. Then the β- feeding to the 2149-keV level is (100 - 2.30 (15)) % = 97.70 (15) %. The log *ft* values were calculated using the LOGFT program from the ENSDF evaluation package. The log *f* values are based on the work of Gove and Martin (1971Go40).

2.2. Gamma Transitions and Electron Internal Conversion Coefficients

The γ–ray transition energy data are presented in Table 2. Statistical analysis using the LWEIGHT program has been performed and the corresponding gamma-ray energies were deduced (the last column of Table 2). With those energies, the level scheme was fitted using the *gtol* program from the ENSDF analysis package and new level energies (shown in Table 1) were obtained.

The γ–ray transition multipolarities were taken from the ENSDF evaluation of Martin (1991Ma16) and the recent work of Gromov (2000Gr35) and Ardisson (1998Ar03). The electron conversion coefficients were calculated using the BrIcc code (2008Ki07).

Table 1. Level energies, quantum numbers, $E_{\beta0,\iota\ max}$, P_{β} and log *ft* values in decay of ^{209}Tl (J^{π}=1/2^{+})

Level energy (keV)	**J^{π}**	**$E_{\beta-\ max}$ (keV)**	**P_{β} (%)**	**Nature**	**log *ft***
3388.96 (13)	(1/2,3/2)	587 (8)	0.420 (22)		
3361.36 (17)	(1/2,3/2)	615 (8)	0.10 (3)		
3069.72 (13)	3/2-	906 (8)	0.645 (16)	first forbidden	6.3
2905.14 (25)	3/2-	1071 (8)	0.70 (9)	first forbidden	6.5
2524.14 (25)	(1/2,3/2)+	1451 (8)	0.070 (15)	allowed	8.0
2460.8 (3)	(5/2)-	1515 (8)	0.031 (16)	first forbidden unique	9.2

2315.68 (13)	(3/2)-	1660 (8)	0.32 (11)	first forbidden	7.5
2149.29 (6)	1/2-	1827 (8)	97.70 (15)	first forbidden	5.2
2032.07 (6)	1/2+	1944 (8)	<0.1	allowed	> 8.3
1566.94 (5)	5/2+				
0.0	9/2+				

The gamma-ray emission probability data are presented in Table 3. The unplaced gamma rays and their emission probabilities are presented in Table 4. Future work is merited to obtain a more complete decay scheme of ^{209}Tl.

3. Atomic Data

The Atomic data (Fluorescence yields, X-Ray energies and Relative probabilities, and Auger electrons energies and Relative probabilities) were provided by the Saisinuc software (2008DuZX). Details regarding the origin of these data can be found in 1996Sc06, 1998ScZM, 1999ScZX, 2000Sc47 and 2003De44.

Table 2. Measured, deduced and adopted gamma-ray energies in β^{-}–decay of ^{209}Tl

2003ChZV	2000Gr35	1999GrZT	1998Ar03	1993El08	1989Ko26	1986He06	1981Di14	1977Vy02	adopted
	117.18 (10)	117.1 (3)	117.24 (5)	117.24 (1)	117.21 (1)		117.25 (5)	117.211 (21)	117.224 (7)
			284.04 (23)	284.04 (25)					284.04 (23)
			311.5 (3)	311.5 (3)					311.5 (3)
			375.5 (2)	375.5 (2)					375.5 (2)
465.2	465.21 (4)	465.0 (4)	465.10 (5)	465.10 (1)	465.14 (1)	465.4 (1)	465.1 (2)	465.065 (25)	465.128 (24)
582.4	582.4 (2)								582.4 (2)
	748.5 (3)		748.0 (3)	748.0 (3)					748.3 (2)
	755.6 (3)								755.6(3)
	873.5 (4)								873.5 (4)
920.2	920.8 (1)	919.9 (3)	920.34 (9)	920.34 (7)	920.2 (3)				920.43 (11)
1239.8	1239.7 (2)	1239.2 (3)	1239.76 (15)	1239.76 (15)					1239.66 (11)
1329.2	1329.3 (3)	1329.6 (3)	1329.3 (3)	1329.3 (3)	1239.5 (5)				1329.29 (16)
1566.9	1566.9 (3)	1566.7 (3)	1566.96 (5)	1566.96 (1)	1567.11 (2)		1566.9 (2)	1566.95 (6)	1566.93 (5)
	2149.0 (10)								2149.0 (10)
2315.9	2315.9 (3)	2315.7 (3)							2315.80 (21)

Table 3. Measured, deduced and adopted γ–ray emission probabilities for γ–ray transitions in β^-–decay of ^{209}Tl

Eg, keV	2003ChZV	2000Gr35	1999GrZT	1998Ar03	1993El08	1989Ko26	1981Di14	1977Vy02	adopted
117.24 (1)		78 (4)	74 (2)	73 (4)	73 (1)	85 (4) *	85.6 (59) *	84 (2) *	77.22 (27) [a)]
284.04 (25)				0.14 (7)	0.14 (7)				0.14 (7)
311.5 (3)				0.028 (14)	0.028 (14)				0.028 (14)
375.5 (2)				0.070 (15)	0.070 (15)				0.070 (15)
465.10 (1)	80.4 (21) *	97 (5)	93.2 (16) *	95 (5)	95 (5)	96 (4)	99.1 (64)	100 (3) *	96.62 (5) [a)]
582.4	0.33 (3)	0.28 (4)							0.312 (24)
748.5 (3)		0.07 (3)		0.09 (3)	0.086 (30)				0.080 (21)
755.6(3)		0.11 (2)							0.11 (2)
873.5 (4)		0.59 (8)							0.59 (8)
920.8 (1)	0.62 (3)	0.63 (5)	0.63 (2)	0.70 (7)	0.70 (7)	0.63 (6)			0.631 (15)
1239.8	0.45 (4)	0.42 (7)	0.41 (3)	0.31 (12)	0.31 (12)				0.420 (22)
1329.2	0.14	0.10 (3)	0.21 (3)	0.026 (5)	0.026 (5)	0.42 (4)			0.10 (3)
1566.9	100 (1)	100 (5)	100.0 (8)	100 (5)	100 (5)	100 (4)	100.6 (64)	93 (3) *	99.707 (5) [a)]
2149.0 (10)	<0.0006	0.015 (5)							0.015 (5)
2315.9 (3)	0.0284 (24)	0.03 (1)	0.030 (5)						0.0288 (21)

* not included in the statistical analysis

[a)] deduced from $100/(1+\alpha_T)$ due to cascading.

Table 4. Gamma-ray energies and emission probabilities for transitions in β^-–decay of ^{209}Tl, which were not placed in the decay scheme

2003ChZV		2000Gr35		1999GrZT		1998Ar03	
		469.9	0.12 (3)			469.7 (3)	0.03 (2)
		860.5 (3)	0.26 (4)				
		890.0 (4)	0.12 (3)				
		902.8 (4)	0.10 (2)				
970.3	0.054 (15)						
		1661.1 (5)	0.10 (2)				
		1673.2 (4)	0.48 (4)				
		1781.7 (5)	0.04 (2)				
				2005.3 (2)	0.020 (5)		
2032.1	<0.019	2032.1 (5)	0.001				
2548.2	0.015 (6)						

4. References

1950Ha64	F. Hagemann. Phys. Rev. 79 (1950) 534 (Half-life)
1971Go40	N.B. Gove, M.J. Martin. Nucl. Data Tables A10 (1971) 205 (Log ft values)
1977Vy02	T. Vylov, N.A. Golovkov, B.S. Dzhelepov, R.B. Ivanov, M.A. Mikhailova, Y.V. Norseev, V.G. Chumin. Bull. Acad. Sci. USSR, Phys.Ser. 41 (1977) 85 (Gamma-ray emission energies and probabilities)
1981Di14	J.K. Dickens, J.W. McConnell. Radiochem. Radioanal. Lett. 47 (1981) 331 (Gamma-ray emission energies and probabilities)
1986He06	R.G. Helmer, C.W. Reich, M.A. Lee, I. Ahmad. Appl. Radiat. Isot. 37 (1986) 139 (Gamma-ray emission energies and probabilities)
1989Ko26	M.C. Kouassi, A. Hachem, C. Ardisson, G. Ardisson. Nucl. Instrum. Methods Phys. Res. A280 (1989) 424 (Gamma-ray emission energies and probabilities)
1991Ma16	M.J. Martin. Nucl. Data Sheets 63 (1991) 723 (Nuclear levels, multipolarities)
1993El08	O. El Samad, J. Dalmasso, G. Barci-Funel, G. Ardisson. Radiochim. Acta 62 (1993) 65 (Gamma-ray emission energies and probabilities)
1996Sc06	E. Schönfeld, H. Janssen. Nucl. Instrum. Methods Phys. Res. A369 (1996) 527 (K-shell fluorescence yields)
1998ScZM	E. Schönfeld, G. Rodloff. Report PTB-6.11-98-1 Braunschweig (1998) (K Auger electron energies)
1988Ar03	G. Ardisson, V. Barci, O. El Samad. Phys. Rev. C57 (1998) 612 (Gamma-ray emission energies and probabilities)
1999GrZT	K.Ya. Gromov, Sh.R. Malikov, T.M. Muminov, Zh.K. Samatov, Zh. Sehrehehtehr, V.I. Fominykh, V.V. Tsupko-Sitnikov, V.G. Chumin. Proc. 49th Ann. Conf. Nucl. Spectrosc. Struct. At. Nuclei, Dubna (1999) 117 (Gamma-ray emission energies and probabilities)
1999Sc47	E. Schönfeld, G. Rodloff. Report PTB-6.11-1999-1 Braunschweig (1999) (K X-ray energies and relative emission probabilities)
2000Sc47	E. Schönfeld, H. Janssen. Appl. Radiat. Isot. 52 (2000) 595 (EMISSION program and X-ray and Auger electron emission probabilities)
2000Gr35	K.Ya. Gromov, S.A. Kudrya, Sh.R. Malikov, T.M. Muminov, Zh.K. Samatov, Zh. Sereeter, V.I. Fominykh, V.G. Chumin. Bull. Rus. Acad. Sci. Phys. 64 (2000) 1770 (Gamma-ray emission energies and probabilities)
2003Au03	G. Audi, A.H. Wapstra, C. Thibault. Nucl. Phys. A729 (2003) 337 (Q value)
2003De44	R.D. Deslattes, E.G. Kessler Jr., P. Indelicato, L. de Billy, E. Lindroth, J. Anton. Rev. Mod. Phys. 75 (2003) 35 (K and L X-ray energies)
2003ChZV	V.G. Chumin, V.I. Fominykh, K.Ya. Gromov, A.A. Klimenko, S.A. Kudrya, A.A. Smolnikov, S.I. Vasiliev. Proc. 53rd Ann. Conf. Nucl. Spectrosc. Struct. At. Nuclei, Moscow (2003) 105 (Gamma-ray emission energies and probabilities)
2008Ki07	T. Kibédi, T.W. Burrows, M.B. Trzhaskovskaya, P.M. Davidson, C.W. Nestor Jr.. Nucl. Instrum. Methods Phys. Res. A589 (2008) 202 (Theoretical ICCs)
2008DuZX	C. Dulieu, M.M. Bé, V. Chisté. Proc. Int. Conf. on Nuclear Data for Science and Technology, Nice, France, 22-27 April 2007 (2008) 97 (SAISINUC software)

^{209}Pb - Comments on evaluation of decay data
by F. G. Kondev

This evaluation was completed in February 2011, with the same literature cut off date, as a part of ANL commitment to the IAEA-CRP on "Updated Decay Data Library for Actinides".

1 Decay Scheme

The nuclide ^{209}Pb ($J^\pi = 9/2^+$) disintegrates 100 % by β^- emissions with a single β^--decay branch to the ground state ($J^\pi = 9/2^-$) of the daughter nuclide ^{209}Bi. The level schemes of ^{209}Pb and ^{209}Bi, including level energies and J^π values, are based on the ENSDF evaluation of Martin (1991Ma16).

2 Nuclear Data

Adopted Q(β^-) value of 644.0 (12) keV is taken from the evaluation of Audi *et al.* (2003Au03).

The experimental half-life data for the ^{209}Pb ground state are listed in Table 1. The LRSW value of $T_{1/2}$ = 3.277 (15) h was adopted (χ^2_ν =1.87, which is smaller than the critical value of $\chi^2_{\nu\ cryt}$ = 3.32 (99 % confidence level)).

Table 1. Experimental data for the half-life of ^{209}Pb.

Author	$T_{1/2}$ (h)	Used in evaluation
1972Be44	3.253 (14)	Yes
1971Pe03	3.31 (3)	Yes
1959Po64	3.31 (3)	Yes
1942Ma03	3.3 (1)	Yes
1941Fa04	3.32(3)	Yes
1940Kr08	2.75 (5)	No

2.1 β- Transitions

The decay of ^{209}Pb proceeds with a single β^- transition directly to the ^{209}Bi ground state. The maximum β^--decay energy recommended in Table 2 was deduced from Q(β^-) = 644.0 (12) keV (2003Au03). The log *ft* value was calculated using the LOGFT program from the ENSDF evaluation package, which is based on the work of Gove and Martin (1971Go40).

Table 2. Level energy, quantum number, $E_{\beta 0,\iota\ max}$, P_β and log *ft* value in decay of ^{209}Pb.

	Level energy (keV)	J^π	$E_{\beta-\ max}$ (keV)	P_β (%)	Nature	log *ft*
$\beta_{0,0}$	0.0	9/2-	644.0 (12)	100	First forbidden non-unique	5.536 (4)

3 References

1940Kr08	R. S. Krishnan, E. A. Nahum. Proc. Cambridge Phil. Soc. 36(1940)490 (Half-life)
1941Fa04	K. Fajans, A. F. Voigt. Phys. Rev. 60(1941) 619 (Half-life)
1942Ma03	W. Maurer, W. Ramm. Z. Phys. 119 (1942)602 (Half-life)
1959Po64	A. Poularikas, R.W. Fink. Phys. Rev. 115(1959)989 (Half-life)
1971Go40	N. B. Gove, M. J. Martin. Nucl. Data Tables A10(1971)205 (log ft values)
1971Pe03	B. I. Persson, I. Plesser, J.W. Sunier. Nucl. Phys. A167(1971)470 (Half-life)
1972Be44	H. Behrens, M. Kobelt, W. G. Thies, H. Appel. Z. Phys. 252(1972)349 (Half-life)
1991Ma16	M. J. Martin. Nucl. Data Sheets 63(1991)723 (Nuclear levels)
2003Au03	G. Audi, A. H. Wapstra, C. Thibault. Nucl. Phys. A729(2003)337 (Q value)

^{209}Po - Comments on evaluation of decay data
by V. Chisté and M. M. Bé

This evaluation was completed in December 2009. The literature available by September 2009 was included.

1 Decay Scheme

^{209}Po disintegrates by alpha emission to excited levels and to the ground state level of ^{205}Pb and by electron capture to the 896-keV excited level of ^{209}Bi.

A good agreement was found between the adopted Q_{α} and Q_{EC} values from Audi (2003Au03) and the effective Q values, Q_{α} (4957 (2) keV) and Q_{EC} (1891 (20) keV), calculated from the decay scheme data (and branching ratio).

2 Nuclear Data

The Q values are from the atomic mass evaluation of Audi *et al.* (2003Au03).

Experimental ^{209}Po half-life values (in years) are given in Table 1.

Table 1: Experimental values of ^{209}Po half-life.

Reference	Experimental value (a)	Comments
C. G. Andre (1956An05)	102 (5)	From ^{209}Po/^{208}Po mass and activity ratios and $T_{1/2}$(^{208}Po) = 2.898 (2) a (see 1991Ma16).
R. Collé (2007Co07)	128 (7)	Decay data from two separate primary standardizations of a ^{209}Po solution standard, carried out ~ 12 years apart.
Recommended value	115 (13)	$\chi^2 = 6.9$

The value from 2007Co07 is not a direct measurement of the ^{209}Po half-life. R. Collé said in a private communication: “My paper which stated the value **128 a** was not a new determination…The whole point was to show that there was evidence to suggest and support that the extant **102 a** value is very wrong, perhaps by 25 %”.
However, to take into account all scarce information available, the evaluators have chosen to adopt the simple mean of the two existing values (1956An05 and 2007Co07) with an uncertainty covering them. Then, the recommended value is 115 (13) a.

2.1 α Transitions and Emissions

The energies of the α-particle transitions given in Section 2.1 have been obtained from the Q_{α} (2003Au03) and the ^{205}Pb level energies from F. G. Kondev (2004Ko28), given in Table 2.

Table 2: ^{205}Pb levels populated in the ^{209}Po α-decay.

Level number	Energy (keV)	Spin and parity	Half-life	Probability of α transition (%)
0	0.0	$5/2^-$	17.3 (7) 10^6 a	19.8 (32)
1	2.329 (7)	$1/2^-$	24.2 (4) µs	79.2 (32)
2	262.833 (25)	$3/2^-$		0.548 (7)

The energies of the $\alpha_{0,0}$, $\alpha_{0,1}$ and $\alpha_{0,2}$ emissions given in Section 4 are from A. M. Mandal (1989Ma05). In 1989Ma05, two weak alpha transitions of 4310 and 4110 keV respectively, were reported. These alpha transitions were not reported here by the evaluators, because other authors have doubts about their existence (1996Sc24, 2004Ko28).

The transition intensity of the $\alpha_{0,2}$ transition has been deduced from the P(γ + ce) decay scheme balance. For the ($\alpha_{0,0}$ + $\alpha_{0,1}$), an unresolved doublet, the evaluators decided to follow the explanation given by V. Chechev (private communication and based on the Schmorak article (1980Sc26)):
"Schmorak found, for odd-A nuclides, that all known cases of hindrance factors (HF) for $p_{1/2}$ to $p_{1/2}$ favoured alpha transitions are grouped around HF = 1.3. For the Po-209 alpha transition to the 2.3 keV excited level (1/2-) in Pb-205, this allows us to adopt HF=1.3. From HF=1.3, alpha intensity is derived being approximately 80 %.
Then, for $p_{1/2}$ to $f_{5/2}$ alpha transitions, which interest us, i.e. the Po-209 alpha transition to the 5/2- ground state of Pb-205, the HF (= 6) is deduced from known (measured) HF for such alpha transitions (Rn-211 to Po-207: 6.75; Ra-213 to Rn-209: 6.39; Th-215 to Ra-211: 6.5) and then, an alpha intensity of approximately 20 % is derived.
Therefore, a ratio of 80/20 (1980Sc26) can be derived from HF systematic and analysis of level characteristics."

Then the total alpha transition intensity was deduced from the P($\alpha_{0,2}$) (= 0.548 (7) %) and P_{EC} (= 0.454 (7) %):

P($\alpha_{0,0}$ + $\alpha_{0,1}$) = 100 - P_{EC} - P($\alpha_{0,2}$) = 98.998 (10) %.

With this value of P($\alpha_{0,0}$ + $\alpha_{0,1}$), using the estimation P($\alpha_{0,1}$)/ P($\alpha_{0,0}$) = 80/20 and accepting a relative uncertainty equal to approximately 20 %, the evaluators have obtained the individual values:

P($\alpha_{0,1}$) = 79.2 (32) %
P($\alpha_{0,0}$) = 19.8 (32) %

2.2 Electron Capture Transition

The energy of the electron capture transition has been obtained from the Q(EC) value (2003Au03) and the ^{209}Bi level energy of 896.29 (5) keV given by M. J. Martin (1991Ma16).

The electron capture probability (P_{EC} = 0.454 (7) %) has been deduced from gamma-ray transition intensity imbalance at the 896-keV level.

P_K, P_L, P_M values have been calculated for 2nd forbidden unique electron-capture transition in the decay of ^{209}Po to the excited state in ^{209}Bi using the LOGFT computer program.

2.3 γ Transitions

The gamma-ray transition with energy of 2.328 (7) keV has not been observed directly in the ^{209}Po decay but it was studied in the decay of ^{209}Bi to ^{205}Pb (1971Jo06). The transition probability for this gamma-ray has been obtained from the intensity balance at the ^{205}Pb 2.3-keV level.

The transitions probabilities values for the remaining gamma-rays have been deduced using the γ-ray emission probabilities and the relevant internal conversion coefficients (see **4.2 Gamma Emissions**).

For the three (M1 + E2) γ transitions (^{205}Pb: 260- and 262-keV; ^{209}Bi: 896-keV), the mixing ratios (δ) were deduced by comparison between experimental values of K internal conversion coefficients and the theoretical K ICC calculated using the BrIcc computer code (2008Ki07).

Table 3 shows the experimental and evaluated values of α_K, as well as the deduced mixing ratios.

Table 3: Experimental and evaluated internal conversion coefficients and mixing ratios.

Energy (keV) Reference	260	262	896
G. R. Hagee (1966Ha29)	0.495 (10)	0.495 (10)	0.0170 (5)
A. M. Mandal (1989Ma05)	0.49 (5)	0.49 (5)	
F. Schima (1996Sc24)	0.538 (20)	0.524 (20)	
Evaluated α_K	0.503 (12)	0.500 (9)	0.0170 (5)
χ^2	1.9	0.9	-
δ (mixing ratio)	0.16 (6)	0.05 (7)	-0.62 (4)
α_K theoretical (BRICC)	0.503 (12)	0.500 (9)	0.0170 (5)
α_T theoretical (BRICC)	0.617 (13)	0.612 (10)	0.0208 (6)

The theoretical internal conversion coefficients (ICCs) and the associated uncertainties given in Table 3 have been obtained using the BrIcc computer code with “the frozen orbital approximation” (2008Ki07).

3 Atomic Data

Atomic values, ω_K, ϖ_L and n_{KL} and X-ray and Auger electron relative probabilities are from Schönfeld and Janβen (1996Sc06).

4 Emissions

4.1 K x-rays

The X-ray absolute emission probabilities have been calculated from the decay scheme data using the EMISSION computer program and compared in Table 4 with the measured values. These values are in a slight agreement; it is difficult to draw a definite conclusion because there is an unresolved doublet, the Bi $K_{\alpha 2}$ – Pb $K_{\alpha 1}$ at 74.89 keV, which is difficult to separate in the spectrum analysis.

Table 4: Experimental and recommended (calculated) values of K_α X-ray absolute emission probabilities.

	F. Schima (1996Sc24)	Recommended values
Bi K_α X-ray (74.82 – 77.11 keV)	0.202 (5)	0.248 (3)
Pb K_α X-ray (72.80 – 74.97 keV)	0.136 (5)	0.128 (2)

4.2 Gamma emissions

The energies of the γ-rays given in section 6.2 are from F. G. Kondev (2004Ko28).
The experimental and recommended values of γ-ray emission probabilities are given in Table 5.

Table 5: Experimental and recommended values of γ-ray emission probabilities.

E_γ (keV)	G. R. Hagee (1966Ha29)[a]	A. M. Mandal (1989Ma05)[b]	F. Schima (1996Sc24)	Recommended values.
260.5 (1)	0.391	100	0.254 (3)	0.254 (3)
262.8 (1)	0.391	33.3 (16)	0.085 (2)	0.085 (2)
896.6 (1)	0.263	108.1 (75)	0.445 (7)	0.445 (7)

[a] G. R. Hagee was unable to resolve the 260.5- and 262.8-keV γ-ray doublet and the values are given without uncertainties. Not used.
[b] A. M. Mandal quoted relative intensities normalized to the 260.5-keV γ-ray.

The Mandal values (1989Ma05) were omitted from analysis because of a lack of information in the article about the experimental measurements carried out and, therefore on the results. Then, the adopted values of the absolute emission intensities are the most recent values of F. J. Schima (1996Sc24).

5 Electron emissions

The conversion electron emission probabilities have been deduced from ICC values and γ-ray emission probabilities.

6 References

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^{210}Tl - Comments on evaluation of decay data
by V. Chisté and M. M. Bé

This evaluation was completed in 2007. Literature available by August 2007 has been included.

1 Decay Scheme

^{210}Tl disintegrates by beta minus emission to excited levels of ^{210}Pb. A weak delayed neutron emission was reported (1961St20 and 1957Ko42). Level energies, spins and parities are from the mass-chain evaluation of E. Browne (2003Br13) and B. Harmatz (1981Ha54).

This decay scheme is mainly based on the measurements of P. Weinzierl (1964We06). Several inconsistencies appeared :

- β branching to levels : 3879-, 3458-, and 3069-keV were deduced from γ-ray transition intensity imbalance. β^- feedings to the 1096 - and 1192-keV levels are uncertain. There is no experimental evidence for β^- transitions with energy > 3 MeV to these levels. β^- feedings the 1869-, 2208- and 2412-keV levels, suggested by γ-ray transition intensity imbalances (< 10 %, < 9 % and < 12 % , respectively), are uncertain.

- An 83-keV γ-ray is not placed in the present decay scheme as suggested by B. Harmatz (1981Ha54) (transition between 1275-keV level and 1192-keV level), because there is no experimental evidence that the 1275-keV level in ^{210}Pb was populated in the β^- decay of ^{210}Tl.

These discrepancies cannot be resolved without new experimental results. New measurements are strongly suggested.

Some agreement was found between the adopted Q(β^-) value of Audi and the effective Q(β^-) value of 5470 (1000) keV calculated from decay scheme data, which indicates a consistency and correctness of the decay scheme.

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).

Experimental ^{210}Tl half-life values (in minutes) are given in Table 1:

Table 1: Experimental values of ^{210}Tl half-life.

Reference	Experimental value (min)	Comments
M. Curie (1931Cu01)	1.32	Not used. No uncertainty.
A.V. Kogan (1957Ko42)	1.50 (25)	
P. Weinzierl (1964We06)	1.30 (3)	
Recommended value	**1.30 (3)**	χ^2 = 0.63

A weighted average has been calculated using Lweight computer program (version 3). The largest contribution to the weighted average comes from P. Weinzierl (1964We06), amounting to a statistical weight of 98 %.

The recommended value of ^{210}Tl half-life is the weighted average of 1.30 minutes with an internal uncertainty of 0.03 minutes. The reduced-χ^2 value is 0.63.

2.1 b$^-$ Transitions and Emissions.

The end-point energies of the β^- transitions in the decay of ^{210}Tl → ^{210}Pb have been obtained from the Q(β^-) value (2003Au03) and the level energies given by E. Browne (2003Br13).

The adopted β^- transition probabilities were deduced from the P(γ + ce) balance at each level of the decay scheme. Table 2 shows the adopted β^- transition probabilities compared with the only three β^- transitions reported by P. Weinzierl (1964We06). No β^- transitions with $E_{\beta-}$ > 3MeV were observed by these authors.

Table 2: Experimental and recommended (calculated) values of β^- transition probabilities.

Level	Energy (keV)	P. Weinzierl (1964We06)	Adopted values
11	1380 (12)	25 %	2 %
10	1603 (12)		7 %
9	1860 (12)	56 %	24 %
8	2024 (12)		10 %
7	2413 (12)	19 %	10 %
3	4290 (12)		31 %
2	4386 (12)		13 %

The sum of the adopted β^- transition probabilities is equal to 97 %. The 3 % missing cannot be placed in the decay scheme without more information about the β^- decay of ^{210}Tl.

The values of lg ft and the average β^- energies have been calculated using the computer program LOGFT for β^- transitions.

2.2 g Transitions.

The transition probabilities were deduced from the absolute γ-ray emission intensities and the relevant internal conversion coefficients. (see **5.2** g **Emissions**).

Multipolarities of the γ-ray transitions were deduced from conversion electron measurements and K/L ratios of 1964We06:

83-keV γ-ray: [E2]	97-keV γ-ray: M1 + E2	296-keV γ-ray: E2
356-keV γ-ray: [M1]	356-keV γ-ray: [M1]	799-keV γ-ray: E2
1070-keV γ-ray: [E1]		

The internal conversion coefficients (ICC's) for these γ-ray transitions were calculated using the BrIcc computer program (calculation for 'frozen orbital approximation'), which interpolates from theoretical values of I. M. Band *et al.* (2002Ba85).
Due to the large uncertainty on the 83- and 97-keV transition energy, only estimated ICC values are given.

3 Atomic Data.

Atomic values, ω_K, ϖ_L and n_{KL} and the X-ray relative probabilities are from Schönfeld and Janßen (1996Sc06).

4 Electron Emissions.

The conversion electrons emission probabilities have been deduced using the γ-ray emission intensities and ICC's.

5 Photon Emissions.

5.1 X-ray Emissions.

The X-ray absolute intensities have been calculated fromγ-ray data and ICC using the EMISSION computer program. The KX-ray intensity is compared in Table 3 to the measured value of P. Weinzierl (1964We06).

Table 3: Experimental and recommended (calculated) values of X-ray absolute intensities.

	P. Weinzierl (1964We04)	Recommended value
K x-ray	20 (4) %	23 (11) %

5.2 g Emissions.

The energies of the γ-ray emissions given in Section 5 are from E. Browne (2003Br13).

The experimental relative γ-ray emission intensities measured by P. Weinzierl (1964We06) (single experimental data set found in the literature) given in Table 4 are relative to that of the 799-keV γ-ray. Only one set of measured data (1964We06) is available.

Table 4: The experimental data set of the relative γ-ray emission intensities.

Energy (keV)	Relative γ-ray Emission intensity (%) (1964We06)
83 (a)	2.0
97	4 (2)
296	80 (10)
356 (a)	4 (2)
382 (a)	3 (2)
480	2 (1)
670 (a)	2 (1)
799	100
860	7 (2)
910 (a)	3 (2)
1070	12 (5)
1110	7 (2)
1210	17 (4)
1316	21 (5)
1410	5 (2)
1490 (a)	2 (1)
1540 (a)	2 (1)
1590	2 (1)
1650 (a)	2 (1)
2010	7 (2)
2090 (a)	5 (2)
2270	3 (2)
2360	8 (3)
2430	9 (3)

(a) γ-ray not placed in level scheme as explained in Weinzierl (1964We06).

The normalization factor of **98.969 (30)** to convert the relative γ–ray emission intensities to absolute intensities was obtained using the formula of :

$$N = \left(\frac{100}{(1 \; + \; a_T)P_{rel}(799g)} \right)$$

The uncertainties were calculated through their propagation on the above formula.

The evaluated relative and absolute γ-ray emission intensities are given in Table 5.

Table 5: Evaluated relative and absolute γ-ray emission intensities.

Energy (keV)	Relative γ-ray Emission intensity (%)	Absolute γ-ray emission intensity (%)
83(a)	2.0	1.98 (40)
97	4 (2)	4 (2)
296	80 (10)	79 (10)
356 (a)	4 (2)	4 (2)
382 (a)	3 (2)	3 (2)
480	2 (1)	2 (1)
670 (a)	2 (1)	2 (1)
799	100	98.969 (30)
860	7 (2)	6.9 (20)
910 (a)	3 (2)	3 (2)
1070	12 (5)	11.9 (49)
1110	7 (2)	6.9 (20)
1210	17 (4)	16.8 (40)
1316	21 (5)	20.8 (50)
1410	5 (2)	4.9 (20)
1490 (a)	2 (1)	2 (1)
1540 (a)	2 (1)	2 (1)
1590	2 (1)	2 (1)
1650 (a)	2 (1)	2 (1)
2010	7 (2)	6.9 (20)
2090 (a)	5 (2)	4.9 (20)
2270	3 (2)	3 (2)
2360	8 (3)	7.9 (30)
2430	9 (3)	8.9 (30)

(a) γ-ray not placed in level scheme as explained in Weinzierl (1964We06).

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^{210}Pb - Comments on evaluation of decay data
by V. Chisté and M. M. Bé

This evaluation was completed in 2007. Literature available by October 2007 has been included.

1 Decay Scheme

^{210}Pb disintegrates by beta minus emission to an excited level and to the ground state level of ^{210}Pb. A weak alpha transition to the ^{206}Hg ground state has been observed (1.9 (4) 10^{-6} %). Spins and parities are from the ENSDF mass-chain evaluations by E. Browne (2003Br13 for A = 210) and R. G. Helmer (1990He18 for A = 206).

The good agreement found between the adopted Q(β^-) value of Audi and the effective Q(β^-) value of 63.9 (11) keV calculated from decay scheme data indicates the completeness and correctness of the decay scheme.

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).

Experimental ^{210}Pb half-life values (in years) are given in Table 1:

Table 1: Experimental values of ^{210}Pb half-life.

Reference	Experimental value (a)	Comments
G. N. Antonoff (1910An**)	16.5	Not used. No uncertainty. ZnS counting.
I. Curie (1929Cu**)	23	Not used. No uncertainty. α counting.
M. Curie (1931Cu01)	19.5	Not used. No uncertainty.
F. Wagner (1950Wa**)	25.4 (15)	Ion Chamber.
R. J. Tobailem (1955To14)	19.40 (35)	Ion Chamber.
W. F. Merritt (1957Me47)	22.4 (4)	4π proportional counter.
G. Harbottle (1959Ha20)	20.4 (3)	Ion Chamber.
B. D. Pate (1959Pa03)	23.3 (5)	4π proportional counter.
W. R. Eckelmann (1960Ec01)	21.4 (5)	Geological.
L. Imre (1963Im02)	22.85 (70)	β counting.
H. Ramthun (1964Ra12)	21.96 (51)	Calorimetry.
H. R. von Gunten (1967Vo04)	22.2 (10)	Proportional counter.
A. Höndorf (1969Ho06)	22.26 (11)	α spectrometry.
G. A. Rech (2002Re18)	21.8 (3)	γ spectrometry.
Adopted value	**22.23 (12)**	χ^2 = 1.53

The weighted average has been calculated using LWEIGHT computer program (version 3).

The evaluators have chosen to take into account the eleven experimental values with reported uncertainties found in the literature and given in Table 1. The values of Wagner (1950Wa**), Tobailem (1955To14) and Harbottle (1959Ha20) are rejected by the LWEIGHT program, because they are outliers, based on the Chauvenet's criterion. The largest contribution (71 %) to the weighted average comes from the value of Höndorf (1969Ho06).

The adopted value of ^{210}Pb half-life is a weighted average of **22.23 a** and the external uncertainty of **0.12 a**. The reduced-χ^2 value is 1.53.

2.1 a Transitions and Emissions

The transition energy of the α-particles group to the ground of ^{206}Hg given in Section 2.1 is from Q_α (2003Au03).

For the probability of the α transition to the ground state of ^{206}Hg, the available published data are given in Table 2.

Table 2: Experimental and adopted values of the α transition probability to the ground state of ^{206}Hg.

Reference	Experimental value (10^{-6} %)	Comments
M. Nurmia (1961Nu01)	1.8 (5)	Superseded by 1962Ka27
P. Kauranen (1962Ka27)	1.7 (3)	
G. K. Wolf (1964Wo05)	2.7 (6)	
Adopted value	**1.9 (4)**	χ^2 = 2.22

The adopted value of α transition to the ground state of ^{206}Hg is the weighted average, calculated using LWEIGHT computer program, of **1.9 10^{-6} %** with the external uncertainty of **0.4 10^{-6} %**. The reduced-χ^2 value is 2.22.

2.2 b$^-$ Transitions and Emissions

The end-point energies of the β^- transitions in the decay of ^{210}Pb → ^{210}Bi have been obtained from the $Q_{\beta-}$ (2003Au03) value and the level energies of R. G. Helmer (1990He18), given in Table 3.

Table 3: ^{210}Bi level populated in the decay of ^{210}Pb.

Level Number	Level energy, (keV)	Spin and parity.
0	0	1^-
1	46.539 (1)	0^-

For these two levels, the adopted β^- transition probabilities and the associated uncertainties were deduced from the γ transition probability balance at each level of the decay scheme, taking into account, also the α transition probability to the ground state of ^{206}Hg. In the table 4, our adopted values of β^- transitions probabilities are compared with the experimental results found in the literature: C. S. Wu (1953Wu28), J. Tousset (1957To16 and 1958To10), W. Stanners (1956St99) and I. M. Rogachev (1963Ro31). Except to C. S. Wu (1953Wu28), a fair agreement has been found, within the uncertainty limits, between the experimental results and the recommended values for the 17-keV and 63.5-keV β^- transitions.

Table 4: Adopted and experimental values of β^- transition probabilities.

	17-keV β^- transition	63.5-keV β^- transition
C. S. Wu (1953Wu28)	92 (5) %	8 (5) %
J. Tousset (1957To16)		19 (4) %
J. Tousset (1958To10)	81 (14) %	19 (4) %
W. Stanners (1956St99)	84.5 (35) %	15.5 (35) %
I. M. Rogachev (1963Ro31)		≤ 19 (2) %
Adopted value	80.2 (13) %	19.8 (13) %

The values of lg ft and average β^- energies have been calculated with the program LOGFT for the 1st forbidden β^- transitions.

2.3 g Transitions

The 46.5-keV γ-ray transition probability was calculated using the γ-ray emission intensity (see **5.2** g **Emissions**) and the relevant internal conversion coefficient. Multipolarity of this γ-ray transition is M1 (from E. Browne (2003Br13)).

The internal conversion coefficients (ICC) and their associated uncertainties for 46.5-keV γ-ray transition have been calculated using the BrIcc computer program (calculation for 'hole'), which interpolated from theoretical values of I. M. Band (2002Ba85). The α_T value is then 17.86 (25) compared to the previous value of 19.0 (6) from Rösel tables.

3 Atomic Data

Atomic values, ω_K, $\overline{\omega}_L$ and n_{KL} and the X-ray relative probabilities are from Schönfeld and Janßen (1996Sc06).

4 Electron Emissions

The conversion electrons emission probabilities have been deduced using the γ-ray emission intensities and ICC's. The calculated total conversion electrons intensity of 75.2 (10) % is in fair agreement with the measured value of 81 (4) % from W. Stanners (1956St99).

5 Photon Emissions

5.1 X-ray Emissions

The X-ray absolute intensities have been calculated from γ-ray data and ICC using the EMISSION computer program and compared in Table 5 with the measured values found in the literature. For L_l, L_α and L_η x-rays, a good agreement was found between the experimental results given by 1987Me17 and 1990Sc08 and the recommended values deduced from decay scheme balance.

Table 5: Experimental and recommended (calculated) values of L X-ray absolute intensities.

	R. W. Fink (1957Fi06)	R. J. Gehrke (1971Ge11)	D. Metha (1987Me17)[a]	U. Schötzig (1990Sc08)	Recommended Values
L_l			0.584 (18)	0.55 (3)	0.552 (17)
L_α			10.27 (32)	9.48 (17)	10.3 (3)
L_η			0.074 (4)	0.075 (4)	0.075 (2)
L_β			11.6 (4)	10.9 (4)	9.05 (13)
L_γ			2.64 (8)	2.36 (5)	1.97 (3)
L total	23.8 (20)	22.8 (15)	25.2 (3)	23.4 (4)	22.0 (5)

[a] Normalized with I_γ (46.5-keV) = 4.252 (40) % (see **5.2** γ Emissions.)

5.2 g Emissions

The energy of the γ-ray emission given in Section 5 is from R. G. Helmer (1981He15 and 2000He14).

For the 46.5-keV γ-ray from ^{210}Bi, the experimental data set of absolute γ-ray emission intensity and adopted value in this evaluation are given in Table 6.

Table 6: The experimental data set of the relative γ-ray emission intensity.

Reference	Experimental values (%)	Comments
D. K. Butt (1951Bu37)	3.5 (4)	Not used by the evaluators.
C. S. Wu (1953Wu28)	2.8 (6)	Not used by the evaluators.
P. E. Damon (1954Da23)	3.8 (6)	Not used by the evaluators.
R. W. Fink (1957Fi06)	4.5 (4)	
I. Y. Krause (1958Kr71)	4.05 (8)	Not used by the evaluators.
K. Ya. Gromov (1969Gr33)	4.8 (6)	
K. Debertin (1983De11)	4.18 (9)	Superseded by 1990Sc08.
Y. Hino (1990Hi03)	4.26 (7)	
U. Schötzig (1990Sc08)	4.24 (5)	
Adopted value	4.252 (40)	$\chi^2 = 0.42$

The sets of values from D. K. Butt (1951Bu37), C. S. Wu (1953Wu28) and P. E. Damon (1954Da23) were omitted from analysis due to discrepancy with the other data and a lack of information in the articles about experimental measurements carried out and, therefore on the results.

The original uncertainty given by I. Y. Krause (1958Kr71) (= 0.08) seems under-estimated for the measurement method (NaI spectrometry) then it was decided to omit this value from the analysis.

The adopted value for 46.5-keV γ-ray emission intensity is the weighted average, calculated using LWEIGHT computer program, of **4.252 %** with the internal uncertainty of **0.040 %**. The reduced-χ^2 value is 0.42.

The evaluated absolute 46.5-keV γ-ray emission and transition probabilities are given in Table 7.

Table 7: Recommended absolute 46.5-keV γ-ray emission and transition probabilities.

Energy (keV)	Absolute γ-ray emission probability (%)	Absolute γ-ray transition probability (%)
46.539 (1)	4.252 (40)	80.2 (13)

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^{210}Bi - Comments on evaluation of decay data
by V. Chisté and M. M. Bé

This evaluation was completed in 2008. Literature available by January 2008 was included.

1 Decay Scheme

^{210}Bi disintegrates by beta minus emission to the ground state level of ^{210}Po. Weak alpha transitions to excited levels of ^{206}Tl have been observed (1.40 (15) 10^{-4} %). Spins and parities are from the ENSDF mass-chain evaluations E. Browne (2003Br13 for A = 210). For ^{206}Tl, spins and parities are from L. I. Rusinov measurements (1961Ru02).

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).

Experimental ^{210}Bi half-life values (in days) are given in Table 1:

Table 1: Experimental values of ^{210}Bi half-life.

Reference	Experimental value (d)	Comments
A. Pompéi (1935Po01)	5.02 (1)	Ionization chamber.
N. Hole (1944Ho**)	5.15 (10)	GM counter.
F. Begemann (1952Be22)	5.02 (2)	GM counter.
E. E. Lockett (1953Lo09)	4.989 (13)	Ionization chamber.
J. Robert (1956Ro18)	5.013 (5)	Ionization chamber.Superseded by 1959Ro51
J. Robert (1959Ro51)	5.013 (5)	Ionization chamber.
Recommended value	**5.012 (5)**	χ^2 = 1.32

The weighted average has been calculated using the LWEIGHT computer program (version 3).

The evaluators have chosen to use just five experimental values with uncertainties given in Table 1. The value of Hole (1944Ho**) has been rejected by the LWEIGHT program because it is an outlier, based on the Chauvenet's criterion. With this data set, the largest contribution to the weighted average comes from the value of Robert (1959Ro51) amounting to 68 % of the total statistical weight.

The recommended value of ^{210}Bi half-life is the weighted average of **5.012 d** with an external uncertainty of **0.005 d**. The reduced-χ^2 value is 1.32.

2.1 a Transitions and Emissions

The recommended values of emission energies of the α-particles are given by A. Rytz (1991Ry01).

Table 2: Experimental values of emission energies of the α-particles.

Reference	$\alpha_{0,1}$ (keV)	$\alpha_{0,2}$ (keV)	Comments
R. J. Walen (1960Wa14)	4686 (2)	4649 (2)	Uncertainty given by Rytz.
P. Kauranen (1962Ka27)	4700	4660	Not used: no uncertainty.
R. C. Lange (1969La18)	4697 (5)	4660 (5)	Uncertainty given by Rytz.
Recommended value (1991Ry01)	**4687 (4)**	**4650 (4)**	χ^2 = 4.2. External uncertainty.

Several experimental values of the α branching to ^{206}Tl are given in Table 3.

Table 3: Experimental and recommended values of total α branching for $^{210}Bi \rightarrow {}^{206}Tl$.

Reference	Experimental value (10^{-4} %)	Comments
E. Broda (1947Br36)	0.5	Not used: no uncertainty.
R. J. Walen(1959Wa05)	1.25	Not used: no uncertainty.
R. W. Fink (1956Fi09)	1.7 (2)	
M. Nurmia (1961Nu01)	1.9 (4)	Superseded by 1962Ka27
P. Kauranen (1962Ka27)	1.32 (10)	
Recommended value	**1.40 (15)**	$\chi^2 = 2.9$

The weighted average has been calculated using the LWEIGHT computer program (version 3).

The value given by M. Nurmia (1961Nu01) is from the same laboratory as 1962Ka27, thus, it was not included in the averaging procedure. Then, the recommended alpha transition branching is the average of the values given by R. W. Fink (1956Fi09) and P. Kauranen (1962Ka27).

The recommended value of α transitions to the excited levels of ^{206}Tl is the weighted average of **1.40 10^{-4} %** with an external uncertainty of **0.15 10^{-4} %**. The reduced-χ^2 value is 2.9.

The individual α particle probabilities to the 265 -keV and 304-keV levels are (1959Wa05, 1960 Wa14) 0.56 (6) 10^{-4} % and 0.84 (9) 10^{-4} %, respectively.

2.2 b$^-$ Transitions and Emissions

The end-point energy of the β^- transition in the decay of $^{210}Bi \rightarrow {}^{210}Po$ is from the $Q_{\beta-}$(2003Au03). The recommended and experimental values are shown in Table 4.

Table 4: Experimental and recommended values of the end-point energy of the β^- transition.

Reference	$E_{\beta-}$ (keV)
A. Flammersfeld (1939Fl02)	1170
G. J. Neary (1940Ne04)	1170
E. A. Plassmann (1954Pl30)	1155 (5)
H. Daniel (1962Da03)	1160.5 (5)
S. T. Hsue(1967Hs01)	1161.5 (15)
D. Flothmann (1969Fl02)	1153
Recommended value (2003Au03)	**1162.1 (8)**

For the $\beta_{0,0}$ transition probability and associated uncertainty, the following relation was applied:
$P_{\beta 0,0} = 100\ \% - P_{\alpha}$,
where $P_{\alpha} = 1.40\ (15)\ 10^{-4}$ % (see 2.2 α Transitions and Emissions). Then: $P_{\beta 0,0} = 99.99986\ (2)$ %.

The lg ft value and the average β^- energy have been calculated with the program LOGFT for a 1st forbidden transition.

2.3 g Transitions and Emissions

Multipolarity of γ-ray transitions are from L. I. Rusinov (1961Ru02):
265-keV γ-ray: E2
304-keV γ-ray: M1

The γ-ray transition probabilities following the α-decay of $^{210}Bi \rightarrow {}^{206}Tl$ were deduced from the decay-scheme balance using the recommended α-particle intensity values given in section 2.1 α Transitions and Emissions, shown in Table 5.

Table 5: Adopted values of α transition and γ-ray emission probabilities.

γ-ray energy (keV)*	α probability (%)	γ-ray absolute transition probability (%)	γ-ray absolute emission probability (%)
265.832 (5)	0.000 056 (6)	0.000 056 (6)	0.000 048 (5)
304.896 (6)	0.000 084 (9)	0.000 084 (9)	0.000 061 (7)

*From 1999Br39

The γ-ray emission intensities were obtained using theγ-ray transition probabilities (given in Table 6)and the relevant internal conversion coefficients, calculated using the BrIcc computer code (calculation for 'hole'), which interpolated from theoretical values of I. M. Band (2002Ba85) .

3 Atomic Data

Atomic values, ω_K, ϖ_L and n_{KL} are from Schönfeld and Janβen (1996Sc06).

4 References

1935Po01 – A. Pompéi, J. Phys. Radium 6(1935)471 [Half-life].
1939Fl02 – A. Flammersfeld, Z. Phys. 112(1939)727 [$E_{\beta-}$].
1940Ne04 – G. J. Neary, Proc. Roy. Soc. (London) 175A(1940)71 [$E_{\beta-}$].
1944Ho** – N. Hole, Ark. Mat., Astron. Fys. 31B(1944)1 [Half-life].
1947Br36 – E. Broda, N. Feather, Proc. Roy. Soc. (London) 191A(1947)20 [α- branching].
1952Be22 – F. Begemann, F. G. Houtermans, Z. Naturforsch. 7a(1952)143 [Half-life].
1953Lo09 – E. E. Lockett, R. H. Thomas, Nucleonics 11(1953)14 [Half-life].
1954Pl30 – E. A. Plassmann, L. M. Langer, Phys. Rev. 96(1954)1593 [$E_{\beta-}$].
1956Ro18 – J. Robert, J. Tobailem, J. Phys. Radium 17(1956)440 [Half-life].
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1959Ro51 – J. Robert, Ann. Phys. (Paris) 4(1959)440 [Half-life].
1959Wa05 – R. J. Walen, G. Bastin-Scoffier, J. Phys. Radium 20(1959)589 [α- branching].
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1962Ka27 – P. Kauranen, Ann. Acad. Sci. Fennicae, Ser. A VI, 96(1962) [α- branching, E_α].
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1969Fl02 – D. Flothmann, W. Wiesner, R. Löhken, H. Rebel, Z. Phys. 225(1969)164 [$E_{\beta-}$].
1969La18 – R. C. Lange, G. R. Hagee, A. R. Campbell, Nucl. Phys. A133(1969)273 [E_α].
1991Ry01 – A. Rytz, At. Data Nucl. Data Tables 47(1991)205 [E_α].
1996Sc06 – E. Schönfeld, H. Janβen, Nucl. Instrum. Meth. Phys. Res. A369(1996)527 [Atomic data].
1999Br39 – E. Browne, Nucl. Data Sheets 88(1999)29 [level energy].
2002Ba85 – I. M. Band, M. B. Trzhaskovskaya, C. W. Nestor, Jr., P. O. Tikkanen, S. Raman, Atomic Data Nucl. Data Tables 81(2002)1 [Theoretical ICC].
2003Au03 – G. Audi, A. H. Wapstra, C. Thibault, Nucl. Phys. A729(2003)129 [Q].
2003Br13 – E. Browne, Nucl. Data Sheets 99(2003)483 [Spin, parity, level energy].

^{210}Po - Comments on evaluation of decay data
by V. Chisté and M. M. Bé

This evaluation was completed in 2008. Literature available by February 2008 was included.

1 Decay Scheme

^{210}Po disintegrates by alpha emission to the 803 -keV excited level and ground state level of ^{206}Pb. Energy levels, spins and parities are from the ENSDF mass -chain evaluations R.G. Helmer (1990He18) and E. Browne (1999Br39).

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).

Experimental ^{210}Po half-life values (in days) are given in Table 1:

Table 1: Experimental values of ^{210}Po half-life.

Reference	Experimental value (d)	Comments
E. V. Schweidler (1912Sc**)	136.5	Not used: no uncertainty.
M. Curie (1920Cu**)	140.0	Not used: no uncertainty.
A. Dorabialska (1931Do**)	137.6 (6)	Calorimetry.
A. S. Sanielevici (1936Sa**)	139.6 (14)	Calorimetry.
W. H. Beamer (1949Be54)	138.30 (14)	Calorimetry.
D. C. Ginnings (1953Gi10)	138.39 (14)	Calorimetry.
M. L. Curtis (1953Cu46)	138.374 (32)	α counting.
J. F. Eichelberger (1954Ei20)	138.400 (6)	Calorimetry. Not used. Superseded by 1964EiZZ.
J. F. Eichelberger (1964EiZZ)	138.3763 (17)	Calorimetry
Recommended value	**138.3763 (17)**	$\chi^2 = 0.10$

The weighted average has been calculated using LWEIGHT computer program (version 3).

The evaluators have chosen to use six experimental values with uncertainty found in the literature and given in Table 1. The values of A. Dorabialska (1931Do**) and A. S. Sanielevici (1936Sa**) have been rejected by the LWEIGHT program, they are statistical outliers, based on the Chauvenet's criterion. With this data set, the largest contribution (99 %) to weighted average comes from the value of J. F. Eichelberger (1964EiZZ).

The recommended value of ^{210}Po half-life is the weighted average of **138.3763 d** with an internal uncertainty of **0.0017 d**. The reduced-χ^2 value is 0.10.

2.1 a Transitions and Emissions

The recommended value of $\alpha_{0,0}$ emission energy is given by A. Rytz (1991Ry01), based on a measurement by D. J. Gorman (1973Go39). The experimental and recommended values of $\alpha_{0,0}$ emission energy are shown in Table 2.

Table 2: Experimental and recommended (calculated) values of $\alpha_{0,0}$ emission energy.

Reference	$\alpha_{0,0}$ emission energy (keV)	Comments
S. Rosenblum (1933Ro03)	5298 (6)	
W. B. Lewis (1934Le01)	5298 (21)	
E. R. Collins (1953Co64)	5304.3 (29)	
G. H. Briggs (1954Br07)	5300.6 (26)	Evaluated value reported by author.
I. I. Agapkin (1957Ag15)	5297.8 (15)	
F. A. White (1958Wh09)	5305.4 (10)	
C. P. Browne (1960Br20)	5308.6 (30)	
E. H. Beckner (1961Be13)	5302.5 (15)	
A. Rytz (1961Ry05)	5304.9 (6)	
D. J. Gorman (1973Go39)	5304.51 (7)	
Recommended value (1991Ry01)	**5304.33 (7)**	

For $\alpha_{0,1}$, the emission energy has been obtained from Q_α(2003Au03) = 5407.46 (7) keV and the level energy given in Table 3 from R. G. Helmer (1990He18).

Table 3: ^{206}Pb excited level populated in the decay of ^{210}Po.

Level Number	Level energy, (keV)	Spin and parity.
1	803.10 (5)	2^+

The emission intensities of the α-particles have been deduced from the P(γ + ce) decay scheme balance at each level and shown in Table 4.

Table 4: Emission intensities of the α-particles.

α emission energy (keV)	Emission Intensities (%)
4516.66 (9)	0.00124 (4)
5304.33 (7)	99.99876 (4)

The ratio Iα(4516)/ Iα(5304), with the recommended values (Table 4), is 1.24 (4) 10^{-5}, which can be compared with the measured value of 1.07 (2) 10^{-5} (1958Ba45).

2.2 g Transitions

The transition probability was calculated using the experimental 803 -keV γ-ray emission intensity and the relevant internal conversion coefficient (see **4.2** g **Emissions**).

Multipolarity of the 803-keV γ-ray transition (E2) is given by S. de Benedetti (1952De08).

The internal conversion coefficient (ICC) for the the 803 -keV γ-ray transition has been interpolated from theoretical values of I. M. Band (2002Ba85) using the BRICC computer program (calculation for 'hole').

3 Atomic Data

Atomic values, ω_K, $\bar{\omega}_L$ and n_{KL} and the X-ray relative probabilities are from Schönfeld and Janßen (1996Sc06).

4 Photon Emissions

4.1 X-rays

The X-ray absolute intensities have been calculated from γ-ray data and ICC using the EMISSION computer program.

4.2 g Emissions

The energies of the γ-ray emission given in section 5.2 is from R. G. Helmer (1990He18).

For the 803-keV γ-ray, the experimental data set of γ-ray emission intensity is given in Table 5.

Table 5: The experimental data set of the γ-ray emission intensity.

Reference	Experimental values (10^{-3} %)	Comments
M. A. Grace (1951Gr15)	1.80 (14)	
M. Riou (1952Ri04)	1.6 (2)	
W. C. Barber (1952Ba20)	1.5 (4)	
O. Rojo (1955Ro30)	1.20 (12)	
R. W. Hayward (1955Ha09)	1.21 (6)	
A. Ascoli (1956As46)	1.21 (8)	
N. S. Shimanskaia (1956Sh24)	1.2 (2)	
V. V. Ovechkin (1957Ov09)	1.22 (9)	
Recommended value	**1.23 (4)**	χ^2 = 0.69

The weighted average has been calculated using LWEIGHT computer program (version 3).

The evaluators have used the eight experimental values given with uncertainties in the literature and shown in Table 5. The value of M.A. Grace (1951Gr15) has been rejected by the LWEIGHT program, as statistical outlier, based on the Chauvenet's criterion. In the data set of seven values, the largest contribution (41%) to the weighted average comes from the value of R.W. Hayward (1955Ha09).

The recommended value of the relative γ-ray emission intensity is the weighted average of **1.23 10^{-3} %** with the internal uncertainty of **0.04 10^{-3} %**, and a reduced-χ^2 value of 0.69.

5 References

1912Sc** – E. V. Schweidler, Verh. Deutsch Phys. Ges. 14(1912)539 [Half-life].
1920Cu** – M. Curie, J. Phys. Radium 1(1920)12 [Half-life].
1931Do** – A. Dorabialska, Roczniki Chem. (Poland) 11(1931)475 [Half-life].
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1934Le01 – W. B. Lewis, B. V. Bowden, Proc. Roy. Soc. (London) A145(1934)235 [E_α].
1936Sa** – A. S. Sanielevici, J. Chim. Phys. 33(1936)759 [Half-life].
1949Be54 – W. H. Beamer, C. R. Maxwell, J. Chem. Phys. 17(1949)1293 [Half-life].
1951Gr15 – M. A. Grace, R. A. Allen, D. West, H. Halban, Proc. Roy. Soc. (London) A64(1951)493 [I_γ].
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1952Ri14 – M. Riou, J. Phys. Radium 13(1952)244 [I_γ].
1952De08 – S. de Benedetti, G. H. Minton, Phys. Rev. 85(1952)944 [Multipolarity].
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1953Cu46 – M. L. Curtis, Phys. Rev. 92(1953)1489 [Half-life].
1953Co64 – E. R. Collins, C. D. McKenzie, C. A. Ramm, Proc. Roy. Soc. (London) 216A(1953)219 [E_α].
1954Br07 – G. H. Briggs, Rev. Mod. Phys. 26(1954)1 [E_α].
1954Ei20 – J. F. Eichelberger, K. C. Jordan, S. R. Orr, J. R. Parks, Phys. Rev. 96(1954)719 [Half-life].
1955Ha09 – R. W. Hayward, D. D. Hoppes, W. B. Mann, J. Res. Nat. Bur. Stand. 54(1955)47 [I_γ].
1955Ro30 – O. Rojo, M. A. Hakeem, M. Goodrich, Phys. Rev. 99(1955)1629 [I_γ].
1956As46 – A. Ascoli, M. Asdente, E. Germagnoli, Nuovo Cim. 4(1956)946 [I_γ].
1956Sh24 – N. S. Shimanskaia, Soviet Phys. JETP 4(1957)165 [I_γ].
1957Ag15 – I. I. Agapkin, L. L. Gol'din, Bull. Acad. Sci. USSR 21(1958)911 [E_α].
1957Ov09 – V. V. Ovechkin, Bull. Acad. Sci. USSR 21(1958)1627 [I_γ].
1958Ba45 – G. Bastin -Scoffier, R. J. Walen, Compt. Rend. Acad. Sci. (Paris) 247(1958)2333 [$I\alpha(4516)/I\alpha(5304)$].

1958Wh09 – F. A. White, F. M. Rourke, J. C. Shefield, R. P. Schuman, J. R. Huizenga, Phys. Rev. 109(1958)437 [E_α].
1960Br20 – C. P. Browne, J. A. Galey, J. R. Erskine, K. L. Warsh, Phys. Rev. 120(1960)905 [E_α].
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1973Go39 – D. J. Gorman, A. Rytz, Compt. Rend. Acad. Sci. (Paris), Ser. B277(1973)29 [E_α].
1990He18 – R. G. Helmer, Nucl. Data Sheets 61(1990)93 [Energy level, spin, parity].
1991Ry01 – A. Rytz, At. Data Nucl. Data Tables 47(1991)205 [E_α].
1996Sc06 – E. Schönfeld, H. Janβen, Nucl. Instrum. Meth. Phys. Res. A369(1996)527 [Atomic data].
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2002Ba85 – I. M. Band, M. B. Trzhaskovskaya, C. W. Nestor, Jr., P. O. Tikkanen, S. Raman, Atomic Data Nucl. Data Tables 81(2002)1 [Theoretical ICC].
2003Au03 – G. Audi, A. H. Wapstra, C. Thibault, Nucl. Phys. A729(2003)129 [Q].

^{211}Pb - Comments on evaluation of Decay Data

By F.G. Kondev

This evaluation was completed in March 2011, with a literature cut off by the same date, as a part of ANL commitment to the IAEA-CRP on “Updated Decay Data Library for Actinides”.

1. Decay Scheme

The nuclide ^{211}Pb ($J^{\pi}=9/2^{+}$) disintegrates 100 % by β^{-} emissions. The strongest β^{-}-decay branch of 91.28 (12) % populates the $J^{\pi}=9/2^{-}$ ground state of the daughter nuclide ^{211}Bi. The level schemes of ^{211}Pb and ^{211}Bi, including J^{π} values, are based on the ENSDF evaluation of Browne (2004Br45).

2. Nuclear Data

Adopted Q(β^{-}) value of 1367 (6) keV is taken from the evaluation of Audi *et al.* (2003Au03).

The experimental data for the half-life of the ^{211}Pb ground state are very scarce. The value of 36.1 (2) min that is included in ENSDF (2004Br45) originates from the work of Sargent (1939Sa11) and Nurmia (1965Nu03). This value is adopted in the present evaluation, but new measurements are certainly required to confirm this value.

2.1. β^{-} Transitions

The values for the maximum β^{-}-decay energies ($E_{\beta-,max,}$ presented in Table 1) were derived from Q(β^{-}) = 1367 (6) keV (2003Au03) and the level energies deduced in the present evaluation, as detailed in section 2.2. The β^{-}-decay transition probabilities (P_{β}) were deduced from the decay scheme and the corresponding absolute γ–ray transition probabilities. Log *ft* values were calculated using the *LOGFT* program from the ENSDF evaluation package, based on the work of Gove and Martin (1971Go40).

2.2. Gamma Transitions and Electron Internal Conversion Coefficients

The γ–ray transition energy data are presented in Table 2. Statistical analysis using the *LWEIGHT* program has been performed, and the resulting gamma-ray energies are listed in column 13 of Table 2. With those energies, the level scheme was fitted using the *GTOL* program from the ENSDF analysis package, and new level energies were obtained (shown in Table 1). Then adopted gamma-ray energies were determined from the corresponding level energies.

The γ–ray transition multipolarities and mixing ratios were taken from the ENSDF evaluation of Browne (2004Br45). The electron conversion coefficients were calculated using the *BrIcc* code (2008Ki07).

Table 1. Level energies, quantum numbers, $E_{\beta0,\iota\ max}$, P_{β} and log *ft* values in the β^{-} decay of ^{211}Pb ($J^{\pi}=9/2^{+}$).

Level energy (keV)	J^{π}	$E_{\beta-\ max}$ (keV)	P_{β} (%)	Nature	log *ft*
1270.75 (6)	(7/2,9/2,11/2)-	96 (6)	0.0172 (15)	first forbidden non-unique	5.93
1234.3 (4)		133 (6)	0.0009 (3)	-	-
1196.33 (5)		171 (6)	0.019 (4)	-	-
1109.509 (23)	9/2-	257 (6)	1.06 (4)	first forbidden non-unique	5.58
1103.52 (20)		263 (6)	0.0047 (7)	-	-
1080.64 (4)		286 (6)	0.0570 (24)	-	-
1014.38 (4)	(7/2,9/2,11/2)-	-	-	-	-
831.984 (12)	9/2-	535 (6)	6.32 (9)	first forbidden non-unique	5.73

Level energy (keV)	**J$^{\pi}$**	**$E_{\beta- max}$ (keV)**	**P_{β} (%)**	**Nature**	**log *ft***
766.680 (13)	(9/2,11/2)-	600 (6)	< 0.09	first forbidden non-unique	> 7.7
404.834 (9)	7/2-	962 (6)	1.57 (9)	first forbidden non-unique	7.21
0.0	9/2-	1367 (6)	91.28 (12)	first forbidden non-unique	5.99

The gamma-ray emission probability data are presented in Table 3. The reported values were determined relative to $I_{\gamma}(351.07_{\gamma}) = 100$ %, where the 351.07 keV transition depopulates the first $3/2^{+}$ level of the ^{207}Tl nuclide fed in the α decay of ^{211}Bi. The statistical analysis using the *LWEIGHT* program has been performed and *deduced* intensities were obtained (column 14 of Table 3). Using the absolute emission probability of $I_{\gamma}(351.07_{\gamma}) = 13.06$ (12) % (2011Ko04) and %α (^{211}Bi) = 99.724 (4) % (2004Br45), a normalization factor of 0.1302 (12) was obtained. This value was used to determine the *adopted* gamma-ray emission probabilities, which are shown in the last column of Table 3.

A number of weak transitions, summarized in Table 4, have been assigned to the β^{-} decay of ^{211}Pb by 1988Hi14 (five gamma rays), 1971Da34 (nine gamma rays), 1968Ha21 (three gamma rays) and 1968Br17 (one gamma ray). However, the experimental information presented in those articles is insufficient to assign these gamma rays unambiguously to the decay of ^{211}Pb, and hence they were not placed in the proposed decay scheme. None of the above publications reported the same unplaced gamma rays, which facilitated the conclusion made in this evaluation to exclude them from the proposed decay scheme. Further work, including gamma-ray coincidence studies, is merited to obtain a more complete decay scheme for ^{211}Pb.

3. Atomic Data

The atomic data (fluorescence yields, X-ray energies and relative probabilities, and Auger electrons energies and relative probabilities) were provided by the SAISINUC software (2008DuZX). Details regarding the origin of these data can be found in 1996Sc06, 1998ScZM, 1999ScZX, 2000Sc47 and 2003De44.

4. Data Consistency

The adopted Q_{β}-value of 1367 (6) keV (2003Au03) has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{211}Pb beta-decay process (i.e. β^{-}, conversion electrons, γ, etc.):

$$Q_{\beta-}(\text{calc}) \quad = \quad \sum (E_i \times P_i) \quad = \quad 1368\ (6)\ \text{keV}$$

Percentage deviation from the Q-value of Audi *et al.* is 0.0731 (5) %, which supports the derivation of a highly consistent decay scheme.

Table 2. Measured, deduced and adopted gamma-ray energies in β^-–decay of ^{211}Pb.

1988Hi14	1976Bl13	1971Da34	1968Br17	1968Go15	1968Ha21	1967Da20	1967Da10	1965Co06	1965Me07	1963Va05	1962Gi03	deduced, keV	adopted, keV
	65.420 (14)		65.5 (2)	65.4 (2)		65.7 (10)	65.5 (5)		65.502 (8) g)			65.420 (14)	65.304 (18)
		95.0 (2)		95.0 (6)		94.5 (5)						95.0 (2)	95.13 (5)
313.64 (12)	313.58 (9)	313.8 (2)	313.6 (3)	313.6 (5)		313.5 (10)	313 (1)	290 (10)	310 (3)			313.59 (9)	313.96 (4)
342.02 (12)	342.90 (4)*	342.7 (2)		342.7 (3)			342.5 (10)		340 (3)			342.91 (4)	342.829 (26)
	362.062 (17)*		362.9 (5) ?									362.072 (17)	361.846 (16)
404.89 (12)	404.843 (10)	404.84 (4)	404.8 (1)	404.8 (1)	405	404.8 (5)	404.7 (3)	400 (7)	404.84 (4) g)	404	405 (5)	404.853 (10)	404.834 (9)
427.14 (12)	427.078 (10)	426.99 (4)	427.0 (1)	426.9 (1)	427	427.1 (5)	427.0 (3)	430 (7)	426.99 (4) g)	426	425 (5)	427.088 (10)	427.150 (15)
				429.1 (5)								429.1 (5)	429.65 (6)
504.12 (12)		503.3 (4)		503.6 (7)								504.12 (12)	504.07 (6)
	609.33 (4)*	609.5 (2)	609.1 (2)	609.3 (5)		610 (2)			612 (5) f)		615 (5)	609.38 (4)	609.55 (4)
	676.65 (7)*		676.6 (3)	675.2 (3)				650 (10)				676.69 (7)	675.81 (4)
704.66 (12)	704.59 (3)	704.5 (1)	704.5 (2)	704.3 (2)	702	703.3 (8)	703.8 (3)	706 (7)	702 (3)	700	700 (5)	704.64 (3)	704.675 (25)
766.45 (12)	766.47 (3)	766.34 (7)	766.3 (2)	766.4 (1)	766	766.2 (8)	766.2 (3)	758 (7)	766.34 (7) g)		755 (10)	766.51 (3)	766.680 (13)
832.02 (12)	831.96 (3)	831.83 (4)	831.8 (1)	831.8 (1)	832	831.8 (5)	831.7 (5)	830 (7)	831.83 (4) g)	830	830 (2)	832.01 (3)	831.984 (12)
865.87 (24)	865.88 (14)	865.6 (3)	865.5 (3)	865.2 (2)		866 (2)	864 (1)		860 (10)			865.93 (14)	865.92 (6)
1014.71 (12)	1014.59 (5)	1014.7 (2)	1014.4 (3)	1014.1 (5)		1014.8 (10)	1014 (1)		1020 (3)		1020 (10)	1014.64 (5)	1014.38 (4)
1080.10 (13)	1080.11 (6)	1080.2 (1)	1080.0 (3)	1080.0 (5)	1076	1080.9 (10)	1079 (1)	1060 (15)	1076 (3)			1080.16 (6)	1080.64 (4)
1103.52 (20)	1103.7 (8)	1103.4 (4)	1103.0 (6) ?									1103.52 (20)	1103.52 (20)
1109.48 (13)	1109.43 (5)	1109.5 (2)	1109.8 (3)	1109.1 (1)	1106	1109.6 (8)	1108.5 (10)	1100 (15)	1104 (2)	1104	1100 (5)	1109.48 (5)	1109.509 (23)
1196.15 (14)	1196.28 (5)	1196.6 (2)	1196.1 (3)	1195.5 (5)		1196.6 (10)	1194 (1)		1188 (2)			1196.33 (5)	1196.33 (5)
		1234.3 (4)	1234.6 (10)									1234.3 (4)	1234.3 (4)
1270.79 (18)	1270.66 (8)	1270.8 (2)	1270.3 (3)	1270.0 (5)	1265	1271.2 (10)	1269 (1)		1265 (2)			1270.71 (8)	1270.75 (6)

*) value omitted from the statistical data analysis.
g) value reported in 1965Me07, but measured by A. Green, PhD thesis, University of California at Davis with Ge detector (unpublished).

Table 3. Measured, deduced and adopted gamma-ray emissions probabilities for gamma-transitions in β^-–decay of ^{211}Pb.

Eg, keV	1988Hi14	1976Bl13	1971Da34	1968Br17	1968Go15	1968Ha21	1967Da20	1967Da10	1965Co06	1965Me07	1963Va05	1962Gi03	deduced, rel	adopted, %
65		0.57 (6)	0.60 (4)	0.58 (11)			0.10 (5) *	~0.35 *		0.5 (2)			0.59 (3)	0.077 (4)
95			0.14 (2)					~0.10					0.14 (2)	0.018 (3)
314		0.20 (3)	0.24 (3)	0.19 (4)	0.10 (5)		0.26 (5)	0.21 (7)	0.90 (21) *	~0.2 *			0.206 (16)	0.0268 (21)
343		1.63 (13) *	0.27 (4)		0.15 (5)					~0.3 *			0.22 (3)	0.029 (4)
362		0.326 (24)		0.30 (8)									0.324 (23)	0.042 (3)
405	29.3 (9)	30.2 (14)	30.0 (9)	30.8 (15)	29.6 (20)	28.6 (11)	28.0 (28)	29.9 (35)	30.6 (28)	27.4 (12)	26 (5)	34(4)	29.4 (4)	3.83 (6)
427	13.9 (4)	14.2 (7)	13.5 (6)	14.3 (8)	13.7 (10)	11.6 (7)	14.0 (14)	13.9 (17)	21.5 (21) *	14.5 (14)	12.5 (25)	22 (3) *	13.9 (3)	1.81 (4)
429					0.065 (25)								0.065 (25)	0.008 (3)
504	0.045 (6)		0.12 (2) *		~ 0.006 *								0.045 (6)	0.0059 (8)
610		0.407 (24) *	0.18 (3)	0.38 (4)	0.25 (5)		0.30 (6)	0.21 (7)		0.9 (2) *		0.76 (13) *	0.25 (7)	0.033 (9)
676		0.130 (8)		0.173 (15)	0.10 (5)				1.3 (3) *				0.139 (7)	0.0181 (9)
705	3.6 (1)	3.6 (3)	3.77 (19)	3.68 (23)	3.7 (3)	2.9 (1) *	3.0 (3)	3.3 (4)	5.3 (6) *	3.7 (2)	3.8 (11)	5.5 (4) *	3.61 (7)	0.47 (1)
767	4.94 (16)	5.1 (4)	5.55 (28)	5.04 (30)	4.9 (3)	4.5 (1)	4.0 (4)	5.1 (6)	6.3 (6)	5.2 (2)		6.1 (4)	4.8 (3)	0.62 (4)
832	26.7 (8)	25.4 (20)	29.8 (7) *	25.6 (23)	24.1 (17)	27.4 (4)	23.0 (23)	26.4 (35)	26.4 (28)	27.4 (12)	24.8 (25)	34.2 (13) *	26.9 (3)	3.50 (5)
866	0.042 (6)	0.033 (4)	0.050 (8)	0.053 (15)	0.07 (2)		0.03 (1)	0.0347 (14)		0.04 (2)			0.0354 (13)	0.0046 (2)
1014	0.129 (8)	0.122 (8)	0.14 (1)	0.128 (15)	0.15 (1)		0.13 (2)	0.125 (21)		0.14 (2)		0.38 (19) *	0.133 (4)	0.0173 (5)
1081	0.095 (6)	0.090 (7)	0.120 (12)	0.083 (10)	0.08 (1)	0.0025 (1) *	0.08 (2)	0.104 (14)	0.49 (7) *	0.13 (12) *			0.093 (4)	0.0121 (5)
1104	0.033 (4)	0.049 (5)	0.040 (6)	0.023 (5)									0.036 (5)	0.0047 (7)
1110	0.90 (3)	0.82 (6)	1.15 (8)	0.79 (8)	0.81 (6)	0.0105 (7) *	0.70 (15)	0.87 (10)	0.83 (14)	1.03 (10)	1.07 (16)	1.46 (19) *	0.891 (21)	0.116 (3)
1196	0.072 (5)	0.081 (6)	0.10 (1)	0.079 (15)	0.08 (1)		0.08 (2)	0.076 (14)		0.11 (3)			0.079 (3)	0.0103 (4)
1234			0.010 (2)	0.0053 (15)									0.0070 (23)	0.0009 (3)
1271	0.043 (4)	0.057 (5)	0.070 (7)	0.048 (8)	0.08 (1)	0.0006 (1) *	0.05 (1)	0.042 (7)		0.06 (2)			0.052 (9)	0.0068 (12)

*) value omitted in the statistical data analysis.

Table 4. Gamma-ray energies and emission probabilities (relative to $I_\gamma(351.07\gamma) = 100$) for transitions that were not placed in the proposed decay scheme of ^{211}Pb.

Eγ, keV	1988Hi14	1971Da34	1968Ha21	1968Br17
81.0 (2)		0.35 (9)		
83.8 (1)		0.45 (7)		
88.2 (2)		0.13 (3)		
94.3 (3)		0.09 (2)		
97.3 (2)		0.09 (1)		
244			0.003 (1)	
275			0.004 (1)	
478.0 (4)		0.10 (2)		
479.6 (2)	0.04 (1)			
481.1 (4)		0.20 (4)		
481.92 (12)	0.08 (1)			
491.82 (12)	0.032 (6)			
494.2 (3)	0.013 (5)			
500.4 (5)		0.09 (2)		
502.0 (2)	0.028 (6)			
951			0.0017 (1)	
1090.5 (5)		0.020 (5)		
1120 (1)				0.0019 (11)

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^{211}Bi – Comments on Evaluation of Decay Data
by A. Luca

This evaluation was completed in July 2009. The literature available by December 31st, 2008 was included.

1. Evaluation Procedures

The Limitation of Relative Statistical Weight (LWM) method was applied for averaging numbers throughout this evaluation; this method was implemented by using the computer code LWEIGHT, ver. 4 (designed for Excel, MS Office). The uncertainty assigned to an average value in this evaluation is never lower than the lowest uncertainty of any of the experimental input values.

2. Decay Scheme

^{211}Bi decays 99.724 (4) % by alpha particle emissions, populating the ^{207}Tl ground state (83.56 (23) %) and the 351.03 keV excited state (16.16 (23) %). ^{211}Bi has also a weak beta minus decay branch (0.276 (4) %) to the ground state of ^{211}Po; although these β^- particles were not observed experimentally (the low intensity beta-particle emission is obscured by the intense β^- particles emission from the ^{211}Pb sources used for measurements), the existence of the beta minus decay and the adopted value of the corresponding branching ratio are based on the alpha-particle spectrometry measurements of the emission probabilities ratio, $I\alpha(^{211}Po)/(I\alpha(^{211}Po)+I\alpha(^{211}Bi))$, performed by several scientists (see references from Table 1). The adopted value represents the weighted mean of the experimental results published in the literature (see also Table 1, below); an earlier value, 0.32 % (without a quoted uncertainty), determined by Rutherford et al. (1931), was not taken into account. Another important study of the ^{211}Bi decay scheme is presented in the reference 1966Go13. The most recent evaluations of the ^{211}Bi nuclear structure, alpha and beta minus decay data, published in Nuclear Data Sheets, were made by M. J. Martin (1993) and E. Browne (2004). In the present evaluation, the spin and parity of the levels have been adopted from the above mentioned A = 207 and A = 211 ENSDF mass-chain evaluations (1993Ma73 and 2004Br45, respectively).

Table 1: Beta minus branching ratio for the ^{211}Bi decay

Beta minus branching ratio (experimental), %	Reference
0.274 (4)	1967Da10
0.274 (10)	1965Nu03
0.29 (1)	1962Gi04
Recommended value: 0.276 (4) %	

3. Nuclear Data

The adopted alpha decay energy value Q(α) = 6750.33 (46) keV, is from 2003Au03. This value is in very good agreement with the effective Q(α) value of 6750.63 keV (with an uncertainty of 0.21 keV), calculated from the decay scheme data, by using the SAISINUC software, version 2008 April. The adopted beta minus decay energy value Q(β) = 574 (5) keV is also from 2003Au03.

3.1. Half-life

In the literature, four measured ^{211}Bi half-life ($T_{1/2}$) values are reported. All these measurements are old (the most recent is from 1970), so new half-life measurements are needed to improve the quality of the evaluation. The half-life values and their uncertainties are presented in Table 2.

The value recommended by Curie et al. (1931), with an estimated uncertainty added by the evaluator, was included, too. The uncertainty of other two results (1954Sp32 and 1965Nu03) was also estimated by the evaluator. The set of data is consistent and the recommended value, 2.15 minutes, with an uncertainty of 0.02 minutes, is the weighted average (LWM, χ^2_ν=3.7) of the four input values.

Table 2 : ^{211}Bi Half-life values

$T_{1/2}$ (minutes)	Uncertainty of $T_{1/2}$ (minutes)	Reference
2.16	0.08	1931Cu01
2.15	0.02	1954Sp32
2.13	0.03	1965Nu03
2.22	0.06	1970Mu21

3.2. Alpha and Beta transitions and emissions

In the literature, the most important reference that studies measurements of alpha-particle energies and emission intensities for ^{211}Bi alpha transitions is 1991Ry01.

For this evaluation, the two adopted alpha-particle emission energies were calculated as weighted means of the experimental values presented in Table 3 (both data sets are consistent):

Table 3: Energy of the alpha-particles emitted in the ^{211}Bi decay

Alpha-particle group	Energy of the alpha particles (experimental), keV	Reference
$\alpha_{0,1}$	6300 (10)	1989It01
	6278.2 (7)	1991Ry01
	6279 (1)	1992Sc26
	Recommended energy value: 6278.5 (9) keV	
$\alpha_{0,0}$	6622.9 (6)	1971Gr17 and 1991Ry01
	6620 (10)	1989It01
	6621.33 (69)	1991Ry01
	6623 (1)	1992Sc26
	Recommended energy value: 6622.4 (6) keV	

The ratio of the 6278.5 keV to the sum of 6278.5 keV and 6622.4 keV alpha-particle emission probabilities was determined in a similar way, as the weighted mean of four experimental values reported in the literature and presented below, in Table 4. This data set is discrepant and, consequently, the uncertainty was expanded to include in its range the most precise relative value (16.43 (4) from 1967Da10); the adopted value is 16.20 (23). Considering both the experimental results and the normalization condition (modified to take into account the beta minus decay, see section 2), i.e. the sum of the two absolute alpha-particle emission probabilities must be 100 % - 0.276 (4) % = 99.724 (4) %, the computed absolute emission probability of the 6278.5 keV alpha-particles is 16.16 (23) %. The 6622.4 keV alpha-particles absolute emission probability is then 83.56 (23) %.

The beta minus transition is of the first order forbidden type (non-unique) and populates the ground state of ^{211}Po. The beta particles must have a maximum energy of 574 keV (corresponding to the Q(β) value) and an absolute emission probability of 0.276 (4) %. The adopted values of the average beta minus energy (172.9 (18) keV) and log ft (5.99) were obtained by using the LOGFT computer program.

Table 4: Experimental values of the relative alpha-particles emission probability ratio (6278.5 keV) / (6278.5 keV + 6622.4 keV)

Alpha-particle emission probability ratio (6278.5 keV) / (6278.5 keV + 6622.4 keV) x 100	Reference
15.8 (1)	1962Gi04
15.9 (3)	1962Wa18
16.02 (5)	1966Go13
16.43 (4)	1967Da10

3.3. γ- transitions: γ rays and internal conversion electrons

There is a single gamma-ray transition following the ^{211}Bi decay. Both its energy and emission probability were studied by many scientists. Table 5 summarizes the experimental results published in the literature. The adopted energy of this gamma-ray transition is the weighted mean of the 6 values from Table 5 (consistent data set): 351.03 (4) keV.

The absolute emission probability of this gamma-ray was determined from the alpha feeding of 16.16 (23) % to the ^{207}Tl excited state: 16.16 (23) / 1.243 (4) = 13.00 (19) %, where 0.243 (4) is the total internal conversion coefficient (total ICC), which is in good agreement with the experimental values reported in references 1976Bl13 and 1982Mo30 (see Table 5).

All the internal conversion coefficients (ICCs) adopted in this evaluation were computed with the program BrIcc, version 2.2 /2008, using the "Frozen Orbitals" approximation (2008Ki07). The energy range of the internal conversion electrons corresponding to the gamma-ray transition is from 265.5 keV to 351.02 keV, whereas the total number of conversion electrons emitted per 100 disintegrations is 3.17 (7) (i.e.3.17 (7) %)

Table 5: ^{211}Bi γ-ray Energy and Absolute Emission Probability (experimental values)

E_γ (keV)	Uncertainty E_γ (keV)	Absolute Emission Probability (%)	Uncertainty of absolute emission probability (%)	Reference
351.0	0.1	10.70	0.30	1968Br17
351.0	0.3			1973UrZX
351.01	0.04			1975VaYT
351.07	0.05	12.27	1.4	1976Bl13
351.89	0.20	13.3	1.3	1982Mo30
351.06	0.12			1988Hi14

4. Atomic data

The K-shell fluorescence yield (ω_K), the mean L-shell fluorescence yield (ϖ_L) and the mean number of vacancies in the L-shell produced by one vacancy in the K-shell (η_{KL}) were determined using the computer program EMISSION v.3.10, 28-Jan-2003: 0.963 (4), 0.367 (15) and 0.812 (5) respectively.

4.1. Auger electrons and X-rays

The relative probability values of the K Auger electron emissions (KLL, KLX, KXY) normalized to the KLL value, were computed using the same EMISSION computer program. The total numbers of K and L Auger electrons emitted per disintegration were also calculated (in %): 0.096 (11) and 1.620 (21), respectively. The energy ranges for K and L Auger electrons were filled-in by the SAISINUC program, version 2008 April.

The relative probability (normalized to $K_{\alpha1}$ X-rays emission) and the absolute emission probability values of the different groups of K and L X-rays were determined using the same EMISSION program. The adopted values (in %) of the total absolute emission probability of the KX-rays and LX-rays were 2.50 (6) and 0.931 (19), respectively. The energy range values of the K and L X-rays are from the tables linked to SAISINUC.

Only one reference reporting the measurement of the ^{207}Tl KX-rays energies and emission probabilities was found in the literature (1976Bl13). A comparison between these experimental values and the results of this evaluation is presented in Table 6.

For the two K_α X-rays the results are in very good agreement for energy and unsatisfactory for the absolute emission probability values. The Tl-Kα2 and Tl-Kα1 x-ray absolute emission probabilities reported in 1976Bl13 are about 30 % lower than expected (See Table 6). The cause of this serious disagreement is unknown.

For the two K_β X-rays, the energy values are in good agreement, whereas the absolute emission probabilities values again are in clear disagreement. There are at least two possible causes of this disagreement:

- the evaluated values refer to a sum of three components, not only to $K\beta_1$, respectively $K\beta_2$ (see the Note below Table 6);
- the measurements reported in the article 1976Bl13 include also the Rn $K\alpha_1$ X-rays with an energy of 83.788 keV, situated just between the two components of interest; the presence of this additional peak makes the spectral analysis of this region more difficult, considering the software tools available in 1976 (a higher uncertainty than reported for the experimental results is possible).

This second assumption is supported by the very good agreement between the sum of Tl-$K\beta_1$ and Tl-$K\beta_2$ absolute emission probabilities (in %), according to Table 6: 0.542 (12) (evaluated) and 0.55 (6) (experimental).

Neither measurements of ^{207}Tl LX-rays energies nor of emission probabilities were found in the literature, in order to compare them with the results of this evaluation.

Table 6: Comparison of the evaluated Tl KX-rays energy and absolute emission probability values with experimental results from 1976Bl13

X-rays identification	Evaluated energy (keV)	Evaluated Absolute Emission Probability (in %)	Experimental energy (keV)	Experimental absolute emission probability (in %) (1976Bl13)
Tl-Kα_2	70.832	0.726 (16)	70.839 (13)	0.51 (8)
Tl-Kα_1	72.872	1.225 (27)	72.857 (10)	0.82 (12)
Tl-Kβ_1	82.577	0.417 (11) *	83.019 (80)	0.24 (4)
Tl-Kβ_2	84.838	0.124 (4) *	84.720 (50)	0.31 (4)

* Note: the evaluated absolute emission probabilities of the two K_β X-rays include not only the contributions of the Kβ_1 and Kβ_2 components, but also Kβ_3, K''β_5, Kβ_4 and KO$_{2,3}$.

5. Main production mode

The main production mode of ^{211}Bi is by beta minus decay of the ^{211}Pb nuclei (both nuclides are members of the Actinium-Uranium natural radioactive series). ^{211}Bi can be produced also by the alpha decay of ^{215}At (a process of very low probability in the above mentioned radioactive series, because ^{215}At is produced by the weak beta minus decay branch of ^{215}Po, which is about $2.3\cdot10^{-4}$ %).

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^{211}Po – Comments on Evaluation of Decay Data
by A. Luca

This evaluation was completed in August 2009. The literature available by December 31st, 2008 was included.

1. Evaluation Procedures

The Limitation of Relative Statistical Weight (LWM) method was applied for averaging numbers throughout this evaluation; this method was implemented by using the computer code LWEIGHT, ver. 4 (designed for Excel, MS Office). The uncertainty assigned to an average value in this evaluation is never lower than the lowest uncertainty of any of the experimental input values.

2. Decay Scheme

^{211}Po decays 100 % by alpha particle emissions, mainly to the ground state of ^{207}Pb. The most recent evaluations of the ^{211}Po nuclear structure and decay data, published in Nuclear Data Sheets, were done by E. Browne (2004) and M.J. Martin (1993). In the present evaluation, the spin, parity and energy of the levels, together with the multipolarities and mixing ratios of the γ-ray transitions, have been adopted from the A=207 ENSDF mass-chain evaluation 1993Ma73.This data evaluation refers only to the decay of the ^{211}Po ground state, and not to the decay of the ^{211}Po metastable state at 1462 keV (with a half-life of 25.2 s).

3. Nuclear Data

The adopted alpha decay energy value Q(α)=7594.48 (51) keV, is from 2003Au03. This value is in very good agreement with the effective Q(α) value of 7594.2 (20) keV, deduced from average radiation energies from the decay scheme data, by using the SAISINUC software, version 2008 April.

3.1. Half-life

In the literature, five measured ^{211}Po half-life ($T_{1/2}$) values are reported. The value from 1931Cu01 is unrealistically low (in strong disagreement with all the other values), and was excluded from the data set, according to the Chauvenet's criterion implemented by the LWEIGHT computer code. The half-life values and their uncertainties are presented in Table 1. The value recommended by Curie et al. (1931), with an estimated uncertainty added by the evaluator, has been also included. The set of data, excluding the value given in 1931Cu01 is consistent and the recommended half-life value, 0.516 (3) s, is the weighted average (LWM, χ^2_ν=3.7) of the four input values. The reference *Nuclear Science References* (NSR) keynumbers are:

Table 1 : ^{211}Po Half-life values

$T_{1/2}$ (seconds)	Uncertainty of $T_{1/2}$ (seconds)	Reference
0.005	0.005	1931Cu01
0.52	0.02	1954Sp32
0.5	0.1	1954Wi26
0.56	0.04	1958To25
0.516	0.003	1974Ba29

3.2. Alpha transitions and emissions

The most important reference in the literature that studies measurements of alpha-particle energies and emission intensities for ^{211}Po alpha transitions is 1991Ry01.

For this evaluation, three adopted alpha-particle energies were deduced as weighted means of the experimental values presented in Table 2; the complete data set of the main alpha-particle group (7450.2 keV) is consistent, while from the other two data sets, the values from 1953AsZZ were rejected from the weighted mean computations, according to Chauvenet's criterion. The hindrance factors were determined by using the ALPHAD version 2.0a (2006) computer program (developed at BNL/NNDC, USA).

Table 2: Energy of the alpha-particles emitted in the ^{211}Po decay

Alpha-particle group	Energy of the alpha particles (experimental), keV	Reference
$\alpha_{0,2}$	6570 (10)	Leininger et al. (1951)
	6570 (40)	1951Ne02
	6560 (10)	1953AsZZ
	6569 (20)	1953Ho49
	6571 (4)	1968GuZX
	6570.0 (25)	1969Go23
	6568 (1)	1978Ya04
	Recommended energy value: 6568.4 (10) keV	
$\alpha_{0,1}$	6900 (10)	Leininger et al. (1951)
	6900 (40)	1951Ne02
	6880 (10)	1953AsZZ
	6895 (20)	1953Ho49
	6890.7 (25)	1962Wa18
	6891 (4)	1968GuZX
	6892.5 (25)	1969Go23
	6891 (1)	1978Ya04
	Recommended energy value: 6891.2 (10) keV	
$\alpha_{0,0}$	7430 (40)	1951Ne02
	7430 (20)	1953Ho49
	7442 (15)	1954Br07
	7450.3 (2)	1962Wa18, updated in 1991Ry01
	7440 (30)	1963Jo09
	7448 (4)	1968GuZX
	7449.8 (30)	1969Go23, updated in 1991Ry01
	7460 (20)	1969Ha32
	7448 (10)	1970Va13
	7443.3 (20)	1982Bo04, updated in 1991Ry01
	7456.2 (30)	1985La17, updated in 1991Ry01
	Recommended energy value: 7450.2 (3) keV	

The reference 1951Ne02 is the only one that reports the detection of another group of alpha particles emitted in the decay of ^{211}Po, with an energy of 6340 (60) keV and an emission probability of $7\cdot10^{-4}$. In the report UCRL-2325 (1953), R.W. Hoff doesn't confirm the detection of this alpha-particle decay branch, but establishes that there are no alpha-particle groups with emission probabilities higher than $2\cdot10^{-4}$, in the energy range from 6.26 MeV to 6.57 MeV. In a similar study presented in 1969Go23, a maximum limit of $2\cdot10^{-5}$ is given for the emission probability of any alpha-particle group in the energy range (5.88 to 6.43) MeV. As there is no other experimental data to confirm the existence of this branch, the evaluator adopted a decay scheme with only the three alpha particle groups given in Table 2.

The recommended emission probabilities of the alpha-particle emissions of 6568.4 keV and 6891.2 keV are the weighted means of the published experimental values, presented in

Table 3. From the first data set in this table, the values of 1978Ya04 (0.58 (1) %) and 1951Ne02 (0.48 (5) %) were rejected by the Chauvenet's criterion. A similar procedure, applied to the second data set from Table 3, lead to the rejection of the value published in the reference 1962Wa18 (0.70 (14) %).

The adopted emission probability of the main alpha-particle emission, 7450.2 keV, was computed from the normalization condition (the sum of the three alpha-particle emission probabilities is 100 %): 98.936 (19) %.

Table 3: Emission probabilities of the alpha-particles emitted in the ^{211}Po decay

Alpha-particles energy (keV)	Experimental emission probability (%)	Reference
6568.4	0.5 (1)	Leininger et al. (1951)
	0.48 (5)	1951Ne02
	0.53 (1)	1953AsZZ
	0.53 (5)	1953Ho49
	0.53 (3)	1968GuZX
	0.537 (19)	1975Ja04
	0.58 (1)	1978Ya04
	0.513 (9)	1985La17
	Recommended emission probability: 0.523 (9) %; HF=17.9	
6891.2	0.6 (1)	Leininger et al. (1951)
	0.57 (5)	1951Ne02
	0.50 (1)	1953AsZZ
	0.50 (5)	1953Ho49
	0.70 (14)	1962Wa18
	0.57 (3)	1968GuZX
	0.546 (19)	1975Ja04
	0.60 (1)	1978Ya04
	0.524 (9)	1985La17
	Recommended emission probability: 0.541 (17) %; HF=272	
7450.2	**Recommended emission probability: 98.936 (19) %; HF=112**	

3.3. γ- transitions: γ rays and internal conversion electrons

There are only few papers that report measurements of the γ-ray energies and emission probabilities following the ^{211}Po decay: 1954Mi70 and 1975Ja04 (energy values), 1968Br17 and 1985La17 (absolute emission probabilities), respectively. 1975Ja04 and 1972As11 report relative emission probabilities.

The adopted gamma-ray energy values are the weighted means of the experimental values published in 1954Mi70 and 1975Ja04, as presented below in Table 4 (for the 328 keV photons just one measurement was made, and published in 1975Ja04):

Table 4: Gamma-rays energy values in the decay of ^{211}Po

Experimental energy values (keV)	Reference
562 (5)	1954Mi70
569.65 (10)	1975Ja04
Recommended energy value: 569.65 (15) keV	
880 (8)	1954Mi70
897.8 (1)	1975Ja04
Recommended energy value: 897.8 (2) keV	
328.2 (2)	1975Ja04
Recommended energy value: 328.2 (2) keV	

Using the measured 328.2 keV gamma-ray relative photon intensity of 0.6 (2) (the intensity of the 569.65 keV photons is considered as 100, see reference 1975Ja04), the internal conversion coefficients and the intensity balance for each of the two excited states of ^{207}Pb, the corresponding absolute gamma-ray emission probabilities and their uncertainties were computed for all the three γ rays; these data are given below in Table 5. A comparison between the evaluated data and the experimental values (included in the same table, with the corresponding references) shows a good agreement, with the exception of the relative emission probability of 897.8 keV reported by 1985La17.

The internal conversion coefficients were computed with the program BrIcc, version 2.2b/20-Jan-2009, using the "Frozen Orbitals" approximation. In the article of L.J. Jardine (1975), an experimental value of 0.016 (3) was determined for the K-conversion coefficient associated to both gamma-ray transitions of 569.65 keV and 897.8 keV; this value is in good agreement with the theoretical ICC's, computed with BrIcc: 0.01583 (23), respectively 0.0192 (3).

Table 5: γ-rays absolute and relative emission probabilities in the decay of ^{211}Po

E_γ (keV)	Recommended Absolute Emission Probability (%)	Experimental Absolute Emission Probability (%)	Evaluated relative emission probabilities	Experimental relative emission probabilities	Total ICC (α_T)
328.2	0.0032 (11)		0.6 (2)*	0.6 (2)^c	0.334 (5)
569.65	0.534 (17)	0.534 (19)^a 0.512 (36)^b	100	100.0 (14)^b 100^{c,d}	0.0216 (3) E2
897.8	0.507 (9)	0.535 (40)^b	94.9 (35)	104.4 (20)^b 97 (5)^c 83 (11)^d	0.0233 (4) M1

Note: a – reference 1968Br17; b – reference 1985La17; c – reference 1975Ja04;
d – reference 1972As11 (renormalized); * - value adopted from reference 1975Ja04.

4. Atomic data

The K-shell fluorescence yield (ω_K), the mean L-shell fluorescence yield (ϖ_L) and the mean number of vacancies in the L-shell produced by one vacancy in the K-shell (η_{KL}) were determined using the computer program EMISSION v.3.10, 28-Jan-2003: 0.963 (4), 0.379 (15) and 0.811 (5) respectively.

4.1. Auger electrons and X-rays

The relative probability values of the K Auger electron emissions (KLL, KLX, KXY) normalized to the KLL value, were computed using the EMISSION computer program. The total numbers of K and L Auger electrons emitted per 100 disintegrations were also calculated as 0.00071 (8) and 0.01216 (17), respectively. The energy ranges for K and L Auger electrons were filled-in by the SAISINUC program, version 2008 April.

The relative probability (normalized to $K_{\alpha 1}$ X-rays emission) and the absolute emission probability values of the different groups of K and L X-rays were deduced using the EMISSION program. The adopted values of the total absolute emission probability of the KX-rays and LX-rays were 0.0184 (5) % and 0.00740 (16) %, respectively. The energy range values of the K and L X-rays are from the tables linked to SAISINUC.

Neither measurement of ^{207}Pb KX-rays and LX-rays energies nor of emission probabilities was found in the literature in order to compare it with the results of this evaluation.

5. Main production mode

The main production mode of ^{211}Po is by β^- decay of the ^{211}Bi nuclei (in the Actinium-Uranium natural radioactive series).

6. References

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^{211}At - Comments on evaluation of decay data

by A. L. Nichols

Evaluated: August 2010

Evaluation Procedure

Limitation of Relative Statistical Weight Method (LWM) was applied to average the decay data when appropriate.

Decay Scheme

A reasonably simple decay scheme was constructed from the α-particle and γ-ray measurements of Hoff (1953Ho49), Gray (1956Gr11), Golovkov *et al.* (1969Go23), Jardine (1975Ja04), and Chumin *et al.* (2001Ch66), and studies of the α branching fraction by Neumann and Perlman (1951Ne02), Golovkov *et al.* (1969Go23), Afanasiev *et al.* (1970AfZZ), Jardine (1975Ja04), Yanokura *et al.* (1978Ya04), and Lambrecht and Mirzadeh (1985La17).

Nuclear Data

^{211}At is an important α-emitting radionuclide in therapeutic nuclear medicine, along with daughter ^{211}Po.

Half-life

The recommended half-life of 7.216 (7) hours has been adopted from five sets of measurements (1956Gr11, 1959Ra08, 1961Ap01, 1962Th08, 1978Ya04).

Half-life measurements

Reference	Half-life (hours)
1956Gr11	7.20 ± 0.05
1959Ra08	7.23 ± 0.04
1961Ap01	7.214 ± 0.007
1962Th08	7.17 ± 0.09
1978Ya04	7.23 ± 0.02
Recommended value	7.216 ± 0.007

A half-life of 0.516 (3) second was adopted for ^{211}Po from the DDEP evaluation of Luca (July-November 2009), while the ^{207}Bi half-life of 32.9 (14) years was taken from the DDEP evaluation of Bé and Chisté (December 2009). More recently, a further re-evaluation of the half-life of ^{207}Bi by Kondev and Lalkovski resulted in a recommended value of 31.55 (4) years (2011Ko04).

Branching fractions

Neumann and Perlman (1951Ne02), Golovkov *et al.* (1969Go23), Afanasiev *et al.* (1970AfZZ), Jardine (1975Ja04), Yanokura *et al.* (1978Ya04), and Lambrecht and Mirzadeh (1985La17) have determined the α branching fraction for ^{211}At. These data were used to derive an alpha branch of 41.78 (8) %, along with a matching electron-capture branch of 58.22 (8) %.

Reference	BF_α
1951Ne02	0.409 ± 0.005
1969Go23	0.418 ± 0.002
1970AfZZ	0.413 ± 0.013
1975Ja04	0.419 ± 0.005
1978Ya04	0.4174 ± 0.0010
1985La17	0.4194 ± 0.0016
Recommended value	0.4178 ± 0.0008
α branch	(41.78 ± 0.08) %

Q values

Q_{EC} of 785.4 (25) keV and Q_α of 5982.4 (13) keV were adopted from the evaluated tabulations of Audi *et al.* (2003Au03).

Alpha Particles

Alpha-particle measurements reveal a relatively simple α-decay mode (1969Go23, 1975Ja04, 1991Ry01, 2001Ch66). The Q_α of 5982.4 (13) keV (2003Au03) and nuclear level energies as defined by Kondev and Lalkovski (2011Ko04) were used to calculated the alpha-particle energies, while the alpha-particle emission probabilities were primarily adopted from the measurements of Golovkov *et al.* (1969Go23), Afanasiev *et al.* (1970AfZZ), Jardine (1975Ja04) and Chumin *et al.* (2001Ch66).

Alpha-particle emission probabilities per 100 disintegrations of ^{211}At, and hindrance factors.

E_α(keV)	P_α					HF
	1969Go23[*]	1970AfZZ[†]	1975Ja04[#]	2001Ch66[#]	Recommended value	
4895.4 (13)	–	–	–	< 0.000 04	< 0.000 04	> 9.6
4993.4 (13)	–	~ 0.000 4 ?	–	–	~ 0.000 4	~ 3.8
5140.3 (13)	0.001 7 (9)	0.001 5	0.001 0 (3)	0.001 1 (2)	0.001 1 (2)	10.1
5211.9 (13)	0.005 4 (8)	0.006 7	0.003 6 (8)	0.003 9 (3)	0.003 9 (3)	7.3
5869.0 (13)	41.8 (2)	[41.78]	41.93	41.80	41.78 (8)	1.59

[*] Calculated from measurements of the relative alpha-particle emission probabilities.

[†] Calculated from measurements of the relative alpha-particle emission probabilities, but no uncertainties listed; absolute emission probability of 41.78 % was adopted for the 5869.0-keV α particle to convert other data in this study to comparable absolute values.

[#] Calculated from measurements of the relative gamma-ray emission probabilities.

An unweighted mean value of 1.422 (13) was adopted for the radius parameter $r_0(^{207}Bi)$ as derived from the equivalent data for neighboring nuclei (1998Ak04), and used in the calculation of α-hindrance factors (HF):

$$\begin{aligned} r_0(^{207}\mathrm{Bi}) &= [r_0(^{206}\mathrm{Pb}) + r_0(^{208}\mathrm{Po})] / 2 \\ &= [1.40882(10) + 1.4343(34)] / 2 \\ &= 1.422\ (13) \end{aligned}$$

Gamma Rays

Energies

All gamma-ray transition energies and uncertainties were calculated from the structural details of the proposed decay scheme. Nuclear level energies were adopted from Browne for ^{211}Po and from Kondev and Lalkovski for ^{207}Bi (2004Br45, 2011Ko04).

Emission Probabilities

The absolute emission probabilities of the 149.72-, 222.69-, 669.77-, 742.74- and 892.46-keV gamma rays from the α-decay branch were derived from a combination of the alpha-particle emission probabilities populating the ground state and 669.77-, 742.74-, 892.46- and 992.43-keV nuclear levels of ^{207}Bi (1969Go23, 1970AfZZ), relevant relative emission probabilities for these gamma rays (1975Ja04, 1985La17), theoretical internal conversion coefficients of Band *et al.* (2002Ba85, 2008Ki07), and depopulating ratios of the 149.72-, 222.69- and 892.46-keV gamma transitions as quantified by Kondev and Lalkovski (2011Ko04). A weighted mean value of 0.245 (12) was adopted for the absolute emission probability of the 687.7-keV gamma ray from the EC-decay branch, based on the gamma-ray spectroscopy studies of Jardine (1975Ja04) and Lambrecht and Mirzadeh (1985La17).

Gamma-ray emission probabilities relative to 100 % for the 569.7-keV gamma ray of daughter ^{211}Po.

E_γ (keV)	P_γ^{rel}		
	1975Ja04	**1985La17**	**Recommended value**
[569.70]	100	100.0 (14)	–
669.77 (7)	1.1 (2)	–	–
687.2 (7)	79 (4)	83.0 (20)	82 (2)
742.74 (7)	0.3 (1)	–	–

Absolute gamma-ray emission probabilities per 100 disintegrations of ^{211}At.

	E_γ (keV)	P_γ^{abs}		
		1975Ja04*	**1985La17**	**Recommended value**
$\gamma_{3,2}$ (Bi)	149.72 (10)	–	–	~ 0.000 05
$\gamma_{3,1}$ (Bi)	222.69 (10)	–	–	~ 0.000 04
$\gamma_{1,0}$ (Bi)	669.77 (7)	0.003 4 (6)	–	0.003 8 (3)
$\gamma_{1,0}$ (Po)	687.2 (7)	0.245 (12)	0.247 (26)	0.245 (12)
$\gamma_{2,0}$ (Bi)	742.74 (7)	0.000 9 (3)	–	0.001 25 (19)
$\gamma_{3,0}$ (Bi)	892.46 (7)	–	–	~ 0.000 14

* Derived from an absolute emission probability of 0.31 (2) per 100 decay of ^{211}At for the 569.70-keV gamma transition within the α decay of daughter ^{211}Po.

Multipolarities and Internal Conversion Coefficients

The nuclear level schemes specified by Browne for ^{211}Po and Kondev and Lalkovski for ^{207}Bi have been used to define the multipolarities of the gamma transitions on the basis of known spins and parities (2004Br45, 2011Ko04). All known gammas are (M1 + E2) transitions, and their mixing ratios have been derived on the basis of the studies of Astner and Alpsten (1970As07), Schmidt-Ott and Dincklage (1978Sc12), and Herzog *et al.* (1983He09). Recommended internal conversion coefficients have been determined from the frozen orbital approximation of Kibédi *et al.* (2008Ki07), based on the theoretical model of Band *et al.* (2002Ba85, 2002Ra45).

Gamma-ray emissions: recommended energies, emission probabilities, multipolarities and theoretical internal conversion coefficients (frozen orbital approximation).

	E_γ (keV)	P_γ^{abs}	Multipolarity	α_K	α_L	α_{M+}	α_{tot}	
$\gamma_{3,2}$ (Bi)	149.72 (10)	~ 0.000 05	86.2 % M1 + 13.8 % E2 δ = 0.40 (20)	2.3 (3)	0.50 (4)	0.2	3.0 (3)	α
$\gamma_{3,1}$ (Bi)	222.69 (10)	~ 0.000 04	86.2 % M1 + 13.8 % E2 δ = 0.40 (10)	0.76 (5)	0.147 (2)	0.043	0.95 (5)	α
$\gamma_{1,0}$ (Bi)	669.77 (7)	0.003 8 (3)	94.1 % M1 + 5.9 % E2 δ = 0.25 (3)	0.042 6 (8)	0.007 25 (12)	0.002 15	0.052 0 (9)	α
$\gamma_{1,0}$ (Po)	687.2 (7)	0.245 (12)	96.15 % M1 + 3.85 % E2 δ = -0.20 (2)	0.043 7 (7)	0.007 52 (12)	0.002 38	0.053 6 (9)	EC
$\gamma_{2,0}$ (Bi)	742.74 (7)	0.001 25 (19)	91.7 % M1 + 8.3 % E2 δ = 0.30 (3)	0.032 0 (6)	0.005 44 (10)	0.001 66	0.039 1 (7)	α
$\gamma_{3,0}$ (Bi)	892.46 (7)	~ 0.000 14	33.8 % M1 + 66.2 % E2 δ = 1.4 (2)	0.011 7 (11)	0.002 15 (16)	0.000 65	0.014 5 (13)	α

Electron-capture Transitions

Energies

Electron-capture energies were calculated from the nuclear level energies of Browne (2004Br45) and a Q_{EC} value of 785.4 ± 2.5 keV taken from Audi *et al.* (2003Au03).

Transition probabilities

The EC transition probabilities were calculated from BF_{EC} of 0.5822 (8) and the absolute emission probability and theoretical internal conversion coefficients of the 687.2-keV gamma ray.

EC transition probabilities per 100 disintegrations of ^{211}At.

	E_{EC} (keV)	P_{EC}	Transition type	log *ft*	P_K	P_L	P_M
$EC_{0,1}$	98.2 ± 2.6	0.258 ± 0.013	1st forbidden non-unique	5.77	0.015 (17)	0.684 (10)	0.301 (7)
$EC_{0,0}$	785.4 ± 2.5	57.96 ± 0.08	1st forbidden non-unique	5.97	0.773 1 (2)	0.169 3 (1)	0.057 58 (4)

Atomic Data

The x-ray and Auger-electron data have been calculated using the evaluated gamma-ray data, and atomic data from 1996Sc06, 1998ScZM and 1999ScZX. Both the x-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.01, 28 January 2003). This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

K and L X-ray emission probabilities per 100 disintegrations of ^{211}At.

			Energy (keV)	Photons per 100 disint.
XL		(Bi)	9.420 – 15.709	0.000 136 (14)
	XL_{l}	(Bi)	9.420	0.000 003 3 (4)
	XL_{α}	(Bi)	10.731 – 10.839	0.000 063 (7)
	XL_{η}	(Bi)	11.712	0.000 001 03 (15)
	XL_{β}	(Bi)	12.480 – 13.393	0.000 057 (6)
	XL_{γ}	(Bi)	15.248 – 15.709	0.000 011 0 (12)
XK_{α}	$XK_{\alpha 2}$	(Bi)	74.8157 (9)	0.000 098 (15)
	$XK_{\alpha 1}$	(Bi)	77.1088 (10)	0.000 164 (25)
$XK'_{\beta 1}$	$XK_{\beta 3}$	(Bi)	86.835	0.000 056 (9)
	$XK_{\beta 1}$	(Bi)	87.344	
	$XK''_{\beta 5}$	(Bi)	87.862	
$XK'_{\beta 2}$	$XK_{\beta 2}$	(Bi)	89.732	0.000 017 (3)
	$XK_{\beta 4}$	(Bi)	90.074	
	$XKO_{2,3}$	(Bi)	90.421	
XL		(Po)	9.658 – 16.213	18.6 (8)
	XL_{l}	(Po)	9.658	0.465 (12)
	XL_{α}	(Po)	11.016 – 11.130	8.53 (20)
	XL_{η}	(Po)	12.085	0.134 (4)
	XL_{β}	(Po)	12.823 – 13.778	7.76 (14)
	XL_{γ}	(Po)	15.742 – 16.213	1.53 (3)
XK_{α}	$XK_{\alpha 2}$	(Po)	76.864 (4)	12.66 (9)
	$XK_{\alpha 1}$	(Po)	79.293 (5)	21.08 (12)
$XK'_{\beta 1}$	$XK_{\beta 3}$	(Po)	89.256	7.26 (12)
	$XK_{\beta 1}$	(Po)	89.807	
	$XK''_{\beta 5}$	(Po)	90.363	
$XK'_{\beta 2}$	$XK_{\beta 2}$	(Po)	92.263	2.26 (5)
	$XK_{\beta 4}$	(Po)	92.618	
	$XKO_{2,3}$	(Po)	92.983	

Electron energies were determined from electron binding energies tabulated by Larkins (1977La19) and the evaluated gamma-ray energies. Absolute electron emission probabilities were calculated from the evaluated absolute gamma-ray emission probabilities and associated internal conversion coefficients.

Data Consistency

An effective Q-value of 2956.7 (16) keV has been adopted from the atomic mass evaluation of Audi *et al*. (2003Au03) while in the course of formulating the decay scheme of ^{211}At. This value has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{211}At alpha- and EC-decay processes (i.e. α, γ, conversion electrons, etc.):

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 2957\ (5)\ \text{keV}$$

Percentage deviation from the effective Q-value of Audi *et al.* is – (0.01 ± 0.17) %, which supports the derivation of a highly consistent decay scheme.

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^{212}Pb – Comments on evaluation of decay data
by A. L. Nichols

Evaluated: July/August 2001
Re-evaluated: January 2004

Evaluation Procedures

Limitation of Relative Statistical Weight Method (LWM) was applied to average numbers throughout the evaluation. The uncertainty assigned to the average value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

A reasonably simple and consistent decay scheme has been constructed from the gamma-ray measurements of 1960Ro16, 1961Gi02, 1972DaZA, 1978Av01, 1982Sa36, 1983Sc13, 1983Va22, 1984Ge07 and 1992Li05. Only five distinct gamma-ray emissions were identified with ^{212}Pb decay in all of these studies. A further gamma ray has been added in the evolution of the decay scheme (energy of 123.45 keV) to achieve the necessary population-depopulation balance of the 115.183 keV nuclear level of ^{212}Bi.

Low-energy gamma transitions have been postulated to exist in the decay scheme of ^{212}Pb (with energies between 40 and 60 keV). However, this possibility was rejected on the basis of insufficient experimental evidence in the open literature. Further studies are required to resolve this issue, and confirm the correctness of the proposed decay scheme.

Nuclear Data

^{228}Th decay chain is important in quantifying the environmental impact of the decay of naturally-occurring ^{232}Th. Specific radionuclides in this decay chain are noteworthy because of their decay characteristics (^{224}Ra alpha decay to ^{220}Rn; ^{212}Bi and ^{208}Tl gamma-ray emissions).

Half-life

The recommended half-life is the weighted mean of three elderly measurements (1952Bu72, 1953Ma26 and 1955To11). Further studies are merited to determine this value with greater confidence.

Reference	Half-life (h)
1952Bu72	10.67(5)
1953Ma26	10.64(3)
1955To11	10.643(12)
Recommended Value	10.64(1)

Gamma Rays

Energies
All gamma-ray transition energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 1992Ar05 were adopted, and used to determine the energies and associated uncertainties of the gamma-ray transitions between the various populated-depopulated levels.

Emission Probabilities

Weighted mean relative emission probabilities were determined for the 115.183, 176.64, 238.632 and 300.09 keV gamma rays, using the relevant data from the measurements of 1960Ro16, 1961Gi02, 1972DaZA, 1978Av01, 1982Sa36, 1983Sc13, 1983Va22, 1984Ge07 and 1992Li05. The relative emission probability of the 415.27 keV gamma ray was adopted from the studies of 1961Gi02, while a further gamma ray has been added in the evolution of the decay scheme (energy of 123.45 keV) to achieve the necessary population-depopulation balance of the 115.183 keV nuclear level of ^{212}Bi.

Gamma-ray Emission Probabilities: Relative to P_g(238.632 keV) of 100

E_g (keV)	**P_g^{rel}**				
	1960Ro16	1961Gi02	1972DaZA	1978Av01	1982Sa36
115.183(5)	[observed]	1.4(3)	1.3(3)	1.4(1)	1.65(12)
123.45(1)	-	-	-	-	-
176.64(1)	~ 0.5	0.50(10)	0.10(3)	-	-
238.632(2)	100	100	100	100(3)	100(5)
300.09(1)	7.7(4)	6.9(4)	7.7(15)	6.3(2)	6.7(5)
415.27(1)	~ 0.3	0.33(5)	-	-	-

E_g (keV)	**P_g^{rel}** (cont.)				
	1983Sc13	1983Va22	1984Ge07	1992Li05	Recommended Values*
115.183(5)	-	-	1.37(2)	-	1.43(5)
123.45(1)	-	-	-	-	0.22(1)
176.64(1)	-	-	0.12(1)	-	0.12(1)
238.632(2)	100(3)	100(1)	100(1)	100(2)	100(1)
300.09(1)	7.5(2)	7.3(1)	7.6(1)	7.6(3)	7.3(3)
415.27(1)	-	-	-	-	0.33(5)

* Weighted mean values adopted when appropriate using LWEIGHT; remainder derived from proposed decay scheme.

A weighted mean normalisation factor of 0.436(3) was calculated for the emission probabilities from the measurements of 1982Sa36, 1983Sc13, 1983Va22, 1984Ge07 and 1992Li05.

Absolute Gamma-ray Emission Probabilities: Normalisation Factor

E_g (keV)	**P_g^{abs}**					
	1982Sa36	1983Sc13	1983Va22	1984Ge07	1992Li05	Recommended Value*
238.632(2)	0.430(20)	0.435(12)	0.440(6)	0.433(4)	0.441(10)	0.436(3)

* Weighted mean value adopted from LWEIGHT.

Multipolarities and Internal Conversion Coefficients

The nuclear level scheme specified by 1992Ar05 has been used to define the multipolarities of the gamma transitions on the basis of known spins and parities. Limited studies of the internal conversion coefficients support the proposed transition types: 100%M1 for the 115.183, 238.632 and 300.09 keV gamma rays (1957Ni11, 1957Kr49, 1959Se59, 1960Ro16, 1963Da11, 1969Kr06 and 1978Av01); the 176.64 and 415.27 keV gamma rays were also assigned 100%M1 multipolarity, while the 123.45 keV gamma transition was defined as E2.

Multipolarity Assignments

Reference	**E_g (keV)**	**Multipolarity**
1957Ni11	115.183(5)	M1 [K/L = 5(1)]
1957Kr49	115.183(5)	M1
	176.64(1)	E0 [K/L = 1 : 0.18(2)]
	238.632(2)	M1
	300.09(1)	M1

1959Se59	115.183(5) 238.632(2)	M1 $[L_I{:}L_{II}{:}L_{III} \rightarrow 100 : 10.4(3) : 0.88(10)]$ M1 $[L_I{:}L_{II}{:}L_{III} \rightarrow 100 : 10.4(2) : 0.74(5)]$
1960Ro16	115.183(5) 238.632(2)	M1 $[\alpha_K = 5.8(9)]$ M1 $[\alpha_K = 0.74(7)]$
1963Da11	238.632(2) 415.27(1)	M1 M1 $[\alpha_K \sim 0.35]$
1969Kr06	238.632(2)	M1
1978Av01	115.183(5) 238.632(2) 300.09(1)	E2 M1 (+ E2) M1 + E2

Beta-particle Emissions

Energies
All beta-particle energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 1992Ar05 and the Q-value were used to determine the energies and uncertainties of the beta-particle transitions to the various levels.

Emission Probabilities
The beta-particle emission probabilities were calculated from gamma-ray transition probability balances, using the recommended gamma-ray emission probabilities and the theoretical internal conversion coefficients of 1978Ro22:

415.272 keV nuclear level:
[Σ $P_{\gamma i}$ $(1 + \alpha_i)$ depopulating 415.27 keV level]NF was calculated to be 11.65(47)NF; since NF = 0.436(3), beta-particle emission probability is calculated to be 5.1(2)% (0.051(2));

238.632 keV nuclear level:
{[Σ $P_{\gamma i}$ $(1 + \alpha_i)$ depopulating 238.63 keV level] - P_γ(176.64 keV)(1 + α(176.64 keV))}NF was calculated to be 192.7(34)NF; since NF = 0.436(3), beta-particle emission probability is calculated to be 84.0(14)% (0.840(14));

115.183 keV nuclear level:
spin and parity considerations support zero beta decay to this level;
population/depopulation by gamma transitions require balance of the form
Σ $P_{\gamma i}$ $(1 + \alpha_i)$ populating 115.18 keV level should equal P_γ(115.18 keV)(1 + α(115.18 keV)); hence, derivation of transition probability P_γ(123.45 keV) = 0.85(4)NF

ground state (0.0 keV):
(i) through population of ground state: [Σ $P_{\gamma i}$ $(1 + \alpha_i)$ populating ground state]NF + $P_{b_{0,0}}$ = 100
and NF = 0.436(3) to give $P_{b_{0,0}}$ = 10.9(14)% (0.109(14))
(ii) through summation of beta decay and NF = 0.436(3)

$$P_{b_{0,0}} = 10.9(14)\%\ (0.109(14))$$

Beta-particle Emission Probabilities per 100 Disintegrations of ^{212}Pb

E_b(keV)	P_b	
	1948Ma30	Recommended Values*
159(2)	-	5.1(2)
335(2)	-	84.0(14)
574(2)	12(2)	10.9(14)

* Recommended emission probabilities derived from evaluated gamma-ray emission probabilities and theoretical internal conversion coefficients.

Atomic Data

The x-ray data have been calculated using the evaluated gamma -ray data, and the atomic data from 1996Sc06, 1998ScZM and 1999ScZX.

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^{212}Bi – Comments on evaluation of decay data
by A. L. Nichols

Evaluated: July/August 2001
Re-evaluated: January 2004

Evaluation Procedures

Limitation of Relative Statistical Weight Method (LWM) was applied to average numbers throughout the evaluation. The uncertainty assigned to the average value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

^{212}Bi undergoes beta decay to ^{212}Po (BF = 64.07(7)%), and alpha decay to ^{208}Tl (BF = 35.93(7)%). The alpha branching fraction was calculated as the weighted mean of the measurements of 1960Sc07, 1962Be09, 1962Fl03 and 1965Wa09, with the uncertainty increased to include the most precise value of 36.00(3)%.

Reference	a-decay Branching Fraction (BF) %
1960Sc07	35.96(6)
1962Be09	35.81(4)
1962Fl03	36(1)
1965Wa09	36.00(3)*
Recommended Value	35.93(7)

* Uncertainty increased slightly so that weighting does not exceed 0.5.

A reasonably consistent decay scheme has been constructed from a combination of alpha-particle studies by 1951Ry17(two main emissions modified), 1960Wa14, and 1962Be09, and the gamma-ray measurements of 1960Sc07, 1962Be09, 1962Fl03, 1967Be19, 1968Yt02, 1972DaZA, 1978Av01, 1982Sa36, 1983Sc13, 1983Va22, 1984Ge07 and 1992Li05.

Nuclear Data

^{228}Th decay chain is important in quantifying the environmental impact of the decay of naturally-occurring ^{232}Th. Specific radionuclides in this decay chain are noteworthy because of their decay characteristics (^{224}Ra alpha decay to ^{220}Rn; ^{212}Bi and ^{208}Tl gamma-ray emissions).

Half-life

The recommended half-life is the unweighted mean of two somewhat elderly measurements (1914Le01 and 1961Ap03). Further studies are merited to determine this value with greater confidence.

Reference	Half-life (min)
1914Le01	60.480(52)
1961Ap03	60.600(43)
Recommended Value	60.54(6)

Gamma Rays

Energies

All gamma-ray transition energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 1986Ma 17 were adopted, and used to determine the energies and associated uncertainties of the gamma-ray transitions between the various populated-depopulated levels.

Emission Probabilities

The gamma-ray measurements of 1960Sc07, 1962Be09, 1962Fl03, 1967Be19, 1968Yt02, 1972DaZA, 1978Av01, 1982Sa36, 1983Sc13, 1983Va22, 1984Ge07 and 1992Li05 were used to determine the emission probabilities of the major gamma rays. These data have been measured relative to widely differing decay parameters: beta-decay mode, alpha-decay mode, per decay of ^{212}Bi (ie., absolute emission probabilities), and relative to the 583.19 and 2614.51 keV gamma rays of ^{208}Tl. All of these measured data were adjusted to absolute emission probabilities when appropriate, and weighted mean values determined.

Absolute emission probabilities were estimated for the 180.2 and 1800.9 keV gamma rays in the beta-decay mode, and the 433.7, 492.7, 580.5, 620.4, 759 and 807 keV gamma rays in the alpha-decay mode. The latter values were derived from measurements of the low-intensity alpha-particle emission probabilities by 1960Wa14, and involved the introduction of uncertainty estimates that varied between 10% and 50% (depending on the number of significant figures quoted in the measurement of the relevant alpha emission probability).

Published Gamma-ray Emission Probabilities

E_g (keV)	P_g							
	1960Sc07 *	1962Be09	1962Fl03 ‡	1967Be19 #	1968Yt02 $	1972DaZA $	1978Av01 Δ	1982Sa36 ¶
39.858(4) $[\alpha]$	-	-	-	-	-	-	-	0.9(1)
180.2(2) $[\beta^-]$	-	-	-	-	-	-	-	-
288.08(6) $[\alpha]$	-	0.775(40)$^\#$	-	0.82(2)	-	0.9(2)	0.97(5)	0.32(3)
327.94(6) $[\alpha]$	-	0.299(23)$^\#$	-	0.33(1)	-	0.36(7)	-	-
433.7(2) $[\alpha]$	-		-	0.04(1)	-	~ 0.025	-	-
452.8(1) $[\alpha]$	-		-	0.84(2)	-	0.88(17)	1.10(6)	0.42(5)
		1.18(5)$^\#$						
473.6(2) $[\alpha]$	-		-	0.122(8)	-	0.10(3)	-	-
492.7(1) $[\alpha]$	-		-	< 0.008	-	-	-	-
580.5(3) $[\alpha]$	-	-	-	-	-	-	-	-
620.4(3) $[\alpha]$	-	-	-	-	-	-	-	-
727.33(1) $[\beta^-]$	11.1(7)		11.8(24)	-	-	17.6(17)	21.0(8)	6.9(4)
759(1) $[\alpha]$	-	100†	-	-	-	-	-	-
785.37(9) $[\beta^-]$	1.70(26)		-	-	-	2.8(6)	3.26(16)	1.01(7)
807(1) $[\alpha]$	-	-	-	-	-	-	-	-
893.41(2) $[\beta^-]$	0.66(7)	4.9(3)†	0.5(1)	-	-	0.94(19)	-	0.49(8)
952.12(2) $[\beta^-]$	0.16(4)	-	-	-	-	0.46(9)	-	-
1073.6(2) $[\beta^-]$			-	-	-	~ 0.03	-	-
	0.99(8)	10.1(4)†						
1078.63(11) $[\beta^-]$			0.7(1)	-	-	1.4(2)	-	-
1512.70(8) $[\beta^-]$	0.49(5)	3.4(3)†	-	-	0.99(15)	0.8(1)	-	-
1620.74(1) $[\beta^-]$	2.81(20)	20.0(6)†	3.0(6)	-	4.85(50)	3.9(4)	-	-
1679.45(1) $[\beta^-]$	-	-	-	-	0.230(7)	0.16(3)	-	-
1800.9(2) $[\beta^-]$				-	-	-	-	-
	0.17(3)	1.4(2)†	0.5(1)					
1805.96(10) $[\beta^-]$				-	0.41(10)	0.25(5)	-	-

Published Gamma-ray Emission Probabilities (cont.)

E$_g$ (keV)	**P$_g$** (cont.)			
	1983Sc13$^{\Psi}$	1983Va22$^{\Psi}$	1984Ge07$^{\Delta}$	1992Li05$^{\Psi}$
39.858(4) [α]	-	-	3.49(28)	-
180.2(2) [β^-]	-	-	-	-
288.08(6) [α]	0.274(23)	-	1.106(10)	0.389(57)
327.94(6) [α]	0.120(4)	-	0.423(20)	3.23(12)
433.7(2) [α]	-	-	-	-
452.8(1) [α]	0.256(23)	-	1.191(11)	0.370(49)
473.6(2) [α]	-	-	-	-
492.7(1) [α]	-	-	-	-
580.5(3) [α]	-	-	-	-
620.4(3) [α]	-	-	-	-
727.33(1) [β^-]	6.56(15)	7.00(18)	21.63(13)	6.93(18)
759(1) [α]	-	-	-	-
785.37(9) [β^-]	1.07(5)	-	3.62(4)	1.05(5)
807(1) [α]	-	-	-	-
893.41(2) [β^-]	0.352(36)	-	1.25(6)	-
952.12(2) [β^-]	-	-	-	-
1073.6(2) [β^-]	-	-	-	-
1078.63(11) [β^-]	0.58(4)	-	1.85(6)	0.555(41)
1512.70(8) [β^-]	0.276(42)	-	-	-
1620.74(1) [β^-]	1.38(8)	-	4.88(10)	1.44(9)
1679.45(1) [β^-]	-	-	-	-
1800.9(2) [β^-]	-	-	-	-
1805.96(10) [β^-]	-	-	-	-

[*] Emission probabilities expressed in terms of ^{212}Bi β^- decay mode only.

[†] Emission probabilities expressed in terms of (727 + 785) keV gamma rays of ^{212}Bi.

[‡] Emission probabilities relative to ^{212}Po α decay.

[#] Emission probabilities expressed in terms of ^{212}Bi α decay mode only.

[$] Emission probabilities relative to P_γ(2614.51 keV) of ^{208}Tl.

[Δ] Emission probabilities relative to P_γ(583.19 keV) of ^{208}Tl.

[¶] Emission probabilities relative to P_γ(238.63 keV) of ^{212}Pb specified as 0.430(20), compared with recommended value of 0.435(4)).

[Ψ] Absolute emission probabilities.

Absolute Gamma-ray Emission Probabilities per 100 Disintegrations of ^{212}Bi

E_g (keV)	**P_g^{abs}**							
	1960Sc07	1962Be09	1962Fl03	1967Be19	1968Yt02	1972DaZA	1978Av01	1982Sa36
39.858(4) [α]	-	-	-	-	-	-	-	0.9(1)
180.2(2) [β^-]	-	-	-	-	-	-	-	-
288.08(6) [α]	-	0.278(14)	-	0.29(1)	-	0.3(1)	0.35(2)	0.32(3)
327.94(6) [α]	-	0.107(8)	-	0.12(1)	-	0.13(3)	-	-
433.7(2) [α]	-		-	0.014(4)	-	~ 0.009	-	-
452.8(1) [α]	-		-	0.30(1)	-	0.32(6)	0.40(2)	0.42(5)
		0.424(18)						
473.6(2) [α]	-		-	0.044(3)	-	0.04(1)	-	-
492.7(1) [α]	-		-	< 0.003	-	-	-	-
580.5(3) [α]	-	-	-	-	-	-	-	-
620.4(3) [α]	-	-	-	-	-	-	-	-
727.33(1) [β^-]	7.11(45)		7.6(15)	-	-	6.3(6)	7.6(3)	7.0(4)
759(1) [α]	-	[7.85]	-	-	-	-	-	-
785.37(9) [β^-]	1.09(17)		-	-	-	1.0(2)	1.17(6)	1.02(7)
807(1) [α]	-	-	-	-	-	-	-	-
893.41(2) [β^-]	0.42(4)	0.38(2)	0.32(6)	-	-	0.34(7)	-	0.50(8)[§]
952.12(2) [β^-]	0.10(3)	-	-	-	-	0.17(3)	-	-
1073.6(2) [β^-]			-	-	-	~ 0.01		-
	0.63(5)	0.79(3)						
1078.63(11) [β^-]			0.45(6)	-	-	0.50(7)	-	-
1512.70(8) [β^-]	0.31(3)	0.27(2)	-	-	0.36(5)	0.29(4)	-	-
1620.74(1) [β^-]	1.80(13)	1.57(5)	1.9(4)	-	1.74(18)	1.4(1)	-	-
1679.45(1) [β^-]	-	-	-	-	0.083(3)[¶]	0.06(1)	-	-
1800.9(2) [β^-]				-	-	-	-	-
	0.11(2)	0.11(2)	0.32(6)					
1805.96(10) [β^-]				-	0.15(4)	0.09(2)[¶]	-	-

Absolute Gamma-ray Emission Probabilities per 100 Disintegrations of ^{212}Bi (cont.)

E_g (keV)	**P_g^{abs}** (cont.)				
	1983Sc13	1983Va22	1984Ge07	1992Li05	Recommended Values[*]
39.858(4) [α]	-	-	1.07(9)[¶]	-	1.01(3)[†]
180.2(2) [β^-]	-	-	-	-	0.003(1)
288.08(6) [α]	0.274(23)	-	0.339(3)[¶]	0.389(57)	0.32(2)
327.94(6) [α]	0.120(4)[¶]	-	0.129(6)	3.23(12)[Ψ]	0.121(3)
433.7(2) [α]	-	-	-	-	0.0095(20)[‡]
452.8(1) [α]	0.256(23)	-	0.365(3)[¶]	0.370(49)	0.34(3)
473.6(2) [α]	-	-	-	-	0.044(3)
492.7(1) [α]	-	-	-	-	0.04(1)[‡]
580.5(3) [α]	-	-	-	-	0.0010(2)[‡]
620.4(3) [α]	-	-	-	-	0.0038(6)[‡]
727.33(1) [β^-]	6.56(15)	7.00(18)	6.62(4)[¶]	6.93(18)[Ψ]	6.74(12)
759(1) [α]	-	-	-	-	0.00036(18)[‡]
785.37(9) [β^-]	1.07(5)	-	1.11(1)	1.05(5)	1.11(1)
807(1) [α]	-	-	-	-	0.000039(4)[‡]
893.41(2) [β^-]	0.352(36)	-	0.383(18)	-	0.38(1)
952.12(2) [β^-]	-	-	-	-	0.14(4)
1073.6(2) [β^-]	-	-	-	-	0.015(5)[#]
1078.63(11) [β^-]	0.58(4)	-	0.566(18)[¶]	0.555(41)	0.55(2)
1512.70(8) [β^-]	0.276(42)	-	-	-	0.29(1)
1620.74(1) [β^-]	1.38(8)	-	1.49(3)[¶]	1.44(9)	1.51(3)
1679.45(1) [β^-]	-	-	-	-	0.07(1)
1800.9(2) [β^-]	-	-	-	-	0.004(2)
1805.96(10) [β^-]	-	-	-	-	0.12(3)

[*] Weighted mean values adopted when appropriate; remainder derived from proposed decay scheme (see other footnotes).

[†] Determined directly from proposed decay scheme (calculated transition probability and total theoretical internal conversion coefficient).

[‡] Calculated from low-intensity alpha-particle emission probabilities of 1960Wa14.

[#] Estimated from the approximate measurement of 1972DaZA, and used to define Pγ for 180.2 and 1800.9 keV gamma rays.

[¶] Uncertainty increased so that weighting does not exceed 50%.

[§] Datum rejected as outlier, and not included in weighted mean analysis.

[Ψ] Unresolved overlap with other gamma-ray emission(s); data not included in the weighted-mean analysis.

Multipolarities and Internal Conversion Coefficients

Many of the M1 + E2 gamma transitions in the alpha -decay mode were assumed to be close to 100%M1, based on the studies of 1978Av01 and 1982Be09. Specific exceptions to this assumption include:

99.55 %M1 + 0.45 %E2 for 288.08keV,
99.2 %M1 + 0.8 %E2 for 785.37 keV,
99.8 %M1 + 0.2 %E2 for 893.41 keV,
70 %M1 + 30 %E2 for 952.12 keV,
98.2 %M1 + 1.8 % E2 for 1078.63 keV,
90 %M1 + 10 %E2 for 1620.74 keV gamma rays.

Multipolarity Assignments

Reference	E$_g$ (keV)	Multipolarity
1978Av01	288.08(6) [α decay] 452.8(1) [α decay] 727.33(1) [β$^-$ decay] 785.37(9) [β$^-$ decay]	M1 + E2 72%M1 + 28%E2 E2 98%M1 + 2%E2
1982Be09	785.37(9) [β$^-$ decay] 893.41(2) [β$^-$ decay] 952.12(2) [β$^-$ decay] 1078.63(11) [β$^-$ decay]	99.2%M1 + 0.8%E2 M1 (+ ≤ 0.25%E2) 70%M1 + 30%E2 98.2%M1 + 1.8%E2

Reasonable consistency was achieved from the proposed gamma-ray emission probabilities, internal conversion coefficients and alpha-particle emission probabilities. The 39.858 keV gamma ray is particularly important in the alpha branch, and further measurements are required to determine the emission probability of this transition with greater confidence. A value of 1.01(3)% (0.0101(3)) was adopted on the basis of the relevant alpha-particle emission probability, gamma-ray transition probability and a total internal conversion coefficient of 24.6(7).

Alpha-particle Emissions

Energies

All alpha-particle energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies specified by 1986Ma17 and 1992Ar05, and Q-values were used to determine the energies and uncertainties of the alpha-particle transitions to the various levels, while allowing for the significant recoil components.

Emission Probabilities

The main alpha-particle emission probabilities emitted directly by ^{212}Bi were calculated from the evaluated gamma-ray emission probabilities (see above) and theoretical internal conversion coefficients, combined with an alpha branching fraction of 0.3593(7). These data are in excellent agreement with the measured emission probabilities of the two main alpha transitions (1951Ry17, 1960Wa14 and 1962Be09), but deviate considerable for the low-intensity transitions that are poorly resolved. Under such circumstances, the low-intensity alpha-particle data of 60Wa14 were adopted when appropriate, while others were derived from the gamma-ray studies.

Alpha-particle Emission Probabilities

E$_a$(keV)	P$_a^{rel}$				P$_a^{abs}$
	1951Ry17	1960Wa14	1962Be09		Recommended Values*
5298(1)	0.016	0.00011(1)	-	-	5298(1)
5345(1)	0.147	0.001	-	-	5345(1)
5481.3(3)	-	0.014	~ 0.04	~ 0.02	5481.3(3)
5606.63(14)	1.08	1.19	)	)	5606.63(14)
			) 1.35(6)	) 1.22(2)	
5625.4(2)	-	0.1625	)	)	5625.4(2)
5768.27(10)	1.67	1.78	1.63(11)	1.67(2)	5768.27(10)
6050.92(4)	69.86#	69.7	70.2(3)	70.2(2)	6050.92(4)
6090.02(4)	27.16#	27.1	27.0(5)	26.8(2)	6090.02(4)
9498.79(12)†	-	-	-	-	9498.79(12)†
10432.95(12)†	-	-	-	-	10432.95(12)†
10552.1(3)†	-	-	-	-	10552.1(3)†

* Recommended emission probabilities derived from evaluated gamma-ray emission probabilities, theoretical internal conversion coefficients and alpha branching fraction of 0.3593(7), unless stated otherwise (expressed per 100 disintegrations of ^{212}Bi).

‡ Data reported by 1960Wa14 were adopted and adjusted for alpha branch; uncertainties were estimated when not quoted.

† Arises from β$^-$α decay (long-range alpha particles).

\# Data reported incorrectly; re-assigned by evaluator.

Alpha-particle emissions from the $\beta^-\alpha$ decay mode have been observed at energies greater than 9 MeV by 1951Ry17, 1962Be09 and 1965Le08. Some of the excited states of ^{212}Po populated by the beta of ^{212}Bi undergo subsequent alpha decay (in competition with the gamma-ray decay). These nuclear levels at 1800.9, 1679.45 and 727.33 keV emit high-energy alpha particles (energies of 10552.1, 10432.95 and 9498.79 keV, respectively). All measurements were expressed relative to 10^6 emission probability for the 8785.18 keV alpha particle of ^{212}Po, but with no quoted uncertainties. These long-range alpha particles constitute part of the ^{212}Bi decay; and their emission probabilities were determined from the measurements of 1951Ry17, 1962Be09 and 1965Le08:

Alpha-particle Emissions (b$^-$a **Decay)**

E_a (keV)	P_a^{rel}			
	1951Ry17	1962Be09	1965Le08	Mean Value
[8785.18(11)]*	10^6	10^6	10^6	10^6
9498.79(12)	35	45	34	38
10432.95(13)	20	17	10	16
10552.1(3)	170	167	160	166
Total α (of $\beta^-\alpha$)	225	229	204	219(15)

* ^{212}Po alpha decay.

Total α emissions from $\beta^-\alpha$ decay have an estimated mean value of 219 relative to 10^6 for the emission probability of the 8785.18 keV alpha particle of ^{212}Po, with an uncertainty of 15 to cover the range of measured data. Therefore, a mean value of 0.00014 was estimated for the $\beta^-\alpha$ branching fraction, combined with an uncertainty of approximately 7% (BF($\beta^-\alpha$) = 0.00014(1)). Absolute alpha-particle emission probabilities for this small branch were calculated from the mean values and BF($\beta^-\alpha$).

Beta-particle Emissions

Energies

All beta-particle energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 1992Ar05 and the Q-value were used to determine the energies and uncertainties of the beta-particle transitions to the various levels.

Emission Probabilities

The beta-particle emission probabilities were calculated from gamma-ray transition intensity balances, using the recommended gamma-ray emission probabilities and the theoretical internal conversion coefficients of 1978Ro22.

Beta-particle Emission Probabilities

E_b(keV)	P_b	
	1957Bu34	Recommended Values*
448(2)	8.5	0.68(5)
453(2)	-	0.029(1)
575(2)	-	0.21(5)
633(2)	6	1.90(4)
741(2)	-	1.45(2)
1527(2)	10	4.58(21)
2254(2)	63	55.23(21)

* Recommended emission probabilities derived from evaluated gamma-ray emission probabilities, theoretical internal conversion coefficients, beta branching fraction of 64.06(7) % and beta-alpha branching fraction of 0.00014(1) (expressed per 100 disintegrations of ^{212}Bi).

Atomic Data

The x-ray data have been calculated using the evaluated gamma-ray data, and the atomic data from 1996Sc06, 1998ScZM and 1999ScZX.

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^{212}Po – Comments on evaluation of decay data
by A. L. Nichols

Evaluated: July/August 2001
Re-evaluated: January 2004

Evaluation Procedures

Limitation of Relative Statistical Weight Method (LWM) was applied to average numbers throughout the evaluation. The uncertainty assigned to the average value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

^{212}Po is an extremely short-lived radionuclide populated via the beta decay of ^{212}Bi and the alpha decay of ^{216}Rn. Alpha decay of ^{212}Po occurs directly to the ground state of ^{208}Pb.

Nuclear Data

Half-life

Po-212 is an extremely short-lived radionuclide populated primarily via the alpha decay of Rn-216 and the beta decay of Bi-212. The recommended half-life of 3.00(2) x 10^{-7} sec is based on the weighted mean of five sets of measurements (1949Bu09, 1962Fl03, 1963As02, 1972Mc29 and 1975Sa06).

Reference	Half-life (s)
1949Bu09	3.04(4) x 10^{-7}
1962Fl03	3.05(25) x 10^{-7}
1963As02	3.05(5) x 10^{-7}
1972Mc29	3.04(8) x 10^{-7}
	3.00(8) x 10^{-7}
1975Sa06	2.96(2) x 10^{-7*}
Recommended Value	3.00(2) x 10^{-7}

* Uncertainty adjusted to ± 0.03 x 10^{-7} to reduce weighting below 0.5.

Alpha-particle Emission

Energy
The Q-value of 1995Au04 was used to determine the energy and uncertainty of the single alpha-particle transition to the ground state of ^{208}Pb, while allowing for the significant recoil component. Thus, an alpha-particle energy of 8785.18(11) keV was calculated.

Emission Probability
The emission probability of the single alpha particle was defined as 100% (1.00).

Alpha-particle Emission Probabilities per 100 Disintegrations of ^{212}Po

E$_a$(keV)	**P$_a$**
	Recommended Value[*]
8785.18(11)	100.0

[*] Only one α transition directly to the ground state of ^{208}Pb.

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^{213}Bi - Comments on evaluation of the decay data

by Huang Xiaolong, Wang Baosong

This evaluation was completed in 2006. Literature available by January 2006 was included.

1. Decay Scheme

^{213}Bi disintegrates 97.91 (3) % by β^- emission to levels in ^{213}Po and 2.09 (3) % through α decay to ^{209}Tl. ^{213}Bi ground state has J^π = 9/2$^-$ (1992Ak01).

The ^{213}Bi β^- decay scheme was built from the γ-γ coincidence measurements of 1998Ar03 and 2000Gr35. The ^{213}Bi α decay scheme was built from the α–γ coincidence measurements of 1964Gr11, the singles α- particle measurements of 1997Ch53 and γ-γ coincidence measurements of 1998Ar03.

The decay branching ratios have been deduced by the evaluator using the absolute photon intensity (96.58 (10), 1991Ma16) adopted for the 465 keV γ-ray from ^{209}Tl β^- decay and measured absolute intensity (2.022 (26), 1986He06) of the same γ-ray following the ^{213}Bi α decay. Our recommended α decay branching ratio is I_α = 2.09 (3) %, thus $I_{\beta-}$ = 97.91 (3) %.

The three values of the ^{213}Bi α decay branching ratio found in the literature are presented in Table 1. The corresponding β^- branching ratios are: I_β- = 97.84 (11) %, (deduced by 1964Gr11); $I_{\beta-}$ = 97.91 (3) %, (deduced from the measurements of 1986He06); I_β- = 97.80 (3) %, measured in equilibrium with ^{213}Po by 1997Ch53.

Table 1: Measured and recommended branching ratio for ^{213}Bi α decay.

I_α (%)	References	Comments
2.16 (11)	1964Gr11	Deduced from measured I_α
2.09 (3)	1986He06	Deduced from the P_γ(465 keV) from ^{209}Tl following ^{213}Bi α decay and measured value by 1986He06
2.20 (3)	1997Ch53	Measured in equilibrium with ^{213}Po
2.15 (4)		LWM
2.09 (3)		Recommended

The recommended Q(α) value of 5983 (6) keV and Q(β^-) values of 1423 (5) keV in Audi(2003Au03) agrees with the Q(α) value of 5979 (2) keV and Q(β^-) values of 1422 (6) keV, calculated by the evaluator (using program RADLST) from average radiation energies. This agreement supports the completeness and correctness of the decay scheme.

2. Nuclear Data

The Q values are from the 2003Au03 evaluation.

Level energies have been obtained from a least-squares fit to γ-ray energies (GTOL computer code). Spin and parities are from 1992Ak01, 1998Ar03 and 2000Gr35.

The measured and recommended ^{213}Bi half-life values are listed in Table 2.

Table 2: Measured half-life values of ^{213}Bi and recommended value

$T_{1/2}$ (min)	References	Measurement method
46	1947En03	
47 (1)	1950Ha52	Alpha pulse analyzer, 9 $T_{1/2}$
46 (1)	1964Gr11	
45.59 (6)	1973Po16	ZnS(Ag), weighted average of 2 sources, 8 $T_{1/2}$
46.2 (4)		Unweighted mean (except 1947En03)
45.60 (6)		LWM (except 1947En03), χ^2 = 1.07
45.59 (6)	Recommended value	From 1973Po16

The half-life weighted average has been calculated by LWM program. The recommended value is taken from the measurement of 1973Po16.

2.1 β$^-$ transitions

The maximum energies of the β$^-$ transitions in the decay of ^{213}Bi have been deduced from the Q value (2003Au03) and the level energies.

The adopted β$^-$ transition probabilities and the associated uncertainties were deduced from the γ-ray transition probability balance at each level of the decay scheme. Measured and adopted β$^-$ transition probabilities are given in table 3.

Table 3: Measured and adopted probabilities (%) of β$^-$ transitions

Level energy (keV)	1955Ma61	1968Va17	**Adopted value**
0		65 (3)	**66.2 (4)**
292.8			**0.21 (9)**
440.4	32	35 (3)	**30.8 (4)**
600.8			**0.002 5 (19)**
868			**0.012 9 (6)**
1003.6			**0.064 8 (23)**
1045.6			**0.020 (4)**
1100.2			**0.595 (17)**
1119.4			**0.060 8 (20)**
1328.2			**0.0014 (2)**

The values of *lg ft* and average β$^-$ energies have been calculated with the program LOGFT.

2.2 γ-ray Transitions

The γ-ray transition probabilities were calculated using the γ-ray emission intensities and the relevant internal conversion coefficients.

Multipolarities and mixing ratios of γ-ray transitions are from 2000Gr35, 1977Vy02 and 1969DzZZ.

The internal conversion coefficients (ICC) and their associated uncertainties for γ-ray transitions have been obtained using the BrIcc computer program, which uses the “Frozen Orbital” approximation (2002Ba85). Experimental and theoretical conversion coefficients are compared in Table 4.

Table 4: Comparison of the calculated and measured conversion coefficients

E_γ (keV)	Multipolarity	Mixing ratio	α(theory)	α(exp.) 2000Gr35
147.7	E2		$\alpha_T = 1.453$, $\alpha_K = 0.31$, $\alpha_L = 0.85$	$\alpha_K = 0.33$ (14)
292.8	M1+E2	1.2 (+11 -8)	$\alpha_T = 0.3$, $\alpha_K = 0.22$, $\alpha_L = 0.06$	$\alpha_K = 0.20$ (5)
323.7	E2+M1	1.26 (16)	$\alpha_T = 0.178$, $\alpha_K = 0.134$, $\alpha_L = 0.03$	$\alpha_K = 0.131$ (15)
440.44	M1		$\alpha_T = 0.179$, $\alpha_K = 0.146$	$\alpha_K = 0.13$ (2)

2.3 α Transitions

1997Ch53 measured the upper limit for intensity of the E_α(868 keV level) = 5018 keV, and the value is < 10^{-4}. But this measurement did not support the assumption that the 868 keV level is excited in ^{209}TI by the ^{213}Bi α decay. Thus the 868 keV level is not considered here.

Measured energies of alpha particles are listed in table 5. The measured values are in good agreement with the calculated results from Q_α(2003Au03) and the level energies. Our recommended values are from 1964Gr11.

Table 5: Measured and recommended values of α-particle energies (in keV) from ^{213}Bi α decay

1947En02	1964Gr11	1967Dz02	Deduced	Recommended
	5549 (10)		5553 (6)	5549 (10)
5860 (30)	5869 (10)	5870 (6)	5871 (6)	5869 (10)

Experimental and recommended α-particle relative intensities to 100 % α decay are listed in Table 6. Our recommended α-particle relative intensities are deduced from the calculated results of the γ transition probability balance. These calculated results are in good agreement with the measured relative intensities of 1964Gr11 and 1997Ch53.

Table 6: Experimental, recommended α-particle relative intensities to 100 % α decay

E_α(keV)	I_α(%)		
	1964Gr11	1997Ch53	Recommended
5549 (10)	7.4 (14)	6.8 (1)	8.9 (2)
5869 (10)	92.6 (14)	93.2 (14)	91.1 (14)

The recommended α-particle emission intensities are the relative intensities values recommended in table 6 multiplied by 0.0209 (3).

3. Atomic data

Atomic fluorescence yields (ω_K,ϖ_L, ϖ_M, η_{KL} and η_{LM}) are from Schönfeld (1996Sc06).

The X-ray and Auger electron emission intensities have been deduced from γ-ray and conversion electron data by using the computer code RADLST. Measured and calculated X-ray emission intensities are compared in Table 7.

Table 7: Comparison of the calculated and measured X-ray emission intensities

	1972Dz14	Adopted (deduced)
$K_{\alpha1}$	1.6 (2)	1.6 (3)
$K_{\alpha2}$	0.93 (12)	0.99 (15)

The deduced KX-ray emission intensities agree with the measured value of 1972Dz14, thus confirming the completeness of the decay scheme.

4. Electron Emissions.

The conversion electron emission probabilities have been deduced from γ-ray transition data.

5. Photon Emissions

5.1 γ-ray energy values

The measurements of the γ- ray energy value of ^{213}Bi are listed in Table 8 associated with their LWM average value. The recommended values are taken from the LWM of the measurements of 1977Vy02, 1981Di14, 1989Ko26, 1998Ar03 and 2000Gr35, or from 1998Ar03 in the case of only one energy measurement (402.8 keV, 884.6 keV, 886.66 keV, 897.0 keV and 1328.2 keV).

Table 8: Measured and recommended values of γ-ray energy (in keV) for ^{213}Bi

1977Vy02	**1981Di14**	**1989Ko26**	**1998Ar03**	**2000Gr35**	**Recommended**
		147.63 (8)	147.66 (5)	147.7 (1)	147.70 (4)
292.86 (10)	292.85 (2)	292.80 (1)	292.76 (5)	292.81 (1)	292.80 (1)
323.81 (5)	323.7 (2)	323.71 (3)	323.69 (5)	323.80 (4)	323.70 (2)
			402.8 (3)		402.8 (3)
440.42 (2)	440.4 (2)	440.46 (1)	440.43 (5)	440.44 (1)	440.44 (1)
			574.8 (3)	575.2 (5)	574.9 (3)
			600.7 (3)	601.0 (2)	600.9 (2)
			604.9 (3)	604.94 (21)	604.93 (17)
			646.03 (9)	646.0 (1)	646.0 (1)
659.81 (10)	659.7 (2)	659.8 (1)	659.77 (5)	659.74 (2)	659.75 (2)
		710.8 (1)	710.81 (21)	710.82 (3)	710.82 (3)
807.36 (4)	807.3 (2)	807.36 (1)	807.38 (5)	807.37 (1)	807.37 (1)
		826.8 (2)	826.47 (6)	826.59 (5)	826.55 (4)

1977Vy02	1981Di14	1989Ko26	1998Ar03	2000Gr35	Recommended
		868.0 (2)	867.98 (3)	867.93 (3)	867.96 (2)
			880.2 (3)	880.91 (1)	880.91 (1)
			884.6 (3)		884.6 (3)
			886.66 (14)		886.66 (14)
			897.0 (3)		897.0 (3)
		1003.57 (3)	1003.55 (5)	1003.59 (3)	1003.58 (2)
			1045.70 (9)	1045.10 (40)	1045.67 (8)
1100.14 (6)	1100.1 (2)	1100.16 (2)	1100.12 (5)	1100.18 (2)	1100.16 (1)
1119.60 (14)		1119.4 (1)	1119.29 (5)	1119.50 (4)	1119.42 (8)
			1328.2 (3)		1328.2 (3)

5.2 Relative values of the γ-ray intensities

The measurements of the relative γ-ray intensities of ^{213}Bi α decay and β^- decay are listed in table 9 and table 10, respectively.

For α decay, the recommended values are taken from the LWM average of the measurements of 1989Ko26, 1998Ar03 and 2000Gr35. For β^- decay, the recommended values are taken from the LWM average of the measurements of 1986He06, 1989Ko26, 1998Ar03 and 2000Gr35 (according to the availability of the reported data).

Table 9: Measured and recommended relative γ-ray intensities for ^{213}Bi α decay (the intensity of the 440.44 keV γ-ray is considered 100)

E_γ (keV)	I_γ						
	1969ArZV	1977Vy02	1981Di14	1989Ko26	1998Ar03	2000Gr35	Recommended
323.70(2)	0.67 (10)	1.12 (8)	0.660 (15)	0.619 (37)	0.567 (46)	0.618 (32)	0.607 (2)

Table 10: Measured and recommended relative γ-ray intensities for ^{213}Bi γ- decay

E (keV)	I γ							
	1969ArZV	1977Vy02	1981Di14	1986He06	1989Ko26	1998Ar03	2000Gr35	Recommended
147.70 (4)					0.0429 (43)	0.0567 (46)	0.087 (32)	0.049 (3)
292.80 (1)	1.81 (14)	2.65 (38)	1.555 (87)	1.644 (27)	1.571 (63)	1.594 (88)	1.58 (4)	1.613 (20)
402.8 (3)						0.00038 (12)		0.00038 (12)
440.44 (1)	100	100	100	100	100	100	100	100
574.9 (3)						0.00241 (65)	0.0099 (39)	0.0026 (6)
600.9 (2)						0.00268 (84)	0.0165 (32)	0.010 (7)
604.93 (17)						0.00192 (69)	0.0091 (24)	0.0055 (17)
646.0 (1)$^{\times}$						0.00885 (84)	0.0095 (39)	0.0089 (8)
659.75 (2)	0.19 (10)	0.53 (5)	0.185 (6)		0.1476 (89)	0.1383 (77)	0.173 (12)	0.165 (20)
710.82 (3)					0.0429 (43)	0.0391 (42)	0.0469 (39)	0.043 (2)
807.37 (1)	1.14 (14)	1.59 (5)	1.152 (26)	1.119 (46)	1.048 (42)	0.923 (57)	1.114 (71)	1.10 (5)
826.55 (4)					0.0271 (16)	0.0218 (19)	0.0303 (51)	0.0249 (14)
867.96 (2)					0.0476 (29)	0.0425 (42)	0.0484 (43)	0.0467 (21)
880.91 (1)$^{\times}$						0.0111 (38)	0.0165 (16)	0.015 (2)
884.6 (3)$^{\times}$						0.00111 (38)		0.0011 (4)
886.66 (14)						0.00391 (73)		0.0039 (7)
897.0 (3)$^{\times}$						0.00119 (35)		0.0012 (4)
1003.58 (2)					0.205 (12)	0.192 (19)	0.209 (12)	0.205 (8)
1045.67 (8)						0.069 (12)	0.134 (75)	0.071 (12)
1100.16 (1)	1.05 (14)	1.71 (8)	1.000 (24)		1.095 (44)	0.992 (61)	0.988 (67)	1.016 (19)
1119.42 (8)		0.214 (25)			0.238 (14)	0.192 (12)	0.201 (12)	0.208 (7)
1328.2 (3)						0.0015 (5)		0.0015 (5)

$^{\times}$: not placed in level scheme.

5.3 Absolute values of the γ-ray emission probabilities

There is only one measurement of the absolute γ-ray emission probability of the 440.44 keV from ^{213}Bi β^- decay which was measured in equilibrium with ^{229}Th by 1986He06 in 1986. This measurement can be adopted as the normalization factor N, that is, N = 0.261 (3).

The evaluated absolute γ-ray emission probabilities are the relative values evaluated in table 9 and table 10 multiplied by 0.261 (3).

6. References

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^{213}Po - Comments on evaluation of the decay data
by Huang Xiaolong, Wang Baosong

This evaluation was completed in 2007. Literature available by December 2007 was included.

1 Decay Scheme

^{213}Po disintegrates 100 % by α emissions to levels in ^{209}Pb. ^{213}Po ground state has $J^{\pi} = 9/2^{+}$ (2007Ba19).

2 Nuclear Data

The Q value is from the 2003Au03 evaluation.
The level energies, spin and parities are from 2007Ba19.
The measured and evaluated ^{213}Po half-life values are listed in Table 1.

Table 1 - Measured half-life values of ^{213}Po and evaluated value, in μs.

$T_{1/2}$ (μs)	References	measurement method
4.2 (8)	1948Je05	
3.74 (2)	1995WaZQ	Superseded by 1998Wa25
3.70 (3)	1997VaZV	Superseded by 1998Wa25
3.75 (4)	1997Wa27	Si(Au), delayed β-α coincidences
3.65 (4)	1998Wa25	Three-dimensional single-crystal scintillation time spectrometer
3.65	2002Mo46	HPGe and 4π autocorrelation single-crystal scintillation time spectrometer. No uncertainty given
3.70 (5)		Unweighted mean of 1997Wa27 and 1998Wa25
3.70 (5)		Weighted mean of 1997Wa27 and 1998Wa25,χ^2=3.1
3.70 (5)	Recommended value	

Values given by 1995 WaZQ, 1997VaZV, 1997Wa27, and 1998Wa25 have authors in common, thus, they may not be independent of each other. A recommended value of 3.70 (5) μs has been estimated by the evaluator.

2.1 g Transitions

The γ-ray transition probability is calculated using the γ-ray emission intensity and the relevant internal conversion coefficient.

Multipolarity of 778.8 keV γ-ray is from level scheme (not measured).

The internal conversion coefficient (ICC) and their associated uncertainties forγ-ray transitions have been obtained using the BRICC computer program, which uses the "Frozen Orbital" approximation (2002Ba85)

2.2 a Transitions

Measured and recommended alpha particles energies are listed in table 2. The recommended values are from 1964Va20 and 1991Ry01.

Table 2 - Measured and recommended value of α-particle energy from ^{213}Po decay

1964Va20	1982Bo04[a]	1991Ry01[b]	Recommended value
7614 (10)			7614 (10)
8377 (5)	8376 (3)	8375.9 (25)	8375.9 (25)

[a]: Original energies of 1982Bo04 have been increased by 2 keV due to changes in calibration energies (1991Ry01).

[b]: evaluation.

The measured and recommended alpha particle emission probabilities are listed in table 3. The recommended alpha particle emission probabilities have been deduced from γ-ray transition intensity balance.

Table 3 - Measured and recommended α-particle emission probabilities from ^{213}Po decay

E_α (keV)	P_α			
	1964Va20	1969LeZW	1997Ch53	Recommended
7614 (10)	0.003 (1)	0.006 (2)	0.0031 (2)	0.0050 (5)
8375.9 (25)	100	100	99.997 (31)	99.9950 (5)

P_α = 0.0031 (2) % in 1997Ch53 is from an α-particle spectrum. This very weak peak is at the low-energy tail of the intense 8376 -keV α-particle group. Thus, the evaluator has considered its reported intensity to be quite inaccurate, despite the value reported in 1997Ch53.

3. Photon Emissions

There is only one γ-ray emitted from ^{213}Po α decay. Only 1989Ko26 measured the γ-ray energy: 778.8 (3) keV. The present recommended γ-ray energy has been taken from this measurement.

The recommended absolute γ-ray emission probability has been obtained as follows: 1989Ko26 measured the ratio: Iγ(779 keV) / Iγ(440 keV) (in ^{213}Bi β^- decay) = 0.000181 (18). Using Pγ(440 keV) = 26.1 (3) % and %β^- = 0.9791 (3) (2007HuXX) then Pγ(778 keV) = 0.0048 (5) %.

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^{214}Pb - Comments on evaluation of decay data
by V. Chisté and M. M. Bé

This evaluation was completed in 2007. Literature available by January 2007 was included.

1 Decay Scheme

^{214}Pb disintegrates by beta minus emission to the excited levels and to the ground state of ^{214}Bi. Spins and parities are from the mass-chain evaluation of Y. A. Akovali (1988Ak01 and 1995El07 for A = 214).
A good agreement was found between the recommended Q value of Audi and the effective Q value (1024 (11) keV) calculated from the decay scheme data.

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).

The recommended value of ^{214}Pb half-life is 26.8 minutes with an uncertainty of 0.9 minutes from M. Curie (1931Cu01). No recent reference was found in the literature.

2.1 b$^-$ Transitions and Emissions

The maximum energies of theβ^- transitions in the decay of^{214}Pb → ^{214}Bi were obtained from theQ$^-$ value and the level energies given in Table 1 from Y. A. Akovali (1995El07).

Table 1: ^{214}Bi levels populated in the decay of ^{214}Pb.

Level number	Level energy, (keV)	Spin and parity	Half-life
0	0.0	1^-	19.9 (4) min
4	295.224 (2)	1^-	≤ 0.05 ns
5	351.932 (2)	0^-, 1^-	≤ 0.10 ns
7	533.67 (2)	(1^-)	
8	797.24 (9)		
9	839.00 (4)	1^+	

The adopted β^- transition probabilities were deduced from the P(γ + ce) balance at each level of the decay scheme. In the Table 2, the recommended values of β^- transition probabilities are compared with the experimental results found in the literature: E. E. Berlovich (1952Be78) and S. Kageyama (1953Ka40) observed only two β^- transitions 672 -keV and 729 -keV and H. Daniel (1956Da28) and K. O. Nielsen (1957Ni11) observed the1024-keV β^- transition. A fair agreement has been found between the results given by S. Kageyama and the recommended value for the 729-keV β^- transition.

Table 2: Recommended and experimental values of β^- transition probabilities.

	672-keV β^- transition	729-keV β^- transition	1024-keV β^- transition
E. E. Berlovich (1952Be78)	25 %	75 %	
S. Kageyama (1953Ka40)	56 %	44 %	
H. Daniel (1956Da28)			6.3 (20) %
K. O . Nielsen (1957Ni11)			< 10 %
Recommended	46.52 (37) %	41.09 (39) %	9.2 (7) %

The values of lg *ft* and average β^- energies have been calculated with the program LOGFT for the β^- transitions.

2.2 g Transitions

The γ-ray transition probabilities were deduced using the γ-ray emission intensities and the relevant internal conversion coefficients.

Multipolarities and δ (recommended by 1995El07) of these γ-ray transitions and the internal conversion coefficients (ICC's) are shown in Table 3.The internal conversion coefficients have been obtained using:

A - the Icc99v3a computer program (GETICC dialog) which is based on the new tables of Band *et al.* (2002Ba85) (calculation for 'no hole') and Rösel (1978Ro22).
B - the BrIcc computer program ("Frozen orbital approximation") which interpolated from theoretical values of Band *et al.* (2002Ba85).

Table 3: Multipolarities of γ-ray transitions.

E_γ (keV)	Multipolarity	α_T (Band)[a]	α_T (Rösel)[a]	α_T (BRICC)[b]
53.2275 (21)	M1 + E2, δ = 0.030 (10)	1.212 (36) E+01	1.288 (39) E+01	1.214 (19) E+01
241.997 (3)	M1 (+E2), δ = 0.00 (15)	8.37 (25) E-01	8.88 (27) E-01	8.38 (18) E-01
258.87 (3)	M1	6.95 (21) E-01	7.37 (22) E-01	6.96 (10) E-01
274.80 (5)	M1 + E2, δ = 1.0	3.73 (11) E-01	3.92 (12) E-01	3.74 (6) E-01
295.224 (2)	M1 + E2, δ = 0.30 (13)	4.54 (14) E-01	4.82 (14) E-01	4.6 (3) E-01
305.26 (3)	[E1]	2.91 (9) E-02	2.95 (9) E-02	2.92 (4) E-02
351.932 (2)	M1 (+ E2), δ = 0.00 (35)	3.00 (9) E-01	3.19 (10) E-01	3.00 (25) E-01
480.43 (2)	M1 (+E2), δ = 0.0 (10)	1.302 (39) E-01	1.384 (42) E-01	1.3 (5) E-03
487.09 (7)	(E1)	1.046 (31) E-02	1.058 (32) E-02	1.047 (15) E-03
533.66 (2)	[M1,E2]	6.24 (19) E-02	6.57 (20) E-02	6 (4) E-02
543.81 (7)	[E1]	8.34 (25) E-03	8.43 (25) E-03	8.34 (12) E-03
580.13 (3)	(E1)	7.32 (22) E-03	7.40 (22) E-03	7.32 (11) E-03
785.96 (9)	E1	4.07 (12) E-03	4.10 (12) E-03	4.06 (6) E-03
839.00 (4)	(E1)	3.60 (11) E-03	3.63 (11) E-03	3.59 (5) E-03

a: A fractional uncertainty of 3 % was adopted for all conversion coefficients.
b: Associated uncertainties are calculated by BrIcc.

The evaluators have adopted the internal conversion coefficients interpolated from the Rösel's tables, because these ICCs lead to a better decay scheme, where the sum of all the β transition probabilities is equal to 100.6 %. The others two ICC's set of values, Band and BrIcc, lead to an inconsistent decay scheme, where the sum of all β transitions probabilities would be of the order of 102– 103 %. Moreover, the effective Q value, of 1024 (11) keV, calculated from the decay scheme data with Rösel's Icc, is closer to the recommended value of 1019 (11) keV than the 1029 (15) keV with the "No hole" approximation.

3 Atomic Data

Atomic values, ω_K, ϖ_L, ϖ_M, n_{KL} and ω_{LM} and the X-ray and Auger electrons relative probabilities are from Schönfeld and Janβen (1996Sc06).

4 Electron Emissions

The conversion electron emission probabilities have been calculated from γ-ray transition data.

5 Photon Emissions

5.1 X-ray Emissions

The X-ray absolute intensities were calculated from γ-ray data and Rösel's ICC using the EMISSION computer program and compared in Table 4 with the measured values of U. Schötzig (1983Sc13) and E. W. A. Lingeman (1969Li11). A good agreement was found between the experimental results given by 1969Li11 and 1983Sc13 and the recommended values deduced from the decay scheme balance. For the Kβ x-ray, a fair agreement was found between 1969Li11 and the recommended one.

Table 4: Experimental and recommended (calculated) values of X -ray.

	U. Schötzig (1983Sc13)	E. W. A. Lingeman (1969Li10)	Recommended values
Kα x-ray (74.82 + 77.11 keV)	16.3 (4) %	17.3 (20) %	16.73 (23) %
Kβ x-ray		4.3 (8) %	4.69 (10) %

5.2 g Emissions

The γ-ray energy emissions given are from Y. A. Akovali (1995El07).

The experimental relative γ emission intensities in ^{214}Bi are based on all available relative and absolute measurements of γ-rays for the ^{226}Ra decay chain. The normalization factor to convert the relative emission intensities to absolute intensities is the weighted average of the measured absolute γ-ray emission intensities (Table 5) of the most intense line in ^{226}Ra decay chain, presents in the ^{214}Bi disintegration namely the 609.3 keV line.

Table 5: The experimental absolute 609.3 keV gamma-ray emission intensity.

References	Experimental values (%)	Comments
E. W. A. Lingeman (1969Li10)	42.8 (40)	
D. G. Olson (1983Ol01)	45.0 (7)	
U. Schötzig (1983Sc13)	44.6 (5)	
W. –J. Lin (1991Li11)	46.1 (5)	
J. Morel (1998Mo14)	44.8 (6)	Omitted (superseded in 2004Mo07)
J. Morel (2004Mo07)	45.57 (18)	
Recommended value	45.49 (19)	$\chi^2 = 1.45$

The recommended normalization factor is the weighted average of the five experimental values: 45.49 with an external uncertainty of 0.19.

The experimental relative γ emission intensities given in Table 6 are relative to the ^{214}Bi 609-keV γ-ray.

Table 6: The experimental data set of the relative γ emission intensities (next page)

Reference	53-keV γ-ray	107-keV γ-ray	137-keV γ-ray	141-keV γ-ray	170-keV γ-ray	196-keV γ-ray	205-keV γ-ray	216-keV γ-ray	241-keV γ-ray
1964Ew04									16.0 (16)
1969Li10									17.1 (18)[b]
1969Wa27									19.33 (30)[a]
1969Gr33	3.15 (34)[a]								16.2 (17)[a]
1970Mo28									16.10(21)
1975Ha31						0.16 (7)[a]			17.5 (17)[a]
1977Zo01									16.06 (19)[a]
1982Ak03						0.14 (2)[a]			16.1 (24)[a]
1982Fa10					0.020 (8)[a]				16.53 (31)[a]
1983Ol01									16.49 (29)
1983Sc13	2.44 (11)								15.65 (25)
1990Mouze		0.015 (3)			0.032 (6)	0.15 (2)	0.025 (6)	0.022 (5)	16.23 (10)
1991Li11									16.33 (25)
2000Sa32						0.16 (8)	0.026 (12)		16.1 (10)
2002De03	2.329 (23)		0.10 (4)	0.06 (3)					15.896 (48)
2002MoZP	2.329 (23)								15.98 (6)
2004Mo07	2.329 (23)[a]								15.880 (48)[a]
Recommended	2.331 (16)	0.015 (3)			0.032 (6)	0.151 (9)	0.025 (5)	0.022 (5)	15.977 (48)
χ^2	0.5					0.015	0.005		2.0

Reference	258-keV γ-ray	274-keV γ-ray	295-keV γ-ray	305-keV γ-ray	314-keV γ-ray	323-keV γ-ray	351-keV γ-ray	462-keV γ-ray	480-keV γ-ray
1964Ew04			40.46 (40)				77 (8)		
1969Li10	1.32 (22)	1.10 (22)[b]	42.6 (44)[b]		0.220 (44)	0.066 (22)	80 (9)	0.46 (11)	0.66 (15)
1969Wa27			47.87 (91)[a]				87.2 (19)[a]		
1969Gr33	1.16 (7)[a]	1.01 (10)[a]	40.2 (40)[a]		0.137 (23)[a]		79 (7)[a]	0.444 (46)[a]	
1970Mo28			41.45 (56)[b]				79.7 (11)		
1975Ha31	1.24 (12)[a]	0.71 (7)[a]	40.2 (40)[a]	0.050 (25)[a]	0.198 (50)[a]	0.062 (25)[a]	86 (9)[a]	0.446 (50)[a]	0.73 (7)[a]
1977Zo01			42.01 (53)[a]				80.42 (81)[a]		
1982Ak03	1.17 (15)[a]	0.86 (16)[a]	42.2 (54)[a]	0.075 (16)[a]	0.185 (28)[a]	0.072 (40)[a]	82 (11)[a]	0.44 (7)[a]	0.75 (10)[a]
1982Fa10	1.72 (4)[a]		42.52 (59)[a]				81.3 (8)[a]		0.68 (2)[a]
1983Ol01			40.8 (6)				78.7 (11)		
1983Sc13			40.0 (7)				77.2 (9)		
1990Mouze	1.23 (6)	0.84 (6)	41.85 (26)[a]	0.068 (10)	0.17 (2)	0.06 (1)	81.48 (48)[a]	0.40 (4)	0.71 (5)
1991Li11	1.152 (25)	1.042 (25)[b]	42.43 (47)[a]				82.7 (9)[a]	0.486 (20)	0.703 (24)
2000Sa32	1.15 (4)	0.83 (8)	40.8 (12)	0.080 (15)	0.158 (20)	0.084 (20)	78.5 (24)	0.470 (14)	0.74 (3)
2002De03	1.171(9)	0.787 (23)	40.36 (12)				78.16 (23)		0.749 (10)
2002MoZP			40.61 (13)				78.34 (23)		
2004Mo07	1.171(9)[a]	0.760(27)[a]	40.32 (12)[a]				78.10 (23)[a]		0.75 (1)[a]
Recommended	1.169 (8)	0.796 (21)	40.48 (31)	0.0692 (47)	0.169 (13)	0.063 (7)	78.26 (16)	0.469 (12)	0.741 (9)
χ^2	0.56	0.43	0.57	0.56	0.82	0.65	0.52	1.24	0.95

Reference	487-keV γ-ray	533-keV γ-ray	538-keV γ-ray	543-keV γ-ray	580-keV γ-ray	765-keV γ-ray	785-keV γ-ray	839-keV γ-ray
1964Ew04								
1969Li10	0.77 (18)	0.37 (9)			0.70 (13)		2.31 (33)	1.30 (18)
1969Wa27								
1969Gr33	0.91 (23)[a]	0.501 (46)[a]			0.89 (9)[a]		2.41 (23)[a]	1.41 (14)[a]
1970Mo28								
1975Ha31	0.88 (10)[a]	0.408 (50)[a]		0.050 (16)[a]	0.80 (7)[a]		2.48 (25)[a]	1.42 (14)[a]
1977Zo01								
1982Ak03	0.88 (11)[a]	0.42 (5)[a]		0.14 (2)[a]	0.79 (11)[a]		2.32 (32)[a]	1.33 (19)[a]
1982Fa10	0.83 (3)[a]							1.30 (3)[a]
1983Ol01								
1983Sc13							2.286 (45)	
1990Mouze	0.83 (7)	0.39 (3)	0.044 (6)	0.15 (2)	0.76 (6)	0.17 (3)	2.33 (17)	1.29 (10)
1991Li11	0.928 (35)	0.409 (20)			0.774 (31)		2.396 (45)	1.290 (20)
2000Sa32	0.90 (5)	0.39 (3)	0.037 (20)	0.100 (10)	0.74 (4)	0.11 (1)	2.33 (7)	1.29 (4)
2002De03	0.961 (12)				0.823 (11)			
2002MoZP								
2004Mo07	0.961 (12)[a]				0.824 (10)[a]			
Recommended	0.951 (14)	0.399 (14)	0.043 (6)	0.11 (2)	0.811 (13)	0.116 (18)	2.339 (28)	1.290(18)
χ^2	1.54	0.18	0.11	5	1.80	3.6	0.75	0.001

a: Not used by the evaluators (see below).

b: the experimental value has been shown to be outlier value by the Lweight program.

There were omitted from analysis:

a) four sets of values, A. Hachem (1975Ha31), G. Mouze (1981Mo28), H. Akcay (1982Ak03), G. Mouze (1990Mo08) and O. Diallo (1993Di09), because these values comes from the same laboratory of G. Mouze (1990Mo**).

b) the sets of values from K. Ya. Gromov (1969Gr33), G. Wallace (1969Wa27) and M. A. Farouk (1982Fa10), because a lack of information in the articles describing their experimental measurements.

c) the set of values from V. Zobel(1977Zo01), because these values changedthe consistency of the data set when introduced in the preliminary calculation with Lweight program, and produced inconsistent set of data for gamma emission intensities. Therefore, in the case of 295keV and 351-keV γ-rays, the values of G. Mouze (1990Mouze) and W. –J. Lin (1991Li11), consistent with Zobel values, were not used by the evaluators for the weighted mean calculations.

d) the relative γ emission intensity values given by 2004Mo07, because they are those measured by J. U. Delgado (2002De03). In 2004Mo07 article, the author measured the 609.3 keV absolute emission probability (Table 2) and normalized the 2002De03 data set with this value of 45.57 (18).

The adopted values are the weighted means calculated by the Lweight program (version 3).

The evaluated relative and absolute γ-ray emission intensities are given in Table 7.

Table 7: Evaluated relative and absolute γ-ray emission intensities

Energy (keV)	Relative emission intensity	Absolute emission intensity (%)
53.2275 (21)	2.331 (16)	1.060 (9)
107.22 (9)	0.015 (3)	0.0068 (14)
137.45 (30)	0.10 (4)	0.045 (18)
141.3 (6)	0.06 (3)	0.027 (14)
170.07 (6)	0.032 (6)	0.0146 (27)
196.20 (5)	0.151 (9)	0.069 (9)
205.68 (9)	0.025 (5)	0.0114 (23)
216.47 (7)	0.022 (5)	0.0100 (23)
241.997 (3)	15.977 (48)	7.268 (22)
258.87 (3)	1.169 (8)	0.5318 (43)
274.80 (5)	0.796 (21)	0.362 (10)
295.224 (2)	40.48 (8)	18.414 (36)
305.26 (3)	0.0692 (47)	0.0315 (21)

Energy (keV)	Relative emission intensity	Absolute emission intensity (%)
314.32 (7)	0.169 (13)	0.077 (6)
323.83 (4)	0.063 (7)	0.0287 (32)
351.932 (2)	78.26 (16)	35.60 (7)
462.00 (7)	0.469 (12)	0.213 (6)
480.43 (2)	0.741 (9)	0.3371 (43)
487.09 (7)	0.951 (14)	0.433 (7)
533.66 (2)	0.399 (14)	0.182 (6)
538.41 (8)	0.043 (6)	0.0196 (27)
543.81 (7)	0.11 (2)	0.050 (9)
580.13 (3)	0.811 (13)	0.369 (6)
765.96 (9)	0.116 (18)	0.053(8)
785.96 (9)	2.339 (28)	1.064 (13)
839.04 (9)	1.290 (18)	0.587 (8)

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^{214}Bi - Comments on evaluation of decay data
by V. Chisté and M. M. Bé

This evaluation was completed in 2007. Literature available by January 2007 was included.

1 Decay Scheme

^{214}Bi disintegrates by beta minus emissions to excited levels and to the ground state of ^{214}Po (99.979 (13) %) and by alpha emission to excited levels of ^{210}Tl (0.0210 (13) % (1960Wa14)), some alpha emissions of long range from excited levels in ^{214}Po to excited levels in ^{210}Pb have been observed. Spins and parities are from the mass-chain evaluation of Y. A. Akovali (1988Ak01 and 1995El07 for A = 214) and E. Browne (2003Br13 for A = 210).

A good agreement was found between the adopted Q(β^-) value of Audi and the effective Q(β^-) value of 3261 (10) keV calculated from decay scheme data.

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).

The recommended value of ^{214}Bi half-life is 19.9 minutes with an uncertainty of 0.4 minutes from H. Daniel (1956Da06). No recent references were found in the literature.

2.1 b$^-$ Transitions and Emissions

The maximum energies of the β^- transitions in the decay of ^{214}Bi → ^{214}Po have been obtained from the Q$^-$ value (2003Au03) and the level energies given in Table 1 from Y. A. Akovali (1995El07).

Table 1: ^{214}Po levels populated in the decay of ^{214}Bi.

Level Number	Level energy, (keV)	Spin and parity	**Level Number**	Level energy, (keV)	Spin and parity
0	0	0^+	**24**	2293.34 (5)	$1^{(+)}, 2^+$
1	609.316 (7)	2^+	**25**	2348.3 (9)	$1^-, 1^+, 2^+$
4	1377.675 (12)	2^+	**26**	2360.8 (4)	$1^-, 1^+, 2^+$
5	1415.489 (19)	0^+	**27**	2423.19 (15)	$1^+, 2^-, 2^+$
6	1543.375 (14)	2^+	**28**	2447.70 (6)	1^-
7	1661.28 (3)	2^+	**29**	2482.46 (4)	$(2)^+$
8	1712.93 (20)	$(3)^+$	**30**	2505.21 (15)	$1^{(-)}, 2^+$
9	1729.611 (13)	2^+	**31**	2508.2 (2)	
10	1742.98 (3)	0^+	**32**	2544.9 (3)	
11	1764.498 (14)	1^+	**34**	2562.4 (3)	
12	1847.431 (14)	2^+	**35**	2604.66 (14)	$(2)^+$
13	1890.287 (21)	2^+	**36**	2630.85 (17)	$1^-, 1^+, 2^+$
14	1994.63 (3)	$(2)^-$	**37**	2662.29 (12)	(2^+)
15	2010.81 (4)	2^+	**38**	2694.6 (2)	$1^{(-)}, 2^+$
16	2017.3 (5)	0^+	**39**	2698.8 (3)	$1^{(-)}, 2^+$
17	2088.41 (12)	$1^-, 1^+, 2^+$	**40**	2699.2 (2)	$1^{(-)}, 2^+$
18	2118.552 (17)	1^+	**41**	2719.22 (9)	$1^-, 1^+, 2^+$
19	2147.78 (6)	$1^{(-)}, 2^+$	**42**	2728.59 (4)	$(1,2)^+$
20	2192.56 (4)	2^+	**43**	2769.9 (2)	$1^-, 1^+, 2^+$
21	2204.13 (9)	1^+	**44**	2785.9 (2)	$1^-, 1^+, 2^+$
23	2266.39 (18)	$1^{(-)}, 2^+$	**47**	2827.0 (2)	$1^-, 1^+, 2^+$

Level Number	Level energy, (keV)	Spin and parity	Level Number	Level energy, (keV)	Spin and parity
48	2861.1 (3)	$1^-, 1^+, 2^+$	**61**	2986.2 (2)	$(1^-), 2^-, 2^+$
49	2869.6 (2)		**62**	3000.0 (2)	$1^{(-)}, 2^+$
50	2880.3 (2)	$1^-, 1^+, 2^+$	**65**	3014.1 (3)	$1^-, 1^+, 2^+$
51	2893.6 (2)	$1^-, 1^+, 2^+$	**69**	3053.9 (2)	$1^-, 1^+, 2^+$
52	2897.0 (3)		**70**	3068.3 (8)	
53	2919.5 (3)		**72**	3081.7 (3)	$1^-, 1^+, 2^+$
54	2921.8 (4)	$1^-, 1^+, 2^+$	**73**	3094.0 (4)	$(1^-, 2^+)$
55	2928.6 (3)	$1^-, 1^+, 2^+$	**75**	3142.6 (4)	$1^-, 1^+, 2^+$
56	2934.5 (3)	$1^-, 1^+, 2^+$	**76**	3149.2 (5)	$1^-, 1^+, 2^+$
57	2940.6 (2)	$1^{(-)}, 2^-, 2^+$	**77**	3160.4 (6)	$1^-, 1^+, 2^+$
58	2962.8 (7)		**79**	3173.3 (6)	
60	2978.8 (2)	$1^-, 1^+, 2^+$	**80**	3183.6 (4)	$1^-, 1^+, 2^+$

The adopted β^- transition probabilities and the associated uncertainties were deduced from the γ transition probability balance at each level of the decay scheme.

The values of log ft and average β^- energies have been calculated with the program LOGFT for the allowed an 1st forbidden β^- transitions .

2.2 g Transitions

The γ-ray transition probabilities were calculated using the γ-ray emission intensities and the relevant internal conversion coefficients (see **4.2** g **Emissions**).

Multipolarities of γ-ray transitions are from Y. A. Akovali (1995El07 for A = 214) and E. Browne (2003Br13 for A = 210) and shown in Table 2.

Table 2: Multipolarities of γ-ray transitions.

	Multipolarity	E_γ (keV)
^{210}Tl	(M1)	62.5 (10)
^{214}Po	[M1,E2]	221 (1), 386.823 (18), 452.92 (10), 469.756 (18), 474.52 (5), 543.0 (2), 595.32 (7), 633.14 (10), 634.72 (21), 649.19 (7), 661.1 (2), 697.88 (20), 740.73 (18), 752.84 (3), 814.885 (10), 878.03 (12), 915.74 (15), 939.6 (5), 991.49 (19), 1051.964 (31), 1103.61 (20), 1104.79 (19)
	[M1]	252.80 (6), 349.009 (24), 388.941 (50), 461.15 (20), 703.11 (4), 788.6 (5), 1594.81 (8)
	[E1]	268.614 (26), 333.35 (6), 454.850 (26), 487.95 (13), 572.76 (7), 615.53 (10), 617.0 (2), 683.22 (6), 704.9 (3), 786.1 (4), 904.29 (10), 917.8 (3), 1032.37 (8), 1069.96 (8), 1207.70 (3), 1385.314 (31)
	[E2]	405.74 (4), 528 (1),639.62 (10), 832.38 (11), 1133.664 (31), 1172.98 (10), 1543.375 (14)
	(E2)	1407.98 (4)
	(M1 + E2)	1401.494 (41) δ = 1.6 (5)
	E2	609.316 (7), 719.869 (37), 806.173 (20), 1377.675 (12), 1661.28 (6), 1729.611 (13),
	E1	665.445 (23), 2447.86 (10)
	M1 + E2	768.359 (14) δ = 2.8 (7)
		934.059 (16) δ = -0.3 (1)
		1120.295 (15) δ = 0.18 (2)
		1155.182 (16) δ = 0.33 (6)
		1238.115 (12) δ = -0.03 (3)
		1509.236 (15) δ = -0.053 (35)
		1583.244 (40) δ = -0.20 (10)
	M1	821.18 (3), 826.46 (20), 1280.97 (2), 1764.498 (14), 2118.552 (30), 2204.21 (4)

The internal conversion coefficients (ICC) and the associated uncertainties for these γ-ray transitions have been obtained using the BrIcc computer program (calculation for 'hole'), which interpolated the new values from theoretical values of I. M. Band (2002Ba85).

2.3 a Transitions and Emissions

The energies of the α-particle transitions given in Section 2.3 have been obtained from Q_α (2003Au03) and the level energies given by E. Browne (2003Br13) .

The adopted $\alpha_{0,0}$, $\alpha_{0,2}$ and $\alpha_{0,3}$ emission energies are the recommended values of A. Rytz (1991Ry01) and the other α emission energies are from E. Browne (2003Br13).

The recommended α emission probabilities come from the measured values of R. J. Walen (1960Wa14).

For the α of long range, the energy and emission probabilities are from the measurements of C. -F. Leang (1965Le08).

3 Atomic Data

Atomic values, ω_K, ϖ_L, ϖ_M, n_{KL} and $\overline{n}_{LM}$ and the X-ray and Auger electron relative probabilities are from Schönfeld and Janβen (1996Sc06).

4 Electron Emissions

The conversion electron emission probabilities have been deduced from γ-ray transition data.

5 Photon Emissions

5.1 X-ray Emissions

The X-ray absolute intensities have been calculated from γ-ray data and ICC using the EMISSION computer program and compared in Table 3 with the measured values of U. Schötzig (1983Sc13). These values are not consistent, it is difficult to draw a conclusion since, as said in 1983Sc03, "the x-ray spectrum is rather complex, as the Po and Bi x-ray peaks overlap, a deconvolution is difficult".

Table 3: Experimental and recommended (calculated) values of X-ray absolute intensities.

	U. Schötzig (1983Sc13)	Recommended values
Kα x-ray	1.77 (5) %	1.135 (25) %
Kβ x-ray	4.94 (12)	0.320 (9) %

5.2 g Emissions

The γ-ray energies are from Y. A. Akovali (1995El07 for A = 214) and E. Browne (2003Br13 for A = 210).

For the ^{210}Tl γ-rays, the absolute γ-ray emission intensities have been deduced from the α emission intensities measured by R. J. Walen (1960Wa14).

The experimental relative γ-ray emission intensities in ^{214}Po are based on all available relative and absolute measurements of γ-rays for the ^{226}Ra decay chain. The normalization factor to convert the relative γ-ray emission intensities to absolute intensities is the weighted average of the measured values of the 609.3-keV γ-ray absolute intensity (Table 4).

Table 4: The experimental values of 609.3-keV γ-ray absolute intensity.

References	Experimental values (%)	Comments
E. W. A. Lingeman (1969Li10)	42.8 (40)	
D. G. Olson (1983Ol01)	45.0 (7)	
U. Schötzig (1983Sc13)	44.6 (5)	
W. –J. Lin (1991Li11)	46.1 (5)	
J. Morel (1998Mo14)	44.8 (6)	Omitted: superseded by 2004Mo07
J. Morel (2004Mo07)	45.57 (18)	
Recommended value	45.49 (19)	χ^2 = 1.45

Evaluators' recommended normalization factor is the weighted average of the five experimental values: 45.49 with an external uncertainty of 0.19.

The experimental relative γ-ray emission intensities are given in Table 5 relatively to the ^{214}Bi 609-keV γ-ray intensity.

The evaluated relative and absolute γ-ray intensities are given in Table 6.

The adopted values are the weighted means calculated by the Lweight program (version 3).

Table 5: The experimental data set of the relative γ-ray emission intensities. (see next pages)

Energy (keV)	1969Li10	1696Wa27*	1969Gr33*	1975Ha31*	1977Zo01	1982Ak03*	1982Fa10*	1983Ol01	1983Sc13	1990Mouze	1991Li11	2000Sa32	2002De03	2002MoZP	2004Mo07*	Evaluated	χ2
221						0.012 (7)						0.130 (13)				0.130 (13)	
230												0.0063 (21)				0.0063 (21)	
252						0.033 (7)				0.028 (4)		0.019 (7)				0.0258 (39)	1.3
268						0.031 (8)				0.035 (4)		0.059 (28)				0.0355 (40)	0.72
273	0.18 (9)			0.384 (50)		0.25 (5)				0.27 (3)		0.29 (10)	0.265 (23)		0.278 (17)	0.264 (18)	0.33
280	0.132 (22)			0.136 (50)		0.13 (2)				0.13 (2)		0.17 (4)				0.136 (14)	0.42
304	0.18 (9)			0.074 (25)		0.069 (15)				0.055 (5)		0.065 (20)				0.056 (5)	1.1
333			0.148 (23)	0.15 (7)		0.16 (3)				0.14 (1)		0.13 (3)				0.139 (9)	0.1
334	0.132 (44)			0.074 (37)		0.072 (14)				0.066 (8)		0.090 (17)				0.072 (10)	1.8
348										0.34 (5)		0.20 (5)				0.27 (7)	3.9
386	0.68 (26)		1.41 (18)	0.64 (7)		0.64 (10)				0.63 (5)		0.70 (15)	0.651 (12)		0.647 (11)	0.650 (12)	0.10
388	0.81 (26)			0.83 (7)		0.87 (12)				0.85 (1)	0.92 (6)	0.86 (4)	0.888 (14)		0.89 (13)	0.864 (10)	1.5
394				0.019 (9)		0.033 (4)				0.032 (3)		0.024 (3)				0.0280 (40)	3.6
396				0.050 (25)		0.060 (9)				0.059 (7)		0.053 (10)				0.057 (4)	0.24
405	0.33 (9)		0.341 (34)	0.40 (7)		0.38 (5)				0.37 (2)		0.39 (3)				0.375 (16)	0.28
452						0.068 (11)				0.067 (8)						0.067 (8)	
454	0.62 (11)		0.64 (7)	0.64 (7)		0.67 (8)	0.63 (2)			0.64 (3)		0.59 (3)	0.640 (12)		0.642 (12)	0.634 (10)	0.82
461						0.078 (13)				0.14 (2)		0.10 (3)				0.128 (18)	1.2
469						0.30 (5)				0.27 (2)		0.34 (3)				0.292 (32)	3.8
474	0.15 (7)			0.24 (7)		0.23 (4)				0.22 (2)		0.190 (20)				0.203 (14)	0.86
485						0.052 (11)				0.048 (9)		0.035 (20)				0.046 (8)	0.35
487										0.061 (20)						0.061 (20)	
494						0.031 (5)				0.031 (4)		0.019 (3)				0.023 (6)	5.8
496						0.015 (4)				0.015 (4)						0.015 (4)	
501				0.038 (7)		0.041 (7)				0.040 (5)		0.035 (19)				0.0397 (48)	0.06
519				0.0124 (50)		0.035 (6)				0.036 (4)		0.039 (11)				0.0364 (38)	0.07
524				0.033 (12)		0.038 (6)				0.037 (4)		0.039 (13)				0.0372 (38)	0.02
528						0.025 (5)				0.024 (3)		0.022 (11)				0.0239 (29)	0.03
536				0.124 (50)		0.14 (2)				0.14 (2)		0.12 (3)				0.134 (17)	0.31
543	0.22 (7)		0.296 (34)	0.20 (7)		0.14 (2)				0.13 (2)		0.27 (4)				0.194 (46)	3.4
547	0.066 (22)			0.071 (14)		0.08 (1)				0.08 (1)		0.074 (7)				0.075 (6)	0.22
551										0.012 (3)						0.012 (3)	
572	0.132 (44)		0.159 (23)	0.161 (25)		0.17 (2)				0.16 (2)		0.16 (4)				0.156 (17)	0.17

Energy (keV)	1969Li10	1696Wa27*	1969Gr33*	1975Ha31*	1977Zo01	1982Ak03*	1982Fa10*	1983Ol01	1983Sc13	1990Mouze	1991Li11	2000Sa32	2002De03	2002MoZP	2004Mo07*	Evaluated	χ2
595						0.035 (7)				0.038 (4)		0.039 (6)				0.0383 (33)	0.02
600										0.018 (8)						0.018 (8)	
609	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
615	0.20 (7)			0.099 (25)		0.13 (5)				0.12 (2)		0.11 (3)				0.121 (16)	0.71
617				0.074 (25)		0.066 (44)				0.053 (6)		0.077 (11)				0.059 (10)	3.7
626						0.036 (6)						0.009 (3)				0.009 (3)	
630			0.228 (34)	0.037 (12)		0.039 (6)				0.035 (4)		0.039 (5)				0.0366 (31)	0.39
633	0.110 (44)			0.124 (12)		0.12 (2)				0.11 (1)		0.130 (10)				0.120 (7)	1,0
634						0.014 (5)				0.014 (5)						0.014 (5)	
639				0.074 (25)		0.061 (11)				0.065 (10)		0.085 (10)				0.075 (10)	2,0
649	0.110 (44)			0.124 (12)		0.114 (15)				0.13 (2)		0.10 (3)				0.119 (16)	0.37
658						0.037 (8)				0.046 (8)		0.030 (8)				0.038 (8)	2,0
661				0.094 (37)		0.077 (13)				0.11 (2)		0.120 (10)				0.118 (9)	0.2
665	3.08 (44)		3.49 (30)	3.59 (37)		3.36 (37)	2.87 (6)			3.51 (20)	3.21 (7)	3.33 (10)	3.359 (17)	3.386 (21)	3.364 (17)	3.364 (15)	1.4
677						0.012 (5)				0.012 (5)						0.012 (5)	
683	0.176 (44)		0.296 (46)	0.186 (25)		0.18 (3)				0.18 (2)		0.190 (20)				0.184 (13)	0.08
687				0.012 (6)		0.016 (5)				0.015 (4)		0.014 (5)				0.0146 (31)	0.02
693				0.012 (6)		0.012 (5)				0.015 (6)		0.012 (4)				0.0129 (33)	0.17
697	0.154 (44)		0.501 (46)	0.100 (50)		0.14 (2)				0.14 (2)		0.150 (10)				0.148 (9)	0.11
699						0.044 (9)				0.035 (10)						0.035 (10)	
703	1.03 (13)		1.55 (16)	1.14 (12)		1.08 (15)	0.82 (3)			1.11 (7)	1.038 (27)	1.12 (8)				1.053(24)	0.57
704										0.11 (3)		0.113 (29)				0.112 (21)	0.006
708						0.031 (9)				0.042 (11)		0.025 (3)				0.0262 (43)	2.2
710	0.13 (7)		0.364 (34)	0.161 (50)		0.16 (2)				0.16 (2)		0.170 (9)				0.168 (8)	0.25
719	0.84 (11)		1.22 (13)	0.94 (12)		0.90 (13)				0.91 (8)	0.833 (24)	0.91 (3)				0.865 (22)	1.5
722				0.099 (50)		0.075 (11)				0.073 (9)		0.107 (15)				0.082 (15)	3.8
733	0.066 (22)			0.087 (25)		0.086 (12)				0.085 (8)		0.092 (17)				0.084 (7)	0.45
740						0.11 (2)				0.088 (13)		0.095 (5)				0.0941 (47)	0.25
752	0.24 (7)			0.31 (7)		0.30 (4)				0.28 (2)		0.28 (4)				0.278 (17)	0.15
768		9.90 (21)	10.6 (10)	11.4 (12)	10.90 (15)	11.9 (17)	10.64 (20)		10.46 (16)	10.91 (8)	10.86 (14)	10.39 (31)	10.66 (5)	10.77 (3)	10.68 (5)	10.755 (36)	2.3
786	0.64 (18)											0.70 (10)				0.69 (10)	0.09
788										0.041 (8)		0.020 (10)				0.033 (10)	2.7
806	2.42 (44)µ		2.68 (25)	2.97 (37)		2.92 (43)	2.49 (6)			2.90 (22)	2.682 (45)	2.76 (11)	2.788 (22)	2.777 (14)	2.791 (20)	2.774 (13)	1.2
815	0.088 (44)			0.050 (25)		0.087 (13)				0.081 (8)		0.110 (20)				0.085 (7)	0.91
821	0.35 (9)			0.40 (7)		0.37 (6)				0.36 (3)		0.37 (3)				0.364 (21)	0.04

Energy (keV)	1969Li10	1696Wa27*	1969Gr33*	1975Ha31*	1977Zo01	1982Ak03*	1982Fa10*	1983Ol01	1983Sc13	1990Mouze	1991Li11	2000Sa32	2002De03	2002MoZP	2004Mo07*	Evaluated	$\chi2$
826	0.29 (13)			0.21 (7)		0.29 (4)				0.28 (3)		0.29 (4)				0.284 (24)	0.02
832	0.066 (22)			0.062 (25)		0.064 (10)				0.062 (6)		0.080 (3)				0.076 (5)	3.7
847				0.037 (12)		0.052 (12)				0.057 (7)		0.053 (15)				0.035 (13)	0.06
873						0.032 (10)				0.042 (9)		0.040 (10)				0.041 (7)	0.02
878						0.022 (7)				0.026 (6)						0.026 (6)	
904	0.15 (7)			0.198 (50)		0.15 (2)				0.14 (2)		0.16 (4)				0.144 (17)	0.1
915				0.050 (12)		0.070 (14)				0.065 (8)		0.043 (6)				0.051 (11)	4.8
917						0.010 (7)				0.010 (7)						0.010 (7)	
930						0.058 (13)				0.10 (2)		0.08 (3)				0.094 (17)	0.31
934	6.8 (7)	6.26 (18)	7.0 (7)	7.3 (7)	6.93 (10)	7.0 (9)	6.54 (13)		6.75 (9)	6.88 (5)	6.66 (9)	6.70 (20)	6.783 (34)	6.83 (4)	6.788 (34)	6.814 (22)	1.05
939						0.030 (8)				0.028 (8)		0.045 (9)				0.036 (8)	2,0
943			0.205 (34)	0.037 (12)		0.034 (8)				0.037 (6)		0.050 (26)				0.038 (6)	0.24
949						0.009 (6)				0.012 (5)						0.012 (5)	
952										0.013 (5)						0.013 (5)	
961						0.046 (12)				0.03 (2)		0.022 (3)				0.0222 (30)	0.16
964	0.81 (11)		0.78 (8)	0.85 (9)		0.82 (10)				0.80 (5)	0.796 (38)	0.80 (7)				0.799 (27)	0.01
976				0.050 (25)		0.029 (8)				0.033 (5)		0.035 (13)				0.0333 (47)	0.02
991				0.0031 (15)		0.009 (6)				0.022 (5)		0.050 (22)				0.023 (6)	1.5
1013				0.022 (11)						0.018 (3)		0.034 (11)				0.0191 (41)	1.9
1021				0.025 (12)						0.034 (6)		0.036 (15)				0.034 (6)	0.02
1032	0.154 (44)			0.161 (50)						0.13 (1)		0.17 (3)				0.135 (9)	0.9
1038				0.025 (12)						0.018 (3)		0.030 (10)				0.0190 (33)	1.3
1045				0.062 (12)						0.051 (6)		0.037 (20)				0.050 (6)	0.45
1051	0.73 (9)		0.71 (7)	0.68 (7)			0.76 (3)			0.66 (5)	0.692 (24)	0.72 (4)				0.713 (17)	1.1
1067				0.062 (25)						0.055 (20)		0.051 (24)				0.053 (15)	0.02
1069	0.57 (9)		0.73 (14)	0.62 (7)						0.56 (4)	0.605 (33)	0.65 (6)				0.595 (23)	0.59
1103	0.35 (7)			0.21 (10)						0.21 (3)		0.24 (7)				0.233 (33)	1.7
1104			0.250 (34)	0.17 (7)						0.16 (3)						0.16 (3)	
1118										0.015 (8)		0.034 (11)				0.022 (9)	1.9
1120	33.0 (33)	31.90 (73)	29.4 (28)	34.0 (35)	32.72 (39)		33.52 (42)	32.73 (48)	32.31 (46)	33.13 (22)	33.19 (46)	32.3 (10)	32.71 (10)	32.77 (12)	32.74 (10)	32.77 (7)	0.64
1130				0.099 (25)						0.078 (9)		0.080 (11)				0.079 (7)	0.02
1133	0.55 (11)		0.478 (46)	0.62 (6)						0.56 (3)	0.545 (29)	0.57 (3)				0.558 (17)	0.12
1155	3.74 (44)		3.72 (34)	3.96 (50)			3.65 (7)			3.5 (4)	3.583 (46)	3.4 (7)	3.594 (36)	3.595 (17)	3.597 (32)	3.594 (15)	0.06
1167				0.021 (17)						0.027 (4)		0.028 (10)				0.0271 (37)	0.01
1172	0.066 (22)µ			0.113 (41)						0.098 (12)		0.132 (9)				0.120 (16)	5.1

Energy (keV)	1969Li10	1696Wa27*	1969Gr33*	1975Ha31*	1977Zo01	1982Ak03*	1982Fa10*	1983Ol01	1983Sc13	1990Mouze	1991Li11	2000Sa32	2002De03	2002MoZP	2004Mo07*	Evaluated	χ2
1207	1.03 (13)		0.89 (9)	1.10 (11)						0.98 (6)	0.991 (35)	1.04 (7)				0.998 (27)	0.18
1226				0.058 (19)						0.028 (11)		0.074 (20)				0.039 (18)	4.1
1230										0.015 (6)		0.08 (4)				0.016 (10)	2.6
1238	13.4 (13)µ	12.77 (12)	12.8 (11)	14.9 (15)	12.94 (17)		13.25 (22)	13.01 (18)	12.71 (16)	12.87 (9)	12.73 (18)	12.7 (4)	12.83 (6)	12.80 (4)	12.85 (5)	12.819 (29)	0.43
1280	3.30 (44)µ		2.92 (28)	3.59 (50)			3.22 (6)			3.17 (17)	3.144 (46)	3.15 (11)	3.147 (28)	3.159 (16)	3.151 (28)	3.155 (13)	0.05
1284										0.052 (12)		0.020 (7)				0.028 (14)	5.3
1303	0.24 (7)		0.284 (34)	0.25 (6)						0.21 (2)	0.246 (15)	0.20 (5)				0.231 (12)	0.83
1316	0.154 (44)			0.198 (50)						0.16 (2)		0.20 (3)				0.170 (16)	0.69
1330				0.024 (11)						0.026 (3)		0.039 (17)				0.0264 (30)	0.57
1341				0.050 (25)						0.046 (6)		0.059 (29)				0.047 (6)	0.19
1351			0.205 (34)							0.008 (2)		0.014 (4)				0.0092 (24)	1.8
1353				0.0099 (25)						0.008 (2)						0.008 (2)	
1377	9.5 (11)µ	8.70 (48)	9.0 (9)	9.9 (11)	8.87 (15)		8.66 (16)			8.82 (12)	8.79 (14)	8.52 (25)µ	8.689 (19)	8.79 (3)	8.720 (44)	8.722 (25)	2.5
1385	1.76 (33)	1.29 (30)	1.66 (17)	2.04 (20)						1.81 (8)µ	1.664 (40)µ	1.76 (5)	1.744 (17)	1.755 (16)	1.750 (19)	1.750 (11)	1.8
1392				0.041 (19)						0.018 (4)		0.035 (15)				0.0191 (42)	1.2
1401	3.30 (44)µ		3.03 (28)	3.47 (37)						2.91 (16)	2.792 (45)	3.0 (4)	2.924 (20)	2.934 (13)	2.927 (20)	2.923 (16)	2.3
1407	5.7 (7)		5.9 (6)	6.2 (7)						5.37 (6)	4.73 (13)µ	5.5 (5)	5.233 (26)	5.250 (19)	5.245 (42)	5.252 (17)	1.3
1419				0.0111 (25)						0.011 (3)		0.013 (3)				0.0120 (21)	0.22
1470										0.020 (3)		0.035 (15)				0.0206 (29)	0.96
1479	0.110 (44)			0.124 (50)						0.11 (1)		0.14 (3)				0.113 (9)	0.45
1509	4.84 (44)		4.77 (46)	5.45 (50)	4.78 (9)		4.77 (9)		4.57 (11)	4.76 (5)	4.64 (9)	4,63 (15)	4.61 (6)	4.67 (3)	4.64 (6)	4.679 (21)	0.95
1515										0.015 (2)		0.039 (10)				0.0159 (46)	5.5
1538	1.17 (13)µ		0.72 (7)	1.14 (12)						0.95 (6)	0.827 (31)	0.98 (5)				0.882 (49)	4.1
1543	0.75 (18)			0.74 (7)						0.68 (4)	0.44 (11)	0.67 (3)				0.664 (29)	1.5
1583	1.60 (15)		1.47 (5)	1.86 (19)			1.57 (3)			1.58 (8)	1.517 (34)	1.64 (17)		1.556 (13)		1.555 (11)	0.39
1594	0.66 (20)		0.51 (6)	0.69 (6)						0.61 (4)	0.55 (8)	0.63 (10)				0.603 (33)	0.21
1599	0.75 (20)		0.66 (7)	0.85 (11)						0.72 (4)	0.51 (12)	0.73 (7)				0.707 (33)	0.98
1636				0.040 (12)						0.024 (3)		0.06 (3)				0.0244 (36)	1.4
1657				0.16 (7)						0.10 (1)		0.14 (3)				0.104 (12)	1.6
1661	2.55 (26)		2.49 (20)	2.72 (25)			2.55 (5)			2.33 (12)	2.53 (7)	2.37 (22)	2.271 (34)	2.299 (14)	2.284 (34)	2.304(20)	2.5
1665										0.018 (3)		0.046 (9)				0.032 (14)	4.8
1683	0.53 (9)		0.52 (6)	0.56 (6)						0.49 (3)	0.475 (13)	0.43 (4)		0.481 (9)		0.478 (7)	0.52
1711												0.050 (10)				0.050 (10)	
1729	7.03 (9)µ	6.94 (20)	6.6 (6)	7.5 (7)	6.29 (10)		6.56 (12)			6.60 (4)µ	6.42 (9)	6.33 (15)	6.226 (31)	6.25 (3)	6.229 (31)	6.251 (22)	1.2
1751										0.002 (1)						0.002 (1)	

Energy (keV)	1969Li10	1696Wa27*	1969Gr33*	1975Ha31*	1977Zo01	1982Ak03*	1982Fa10*	1983Ol01	1983Sc13	1990Mouze	1991Li11	2000Sa32	2002De03	2002MoZP	2004Mo07*	Evaluated	χ2
1764	36.7 (35)µ	35.34 (10)	34.4 (34)	40.0 (40)	34.23 (44)		34.91 (41)		33.2(7)	34.48 (25)	33.85 (46)	33.3 (10)	33.54 (10)	33.63 (9)	33.56 (10)	33.66 (10)	2.5
1813				0.026 (10)						0.024 (2)		0.020 (10)				0.0238 (20)	0.15
1838	0.81 (11)		0.88 (8)	0.89 (10)						0.74 (3)		0.77 (4)				0.753(23)	0.32
1847	5.1 (7)µ		4.76 (46)	5.32 (50)	4.52 (9)		4.59 (9)			4.57 (6)		4.35 (13)	4.448 (36)	4.42 (3)	4.457 (31)	4.451 (26)	1.6
1873	0.48 (11)		0.478 (46)	0.557 (50)						0.46 (2)		0.51 (5)				0.467 (18)	0.44
1890	0.22 (7)		0.205 (46)	0.21 (7)						0.17 (1)		0.17 (3)				0.171 (9)	0.25
1895	0.40 (9)		0.432 (46)	0.37 (6)						0.31 (2)		0.35 (4)				0.321 (18)	0.8
1898				0.136 (50)						0.11 (2)		0.10 (3)				0.107 (17)	0.08
1935			0.432 (46)	0.111 (50)						0.067 (7)		0.16 (4)				0.070 (16)	5.2
1994										0.005 (1)		0.010 (5)				0.0052 (10)	0.96
2010	0.081 (13)			0.111 (12)						0.100 (5)		0.093 (5)				0.0954 (37)	1.1
2021				0.074 (12)						0.045 (5)		0.057 (11)				0.0471 (46)	0.99
2052	0.154 (44)		0.250 (34)	0.173 (25)						0.15 (1)		0.16 (3)				0.151 (9)	0.52
2085	0.022 (7)			0.0198 (50)						0.018 (1)						0.0181 (10)	0.32
2089	0.110 (22)		0.137 (46)	0.124 (12)						0.096 (5)		0.12 (3)				0.0973 (48)	0.49
2109	0.220 (44)		0.20 (6)	0.235 (50)					0.180 (9)	0.19 (1)		0.17 (3)				0.185 (6)	0.48
2118	2.86 (33)µ	2.76 (13)	2.61 (23)	3.03 (31)	2.53 (5)		2.51 (5)		2.57 (7)	2.56 (3)		2.65 (25)µ	2.536 (20)	2.548 (21)	2.537 (20)	2.545 (12)	0.17
2147	0.026 (7)			0.036 (10)						0.029 (2)		0.050 (10)				0.0295 (28)	2.3
2160										0.004 (1)		0.026 (1)				0.015 (11)	
2176										0.007 (1)		0.015 (6)				0.0072 (13)	1.7
2192	0.154 (44)			0.161 (50)					0.070 (13)	0.073 (6)		0.093 (5)				0.084 (7)	3.4
2204	11.7 (11)µ	11.22 (47)	11.37 (24)	12.38 (27)	10.77 (20)		10.66 (20)		10.95 (70)	11.02 (9)		11.1 (3)	10.74 (5)	10.75 (9)	10.76 (5)	10.80 (5)	1.8
2251				0.015 (7)						0.012 (1)						0.012 (1)	
2260			0.057 (23)	0.0149 (50)						0.019 (1)		0.020 (3)				0.0191 (9)	0.1
2266	0.033 (7)			0.045 (12)						0.037 (2)		0.034 (4)				0.0362 (17)	0.34
2270				0.0111 (50)						0.0029 (5)		0.010 (5)				0.0030 (7)	2,0
2284										0.011 (1)		0.011 (3)				0.0110 (9)	
2287										0.010 (1)						0.010 (1)	
2293	0.73 (9)		0.67 (7)	0.83 (9)			0.67 (2)		0.662 (20)	0.67 (3)		0.72 (6)	0.665 (17)	0.677 (10)	0.665 (17)	0.673 (8)	0.57
2310										0.003 (2)						0.003 (2)	
2312	0.020 (7)			0.0235 (50)						0.019 (2)		0.018 (5)				0.0189 (18)	0.029
2319										0.0009 (3)		0.0050 (10)				0.0030 (20)	8.4
2325				0.0040 (20)						0.0037 (4)		0.009 (3)				0.0038 (7)	3.1
2331	0.046 (9)		0.034 (11)	0.0557 (50)						0.048 (3)		0.076 (7)				0.056 (9)	5.7
2348										0.0003 (2)						0.0003 (2)	

Energy (keV)	1969Li10	1696Wa27*	1969Gr33*	1975Ha31*	1977Zo01	1982Ak03*	1982Fa10*	1983Ol01	1983Sc13	1990Mouze	1991Li11	2000Sa32	2002De03	2002MoZP	2004Mo07*	Evaluated	χ2
2353										0.0008 (3)						0.0008 (3)	
2361				0.0040 (12)						0,0033 (3)		0.0060 (10)				0.0046 (14)	3.6
2369										0.006 (1)		0.008 (3)				0.0062 (9)	0.4
2376	0.0132 (44)		0.057 (23)	0.022 (7)						0.019 (1)		0.034 (7)				0.0190 (17)	3.2
2390				0.0042 (10)						0.0034 (3)		0.006 (3)				0.00343 (30)	0.74
2405										0.0009 (3)		0.0040 (10)				0.0024 (16)	4.8
2423	0.0132 (44)			0.0115 (40)						0.010 (1)		0.018 (4)				0.0106 (14)	2.1
2444										0,018 (9)						0.018 (9)	
2447	3.63 (40)µ	3.32 (6)	3.79 (28)	3.96 (37)	3.32 (8)		3.28 (6)			3.42 (3)		3.30 (10)	3.402 (24)	3.41 (4)	3.408 (24)	3.403 (16)	0.50
2459										0.0031 (5)						0.0031 (5)	
2482				0.0046 (19)						0.0021 (4)						0.0021 (4)	6.1
2505	0.0154 (44)			0.0149 (37)						0.012 (1)		0.025 (7)				0.0124 (13)	1.9
2550										0.0007 (2)						0.0007 (2)	
2562										0.0004 (3)						0.0004 (3)	
2564										0.0003(2)						0.0003(2)	
2604				0.00099 (25)						0.0008 (2)						0.0008 (2)	
2630				0.0020 (10)						0.0018 (3)		0.0050 (17)				0.0019 (5)	3.4
2662										0.0006 (2)		0.0004 (1)				0.00044 (9)	0.8
2694	0.068 (9)		0.072 (34)	0.079 (7)			0.078 (2)			0.066 (3)		0.062 (4)				0.072 (6)	4.5
2699	0.0110 (44)			0.0050 (19)						0.0061 (5)						0.0062 (5)	1.2
2719	0.0033 (11)			0.0040 (12)						0.0038 (4)						0.00374 (38)	0.18
2769	0.057 (9)		0.057 (23)	0.062 (7)			0.047 (2)			0.053 (3)		0.048 (15)				0.0494 (17)	1.2
2785	0.0110 (22)			0.0149 (25)						0.012 (1)		0.030 (11)				0.0120 (11)	1.4
2826	0.0046 (11)			0.0062 (12)						0.0048 (4)		0.011 (6)				0.00480 (38)	0.55
2861				0.00074 (37)						0.0009 (2)		0.008 (5)				0.00091 (28)	2.01
2880	0.0176 (33)		0.019 (6)	0.024 (7)						0.020 (2)		0.030 (3)				0.0222 (35)	4.8
2893	0.0132 (33)		0.016 (7)	0.0149 (37)						0.012 (1)		0.017 (3)				0.0126 (10)	1.3
2921	0.035 (7)		0.032 (11)	0.037 (6)						0.029 (1)		0.035 (4)				0.0295 (11)	1.4
2928				0.0026 (10)						0.0024 (2)						0.0024 (2)	
2934				0.00124 (50)						0.0010 (2)		0.005 (3)				0.00102 (27)	1.8
2978	0.031 (7)		0.038 (23)	0.037 (6)			0.029 (2)			0.030 (1)		0.034 (7)				0.0302 (9)	0.85
2999	0.0220 (44)		0.015 (7)	0.024 (6)						0.019 (1)		0.030 (5)				0.0195 (15)	2.5
3053	0.046 (7)		0.046 (23)	0.053 (7)						0.041 (2)		0.057 (3)				0.048 (7)	1.8
3081	0.0110 (44)			0.0124 (37)						0.011 (1)		0.020 (4)				0.0115 (15)	2.4
3093				0.00111 (37)						0.0008 (1)		0.0010 (3)				0.00082 (9)	0.4

Energy (keV)	1969Li10	1696Wa27*	1969Gr33*	1975Ha31*	1977Zo01	1982Ak03*	1982Fa10*	1983Ol01	1983Sc13	1990Mouze	1991Li11	2000Sa32	2002De03	2002MoZP	2004Mo07*	Evaluated	$\chi2$
3142	0.0022 (9)			0.0035 (12)						0.0026 (2)		0.0060 (28)				0.00260 (19)	0.84
3149										0.00019						0.00019	
3160	0.00110 (44)			0.00111 (50)						0.0010 (2)		0.0030 (17)				0.00104 (18)	0.7
3183	0.00110 (44)			0.0032 (10)						0.0028 (2)		0.0060 (10)				0.0023 (10)	1.3

*: Not used by the evaluators (see below).
µ: the experimental value has been shown to be outlier value by the Lweight program.

There were omitted from analysis:

a) four sets of values, A. Hachem (1975Ha31), G. Mouze (1981Mo28), H. Akcay (1982Ak03), G. Mouze (1990Mo08) and O. Diallo (1993Di09), because these values come from the same laboratory of G. Mouze (1990Mo**).

b) the sets of values from K. Ya. Gromov (1969Gr33), G. Wallace (1969Wa27) and M. A. Farouk (1982Fa10), because of a lack of information in the articles about the experimental measurements carried out and, therefore on the results.

c) the relative γ-ray intensity values given in 2004Mo07, because they are those measured by J. U. Delgado (2002De03). In 2004Mo07, the author measured the absolute 609.3-keV γ-ray emission probability (Table 5) and normalized the 2002De03 data set with their value of 45.57 (18).

Table 6: Evaluated relative and absolute γ-ray intensities.

Energy (keV)	Relative γ-ray intensity (%)	Absolute γ-ray intensity (%)	Energy (keV)	Relative γ-ray intensity (%)	Absolute γ-ray intensity (%)	Energy (keV)	Relative γ-ray intensity (%)	Absolute γ-ray intensity (%)	Energy (keV)	Relative emission intensity (%)	Absolute γ-ray intensity (%)
221	0.130 (13)	0.059 (6)	**703**	1.053(24)	0.479 (11)	**1238**	12.819 (29)	5.831 (14)	**2204**	10.80 (5)	4.913 (23)
230	0.0063 (21)	0.0029 (10)	**704**	0.112 (21)	0.051 (10)	**1280**	3.155 (13)	1.435 (6)	**2251**	0.012 (1)	0.0055 (5)
252	0.0258 (39)	0.0117 (18)	**708**	0.0262 (43)	0.0119 (20)	**1284**	0.028 (14)	0.013 (6)	**2260**	0.0191 (9)	0.0087 (4)
268	0.0355 (40)	0.0161 (18)	**710**	0.168 (8)	0.076 (4)	**1303**	0.231 (12)	0.105 (5)	**2266**	0.0362 (17)	0.0165 (8)
273	0.264 (18)	0.120 (8)	**719**	0.865 (22)	0.393 (10)	**1316**	0.170 (16)	0.077 (7)	**2270**	0.0030 (7)	0.0014 (3)
280	0.136 (14)	0.062 (6)	**722**	0.082 (15)	0.037 (7)	**1330**	0.0264 (30)	0.0120 (14)	**2284**	0.0110 (9)	0.0050(4)
304	0.056 (5)	0.0255 (23)	**733**	0.084 (7)	0.038 (3)	**1341**	0.047 (6)	0.0214 (27)	**2287**	0.010 (1)	0.0046 (5)
333	0.139 (9)	0.063 (4)	**740**	0.0941 (47)	0.0428 (21)	**1351**	0.0092 (24)	0.0042 (11)	**2293**	0.673 (8)	0.306 (4)
334	0.072 (10)	0.033 (5)	**752**	0.278 (17)	0.126 (8)	**1353**	0.008 (2)	0.0036 (9)	**2310**	0.003 (2)	0.0014 (9)
348	0.27 (7)	0.123 (32)	**768**	10.755 (36)	4.892 (16)	**1377**	8.722 (25)	3.968 (11)	**2312**	0.0189 (18)	0.0086 (8)
386	0.650 (12)	0.296 (5)	**786**	0.69 (10)	0.31 (5)	**1385**	1.750 (11)	0.796 (5)	**2319**	0.0030 (20)	0.0014 (9)
388	0.864 (10)	0.394 (5)	**788**	0.033 (10)	0.015 (5)	**1392**	0.0191 (42)	0.0087 (19)	**2325**	0.0038 (7)	0.0017 (3)
394	0.0280 (40)	0.0127 (18)	**806**	2.774 (13)	1.262 (6)	**1401**	2.923 (16)	1.330 (7)	**2331**	0.056 (9)	0.026 (4)
396	0.057 (4)	0.0259 (18)	**815**	0.085 (7)	0.039 (3)	**1407**	5.252 (17)	2.389 (8)	**2348**	0.003 (2)	0.0014 (9)
405	0.375 (16)	0.171 (7)	**821**	0.364 (21)	0.166 (10)	**1419**	0.0120 (21)	0.0055 (10)	**2353**	0.0008 (3)	0.00036 (14)
452	0.067 (8)	0.031 (4)	**826**	0.284 (24)	0.129 (11)	**1470**	0.0206 (29)	0.0094 (13)	**2361**	0.0046 (14)	0.0021 (6)
454	0.634 (10)	0.288 (5)	**832**	0.076 (5)	0.035 (2)	**1479**	0.113 (9)	0.051 (4)	**2369**	0.0062 (9)	0.0028 (4)
461	0.128 (18)	0.058 (8)	**847**	0.035 (13)	0.016 (6)	**1509**	4.679 (21)	2.128 (10)	**2376**	0.0190 (17)	0.0086 (8)
469	0.292 (32)	0.133 (15)	**873**	0.041 (7)	0.019 (3)	**1515**	0.0159 (46)	0.0072 (21)	**2390**	0.00343 (30)	0.00156 (14)
474	0.203 (14)	0.092 (6)	**878**	0.026 (6)	0.0118 (27)	**1538**	0.882 (49)	0.401 (22)	**2405**	0.0024 (16)	0.0011 (7)
485	0.046 (8)	0.021 (4)	**904**	0.144 (17)	0.066 (8)	**1543**	0.664 (29)	0.302 (13)	**2423**	0.0106 (14)	0.0048 (6)
487	0.061 (20)	0.028 (9)	**915**	0.051 (11)	0.023 (5)	**1583**	1.555 (11)	0.707 (5)	**2444**	0.018 (9)	0.008 (4)
494	0.023 (6)	0.011 (3)	**917**	0.010 (7)	0.005 (3)	**1594**	0.603 (33)	0.274 (15)	**2447**	3.403 (16)	1.548 (7)
496	0.015 (4)	0.0068 (18)	**930**	0.094 (17)	0.043 (8)	**1599**	0.707 (33)	0.322 (15)	**2459**	0.0031 (5)	0.00141 (23)
501	0.0397 (48)	0.0181 (22)	**934**	6.814 (22)	3.100 (10)	**1636**	0.0244 (36)	0.0111 (16)	**2482**	0.0021 (4)	0.00096 (18)
519	0.0364 (38)	0.0166 (17)	**939**	0.036 (8)	0.016 (4)	**1657**	0.104 (12)	0.047 (5)	**2505**	0.0124 (13)	0.0056 (6)

Energy (keV)	Relative γ-ray intensity (%)	Absolute γ-ray intensity (%)	**Energy (keV)**	Relative γ-ray intensity (%)	Absolute γ-ray intensity (%)	**Energy (keV)**	Relative γ-ray intensity (%)	Absolute γ-ray intensity (%)	**Energy (keV)**	Relative emission intensity (%)	Absolute γ-ray intensity (%)
524	0.0372 (38)	0.0169 (17)	**943**	0.038 (6)	0.017 (3)	**1661**	2.304(20)	1.048 (9)	**2550**	0.0007 (2)	0.00032 (9)
528	0.0239 (29)	0.0109 (13)	**949**	0.012 (5)	0.0055 (23)	**1665**	0.032 (14)	0.015 (6)	**2562**	0.0004 (2)	0.00018 (9)
536	0.134 (17)	0.061 (8)	**952**	0.013 (5)	0.0059 (23)	**1683**	0.478 (7)	0.217 (3)	**2564**	0.0003(2)	0.00014 (9)
543	0.194 (46)	0.088 (21)	**961**	0.0222 (30)	0.0101 (14)	**1711**	0.050 (10)	0.023 (5)	**2604**	0.0008 (2)	0,00036 (9)
547	0.075 (6)	0.034 (3)	**964**	0.799 (27)	0.363 (12)	**1729**	6.251 (22)	2.844 (10)	**2630**	0.0019 (5)	0,00086 (23)
551	0.012 (3)	0.0055 (14)	**976**	0.0333 (47)	0.0151 (21)	**1751**	0.002 (1)	0.0009 (5)	**2662**	0.00044 (9)	0,00020 (4)
572	0.156 (17)	0.071 (8)	**991**	0.023 (6)	0.011 (3)	**1764**	33.66 (10)	15.31 (5)	**2694**	0.072 (6)	0.033 (3)
595	0.0383 (33)	0.0174 (15)	**1013**	0.0191 (41)	0.0087 (19)	**1813**	0.0238 (20)	0.0108 (9)	**2699**	0.0062 (5)	0.00282 (23)
600	0.018 (8)	0.008 (4)	**1021**	0.034 (6)	0.016 (3)	**1838**	0.753(23)	0.343 (10)	**2719**	0.00374 (38)	0.00170 (17)
609	100	45.49 (19)	**1032**	0.135 (9)	0.061 (4)	**1847**	4.451 (26)	2.025 (12)	**2769**	0.0494 (17)	0.0225 (8)
615	0.121 (16)	0.055 (7)	**1038**	0.0190 (33)	0.0086 (15)	**1873**	0.467 (18)	0.212 (8)	**2785**	0.0120 (11)	0.0055 (5)
617	0.059 (10)	0.027 (5)	**1045**	0.050 (6)	0.023(3)	**1890**	0.171 (9)	0.078 (4)	**2826**	0.00480 (38)	0.00218 (17)
626	0.009 (3)	0.0041 (14)	**1051**	0.713 (17)	0.324 (8)	**1895**	0.321 (18)	0.146 (8)	**2861**	0.00091 (28)	0.00041 (13)
630	0.0366 (31)	0.0166 (14)	**1067**	0.053 (15)	0.024 (7)	**1898**	0.107 (17)	0.049 (8)	**2880**	0.0222 (35)	0.0101 (16)
633	0.120 (7)	0.055 (3)	**1069**	0.595 (23)	0.271 (10)	**1935**	0.070 (16)	0.032 (7)	**2893**	0.0126 (10)	0.0057 (5)
634	0.014 (5)	0.0064 (23)	**1103**	0.233 (33)	0.106 (15)	**1994**	0.0052 (10)	0.0024 (5)	**2921**	0.0295 (11)	0.0134 (5)
639	0.075 (10)	0.034 (5)	**1104**	0.16 (3)	0.073 (14)	**2010**	0.0954 (37)	0.0434 (17)	**2928**	0.0024 (2)	0.00109 (9)
649	0.119 (16)	0.054 (7)	**1118**	0.022 (9)	0.010 (4)	**2021**	0.0471 (46)	0.0214 (21)	**2934**	0.00102 (27)	0.00046 (12)
658	0.038 (8)	0.017 (4)	**1120**	32.77 (7)	14.91 (3)	**2052**	0.151 (9)	0.069 (4)	**2978**	0.0302 (9)	0.0137 (4)
661	0.118 (9)	0.054 (4)	**1130**	0.079 (7)	0.036 (3)	**2085**	0.0181 (10)	0.0082 (5)	**2999**	0.0195 (15)	0.0089 (7)
665	3.364 (15)	1.530 (7)	**1133**	0.558 (17)	0.254 (8)	**2089**	0.0973 (48)	0.0443 (22)	**3053**	0.048 (7)	0.022 (3)
677	0.012 (5)	0.0055 (23)	**1155**	3.594 (15)	1.635 (7)	**2109**	0.185 (6)	0.084 (3)	**3081**	0.0115 (15)	0.0052 (7)
683	0.184 (13)	0.084 (6)	**1167**	0.0271 (37)	0.0123 (17)	**2118**	2.545 (12)	1.158 (5)	**3093**	0.00082 (9)	0.00037 (4)
687	0.0146 (31)	0.0066 (14)	**1172**	0.120 (16)	0.055 (7)	**2147**	0.0295 (28)	0.0134 (13)	**3142**	0.00260 (19)	0,00118 (9)
693	0.0129 (33)	0.0059 (15)	**1207**	0.998 (27)	0.454 (12)	**2160**	0.015 (11)	0.007 (5)	**3149**	0.00019	0.00019
697	0.148 (9)	0.067 (4)	**1226**	0.039 (18)	0.018 (8)	**2176**	0.0072 (13)	0.0033 (6)	**3160**	0.00104 (18)	0.00047 (8)
699	0.035 (10)	0.016(5)	**1230**	0.016 (10)	0.007 (5)	**2192**	0.084 (7)	0.038 (3)	**3183**	0.0023 (10)	0.0011 (5)

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^{214}Po - Comments on evaluation of decay data
by V. Chisté and M. M. Bé

This evaluation was completed in 2007. Literature available by January 2007 was included.

1 Decay Scheme

^{214}Po disintegrates by alpha emissions mainly to the ground state level of ^{210}Pb. Spins and parities are from the mass-chain evaluation of Y. A. Akovali (1995El07 for A = 214) and E. Browne (1992Br01 and 2003Br13 for A = 210).
A good agreement was found between the recommended Q value of Audi and the effective Q value (7833.24 (10) keV) calculated from decay scheme data.

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).
Experimental ^{214}Po half-life values (in µs) are given in Table 1:

Table 1: Experimental values of ^{214}Po half-life.

Reference	Experimental value (µs)	Comments
J. V. Dunworth (1939Du**)	150 (20)	Not used.
J. Rotblat (1941Ro**)	145 (5)	Not used.
A. G. Ward (1942Wa04)	148 (6)	Not used.
J. C. Jacobsen (1943Ja**)	155 (5)	Not used.
G. von Dardel (1950Vo02)	163.7 (18)	Original uncertainty increased
R. Ballini (1953Ba60)	158 (2)	
K. W. Ogilvie (1960Og01)	159.5 (30)	
T. Dobrowolski (1961Do02)	164.3 (18)	
A. Erlik (1971Er02)	165 (3)	
J. W. Zhou (1993Zh30)	160 (12)	
Recommended value	**162.3 (12)**	χ^2 = 1.6

The first four and less precise historical values were omitted from analysis. The G. von Dardel uncertainty value (1950Vo02) of 0.2, which seems not realistic, was increased to 1.8 the smallest of the other experimental values obtained with the same method.
Using the LWEIGHT computer program (version 3) with the remaining set of 6 data, the weighted average is **162.3 ms** with an external uncertainty of **1.2 ms**. The reduced-χ^2 value is 1.82.

The largest contribution to weighted average comes from the value of G. von Dardel (1950Vo02) and T. Dobrowolski (1961Do02), each of them amounting per 28 %.

2.1 a Transitions and Emissions

The energies of the α-particle transitions given in Section 2.1 were obtained from Q_α (2003Au03) and level energies.

The energy of $\alpha_{0,0}$ emission given in section 4 is the weighted average of the measured values of A. Rytz (1961Ry02) and B. Grennberg (1971Gr17), with the recommendations given by A. Rytz (1991Ry01) where the original energies given by 1961Ry02 and 1971Gr17 have been readjusted due to changes in calibration energies. For the $\alpha_{0,1}$ and $\alpha_{0,2}$, the emission energies were deduced from Q_α (2003Au03), level energy and taking the nucleus recoil into account.

The α emission probabilities have been deduced from the value of the γ-ray transition probability decay-scheme balances for the corresponding levels. (see **2.2 Gamma Transitions**).

2.2 g Transitions

The γ-ray transition probabilities were obtained using the γ-ray emission intensities, measured by 1976Ku08, and the relevant internal conversion coefficients (see **4.2** g **Emissions**).
Multipolarities of the γ-ray transitions (E2) are from 1992Br01 and 2003Br13.

The internal conversion coefficients (ICC) for the γ-ray transitions have been deduced using the BrIcc computer program (calculation for ‘hole’), which interpolated the new values from 2006Ra03.

3 Atomic Data

Atomic values, ω_K, ϖ_L and n_{KL} and the X-ray relative probabilities are from Schönfeld and Janßen (1996Sc06).

4 Photon Emissions

4.1 X-ray Emissions

The X-ray absolute intensities were calculated from γ-ray data and ICC using the EMISSION computer program.

4.2 g Emissions

The γ-ray energies given in section 5.2 are from W. Kurcewicz (1976Ku08).

The absolute γ-ray emission intensities have been deduced from the relative γ-ray emission intensities measured by W. Kurcewicz (1976Ku08) in relative value and normalized with the 324.22-keV γ-ray in ^{222}Ra decay, as measured by A. Peghaire (1969Pe17) to be 2.77 (8) %. In the table 2, the relative emission intensities and the recommended values of absolute emission intensities are shown.

Table 2: Recommended (deduced) values of γ-ray absolute emission intensities

Energy (keV)	Relative Emission Intensity (%)	Recommended value
298 (1)	0.06 (2)	0.000052 (18) %
799.7 (1)	11.9 (5)	0.0104 (6) %

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^{215}Bi – Comments on evaluation of decay data
by A. L. Nichols and F. G. Kondev

Evaluated: June 2011

Evaluation Procedure

Limitation of Relative Statistical Weight Method (LWM) was applied to average numbers throughout the evaluation. The uncertainty assigned to the average value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

The ^{215}Bi ground state (J^π = (9/2$^-$)) decays 100 % by β^- emission to various excited levels and the ground state of ^{215}Po. A reasonably complex but inadequate decay scheme has been constructed primarily from the gamma-ray measurements of Kurpeta *et al.* (2003Ku26) in which 19 distinct gamma-ray emissions were identified with the β^- decay of ^{215}Bi. Although these authors assessed that there is no direct beta decay to the ground state of ^{215}Po, their reported absolute emission probabilities for the gamma rays populating the ground state are in conflict with this proposal.

Direct β^- feeding to the ground state of daughter ^{215}Po has not been satisfactorily determined. Therefore, the evaluators resorted to comparisons with the β^- decay of other odd-even Bi radionuclides (^{213}Bi) and β^--decay theory in order to define the β^- and γ emission probabilities in absolute terms. Further studies are required to clarify and define more clearly the ^{215}Bi decay scheme, particularly with respect to the absolute gamma-ray emission probabilities and quantification of direct β^- feeding to the ground state of daughter ^{215}Po.

Nuclear Data

^{215}Bi is part of the (4n + 3) naturally-occurring decay chain, and of relevance in quantifying the environmental impact of ^{235}U and decay-chain products. Specific radionuclides in this decay chain are noteworthy because of their decay characteristics (^{215}Po, ^{211}Bi and ^{211}Po alpha decay).

Half-life

^{215}Bi was first observed by 1953Hy83, and assigned a half-life of (8 ± 2) min. However, the recommended half-life is the weighted mean of three more recent measurements (1965Nu03, 1989Bu09 and 1990Ru02).

Reference	Half-life (min)
1965Nu03	7.4 (6)
1989Bu09	7.5 (4)
1990Ru02	7.7 (2)
Recommended value	7.6 (2)

^{215}Po half-life of 1.781 (4) millisecond was adopted from the evaluation of Browne (2001Br31).

Q value

Q^- of 2189 (15) keV was adopted from the evaluated tabulations of Audi *et al.* (2003Au03).

Beta particles

Energies

All beta-particle energies were calculated from the structural details of the proposed decay scheme. A combination of nuclear level energies recommended by 2001Br31 and derived from 2003Ku26, and a Q-value of 2189 (15) keV (2003Au03) were used to determine the energies and uncertainties of the beta-particle emissions to the various levels.

Adopted nuclear levels of ^{215}Po: Energy, J^{π} and origins (2001Br31, 2003Ku26).

Nuclear level	**Nuclear level energy (keV)**	**J^{π}**	**Origins**
0	0.0	9/2 +	**^{215}Bi β^- decay**, ^{219}Rn α decay
1	271.228 ± 0.010	7/2 +	**^{215}Bi β^- decay**, ^{219}Rn α decay
2	293.56 ± 0.04	11/2 +	**^{215}Bi β^- decay**, ^{219}Rn α decay
3	401.812 ± 0.010	5/2 +	**^{215}Bi β^- decay**, ^{219}Rn α decay
4	517.60 ± 0.06	7/2 +, 9/2 +	**^{215}Bi β^- decay**, ^{219}Rn α decay
5	608.30 ± 0.07	(11/2 +, 13/2 +)	**^{215}Bi β^- decay**, ^{219}Rn α decay
6	676.66 ± 0.07		**^{215}Bi β^- decay**, ^{219}Rn α decay
7	708.1 ± 0.5		^{219}Rn α decay
8	732.7 ± 0.4		^{219}Rn α decay
9	835.32 ± 0.22		**^{215}Bi β^- decay**, ^{219}Rn α decay
10	877.2 ± 0.6		^{219}Rn α decay
11	891.1 ± 0.3		^{219}Rn α decay
12	930 ± 1		^{219}Rn α decay
13	1073.7 ± 0.4	(5/2 +)	^{219}Rn α decay
14	1077.6 ± 2.0*		**^{215}Bi β^- decay**
15	1094.2 ± 1.0		^{219}Rn α decay
16	1176.2 ± 2.0*		**^{215}Bi β^- decay**
17	1294.5 ± 0.1*		**^{215}Bi β^- decay**
18	1398.8 ± 0.4*		**^{215}Bi β^- decay**

* Calculated from the energies of the depopulating gamma rays (2003Ku26), and the lower-energy nuclear levels that they populate.

Emission Probabilities

Direct beta-particle feeding to the ground state of ^{215}Po has not been unambiguously defined from the various γ-ray measurements. Under these circumstances, a systematic assessment of the appropriate properties of odd-even Bi nuclides in the vicinity of ^{215}Bi has been undertaken to explore whether a reasonable approximation can be made of beta decay directly to the ground state of ^{215}Po (1991Ma16, 2001Br31, 2003Ak06, 2004Br45, 2007Ba19).

(a) Spin and parity of ^{215}Bi

Nuclide	^{209}Bi	^{211}Bi	^{213}Bi	^{215}Bi	^{217}Bi
β^- decay	stable	0.28 %	97.91 %	100 %	100 %
Direct β^- decay to ground state	–	0.28 %	65.9 %	?	?
α decay	stable	99.72 %	2.09 %	–	–
Spin and parity	$9/2^-$	$9/2^-$	$9/2^-$	$(9/2^-)$	?
Spin and parity of Po ground state	$1/2^-$	$9/2^+$	$9/2^+$	$9/2^+$	$(11/2^+)$

Spins and parities of $9/2^-$ are well defined for ^{209,211,213}Bi, and can be similarly assigned with reasonable confidence as $(9/2^-)$ for ^{215}Bi.

(b) Direct beta-particle feeding of ^{215}Bi to the ground state of ^{215}Po

Population-depopulation balances have been calculated on the basis of the relative emission probabilities of the gamma rays (see below) in order to derive relative beta-particle emission probabilities to all of the excited nuclear levels of ^{215}Po.

The β^- decay of ^{215}Bi was assumed to occur primarily via first forbidden non-unique transitions to the ground state ($9/2^+$) and 293.56-keV nuclear level ($11/2^+$) of ^{215}Po. The preparation of recommended decay-data files for DDEP necessitates the formulation of decay schemes that are based on absolute emission and transition probabilities that frequently encompass well-defined normalization factors in conjunction with accurate relative emission probabilities and various other nuclear parameters (e.g. internal conversion coefficients). This ideal situation cannot be achieved for ^{215}Bi because of existing inadequacies in the measured data. Therefore, the main β^- branches populate the 293.56-keV nuclear level and ground state of ^{215}Po, and their important emission probabilities have been derived somewhat unusually through application of the fifth-power law of β^- decay (1933Sa01, 1955Ev23, 1963KaZZ).

A general approximation has been formulated for the ratio of allowed beta-particle emission probabilities, based on the observation that the mean life (τ) for partial β^- decay is inversely proportional to the fifth power of the β^- end-point energy (1955Ev23, 1963KaZZ):

$$\frac{1}{\tau_\beta} \propto [(M(Z) - M(Z \pm 1)c^2)]^5$$

where

$$\tau_\beta = \frac{\tau_{exp}}{P_\beta} \text{ and } \tau_{exp} \text{ is the lifetime of the parent nuclide.}$$

Therefore

$$\frac{1}{\tau_\beta} \sim (E_\beta)^5$$

This approximation has been applied to the major first-forbidden non-unique beta-particle emissions of ^{215}Bi directly to the ground state of ^{215}Po (($9/2^-$) → $9/2^+$)

$$\frac{1}{\tau_{0,0}} \sim (E_{\beta_{0,0}})^5 \qquad (1)$$

and to the 293.56-keV nuclear level of ^{215}Po (($9/2^-$) → $11/2^+$)

$$\frac{1}{\tau_{0,2}} \sim (E_{\beta_{0,2}})^5 \qquad (2)$$

Combining equations (1) and (2):

$$\frac{\tau_{0,2}}{\tau_{0,0}} = \frac{P_{\beta_{0,0}}}{P_{\beta_{0,2}}} \sim \left(\frac{E_{\beta_{0,0}}}{E_{\beta_{0,2}}}\right)^5 = \left[\frac{2189(15)}{1895(15)}\right]^5 = 1.155^5 \sim 2.055$$

where $P_{\beta_{0,0}}$ and $P_{\beta_{0,2}}$ are the β-particle emission probabilities to the ground state and 293.56-keV nuclear level, respectively.

The proposed decay scheme, recommended relative emission probabilities of the gamma rays and α_{total} have been used to determine a $P_{\beta_{0,2}}^{rel}$ value of 125 (7) by the appropriate summation of the measured gamma population/depopulation of the 293.56-keV nuclear level. Therefore:

$$P_{\beta_{0,0}}^{rel} \sim 2.055 \times 125\,(7) = 257\,(14)$$

with an uncertainty assigned in a somewhat arbitrary manner on the basis of the uncertainty derived for $P_{\beta_{0,2}}^{rel}$.

The normalization factor (*NF*) for the relative emission probabilities of both the β⁻ particles and γ rays has been determined from the total βγ transitions populating the ground state of ^{215}Po directly:

$$P_{\beta_{0,0}}^{rel} \times NF + \sum P_{\gamma}^{rel}(1+\alpha_{total}) \times NF = 100$$

$$257\,(14) \times NF + \left[164\,(7) \times NF\right] = 100$$

$$NF = 100/421\,(16) = 0.238\,(9)$$

Both P_{β}^{abs} to the ground state and 293.56-keV nuclear level of ^{215}Po were simply calculated from their P_{β}^{rel} values and *NF*, and are coupled together on the basis of crude estimates of their uncertainties (i.e. arbitrary uncertainty of 20 % assigned to the value of $P_{\beta^-_{0,2}}$):

$P_{\beta_{0,2}}^{abs}$ of 30 (6) %
and $P_{\beta_{0,0}}^{abs}$ of 61 (6) %.

These data should be treated with a high degree of caution. Their derivation also impacts significantly on the quantification of the other beta-particle emission probabilities.

Apart from the beta-particle emission directly to the ground state of ^{215}Po, the relative emission probabilities of all of the other beta-particle decays were calculated from population-depopulation balances of the relative gamma transition probabilities, as derived from the relative gamma-ray emission probabilities and internal conversion coefficients determined from the frozen orbital approximation of Kibédi *et al.* (2008Ki07) based on the theoretical model of Band *et al.* (2002Ba85, 2002Ra45). Direct beta population of the 271.228-keV nuclear level of ^{215}Po was calculated to be zero from the calculation of the known gamma transition probabilities populating and depopulating this particular excited state ((9/2$^-$) to 7/2$^+$ (1st forbidden non-unique)).

Beta-particle emission probabilities per 100 disintegrations of ^{215}Bi, transition type and log *ft*.

E_β(keV)	P_β	transition type[‡]	log *ft*[#]
	Recommended value		
790 (15)	2.8 (1)[*]	[1st forbidden non-unique]	6.00
895 (15)	2.0 (2)[*]	[1st forbidden non-unique]	6.34
1013 (15)	0.2 (1)[*]	[1st forbidden non-unique]	7.5
1111 (15)	0.7 (1)[*]	[1st forbidden non-unique]	7.1
1354 (15)	1.5 (1)[*]	[1st forbidden non-unique]	7.10
1512 (15)	0.5 (1)[*]	[1st forbidden non-unique]	7.8
1581 (15)	0.7 (1)[*]	(1st forbidden non-unique)	7.7
1671 (15)	0.3 (2)[*]	(1st forbidden non-unique)	8.1
1787 (15)	0.5 (1)[*]	(1st forbidden unique)	9.0
1895 (15)	30 (6) [*†]	(1st forbidden non-unique)	6.35
1918 (15)	–	(1st forbidden non-unique)	–
2189 (15)	61 (6)[†]	(1st forbidden non-unique)	6.28
	Σ 100 (8)		

[*] Recommended absolute β^- emission probabilities derived from the relative gamma-ray emission probabilities, normalization factor of 0.238 (9), and theoretical internal conversion coefficients.

[†] Absolute emission probabilities calculated from fifth-power relationship of β^- end-point energies, with an arbitrary estimated uncertainty of 20 % assigned to the 1895-keV β^- emission probability.

[‡] Transition types within square brackets [] are not based on any spin-parity assignments – they have been assumed to be first forbidden non-unique as observed for the majority of the higher-energy β^- transitions.

[#] Log *ft* values calculated on the assumption of first forbidden non-unique transitions, apart from the 1787-keV beta emission (defined as most likely to be first forbidden unique).

The observed systematics of the two principle emissions in β^- decay for odd-even nuclides has been used in a quantitative manner to derive beta-particle emission probabilities in absolute terms. This approach is both approximate and of highly questionable merit – under these unsatisfactory circumstances, further experimental studies are required to determine direct β^- feeding to the ground state of daughter ^{215}Po with good accuracy.

Gamma rays

Energies

All gamma-ray transition energies were calculated from the structural details of the proposed decay scheme derived from 2001Br01 and 2003Ku26. The lower-energy nuclear level energies of 2001Br31 were adopted, along with higher-energy nuclear levels calculated from the gamma-ray studies of 2003Ku26. These data were subsequently used to re-determine the energies and associated uncertainties of the gamma-ray transitions between the various populated-depopulated levels.

Emission Probabilities

The only known experimental studies of relevance in defining the decay scheme of ^{215}Bi are the measurements by Ruchowska *et al.* (1990Ru02) in which the emission probabilities of seven gamma-ray transitions were quantified in terms of Pγ(293.56 keV) of 1000 (redefined as 100 %), and the more extensive studies of Kurpeta *et al.* (2003Ku26) in which the emission probabilities of 19 gamma-ray transitions were quantified.

Table 3 and Fig. 6 of 2003Ku26 contain highly questionable absolute β-particle and γ-ray emission probabilities. While the resulting γ-ray transition probabilities populating the ^{215}Po ground state directly sum to only 57.6 %, no direct β^- decay is advocated to achieve a correct summation of 100 %. Private communications between Kurpeta (Institute of Experimental Physics, Warsaw University) and Kondev (ANL), April 2011, have clarified the caption of Table 3: γ intensities listed in this table are relative and not absolute (defined erroneously as %

per decay). Therefore, these γ-ray emission probabilities have been re-defined as relative to Pγ(293.56 keV) of 100 %.

A number of unobserved low-intensity gamma rays have also been introduced by considering the equivalent gamma-ray studies of the α decay of ^{219}Rn – this process results in the introduction of the 130.58-, 224.04- and 405.43-keV gamma transitions, each with relative emission probabilities of less than 0.15 %.

Gamma-ray emission probabilities: as published, and relative to P_γ(293.56 keV) of 100 %.

Eγ (keV)	**P_γ^{rel}**			
	1990Ru02	**2003Ku26†** **as published**	**adjusted**	**Recommended value***
130.58 (1)	–	–	–	0.039(4)‡
224.04 (7)	–	–	–	0.14 (2)‡
271.228 (10)	5.5 (5)	2.9 (1)	8.2 (3)	8.2 (3)
293.56 (4)	100 (7)	35.2 (11)	100 (3)	100 (3)
383.10 (8)	–	0.2 (1)	0.6 (3)	0.6 (3)
401.81 (1)	1.0 (4)	0.7 (1)	2.0 (3)	2.0 (3)
405.43 (7)	–	–	–	0.024 (4)‡
517.60 (6)	1.9 (3)	1.5 (1)	4.3 (3)	4.3 (3)
541.76 (22)	–	0.3 (1)	0.9 (3)	0.9 (3)
564.09 (22)	1.3 (3)	1.0 (1)	2.8 (3)	2.8 (3)
608.30 (7)	–	1.0 (1)	2.8 (3)	2.8 (3)
676.66 (7)	0.6 (2)	0.6 (1)	1.7 (3)	1.7 (3)
776.9 (1)	–	1.2 (2)	3.4 (6)	3.4 (6)
784 (2)	–	0.5 (1)	1.4 (3)	1.4 (3)
806.4 (20)	–	0.6 (1)	1.7 (3)	1.7 (3)
835.32 (22)	1.4 (3)	0.9 (1)	2.6 (3)	2.6 (3)
905 (2)	–	0.3 (1)	0.9 (3)	0.9 (3)
1023.3 (1)	–	0.9 (1)	2.6 (3)	2.6 (3)
1105.2 (4)	–	2.2 (1)	6.3 (3)	6.3 (3)
1127.6 (4)	–	0.7 (1)	2.0 (3)	2.0 (3)
1294.5 (1)	–	0.9 (1)	2.6 (3)	2.6 (3)
1398.8 (4)	–	1.2 (1)	3.4 (3)	3.4 (3)

† Published as absolute emission probabilities of doubtful overall pedigree (transition probabilities directly populating the ^{215}Po ground state only sum to 57.6 %, while direct β^- decay of zero is advocated); J. Kurpeta (Institute of Experimental Physics, Warsaw University), private communication to F.G. Kondev (ANL), 27 April 2011, concerning caption of Table 3 (2003Ku26): γ intensities are relative and not % per decay – therefore, emission probabilities have been adjusted to be relative to Pγ(293.56 keV) of 100 %.

* Recommended data biased completely towards the more extensive measurements of 2003Ku26.

‡ Derived from equivalent γ-ray measurements of ^{219}Rn α decay.

Major disagreements are observed between the emission probability measurements of 1990Ru02 and 2003Ku26 that negate the merit of any form of weighted-mean analysis. Under these circumstances, the more comprehensive data of 2003Ku26 have been adopted relative to Pγ(293.56 keV) of 100 %.

Multipolarities and Internal Conversion Coefficients

The decay scheme specified by 2001Br31 has been used to define the multipolarity of specific gamma transitions on the basis of the known spins and parities of the nuclear levels. Thus, the 224.04- and 401.81-keV gamma-ray emissions are adjudged to be E2 transitions. Multipolarity mixing ratios for the 130.58- and 271.228-keV gamma transitions of 0.60 (6) and 4.0 (4), respectively, were derived from the K/L and L sub-shell conversion-electron ratios determined by Davidson and Connor (1970Da09), while the 293.56- and 517.60-keV gamma-ray emissions were arbitrarily assigned mixing ratios of 1.0 (2) (i.e. 50 % M1 + 50 % E2). Recommended internal conversion coefficients have been determined from the frozen orbital approximation of Kibédi *et al.* (2008Ki07), based on the theoretical model of Band *et al.* (2002Ba85, 2002Ra45).

Gamma-ray emissions: multipolarities and theoretical internal conversion coefficients (frozen orbital approximation).

E_γ (keV)	Multipolarity	α_K	α_L	α_{M+}	α_{total}
130.58 (1)	73.5%M1 + 26.5%E2 δ = 0.60(6)	3.19 (16)	0.94 (4)	0.31	4.44 (13)
224.04 (7)	(E2)	0.1296 (19)	0.1407 (20)	0.0487	0.319 (5)
271.228 (10)	6%M1 + 94%E2 δ = 4.0(4)	0.111 (6)	0.0668 (11)	0.0232	0.201 (7)
293.56 (4)	(50%M1 + 50%E2) δ = 1.0(2)	0.25 (4)	0.062 (4)	0.028	0.34 (5)
383.10 (8)	–	–	–	–	–
401.81 (1)	E2	0.0351 (5)	0.01528 (22)	0.00512	0.0555 (8)
405.43 (7)	–	–	–	–	–
517.60 (6)	50%M1 + 50%E2 δ = 1.0(2)	0.058 (9)	0.0115 (11)	0.0035	0.073 (10)
541.76 (22)	–	–	–	–	–
564.09 (22)	–	–	–	–	–
608.30 (7)	(M1 + E2)	–	–	–	–
676.66 (7)	–	–	–	–	–
776.9 (1)	–	–	–	–	–
784 (2)	–	–	–	–	–
806.4 (20)	–	–	–	–	–
835.32 (22)	–	–	–	–	–
905 (2)	–	–	–	–	–
1023.3 (1)	–	–	–	–	–
1105.2 (4)	–	–	–	–	–
1127.6 (4)	–	–	–	–	–
1294.5 (1)	–	–	–	–	–
1398.8 (4)	–	–	–	–	–

While a decay scheme has been formulated from the gamma-ray emission probability measurements of Kurpeta *et al.* (2003Ku26), further studies are required to determine the absolute and relative gamma-ray emission probabilities and also quantify any direct β^- feeding to the ground state of daughter ^{215}Po with much greater confidence. Such work would assist greatly to remove the severe doubts associated with the proposed decay scheme.

Atomic Data

The x-ray data have been calculated using the evaluated gamma-ray data, and the atomic data from 1996Sc06, 1998ScZM and 1999ScZX. Both the x-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.01, 28 January 2003). This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

K and L X-ray emission probabilities per 100 disintegrations of ^{215}Bi.

			Energy (keV)		Photons per 100 disint.
XL		(Po)	9.658 – 16.213		2.7 (3)
	XL$_l$	(Po)	9.658		0.065 (8)
	XL$_\alpha$	(Po)	11.016 – 11.130		1.20 (13)
	XL$_\eta$	(Po)	12.085		0.022 (3)
	XL$_\beta$	(Po)	12.823 – 13.778		1.18 (11)
	XL$_\gamma$	(Po)	15.742 – 16.213		0.24 (2)
XK$_\alpha$	XK$_{\alpha 2}$	(Po)	76.864 (4)		1.8 (3)
	XK$_{\alpha 1}$	(Po)	79.293 (5)		3.0 (5)
XK$'_{\beta 1}$	XK$_{\beta 3}$	(Po)	89.256	)	
	XK$_{\beta 1}$	(Po)	89.807	)	1.02 (16)
	XK$''_{\beta 5}$	(Po)	90.363	)	
XK$'_{\beta 2}$	XK$_{\beta 2}$	(Po)	92.263	)	
	XK$_{\beta 4}$	(Po)	92.618	)	0.32 (5)
	XKO$_{2,3}$	(Po)	92.983	)	

Electron energies were determined from electron binding energies tabulated by Larkins (1977La19) and the evaluated gamma-ray energies. Absolute electron emission probabilities were calculated from the evaluated absolute gamma-ray emission probabilities and associated internal conversion coefficients.

Data Consistency

A Q_β-value of 2189 (15) keV has been adopted from the atomic mass evaluation of Audi *et al.* (2003Au03) while in the course of formulating the decay scheme of ^{215}Bi. This value has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{215}Bi beta-decay process (i.e. β^-, conversion electrons, γ, etc.):

$$\text{calculated Q-value} \quad = \quad \sum (E_i \times P_i) \quad = \quad 2190\ (170)\ \text{keV}$$

Percentage deviation from the Q-value of Audi *et al.* is (0 ± 8) %, which supports the derivation of a highly consistent decay scheme with a large variant.

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^{215}Po -Comments on evaluation of decay data
by V.P. Chechev

This evaluation was done in November 2010 with a literature cut-off by the same date.

1. DECAY SCHEME

^{215}Po decays 100 % to levels of ^{211}Pb by emission of α particles and 2.3 (2) × 10^{-4} % to ^{215}At by emission of β^- particles. The structure of the adopted scheme of ^{215}Po decay is based on the experiment of 1998Li53 and the evaluation by E. Browne (2004Br45). The existence of the alpha-particle group with energy of 6950 keV, reported in 1962Wa18, 1971Gr17, was not confirmed in 1998Li53 and the relevant ^{211}Pb level of 447 keV was omitted in this evaluation. Similarly, the questionable ^{211}Pb level of 762 keV, determined by the alpha-particle group with energy of 6636 keV and intensity of ~ 3 × 10^{-4} %, has not been adopted.

The decay scheme of ^{215}Po is not completed as only approximate information is available for weak gamma transitions following α decay, their gamma-ray emission probabilities and multipolarities have not been determined, and, in fact, the ^{211}Pb levels were deduced only from measurements of alpha-particle groups. In respect of ^{215}Po β^- decay, the β^- - spectrum has not been measured and a fine structure of β^- decay is unknown.

The current evaluated data are supported by the agreement between Q(calculated) = 7526.2 (22) keV, deduced from the calculated average energies of all emissions, and Q(α) = 7526.3 (8) keV, adopted from 2003Au03. Percentage deviation of Q(calculated) from the Q(α) of Audi *et al.* (2003Au03) is (0.0 ± 0.3) %.

2. NUCLEAR DATA

Q(α) and Q(β^-) values are from Audi et al. (2003Au03).

The ^{215}Po half-life is based on the experimental results given in Table 1.

Table 1. Experimental values of ^{215}Po half-life

Reference	Author(s)	Half-life (ms)	Method
1942Wa04	Ward	1.83 (4)	Observations with a single Geiger counter
1961Vo06	Volkov et al.	1.778 (5)	Measurements with ionization alpha-spectrometer equipped by time analyzer
1971Er02	Erlik et al.	1.785 (10)	Time interval analyzer method
1971Er02	Erlik et al.	1.784 (8)	Multichannel delay coincidence method

The set of the four experimental values is consistent. The weighted average for this data set is 1.781 with the internal uncertainty of 0.0039 and an external uncertainty of 0.0033 ($\chi^2/\nu = 0.72$).

The recommended value of the **^{215}Po half-life** is **1.781 (4) ms**.

β^- branching of 2.3 (2) × 10^{-4} % was adopted from the measurement of 1950Av61. With this value the α branching is obtained to be 99.999 77 (2) %.

2.1. Alpha Transitions

The alpha transition energies have been obtained from the Q(α) value and ^{211}Pb level energies given in Table 2 from 2004Br45. The uncertainties in the energies of levels 2 - 7 have been adopted ± 3 keV taking into account the average discrepancy of experimental and calculated alpha-particle energies (Table 3) and as provided by uncertainties of gamma ray energies from 1998Li53 ≥ 1.0 keV for all γ rays, except for γ438.9 keV.

Table 2. ^{211}Pb levels populated in ^{215}Po α-decay

Level	Energy (keV)	Spin and parity	Half-life	Probability of α- transition (%)
0	0.0	9/2+	36.1(4) min	99.934 (20)
1	438.9 (2)	(7/2)+		0.06 (2)
2	584 (3)			4 (2) × 10^{-4}
3	598 (3)	(5/2+)		1.6 (5) × 10^{-3}
4	643 (3)	11/2+		8 (3) × 10^{-4}
5	733 (3)	(13/2+)		8 (3) × 10^{-4}
6	815 (3)	(9/2+)		2.0 (6) × 10^{-3}
7	894 (3)	(11/2+)		3 × 10^{-4}

The alpha transitions in ^{215}Po decay were observed in a number of works by study of an ^{223}Ra alpha emitting source (1962Wa18, 1965Va10, 1970Da09, 1998Li53). In 1962Wa18 the ^{215}Po alpha spectrum was measured with magnetic spectrometer. In 1965Va10 the coincidence of $\gamma_{1,0}$ (438.9 keV)-gamma ray with $\alpha_{0,1}$ (6.95 MeV) was observed. In 1970Da09 the alpha transition probability (P(α)) was measured for $\alpha_{0,1}$ (6.95 MeV)-transition. Most accurate and detailed data were obtained by 1998Li53 with use of α–γ coincidences. These measurement results have been adopted for the recommended P(α) and compared in Table 3 with other available poor experimental data.

Table 3. Experimental ^{215}Po alpha transition probability values (P(α))

α-particle energy (keV)	1962Wa18	1970Da09	1998Li53
7386	100		99.93
6955	≈ 0.056	≈ 0.1	0.06 (2)
6813			4 (2) × 10^{-4}
6799			1.6 (5) × 10^{-3}
6755			8 (3) × 10^{-4}
6667			8 (3) × 10^{-4}
6586			2.0 (6) × 10^{-3}
6509			~ 3 × 10^{-4}

The accurate P($\alpha_{0,0}$) value has been deduced from ΣP($\alpha_{0,i}$) = 99.999 77 (2) %, (i = 0, 1,...7) and, the individual adopted P($\alpha_{0,i}$), (i = 1 – 7).

The α decay hindrance factors were calculated using the ALPHAD computer program from the ENSDF evaluation package with r_0 (^{211}Pb) = 1.5393 fm (2004Br45).

2.2. Gamma Transitions and Internal Conversion Coefficients

Information on the gamma-ray transition probabilities and the gamma-ray multipolarities is not available, except for γ438.9 keV (1968Br17, 1970Da09, 1998Li53, see §6.2.2). The gamma-ray transition probability $P_{\gamma+ce}$ ($\gamma_{1,0}$ - 438.9 keV) was then deduced from the probability balance: P($\alpha_{0,1}$) = $P_{\gamma+ce}$ ($\gamma_{1,0}$ - 438.9 keV). The multipolarity of this gamma-ray transition has been adopted as being E2. In 1998Li53 a multipolarity higher than a pure E2 was reported from the relative intensity P(KX) / P_γ (438.9 keV) = 0.034 (10), then it was noted that a small amount of M1 cannot be ruled out.

ICCs have been interpolated using the BrIcc computer program, version v2.2a, data set BriccFO (2008Ki07).

3. ATOMIC DATA

The fluorescence yields, X-ray energies and relative probabilities, and Auger electrons energies and relative probabilities are from the SAISINUC software.

4. ALPHA EMISSIONS

The energy of the alpha-particle group $\alpha_{0,0}$ that populates the ^{211}Pb ground state is the absolute measurement result from 1971Gr17 adjusted in 1991Ry01 for change in calibration standards: E($\alpha_{0,0}$) = 7386.1 (8) keV. Latter coincides with the value deduced by the evaluator from the adopted Q(α) taking into account the recoil energy for ^{211}Pb.

The energy of alpha-particle group $\alpha_{0,1}$ of 6955.4 (8) keV has been deduced from the Q(α) value taking into account the level energy of 439.8 (2) keV and the recoil energy for ^{211}Pb. The above value of E($\alpha_{0,1}$) can be compared to the measured E($\alpha_{0,1}$) of 6956.7 keV (without uncertainty) by 1962Wa18, 1971Gr17 and of 6954 (3) keV by 1998Li53 with adjustement adopted in 2004Br45.

The energies of remaining alpha-particle groups have been deduced from Q(α) and the relevant ^{211}Pb level energies. In Table 4 the deduced (recommended) E(α) are compared with the experimental values from the measurements of 1998Li53 adjusted in 2004Br45 to the adopted E($\alpha_{0,0}$)= 7386.1 (8) keV.

Table 4. Experimental and deduced (recommended) ^{215}Po alpha-particle energies (E(α))

Level	Level energy (keV)	α-transition energy	Experimental E(α) (1998Li53) [a]	Deduced E(α) (recommended)
0	0.0	7526.3 (8)	7386.1 (8)	7386.1 (8)
1	438.9 (2)	7087.4 (10)	6954 (3)	6955.4 (8)
2	584 (3)	6942 (3)	6819 (15)	6813 (3)
3	598 (3)	6928 (3)	6803 (8)	6799 (3)
4	643 (3)	6883 (3)	6754 (10)	6755 (3)

Level	Level energy (keV)	α-transition energy	Experimental E(α) (1998Li53) [a]	Deduced E(α) (recommended)
5	733 (3)	6793 (3)	6671 (10)	6667 (3)
6	815 (3)	6711 (3)	6589 (8)	6586 (3)
7	894 (3)	6632 (3)	6519 (20)	6509 (3)

[a] E(α) have been adjusted to the adopted E($\alpha_{0,0}$) = 7386.1 (8) keV.

5. ELECTRON EMISSIONS

The energies of the conversion electrons for the γ438.9 keV transition have been obtained from the gamma-ray transition energy and the atomic electron binding energies.

The emission probabilities of the conversion electrons have been deduced using the P_γ and ICC values.

The absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program.

6. PHOTON EMISSIONS

6.1 X - Ray emissions

The absolute emission probabilities of Pb KX- and LX-rays were calculated using the EMISSION computer program. The total emission probability of Pb KX-rays in decay of ^{215}Po was determined relatively to $P_\gamma(\gamma_{1,0}$ - 438.9 keV) (1998Li53). The experimental P(KX)/$P_\gamma(\gamma_{1,0}$ - 438.9 keV) = 0.034 (10) agrees with the value of 0.029 (14) calculated with the EMISSION code.

The agreement between measured and calculated KX-ray emission probabilities supports the recommended γ-ray emission probability and assigned multipolarity for $\gamma_{1,0}$ - 438.9 keV.

6.2. Gamma emissions

6.2.1. Gamma ray energies

The gamma-ray energies (E_γ) have been taken from the measurements of 1998Li53. The uncertainties on the gamma-ray energies higher than 500 keV have been assumed being ± 3 keV (see section **2.1**). Other measurements of E ($\gamma_{1,0}$ - 438.9 keV) are reported in 1968Br17 (438.7 (3) keV) and in 1970Da09 (438.9 keV – without uncertainty).

6.2.2. Gamma ray emission probabilities

There is no available information on the gamma-ray emission probabilities, except for P(γ438.9 keV): 0.048 (5) % (1968Br17) and 0.064 (2) % (1970Da09). These discrepant values do not conflict with the recommended value of P(γ438.9 keV) = 0.058 (19) % deduced by the evaluator from the alpha transition probability P($\alpha_{0,1}$) = 0.06 (2) % and total internal conversion coefficient α_T = 0.0405 (6) under the assumption of E2 multipolarity.

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^{215}At -Comments on evaluation of decay data
by V.P. Chechev

This evaluation was done in December 2010 with a literature cut-off by the same date.

1. DECAY SCHEME

^{215}At decays 100 % to levels of ^{211}Bi by emission of α particles. The adopted ^{211}Bi levels populated in the ^{215}At decay are based on the experiment of 1966Gr07 and the evaluation by Browne (2004Br45).

The decay scheme of ^{215}At seems to be incomplete as the alpha decays to higher levels in daughter ^{211}Bi, which are known from the β^- decay of ^{211}Pb (see ^{211}Bi Adopted Levels, Gammas of 2004Br45), are not observed yet.

The current evaluated data are supported by the agreement between Q(calculated) = 8178 (5) keV, deduced from the calculated average energies of all emissions, and Q(α) = 8178 (4) keV, adopted from 2003Au03.

2. NUCLEAR DATA

Q(α) is from 2003Au03 where this value has been deduced from the measurement of α-particle energy E($\alpha_{0,0}$) = 8026 (4) keV by 1982Bo04 recommended in 1991Ry01.

The ^{215}At half-life of 0.10 (2) ms is from the single measurement of 1951Me10.

2.1. Alpha Transitions

The alpha transition energies have been obtained from the Q(α) value and ^{211}Bi level energies given in Table 1 from ^{211}Bi Adopted Levels, Gammas of 2004Br45.

Table 1. ^{211}Bi levels populated in ^{215}At α-decay

Level	Energy (keV)	Spin and parity	Half-life	Probability of α-transition (%)
0	0.0	9/2–	2.14 (2) min	99.95 (2)
1	404.854 (9)	7/2–	0.317 (11) ns	0.05 (2)

The alpha transition probability P ($\alpha_{0,1}$) is from the measurement of 1966Gr07 by means of α–γ coincidence technique with surface-barrier semi-conductor and NaI(Tl) detectors. The accurate P($\alpha_{0,0}$) value has been deduced from the expression of P($\alpha_{0,0}$) + P($\alpha_{0,1}$) = 100 %.

The α decay hindrance factors have been calculated using the ALPHAD computer program from the ENSDF evaluation package with r_0 (^{211}Pb) = 1.5443 fm (2004Br45).

2.2. Gamma Transitions and Internal Conversion Coefficients

The 405-keV gamma-ray transition probability has been deduced from the intensity balance at the 405-keV level using the adopted alpha transition probability P($\alpha_{0,1}$) and total internal conversion coefficient (ICC) α_T for $\gamma_{1,0}$ (405 keV). The multipolarity (M1+E2) and E2/M1 mixing ratio (δ) of -1.1 (1) have been taken from 2004Br45. These are based on the measurements of conversion electrons in ^{211}Pb β^- decay and γ(θ) measurements with polarized ^{211}Bi nuclei. ICCs α_T, α_K, α_L, α_M have been interpolated using the BrIcc computer program, version v2.2a, data set BrIccFO (2008Ki07).

3. ATOMIC DATA

The fluorescence yields, X-ray energies and relative probabilities, and Auger electrons energies and relative probabilities are from the SAISINUC software.

4. ALPHA EMISSIONS

The energy of alpha-particle group $\alpha_{0,0}$ that populates the ^{211}Bi ground state is the measured value from 1982Bo04 recommended in 1991Ry01. In 1966Gr07 the measured value of 8.00 (1) MeV was reported.

The energy of alpha-particle group $\alpha_{0,1}$ of 7628 (4) keV has been deduced from the Q(α) value taking into account the level energy of 404.854 (9) keV and the recoil energy for ^{211}Bi. The above value of E($\alpha_{0,1}$) can be compared to the value of 7626 (15) keV as measured by 1966Gr07 and adjusted by the evaluator to the adopted E($\alpha_{0,0}$) = 8026 (4) keV (the original value of 1966Gr07 is 7.60 (1) MeV).

The earlier measured energy of α–emission in the decay of ^{215}At is 8.00 (2) MeV (1951Me10).

5. ELECTRON EMISSIONS

The energies of the conversion electrons for $\gamma_{1,0}$ (405 keV) have been obtained from the gamma-ray transition energy and the atomic electron binding energies.

The emission probabilities of the conversion electrons have been deduced using the P_γ and ICC values.

The absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program.

6. PHOTON EMISSIONS

6.1 X - Ray emissions

The absolute emission probabilities of Pb KX- and LX-rays were calculated using the EMISSION computer program.

6.2. Gamma emissions

6.2.1. Gamma ray energies

The 405-keV gamma-ray energy has been adopted from the 405-keV level energy. In 1966Gr07 this energy was obtained from the ^{215}At α decay as ≈ 404 keV.

6.2.2. Gamma ray emission probabilities

The 405-keV gamma-ray emission probability has been deduced from the alpha transition probability P($\alpha_{0,1}$) = 0.05 (2) % and total internal conversion coefficient α_T = 0.122 (8).

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(Band-Raman ICC for γ-ray transitions)

^{216}Po – Comments on evaluation of decay data
by A. L. Nichols

Evaluated: July/August 2001
Re-evaluated: January 2004

Evaluation Procedures

Limitation of Relative Statistical Weight Method (LWM) was applied to average numbers throughout the evaluation. The uncertainty assigned to the average value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

A simple decay scheme was derived from the gamma-ray studies of 1977Ku15, with an absolute emission probability of 0.0019(3)% for the single 804.9 keV gamma ray. This value and theoretical internal conversion coefficients were used to calculate the alpha -particle emission probabilities. Alpha -particle studies are required to confirm the validity of the proposed decay scheme.

Nuclear Data

The ^{228}Th decay chain is important in quantifying the environmental impact of the decay of naturally-occurring ^{232}Th.

Half-life

The recommended half-life is the weighted mean of three somewhat elderly measurements (1911Mo01, 1942Wa04 and 1963Di05). Further studies are merited to determine this value with greater confidence.

Reference	Half-life (s)
1911Mo01	0.145(15)
1942Wa04	0.158(8)
1963Di05	0.145(2)*
Recommended Value	0.150(5)

* Uncertainty adjusted to ± 0.007 to reduce weighting below 0.5.

Gamma Ray

Energy
The single gamma-ray energy was based on the nuclear level energy of 804.9(5) keV from 1992Ar05.

Emission Probability
The absolute emission probability of the 804.9(5) keV gamma ray was determined from the measurement of 1977Ku15, adjusted for the change from 3.95% (0.0395) to 4.12% (0.0412) of P_γ(240.986 keV) for ^{224}Ra.

Published Gamma-ray Emission Probabilities per 100 Disintegrations of ^{216}Po

E_g (keV)	P_g
	1977Ku15[¶]
804.9(5)	0.0018(3)

[¶] Absolute value in measurements that include P_γ(240.986 keV) of 3.95% for ^{224}Ra.

Absolute Gamma-ray Emission Probabilities per 100 Disintegrations of ^{216}Po

E_g (keV)	P_g^{abs}	
	1977Ku15[†]	Recommended Value
804.9(5)	0.0019(3)	0.0019(3)

[†] Adjusted with respect to evaluated P_γ(240.986 keV) of 4.12(3)% (0.0412) for ^{224}Ra.

Multipolarity and Internal Conversion Coefficients

The decay scheme specified by 1992Ar05 has been used to define the multipolarity of the gamma transition on the basis of the known spins and parities of the two nuclear levels. Theoretical internal conversion coefficients were interpolated from the tabulations of 1978Ro22.

Alpha-particle Emissions

Energies

Alpha-particle energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 1992Ar05 and the Q-value (1995Au04) were used to determine the energies and uncertainties of the alpha-particle transitions to the various levels, while allowing for the significant recoil components.

Emission Probabilities

Both alpha-particle emission probabilities were derived from the weighted mean emission probability of the single gamma transition and theoretical internal conversion coefficients.

Alpha-particle Emission Probabilities per 100 Disintegrations of ^{216}Po

E_a(keV)	P_a	
	1962Wa28	Recommended Values[*]
5988.6(10)	0.0021(4)	0.0019(3)
6778.6(5)	~ 100	99.9981(3)

[*] Recommended emission probabilities derived from evaluated gamma-ray emission probability and theoretical internal conversion coefficients.

Atomic Data

The x-ray data have been calculated using the evaluated gamma-ray data, and the atomic data from 1996Sc06, 1998ScZM and 1999ScZX.

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^{217}At - Comments on evaluation of decay data

Huang Xiaolong, Wang Baosong

This evaluation was completed in 2007. Literature available by December 2007 was included.

1 Decay Scheme

^{217}At disintegrates 99.9933 (24) % by α emission to levels in ^{213}Bi and 0.0067 (24) % by β^- emission to levels in ^{217}Rn. ^{217}At ground state has $J^{\pi} = 9/2^-$ (2007Ba19).

The α decay scheme of ^{217}At was built based on the measurement of 1997Ch19. The β^- decay scheme of ^{217}At has not been studied.

The recommended Q(α) value of 7201.3 (12) keV in Audi (2003Au03) agrees with the Q(α) value of 7197 (5) keV, calculated by the evaluator (using program RADLST) from average radiation energies. This agreement supports the completeness and correctness of the decay scheme.

2 Nuclear Data

The Q values are from the 2003Au03 evaluation.

Level energies have been obtained from a least-squares fit to γ-ray energies (GTOL computer code). Spin and parities are from 2007Ba19.

The measured and evaluated ^{217}At half-life values are listed in Table 1.

Table 1: Measured half-life values of ^{217}At and evaluated value.

$T_{1/2}$ (ms)	References	Measurement method
21	1947En03	
18 (2)	1950Ha52	Alpha pulse analyzer
32.3 (4)	1963Di05	
32.3 (4)	2007Ba19	NDS, from 1963Di05
32.3 (4)	Evaluated value	from 1963Di05

The adopted value is taken from the measurement of 1963Di05.

2.1 γ Transitions

The γ transition probabilities were calculated using the γ-ray emission intensities and the relevant internal conversion coefficients.

Multipolarities and mixing ratios of γ transitions are from 1997Ch19.

The internal conversion coefficients (ICC) and the associated uncertainties for the γ- transitions have been obtained using the BrIcc computer program (2008Ki07).

2.2 α Transitions

The measured and evaluated energies of alpha particles were listed in table 2. The evaluated values are from 1997Ch19, except as noted.

Table 2: Measured and evaluated value of α-particle energy for ^{217}At.

1967Dz02	1977Vy02	1982Bo04	1997Ch19	Evaluation
	6037 (3) [b]			6037 (3) [c]
			6322.0 (16)	6322.0 (16)
6422 (7) [a]				
6486 (7)			6484.7 (16)	6484.7 (16)
6541 (7) [a]				
6619 (7) [a]				
6772 (7) [a]				
6810 (7)			6813.8 (16)	6813.8 (16)
6849 (7) [a]				
7070 (8)	7062 (5)	7071 (2)	7066.9 (16)	7066.9 (16)

[a]: the α transitions reported in 1967Dz02 only, were not confirmed in 1997Ch19 and 1997Ch53. So these alpha transitions have not been taken into account by the evaluators.

[b]: 1977Vy02 assign this α transition to the ^{221}Rn decay;
1997Ch53 assign this α transition to the ^{217}At decay.

[c]: from 1977Vy02.

The measured and evaluated alpha particle emission probabilities were listed in table 3. The evaluated alpha particle emission probabilities were deduced from the transition probability balance. These calculated and adopted values are in good agreement, for the main intensities, with the measured emission probabilities.

Table 3: Measured and adopted α-particle emission probabilities for ^{217}At.

E_α(keV)	P_α (%)				
	1967Dz02	1969LeZW	1997Ch19	1997Ch53	Adopted values
6037 (3)				< 0.002	< 0.002
6322.0 (16)			0.005 (1)	0.012 (6)	0.0049 (4)
6484.7 (16)	0.17 (3)	0.02 (1)	0.021 (2)	0.022 (2)	0.0167 (8)
6813.8 (16)	0.55 (9)	0.06 (2)	0.036 (3)	0.038 (4)	0.0384 (15)
7066.9 (16)	98.5 (10)	99.9 (1)	99.9	> 99.9	99.932 (3)

3. Atomic data

Atomic values (ω_K,ϖ_L, ϖ_M, η_{KL} and η_{LM}) are from Schönfeld (1996Sc06).

The X-ray and Auger electron emission probabilities have been deduced from γ-ray and conversion electron data by using the computer code RADLST.

4. Electron Emissions.

The conversion electron emission probabilities have been deduced from γ-ray transition data.

5. Photon Emissions

5.1 γ-ray energy values

The measured and evaluated γ-ray energies for ^{217}At α decay are listed in table 4. The evaluated values are from 1997Ch19. The 455 keV γ-ray is introduced by evaluators due to probabilities balance. This γ-ray was observed in 1964Va20, but not confirmed by 1997Ch19. 1997Ch53 assigned the 6037 keV α transition and introduced the 1050 keV level.

Table 4: Measured and evaluated value of γ-ray energy for ^{217}At.

1981Di14	1997Ch19	Evaluation
	165.8[a]	165.8[a]
258.5 (2)	257.88 (4)	257.88 (4)
	335.33 (10)	335.33 (10)
		455[b]
	501.0[a]	501.0[a]
593.1 (2)	593.10 (10)	593.10 (10)
	758.9 (1)	758.9 (1)

[a]: not placed in level scheme.
[b]: from 1964Va20.

5.2 Absolute values of the γ-ray emission probabilities

The measured and evaluated γ-ray emission probabilities for ^{217}At α decay are listed in table 5. The evaluated values are from 1997Ch19, except as noted.

Table 5: Measured and evaluated γ-ray emission probabilities for ^{217}At.

E_γ (keV)	P_γ		
	1981Di14	1997Ch19	Evaluation
165.8[a]		< 0.0002	< 0.0002
257.88 (4)	0.065 (5)	0.0287 (7)	0.0287 (7)
335.33 (10)		0.0062 (3)	0.0062 (3)
455			< 0.002[b]
501.0[a]		< 0.0002	< 0.0002
593.10 (10)	0.014 (1)	0.0115 (5)	0.0115 (5)
758.9 (1)		0.0049 (4)	0.0049 (4)

[a]: not placed in level scheme.
[b]: from intensity balance.

6. Branching Ratio

The measured and evaluated branching ratio for ^{217}At β^- decay are listed in table 6. The evaluated β^- decay branching ratio is from 1997Ch53, that's (%β^-) = 0.0067 (24) %. So (% α) = 99.9933 (24) %.

Table 6: Measured and evaluated branching ratio for ^{217}At β^- decay.

$I_{\beta-}$ (%)	References
0.0012 (6)	1969LeZW
0.005	1995Ch74
0.0067 (24)	1997Ch53
0.0067 (24)	Evaluated value, from 1997Ch53

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^{217}Rn - Comments on evaluation of the decay data
by Huang Xiaolong, Wang Baosong

This evaluation was completed in 2007. Literature available by December 2007 was included.

1 Decay Scheme

^{217}Rn disintegrates 100 % by α emission to the levels in ^{213}Po. α decay of ^{217}Rn occurs directly to the ground state of ^{213}Po. ^{217}Rn ground state has $J^{\pi} = 9/2^{+}$ (2007Ba19).

2 Nuclear Data

The Q value is from the 2003Au03 evaluation.
The level energy, spin and parity are from 2007Ba19.
The measured and recommended ^{217}Rn half-life values are listed in Table 1.

Table 1 - Measured half-life values of ^{217}Rn and recommended value, in ms.

$T_{1/2}$ (ms)	References	notes
1.0 (1)	1951Me10	
0.54 (5)	1961Ru06	
0.54 (5)	2007Ba19	Nucl. Data Sheets, from 1961Ru06
0.54 (5)	Recommended value	from 1961Ru06

The recommended value is taken from the measurement of 1961Ru06.

2.1 a Transition

The measured alpha-particle energies are listed in table 2. The Q-value of 2003Au03 was used to determine the energy and uncertainty of the single alpha particle transition to the ground state of ^{213}Po.

An α transition of energy 7507 keV (no uncertainty) with ~ 0.1 % intensity was observed by 1961Ru06. The first excited state in ^{213}Po has been observed at 293 keV in ^{213}Bi decay. If the 7507 keV group belonged to ^{217}Rn, from the 7887 keV it would give 243 keV for the level energy of the first excited state . In addition 1961Ru06 did not observe any α-γ coincidence. The evaluator believes that the uncertain 7507 keV group reported by 1961Ru06 probably belongs to an impurity because no positive identification could be made by 1961Ru06.

Table 2 - Measured and recommended values of α-particle energy from ^{217}Rn decay

1961Ru06	1982Bo04	1991Ry01[a]	Adopted value
7735 (4)	7739 (2)	7741 (2)	**7742 (3)**

a: Original energies of 1982Bo04 have been increased by 2 keV due to changes in calibration energies (1991Ry01).

So the evaluated alpha particle emission probability of the single alpha particle is 100 %.

The alpha hindrance factor HF = 1.49 was calculated using a parameter R0 = 1.562 (8) (2007Ba19), average of R0(^{212}Po) = 1.5649 (8) and R0(^{214}Po) = 1.559 (8) ; (1998Ak04).

3. References

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2007Ba19	M.S.Basunia, Nucl.Data Sheets 108, 633 (2007) [NDS]

^{218}Po - Comments on evaluation of decay data
by V. Chisté and M. M. Bé

This evaluation was completed in 2007. Literature available by January 2007 was included.

1 Decay Scheme

^{218}Po disintegrates by alpha emission mainly (99.978 (3) %) to the ground state level of ^{214}Pb. A weak beta minus emission (0.022 (3) %) to At -218 has been pointed out. Spin and parity are from the mass-chain evaluation of Y. A. Akovali (1987El12, 1995El08, 1998Ak04 for A = 218 and 1995El07 for A = 214) and A. K. Jain (2006Ja03 for A = 218).
A good agreement was found between the recommended Q value of Audi and the effective Q value of 6113.33 (22) keV for the α branch, calculated from the decay scheme data.

2 Nuclear Data

The Q values (α and β^-) are from the atomic mass evaluation of Audi *et al.* (2003Au03).

Experimental ^{218}Po half-life values (in minutes) are given in Table 1:

Table 1: Experimental values of ^{218}Po half-life.

Reference	Experimental value (min)	Comments
M. Curie (931Cu01)	3.05	Not used.
M. Blau (1924Bl02)	3.050 (9)	Not used.
J. R. Van Hise (1982Va09)	3.11 (2)	Uncertainty increased to take into account systematic uncertainty.
G. V. Potapov (1986Po17)	3.093 (6)	Original uncertainty corresponds to two standard deviations.
Recommended value	**3.094 (6)**	χ^2 = 0.66

The recommended value was deduced from the two most recent values of ^{218}Po half-life (1982Va09 and 1986Po17), the value of M. Blau (1924Bl02) was omitted from analysis due to the difficulty in estimating a realistic uncertainty. The original uncertainty value given by Van Hise (1982Va09) is for 2σ, but it seems that they did not take into account the systematic uncertainties so the original uncertainty has been maintained.

A weighted average of 3.094 minutes has been calculated using Lweight computer program (version 3), with an internal uncertainty of 0.006 minutes. The reduced-χ^2 value is 0.66.

2.1 a Transitions and Emissions

The energies of the α-particle transitions given in Section 2.1 were calculated from Q_α (2003Au03) and level energies.

The energy of $\alpha_{0,0}$ emission given in section 4 was measured by 1971Gr17, and following the recommendations given by A. Rytz (1991Ry01) was decreased by 0.20 keV. The $\alpha_{0,1}$, emission energy is from R. J. Walen (1958Wa16).

The $\alpha_{0,1}$ emission probability is the measured value of R. J. Walen (1958Wa16) (0.0011 (11) %).

For the $\alpha_{0,0}$ emission probability and associated uncertainty, the following relation was applied:
$P_{\alpha 0,0} + P_{\alpha 0,1} = 100 - P_{\beta-}(264\ \text{keV})$,
where $P_{\beta-}(264\ \text{keV}) = 0.022\ (3)$ % (given by 1952Hi60, see **2.2**) and $P_{\alpha 0,1} = 0.0011\ (11)$ % (given by 1958Wa16). Taking into account these values, then $P_{\alpha 0,0} = 99.9769\ (32)$ %.

2.2 b$^-$ Transitions and Emissions

The maximum energy of the β^- transition in the decay of ^{218}Po → ^{218}At has been taken from Audi (2003Au03) and, without any other information, is affected to a ground state to ground state transition.

The adopted 260-keV β^- transition probability was measured by F. Hiessberger (1952Hi60), 0.022(3) %, and is in agreement with the two values given by R. J. Walen : 0.0200 (5) % (1949Wa05) and 0.0185 % (1958Wa16), respectively.

2.3 g Transitions and Emissions

The $\gamma_{(1,0)}$ transition probability following the α-decay of ^{218}Po → ^{214}Pb was deduced from the decay-scheme balance using the recommended experimental α-particle intensity value of 0.0011 (11) % given by R. J. Walen (1958Wa16). (see **2.1** a **Transitions and Emissions**).

3 Atomic Data

Atomic values, ω_K, ϖ_L and n_{KL} and the X-ray relative probabilities are from Schönfeld and Janβen (1996Sc06).

4 References

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^{218}At - Comments on evaluation of decay data
by V. Chisté and M. M. Bé

This evaluation was completed in 2007. Literature available by January 2007 was included.

1 Decay Scheme

^{218}At disintegrates by alpha emission (99.9 (1) %) to ^{214}Bi mainly. The γ transitions between the ^{214}Bi levels have not been observed. However, a Q value of 6811 (12) keV is calculated in the disintegration of ^{218}At to ^{214}Bi from the decay scheme data compared to a value of 6867(3) keV from the Audi's tables.This deficiency in the calculated Q value suggests the possible existence of a weak gamma transition from the 62-keV to the ground state levels.
A weak beta minus emission (0.1 (1) %) to Rn-218 has been pointed out (1948Wa20). Spins and paritiesare from the mass-chain evaluation of Y. A. Akovali (1987El12, 1995El08 for A = 218 and 1995El07 for A = 214) and A. K. Jain (2006Ja03 for A = 218).

2 Nuclear Data

The Q values (α and β^-) are from the atomic mass evaluation of Audi *et al.* (2003Au03).

Experimental ^{218}At half-life values (in seconds) are given in Table 1:

Table 1: Experimental values of ^{218}At half-life.

Reference	Experimental value (s)	Comments
R. J. Walen (1949Wa05)	1.3 (2)	Uncertainty increased to take into account systematic uncertainty.
D. G. Burke (1989Bu09)	1.5 (3)	
Recommended value	**1.4 (2)**	χ^2 = 0.31

The original uncertainty value given by R. J. Walen (1949Wa05) was multiplied by 2, in order to take into account the systematic uncertainties which were not considered by 1949Wa05. A weighted average has been calculated using Lweight computer program (version 3).

The recommended value of ^{218}At half-life is the weighted average of **1.4** second with an internal uncertainty of 0.2 second. The reduced-χ^2 value is 0.31.

2.1 a Transitions and Emissions

The energies of the α-particle transitions given in Section 2.1 were calculated from Q_α (2003Au03) and level energies.

The energy of $\alpha_{0,0}$, $\alpha_{0,1}$ and $\alpha_{0,2}$ emissions given in section 3 were measured by R.J. Walen (1963Wa29 (see 1964Hy02) and 1958Wa16), the adopted values are those recommended by A. Rytz (1 991Ry01) where the original energy was decreased by 1 keV, due to a change in calibration energy (1995El07).

The $\alpha_{0,0}$, $\alpha_{0,1}$ and $\alpha_{0,2}$ emission probabilities are the measured values of R. J. Walen (1958Wa16), 3.6, 90.0 and 6.4 respectively, without uncertainties. From R. J. Walen, the total α decay is 99.9 (1) %. Since, there is no precision in the Walen's paper, the uncertainty of 0.1 % from propagation of the β^- transition probability (1948Wa20) has been assigned to each α line.

2.2 b$^-$ Transitions and Emissions

The maximum energy of the β^- transition in the decay of ^{218}At → ^{218}Rn is given by Audi (2003Au03) and, without any other information available, is affected to a ground state to ground state transition.

The adopted β^- transition probability was measured by R. J. Walen (1948Wa20) to be 0.1 (1) %

3 References

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2006Ja03 A. K. Jain, B. Singh, Nucl. Data Sheets 107(2006)1027 [I_α, E_α, spin and parity].

^{218}Rn - Comments on evaluation of decay data
by V. Chisté and M. M. Bé

This evaluation was completed in 2007. Literature available by January 2007 was included.

1 Decay Scheme

^{218}Rn disintegrates by alpha emissions to the 609 -keV level (0.127 (7) %) and to the ground state (99.873 (7) %) of ^{214}Po. Spins and parities are from the mass-chain evaluation of Y. A. Akovali (1987El12, 1995El08, 1998Ak04 and 2006Ja03 for A = 218 and 1995El07 for A = 214).
A good agreement was found between the recommended Q value from Audi and the effective Q value (7262.5 (20) keV) calculated from decay scheme data.

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).

Experimental ^{218}Rn half-life values (in ms) are given in Table 1:

Table 1: Experimental values of ^{218}Rn half-life, in ms.

Reference	Experimental value (ms)	Comments
M.H. Studier (1948St42)	19	
P. A. Tove (1958To25)	39 (4)	
C. P. Ruiz (1961Ru06)	30 (3)	
H. Diamond (1963Di05)	35 (2)	Original uncertainty × 2
A. Erlik (1971Er02)	39 (2)	
Recommended value	**36.0 (19)**	reduced χ^2 = 2.3, critical χ^2 = 3.8

The original uncertainty of Diamond includes statistical uncertainty only, it was multiply by 2 to try to take into account systematic components.
A weighted average has been calculated using Lweight computer program (version 3), then the recommended value of ^{218}Rn half-life is **36.0 ms** with an external uncertainty of **1.9 ms**.

2.1 a Transitions and Emissions

The energies of the α-particle transitions given in Section 2.1 were calculated from Q_α (2003Au03) and the level energies.

The energy of $\alpha_{0,0}$ emission given in section 4 is the weighted average of the two measured values of F. Asaro (1956As38) and J. D. Bowman (1982Bo04), with the recommendations given by A. Rytz (1991Ry01) where the original energy of 1956As38 was increased by 4 keV and the energy of 1982Bo04 was decreased by 4 keV, due to changes in calibration energies (1998Ak04). For the $\alpha_{0,1,}$ the emission energy was calculated from Q_α (2003Au03), the level energy and taking the nucleus recoil into account.

The α emission probabilities were deduced from the level decay -scheme balance (see **2.2 Gamma Transitions**).

2.2 g Transitions

The 609-keV γ-ray transition probability was calculated using the γ-ray emission intensity and the relevant internal conversion coefficient (see **4.2** g **Emissions**).
Multipolarity of this γ-ray transition (E2) is from 1995El04.

The internal conversion coefficient (ICC) for the 609keV γ-ray transition has been calculated using the BrIcc computer program (calculation for 'hole'), based on the theoretical values of I. M. Band (2002Ba85).

3 Atomic Data

Atomic values, ω_K, ϖ_L and n_{KL} and the X-ray relative probabilities are from Schönfeld and Janβen (1996Sc06).

4 Photon Emissions

4.1 X-ray Emissions

The X-ray absolute intensities were calculated from γ-ray data and ICC using the EMISSION computer program.

4.2 g Emissions

The energy of the 609-keV γ-ray given in section 5.2 is from W. Kurcewicz (1976Ku08).

The emission intensity of the 609-keV γ-ray was calculated from the measured relative photon intensity of W. Kurcewicz (1976Ku08), who measured the U-230 decay chain, and from the absolute emission intensity of 2.77 (8) % for the 324.22-keV γ-ray of ^{222}Ra decay, as measured by A. Peghaire (1969Pe17). This 609-keV emission intensity was then deduced being 0.124 (7) %.
This result can be compared with the less precise measured absolute intensities of 0.20 (5) (1956As38) and 0.16 (5) (1963Le17).

5 References

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2003Au03 – G. Audi, A. H. Wapstra, C. Thibault, Nucl. Phys. A729(2003)129 [Q].
2006Ja03 – A. K. Jain, B. Singh, Nucl. Data Sheets 107(2006)1027 [Spin, parity and multipolarity].

^{219}At - Comments on evaluation of decay data
by A. L. Nichols

Evaluated: September 2010

Evaluation Procedure

Limitation of Relative Statistical Weight Method (LWM) was applied to average numbers throughout the evaluation. The uncertainty assigned to the average value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

Very little of substance can be gleaned from the literature concerning the decay characteristics of ^{219}At (2001Br31). Although no γ or β^- emissions have been observed, an alpha group at 6.27 MeV was assigned to ^{219}At by Hyde and Ghiorso (1953Hy83). A simple decay scheme has been constructed with little confidence from this early study. Alpha and β^- feeding directly to the ground states of daughter ^{215}Bi and ^{219}Rn were assumed, but these processes were neither observed satisfactorily nor quantified experimentally. Spin and parity of $7/2^-$ were tentatively assigned to the ground state of ^{219}At to align with $5/2^+$ identified with the ground state of daughter ^{219}Rn (2001Br31), in order to define the proposed single beta-particle emission as first forbidden non-unique. Further spectral studies are required to assemble and quantify the decay scheme of ^{219}At with much greater confidence.

Nuclear Data

Part of the (4n + 3) naturally-occurring decay chain, and of relevance in quantifying the environmental impact of ^{235}U and resulting decay-chain products. Specific radionuclides in this decay chain are noteworthy because of their distinctive decay characteristics (e.g. alpha decay of ^{215}Po, ^{211}Bi and ^{211}Po).

Half-life

The recommended half-life is the weighted mean of only two measurements (1953Hy83 and 1989Bu09).

Reference	Half-life (sec)
1953Hy83	54 (6)
1989Bu09	57 (4)
Recommended value	56 (4)*

* Uncertainty adjusted upwards from ± 3 to ± 4 in line with the most precise value of this limited data set.

Q values

Q^- of 1566 (3) keV and Q_α of 6324 (15) keV were adopted from the evaluated tabulations of Audi *et al.* (2003Au03, 2009AuZZ).

Alpha particle

Energy

The alpha-particle branch of ~ 97 % was assumed to populate the ground state of ^{215}Bi directly. Both the energy and uncertainty of this proposed alpha-particle emission were calculated to be 6208 (15) keV from the evaluated Q-value of 6324 (15) keV (2003Au03, 2009AuZZ).

Emission Probability

The alpha-particle emission probability was calculated from a quoted α/β^- ratio of approximately 30, as determined from measurements of the ^{219}At/^{219}Rn peak ratio (1953Hy83). An ill-defined alpha branch of ~ 97 % can be derived from this ratio without an assigned uncertainty.

Alpha-particle emission probability per 100 disintegrations of ^{219}At, and hindrance factor

E_α(keV)	P_α	HF
	Recommended value	
6208 (15)	~ 97	~ 1.07

An unweighted mean value of 1.547 (9) was adopted for the radius parameter r_0(^{215}Bi) as derived from the equivalent data for neighbouring nuclei (1998Ak04), and used in the calculation of the α-hindrance factor (HF):

$$r_0(^{215}\mathrm{Bi}) = [r_0(^{214}\mathrm{Pb}) + r_0(^{216}\mathrm{Po})] / 2$$

$$= [1.5379\ (7) + 1.5555\ (2)] / 2 = 1.547\ (9)$$

Beta particle

Energy

The beta-particle branch of ~ 3 % was assumed to populate the ground state of ^{219}Rn directly. Therefore, the recommended energy and uncertainty of this single beta-particle transition was adopted from the evaluated Q-value of 1566 (3) keV (2003Au03, 2009AuZZ).

Emission Probability

The beta-particle emission probability was calculated from a quoted α/β^- ratio of approximately 30, as determined from measurements of the ^{219}At/^{219}Rn peak ratio (1953Hy83). A single, ill-defined, first forbidden non-unique transition is proposed directly to the ground state of ^{219}Rn, with an emission probability of ~ 3 % and no assigned uncertainty.

Beta-particle emission probability per 100 disintegrations of ^{219}At, transition type and log *ft*

E_β(keV)	P_β	transition type	log *ft*
	Recommended value		
1566 (3)	~ 3	(1st forbidden non-unique)	~ 6.2

Data Consistency

An effective Q-value of 6181 (15) keV has been adopted from the atomic mass evaluation of Audi *et al*. (2003Au03, 2009AuZZ) while in the course of formulating the decay scheme of ^{219}At. This value has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{219}At alpha- and beta-decay processes:

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 6181\ (15)\ \text{keV}$$

Percentage deviation from the effective Q-value of Audi *et al*. is (0.0 ± 0.3) %, which supports the derivation of a highly consistent decay scheme.

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^{219}Rn – Comments on evaluation of decay data
by A. L. Nichols

Evaluated: October 2010

Evaluation Procedure

Limitation of Relative Statistical Weight Method (LWM) was applied to average numbers throughout the evaluation. The uncertainty assigned to the average value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

A reasonably comprehensive decay scheme has been derived from the alpha-particle studies of 1962Wa18, 1991Ry01 and 1999Li05, and the gamma-ray measurements of 1967Da20, 1968Br17, 1970Da09, 1970Kr08 and 1999Li05.

Nuclear Data

Part of the (4n + 3) decay chain, and of relevance in quantifying the environmental impact of ^{235}U and various decay-chain products. Specific radionuclides in this decay chain are noteworthy because of their distinctive and important decay characteristics (e.g. alpha decay of ^{215}Po, ^{211}Bi and ^{211}Po).

Half-life

The recommended half-life is the weighted mean of two measurements by 1961Ro14, and an additional independent study by 1966Hu20.

Reference	Half-life (s)
1961Ro14	4.01 (6)
	4.00 (5)
1966Hu20	3.96 (1)[#]
Recommended value	3.98 (3)

[#] Uncertainty adjusted to ± 0.04 to reduce weighting below 50 %.

Q value

Q_α of 6946.1 (3) keV was adopted from the evaluated tabulations of Audi *et al.* (2003Au03).

Alpha Particles

Energies

Alpha-particle energies were calculated from the structural details of the proposed decay scheme. While the energies of the alpha-particle emissions have been directly measured by 1962Wa18, 1971Gr07, 1991Ry01 and 1999Li05, the nuclear level energies of 2001Br31 and evaluated Q-value of 6946.1 (3) keV (2003Au03) were preferably used to determine the recommended energies and uncertainties of the alpha-particle transitions, taking into account the significant recoil.

Adopted nuclear levels of ^{215}Po: J^π and origins (2001Br31).

Nuclear level	Nuclear level energy (keV)	J^π	Origins
0	0.0	9/2 +	^{215}Bi β^- decay, **^{219}Rn α decay**
1	271.228 ± 0.010	7/2 +	^{215}Bi β^- decay, **^{219}Rn α decay**
2	293.56 ± 0.04	(11/2) +	^{215}Bi β^- decay, **^{219}Rn α decay**
3	401.812 ± 0.010	5/2 +	^{215}Bi β^- decay, **^{219}Rn α decay**
4	517.60 ± 0.06	7/2 +, 9/2 +	^{215}Bi β^- decay, **^{219}Rn α decay**
5	608.30 ± 0.07	(11/2 +, 13/2 +)	**^{219}Rn α decay**
6	676.66 ± 0.07		^{215}Bi β^- decay, **^{219}Rn α decay**
7	708.1 ± 0.5		**^{219}Rn α decay**
8	732.7 ± 0.4		**^{219}Rn α decay**
9	835.32 ± 0.22		^{215}Bi β^- decay, **^{219}Rn α decay**
10	877.2 ± 0.6		**^{219}Rn α decay**
11	891.1 ± 0.3		**^{219}Rn α decay**
12	930 ± 1		**^{219}Rn α decay**
13	1073.7 ± 0.4	(5/2 +)	**^{219}Rn α decay**
14	1094.2 ± 1.0		**^{219}Rn α decay**

Measured and recommended energies of the alpha-particle emissions of ^{219}Ra.

	E_α (keV)				
	1962Wa18	**1971Gr07**	**1991Ry01**	**1999Li05**	**Recommended value***
$\alpha_{0,14}$	–	–	–	5744 (15)	5745.0 (10)
$\alpha_{0,13}$	–	–	–	5764 (8)	5765.1 (5)
$\alpha_{0,12}$	–	–	–	5900 (15)	5906.2 (10)
$\alpha_{0,11}$	–	–	–	5944 (6)	5944.4 (4)
$\alpha_{0,10}$	–	–	–	5958 (15)	5958.1 (7)
$\alpha_{0,9}$	5999.3	–	–	6000 (6)	5999.2 (4)
$\alpha_{0,8}$	6100.5	–	–	6100 (8)	6099.9 (5)
$\alpha_{0,7}$	~ 6146.2	–	–	6124 (8)	6124.1 (6)
$\alpha_{0,6}$	6157.1	–	–	6158 (4)	6154.9 (3)
$\alpha_{0,5}$	6222.1	–	–	6223 (6)	6222.0 (3)
$\alpha_{0,4}$	6310.3	–	–	6311 (3)	6311.1 (3)
$\alpha_{0,3}$	6423.2	–	6425.0 (10)	6425 (1)	6424.8 (3)
$\alpha_{0,2}$	6527.5	–	–	6530 (2)	6531.0 (3)
$\alpha_{0,1}$	6551.3	–	6552.6 (10)	6553 (1)	6553.0 (3)
$\alpha_{0,0}$	6817.5	6819.3 (3)	6819.1 (3)	6819.1 (3)	6819.2 (3)

* Determined from the nuclear level energies of 2001Br31 and evaluated Q-value of 6946.1 (3) keV (2003Au03).

Emission Probabilities

Alpha-particle emission probabilities were derived from the recommended relative emission probabilities of the gamma rays, a normalisation factor of 0.111 (5), and theoretical internal conversion coefficients (see below). The normalisation factor (F) was determined from the sum of the relative emission probabilities of the alpha particles calculated on the basis of α-γ population/depopulation balances of all the nuclear levels of ^{215}Po:

$$\sum[\text{calculated relative } P_\alpha \text{ to } {}^{215}\text{Po excited states}]F + (\text{absolute } P_\alpha \text{ to } {}^{215}\text{Po ground state}) = 100$$

An absolute P_α of 79.4 (10) % directly to the ^{215}Po ground state was adopted from 1991Ry01. Denoting F as the normalisation factor for the relative emission probabilities of both the gamma rays and alpha particles:

$$186.0626F + 79.4\ (10) = 100$$

$$F = 20.6\ (10) / 186.0626 = 0.1107\ (54) \rightarrow 0.111\ (5)$$

An unweighted mean value of 1.557 (2) was adopted for the radius parameter $r_0(^{215}Po)$ as derived from the equivalent data for neighbouring nuclei (1998Ak04), and used in the calculation of α-hindrance factors (HF):

$$r_0(^{215}Po) = [r_0(^{214}Po) + r_0(^{216}Po)] / 2$$

$$= [1.559(8) + 1.5555(2)] / 2 = 1.557\ (2)$$

Alpha-particle emission probabilities per 100 disintegrations of ^{219}Rn, and hindrance factors.

E_α(keV)	P_α				HF
	1962Wa18	1991Ry01	1999Li05	Recommended value*	
5745.0 (10)	–	–	< 0.0001	0.000 09 (5)	245
5765.1 (5)	–	–	0.001	0.000 94 (19)	33
5906.2 (10)	–	–	–	0.000 09 (5)	1590
5944.4 (4)	–	–	0.002	0.002 1 (3)	103
5958.1 (7)	–	–	0.0001	0.000 3 (1)	830
5999.2 (4)	0.0044	–	0.003	0.003 2 (5)	120
6099.9 (5)	0.003	–	0.001	0.001 23 (12)	880
6124.1 (6)	~ 0.0026	–	0.001	0.000 64 (12)	2170
6154.9 (3)	0.0174	–	0.018	0.018 4 (22)	103
6222.0 (3)	0.0026	–	0.004	0.004 3 (10)	860
6311.1 (3)	0.054	–	0.054	0.048 (3)	184
6424.8 (3)	7.5	7.5 (6)	7.5	7.85 (24)	3.31
6531.0 (3)	0.12	–	0.12	0.098 (5)	710
6553.0 (3)	11.5	12.9 (6)	13	12.6 (3)	6.75
6819.2 (3)	81	79.4 (10)	79.3	79.4 (10)	11.2
				Σ 100.02729 → 100.0 (11)	

* Recommended alpha-particle emission probabilities have been determined by calculating the populating alpha-particle balances of the daughter nuclear levels of ^{215}Po through individual consideration of their gamma population-depopulation, along with the adoption of a normalisation factor of 0.111 (5) for the relative emission probabilities of the observed gamma rays and derived alpha particles.

Gamma Rays

Energies

While the energies of the main gamma-ray emissions have been directly measured by 1967Da20, 1968Br17, 1970Da09, 1970Kr08, 1976Bl13 and 1999Li05, all of the recommended gamma-ray energies were calculated from the nuclear level energies of daughter ^{215}Po as adopted from 2001Br31.

Measured and recommended energies of the main gamma-ray emissions of ^{219}Ra.

	E_γ (keV)						
	1967Da20	1968Br17	1970Da09	1970Kr08	1976Bl13	1999Li05	Recommended value*
$\gamma_{3,1}(Po)$	130.9 (6)	130.5 (3)	130.7 (1)	130.6 (2)	130.588 (29)	130.6 (1)	130.58 (1)
$\gamma_{1,0}(Po)$	271.2 (5)	271.0 (2)	271.20 (5)	271.4 (1)	271.233 (10)	271.23 (5)	271.228 (10)
$\gamma_{2,0}(Po)$	293.2 (6)	293.4 (4)	294.0 (3)	293.8 (2)	293.538 (44)	293.6 (1)	293.56 (4)
$\gamma_{3,0}(Po)$	401.7 (5)	401.7 (1)	401.8 (2)	402.0 (3)	401.811 (10)	401.81 (5)	401.81 (1)
$\gamma_{4,0}(Po)$	517.1 (8)	517.4 (3)	516.5 (5)	–	517.639 (55)	517.5 (1)	517.60 (6)
$\gamma_{6,0}(Po)$	–	676.6 (3)	677.0 (10)	–	676.645 (70)	676.7 (1)	676.66 (7)

* Determined from the recommended nuclear level energies of 2001Br31.

Emission Probabilities

The emission probabilities were determined from measurements of 1967Da20, 1968Br17, 1970Da09, 1970Kr08, 1976Bl13 and 1999Li05. Weighted mean values were calculated for the relative emission probabilities of the 130.58-, 293.56-, 401.81-, 517.60-, 608.30-, 676.66- and 891.1-keV gamma rays, while all others were adopted from the more comprehensive set of data measured by 1999Li05.

Some of the reported gamma-ray emissions were of highly questionable validity, and were not considered for placement in the recommended decay scheme because of their nature and doubtful origins:

(a) 115.4-keV gamma ray was only observed by 1968Br17, and was furthermore labeled by these authors as ill-assigned – removed from consideration.

(b) 221.5-keV gamma ray was judged to be a major gamma emission from the alpha-decay mode of ^{223}Ra – removed from further consideration.

(c) 324.9-and 337.7-keV gamma-ray emission probabilities were expressed only in terms of their upper limits by 1967Da20, and not observed by 1999Li05 – removed from consideration.

(d) 370.9-keV gamma ray was observed by 1965Va10, an emission probability expressed only in terms of an upper limit by 1967Da20, and not observed by 1999Li05 – removed from consideration.

(e) 380-keV gamma ray was only observed by 1965Va10 without a quantified emission probability – removed from consideration.

(f) 438.2-keV gamma ray was judged to be a major gamma emission from the alpha-decay mode of ^{215}Po – removed from further consideration.

(g) 538.2-and 1005-keV gamma rays were observed by 1965Va10, emission probabilities quantified by 1967Da20, and not observed by 1999Li05 – removed from consideration.

(h) 665.5-keV gamma-ray emission probability was assigned an upper limit by 1967Da20 and identified as a possible doublet, and fully quantified as a singlet by 1999Li05 – retained as an unplaced gamma transition emitted in the decay of ^{219}Rn.

Although some of the other observed gamma-ray emissions possess similar origins to the above, these transitions could be more comfortably placed in the proposed decay scheme, lending support to their acceptance and inclusion in the recommended data set.

Published gamma-ray emission probabilities.

E_γ (keV)	P_γ						
	1965Va10[*]	1967Da20[†]	1968Br17[‡]	1970Da09[¶]	1970Kr08	1976Bl13	1999Li05
115.4 (5)	–	–	0.033 (15)	–	–	–	–
130.58 (1)	observed	1.40 (14)	1.30 (25)	1.05 (25)	1.21 (10)	1.16 (12)	1.7 (2)
221.5 (3)	–	–	–	) 0.28 (7)	–	–	–
224.04 (7)	–	–	–	)	–	–	0.013 (2)
271.228 (10)	observed	100	110 (15)	100.00	100.0	105.5 (40)	100 (2)
293.56 (4)	–	0.64 (6)	0.77 (15)	0.59 (15)	0.51 (27)	0.76 (5)	0.68 (4)
322 (1)	–	–	–	–	–	–	0.0008 (4)
324.9 (10)	–	< 0.06	–	–	–	–	–
330.9 (4)	–	–	–	–	–	–	0.0090 (10)
337.7 (10)	–	< 0.08	–	–	–	–	–
370.9 (15)	observed	< 0.1	–	–	–	–	–
373.5 (3)	–	–	–	–	–	–	0.0023 (3)
~ 380	observed	–	–	–	–	–	–
383.1 (1)	–	–	–	–	–	–	0.0040 (6)
401.81 (1)	observed	58 (6)	67 (4)	65.2 (65)	69.0 (30)	61.6 (28)	59.0 (20)
405.4 (1)	–	–	–	–	–	–	0.0023 (4)
436.9 (5)	–	–	–	–	–	–	0.0028 (5)
438.2 (6)	–	0.54 (10)	–	–	–	–	–
461.5 (4)	–	–	–	–	–	–	0.0015 (3)
489.3 (3)	–	–	–	–	–	–	0.0058 (8)
517.60 (6)	observed	0.44 (10)	0.48 (4)	0.22 (5)	–	0.43 (3)	0.40 (2)
538.2 (15)	observed	0.06 (3)	–	–	–	–	–
556.1 (4)	–	–	–	–	–	–	0.0005 (3)
564.1 (2)	observed	< 0.03	–	–	–	–	0.014 (3)
576.6 (10)	–	–	–	–	–	–	0.0008 (4)
608.30 (7)	observed	0.04 (2)	–	–	–	–	0.040 (10)
619.9 (3)	–	–	–	–	–	–	0.003 (1)
665.5 (10)	–	< 0.08[Δ]	–	–	–	–	0.0008 (4)
671.9 (4)	observed	–	–	–	–	–	0.002 (1)
676.66 (7)	–	0.21 (3)	0.23 (2)[Δ]	0.06 (3)	–	0.16 (1)	0.16 (2)
708.1 (5)	–	–	–	–	–	–	0.003 (1)
732.7 (4)	–	–	–	–	–	–	0.0006 (3)
802.5 (4)	–	–	–	–	–	–	0.003 (1)
835.32 (22)	observed	–	–	–	–	–	0.015 (3)
877.2 (6)	–	–	–	–	–	–	0.003 (1)
891.1 (3)	observed	0.015 (7)	–	–	–	–	0.007 (2)
1055 (2)	observed	0.006 (3)	–	–	–	–	–
1073.7 (4)	–	–	–	–	–	–	0.003 (1)

[*] Quantified only in terms of percentage depopulation of a number of ill-defined nuclear levels of ^{215}Po – neither the gamma-ray energies nor this form of relative emission probability were adopted in the subsequent analyses.

[†] Quoted relative emission probabilities of 1967Da20 are based on Pγ(271.228 keV) of 1000, and have been adjusted to Pγ(271.228 keV) of 100.

[‡] Quoted relative emission probabilities of 1968Br17 for ^{219}Rn decay are based on Pγ(271.228 keV) of 0.110 (15), and have been adjusted to Pγ(271.228 keV) of 110 (15).

[¶] Uncertainties in the relative emission probabilities are not defined by 1970Da09, and have been derived from the quoted uncertainties of the absolute emission probabilities.

[Δ] Evidence for the existence of a doublet.

Relative gamma-ray emission probabilities: Relative to P_γ(271.228 keV) of 100 %.

	E_γ (keV)	P_γ						
		1967Da20	**1968Br17**	**1970Da09**	**1970Kr08**	**1976Bl13**	**1999Li05**	**Recommended value**
–	115.4 (5)[*]	–	0.030 (14)	–	–	–	–	–
$\gamma_{3,1}$	130.58 (1)	1.40 (14)	1.18 (23)	1.05 (25)	1.21 (10)	1.10 (11)	1.7 (2)	1.2 (1)
–	221.5 (3)[#]	–	–	) 0.28 (7)	–	–	–	–
$\gamma_{4,2}$	224.04 (7)	–	–	)	–	–	0.013 (2)	0.013 (2)
$\gamma_{1,0}$	271.228 (10)	100	100	100.00	100.0	100	100.0 (20)	100 (2)
$\gamma_{2,0}$	293.56 (4)	0.64 (6)	0.70 (14)	0.59 (15)	0.51 (27)	0.72 (5)	0.68 (4)	0.68 (3)
$\gamma_{12,5}$	322 (1)	–	–	–	–	–	0.0008 (4)	0.0008 (4)
–	324.9 (10)[§]	< 0.06	–	–	–	–	–	–
$\gamma_{8,3}$	330.9 (4)	–	–	–	–	–	0.0090 (10)	0.0090 (10)
–	337.7 (10)[†]	< 0.08	–	–	–	–	–	–
–	370.9 (15)[†]	< 0.1	–	–	–	–	–	–
$\gamma_{11.4}$	373.5 (3)	–	–	–	–	–	0.0023 (3)	0.0023 (3)
–	~ 380[§]	–	–	–	–	–	–	–
$\gamma_{6,2}$	383.1 (1)	–	–	–	–	–	0.0040 (6)	0.0040 (6)
$\gamma_{3,0}$	401.81 (1)	58 (6)	61 (4)	65.2 (65)	69 (3)	58.4 (27)	59.0 (20)	61 (2)
$\gamma_{6,1}$	405.4 (1)	–	–	–	–	–	0.0023 (4)	0.0023 (4)
$\gamma_{7,1}$	436.9 (5)	–	–	–	–	–	0.0028 (5)	0.0028 (5)
–	438.2 (6)[‡]	0.54 (10)	–	–	–	–	–	–
$\gamma_{8,1}$	461.5 (4)	–	–	–	–	–	0.0015 (3)	0.0015 (3)
$\gamma_{11,3}$	489.3 (3)	–	–	–	–	–	0.0058 (8)	0.0058 (8)
$\gamma_{4,0}$	517.60 (6)	0.44 (10)	0.44 (4)	0.22 (5)	–	0.41 (3)	0.40 (2)	0.39 (3)
–	538.2 (15)[†]	0.06 (3)	–	–	–	–	–	–
$\gamma_{13,4}$	556.1 (4)	–	–	–	–	–	0.0005 (3)	0.0005 (3)
$\gamma_{9,1}$	564.1 (2)	< 0.03	–	–	–	–	0.014 (3)	0.014 (3)
$\gamma_{14,4}$	576.6 (10)	–	–	–	–	–	0.0008 (4)	0.0008 (4)
$\gamma_{5,0}$	608.30 (7)	0.04 (2)	–	–	–	–	0.040 (10)	0.040 (9)
$\gamma_{11,1}$	619.9 (3)	–	–	–	–	–	0.003 (1)	0.003 (1)
$\gamma_{-1,1}$	665.5 (10)[¶]	< 0.08[Δ]	–	–	–	–	0.0008 (4)	0.0008 (4)
$\gamma_{13,3}$	671.9 (4)	–	–	–	–	–	0.002 (1)	0.002 (1)
$\gamma_{6,0}$	676.66 (7)	0.21 (3)	0.21 (2)	0.06 (3)	–	0.15 (1)	0.16 (2)	0.16 (2)
$\gamma_{7,0}$	708.1 (5)	–	–	–	–	–	0.003 (1)	0.003 (1)
$\gamma_{8,0}$	732.7 (4)	–	–	–	–	–	0.0006 (3)	0.0006 (3)
$\gamma_{13,1}$	802.5 (4)	–	–	–	–	–	0.003 (1)	0.003 (1)
$\gamma_{9,0}$	835.32 (22)	–	–	–	–	–	0.015 (3)	0.015 (3)
$\gamma_{10,0}$	877.2 (6)	–	–	–	–	–	0.003 (1)	0.003 (1)
$\gamma_{11,0}$	891.1 (3)	0.015 (7)	–	–	–	–	0.007 (2)	0.008 (2)
–	1055 (2)[†]	0.006 (3)	–	–	–	–	–	–
$\gamma_{13,0}$	1073.7 (4)	–	–	–	–	–	0.003 (1)	0.003 (1)

[*] Only observed by 1968Br17, and of doubtful origin – discarded.

[#] Determined from the measurements of 1970Da09, but identified as a gamma-ray emission within the alpha-decay mode of ^{223}Ra – discarded.

[§] Only observed in a qualitative manner by 1965Va10 and 1967Da20, and of doubtful origin – discarded.

[†] Derived only from the measurements of 1967Da20, and of doubtful origin – discarded.

[‡] Determined from the measurements of 1967Da20, but identified as a gamma-ray emission within the alpha-decay mode of ^{215}Po – discarded.

[¶] Derived only from the measurements of 1967Da20 and 1999Li05, and of doubtful origin – unplaced within the proposed ^{219}Rn decay scheme.

[Δ] Evidence for the existence of a doublet.

Multipolarity and Internal Conversion Coefficients

The decay scheme specified by 2001Br31 has been used to define the multipolarity of specific gamma transitions on the basis of the known spins and parities of the nuclear levels. Thus, the 224.04-, 401.81 and 1073.7-keV gamma-ray emissions are adjudged to be E2 transitions. Multipolarity mixing ratios for the 130.58- and 271.228-keV gamma transitions of 0.60 (6) and 4.0 (4), respectively, were derived from the K/L and L sub-shell conversion-electron intensities determined by Davidson and Connor (1970Da09), while the 293.56-, 517.60- and 556.1-keV gamma-ray emissions were arbitrarily assigned mixing ratios of 1.0 (2) (i.e. 50%M1 + 50%E2). Recommended internal conversion coefficients have been determined from the frozen orbital approximation of Kibédi *et al.* (2008Ki07), based on the theoretical model of Band *et al.* (2002Ba85, 2002Ra45).

Gamma-ray emissions: multipolarity and theoretical internal conversion coefficients (frozen orbital approximation).

E_γ (keV)	P_γ^{abs} × 100	Multipolarity	α_K	α_L	α_{M+}	α_{total}
130.58 (1)	0.133 (11)	73.5%M1 + 26.5%E2 δ = 0.60 (6)	3.19 (16)	0.94 (4)	0.31	4.44 (13)
224.04 (7)	0.001 4 (2)	(E2)	0.129 6 (19)	0.140 7 (20)	0.048 7	0.319 (5)
271.228 (10)	11.07 (22)	(6%M1 + 94%E2) δ = 4.0 (4)	0.111 (6)	0.066 8 (11)	0.023 2	0.201 (7)
293.56 (4)	0.075 (3)	(50%M1 + 50%E2) δ = 1.0 (2)	0.25 (4)	0.062 (4)	0.028	0.34 (5)
322 (1)	0.000 09 (5)	–	–	–	–	–
330.9 (4)	0.001 00 (11)	–	–	–	–	–
373.5 (3)	0.000 25 (3)	–	–	–	–	–
383.1 (1)	0.000 44 (7)	–	–	–	–	–
401.81 (1)	6.75 (22)	E2	0.0351 (5)	0.015 28 (22)	0.005 12	0.055 5 (8)
405.4 (1)	0.000 25 (4)	–	–	–	–	–
436.9 (5)	0.000 31 (6)	–	–	–	–	–
461.5 (4)	0.000 17 (3)	–	–	–	–	–
489.3 (3)	0.000 64 (9)	–	–	–	–	–
517.60 (6)	0.043 (3)	(50%M1 + 50%E2) δ = 1.0 (2)	0.058 (9)	0.011 5 (11)	0.003 5	0.073 (10)
556.1 (4)	0.000 06 (4)	(50%M1 + 50%E2) δ = 1.0 (2)	0.048 (7)	0.009 5 (9)	0.003 5	0.061 (8)
564.1 (2)	0.001 5 (3)	–	–	–	–	–
576.6 (10)	0.000 09 (5)	–	–	–	–	–
608.30 (7)	0.004 4 (10)	(M1 + E2)	–	–	–	–
619.9 (3)	0.000 33 (11)	–	–	–	–	–
665.5 (10)	0.000 09 (5)	–	–	–	–	–
671.9 (4)	0.000 22 (11)	M1 + E2	–	–	–	–
676.66 (7)	0.018 (2)	–	–	–	–	–
708.1 (5)	0.000 33 (11)	–	–	–	–	–
732.7 (4)	0.000 07 (4)	–	–	–	–	–
802.5 (4)	0.000 33 (11)	M1 + E2	–	–	–	–
835.32 (22)	0.001 7 (3)	–	–	–	–	–
877.2 (6)	0.000 33 (11)	–	–	–	–	–
891.1 (3)	0.000 9 (2)	–	–	–	–	–
1073.7 (4)	0.000 33 (11)	E2	0.005 10 (8)	0.001 002 (14)	0.000 308	0.006 41 (9)

Atomic Data

The x-ray data have been calculated using the evaluated gamma-ray data, and the atomic data from 1996Sc06, 1998ScZM and 1999ScZX. Both the x-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.01, 28 January 2003). This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

K and L X-ray emission probabilities per 100 disintegrations of ^{219}Rn.

			Energy (keV)	**Photons per 100 disint.**
XL		(Po)	9.658 – 16.213	1.01 (5)
	XL$_{l}$	(Po)	9.658	0.0229 (9)
	XL$_{\alpha}$	(Po)	11.016 – 11.130	0.420 (15)
	XL$_{\eta}$	(Po)	12.085	0.0095 (4)
	XL$_{\beta}$	(Po)	12.823 – 13.778	0.475 (13)
	XL$_{\gamma}$	(Po)	15.742 – 16.213	0.098 (3)
XK$_{\alpha}$	XK$_{\alpha 2}$	(Po)	76.864	0.540 (24)
	XK$_{\alpha 1}$	(Po)	79.293	0.90 (4)
XK$'_{\beta 1}$	XK$_{\beta 3}$	(Po)	89.256	0.309 (15)
	XK$_{\beta 1}$	(Po)	89.807	
	XK$''_{\beta 5}$	(Po)	90.363	
XK$'_{\beta 2}$	XK$_{\beta 2}$	(Po)	92.263	0.096 (5)
	XK$_{\beta 4}$	(Po)	92.618	
	XKO$_{2,3}$	(Po)	92.983	

Electron energies were determined from electron binding energies tabulated by Larkins (1977La19) and the evaluated gamma-ray energies. Absolute electron emission probabilities were calculated from the evaluated absolute gamma-ray emission probabilities and associated internal conversion coefficients.

Data Consistency

A Q$_{\alpha}$-value of 6946.1 (3) keV has been adopted from the atomic mass evaluation of Audi *et al.* (2003Au03) while in the course of formulating the decay scheme of ^{219}Rn. This value has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{219}Rn alpha-decay process (i.e. α, electron, γ, etc.):

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 6945\ (70)\ \text{keV}$$

Percentage deviation from the Q-value of Audi *et al.* is (0.0 ± 1.0) %, which supports the derivation of a highly consistent decay scheme with a rather significant variant.

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^{220}Rn – Comments on evaluation of decay data
by A. L. Nichols

Evaluated: July/August 2001
Re-evaluated: January 2004

Evaluation Procedures

Limitation of Relative Statistical Weight Method (LWM) was applied to average numbers throughout the evaluation. The uncertainty assigned to the average value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

A simple decay scheme has been derived from the gamma-ray studies of 1972DaZA, 1977Ku15, and 1984Ge07. The single 549.76 keV gamma ray had a weighted mean emission probability of 0.115(15)% (0.00115(15)), and this value and theoretical internal conversion coefficients were used to calculate the absolute emission probabilities of the 5748.46 and 6288.22 keV alpha particles to the 549.76 keV and ground states of ^{216}Po, respectively. Alpha-particle studies are required to confirm the validity of the proposed decay scheme.

Nuclear Data

^{228}Th decay chain is important in quantifying the environmental impact of the decay of naturally-occurring ^{232}Th.

Half-life

The recommended half-life is the weighted mean of measurements by 1955Sc81, 1961Ro14, 1963Gi17 and 1966Hu20. Further studies are merited to confirm the most recent studies of 1963Gi17 and 1966Hu20.

Reference	Half-life (s)
1955Sc81	51.5(10)*
1961Ro14	56.6(8)
	56.3(2)
1963Gi17	55.3(3)
1966Hu20	55.61(4)#
Recommended Value	55.8(3)

* Defined as outlier.

\# Uncertainty adjusted to ± 0.16 to reduce weighting below 0.5.

Gamma Ray

Energy

The single gamma-ray energy was based on the nuclear level energy of 549.76(4) keV from 1997Ar04.

Emission Probability

The absolute emission probability of the 549.76(4) keV gamma ray was determined from measurements by 1972DaZA, 1977Ku15 and 1984Ge07. A weighted mean value of 0.115(15)% (0.00115(15)) was derived through LWEIGHT.

Published Gamma-ray Emission Probabilities

E_g (keV)	P_g			
	1956Ma28[†]	1972DaZA[‡]	1977Ku15[¶]	1984Ge07[#]
549.76(4)	0.025	0.29(9)	0.0950(80)	0.43(4)

[†] Defined as accurate to within a factor of 2; rejected from evaluation.
[‡] Relative to P_γ(2614.511 keV) of ^{208}Tl.
[¶] Absolute value in measurements that include P_γ(240.986 keV) of 3.95% for ^{224}Ra.
[#] Relative to P_γ(583.19 keV) of ^{208}Tl.

Absolute Gamma-ray Emission Probabilities per 100 Disintegrations of ^{220}Rn

E_g (keV)	P_g^{abs}			
	1972DaZA[†]	1977Ku15[†]	1984Ge07[†]	Recommended Value[*]
549.76(4)	0.104(32)	0.0991(83)	0.130(3)	0.115(15)

[†] Data adjusted on the basis of the footnotes given above.
[*] Weighted mean value adopted.

Multipolarity and Internal Conversion Coefficients

The decay scheme specified by 1997Ar04 has been used to define the multipolarity of the gamma transition on the basis of the known spins and parities of the two nuclear levels. Theoretical internal conversion coefficients were interpolated from the tabulations of 1978Ro22.

Alpha-particle Emissions

Energies

Alpha-particle energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 1997Ar04 and the Q-value (1995Au04) were used to determine the energies and uncertainties of the alpha-particle transitions to the various levels, while allowing for the significant recoil components.

Emission Probabilities

Both alpha-particle emission probabilities were derived from the weighted mean emission probability of the single gamma transition and theoretical internal conversion coefficients.

Alpha-particle Emission Probabilities per 100 Disintegrations of ^{220}Rn

E_a(keV)	P_a		
	1962Wa28	1977Ku15[#]	Recommended Values[*]
5748.46(14)	0.07(2)	0.097(8)	0.118(15)
6288.22(10)	~ 100	99.9	99.882(15)

[#] Data were deduced from gamma-ray studies.
[*] Recommended emission probabilities derived from evaluated gamma-ray emission probability and theoretical internal conversion coefficients.

Atomic Data

The x-ray data have been calculated using the evaluated gamma-ray data, and the atomic data from 1996Sc06, 1998ScZM and 1999ScZX.

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^{221}Fr - Comments on evaluation of decay data
by Huang Xiaolong and Wang Baosong

This evaluation was completed in 2007. Literature available by December 2007 was included.

1 Decay Scheme

^{221}Fr disintegrates 99.9952 (15) % by α emission to levels in ^{217}At and 0.0048 (15) % by β^- emission to levels in ^{221}Ra. ^{221}Fr ground state has $J^{\pi}=5/2^-$ (2003Ak06).

The α decay scheme of ^{221}Fr was built based on the measurement described in 1995Sh01, 1999Gr33 and 2002Gr36. A study of 1997Ch53 showed the existence of a possible weak ß$^-$ decay of (4.8 ± 1.5) 10^{-3} % to ^{221}Ra. The β^- decay scheme of ^{221}Fr has not been studied.

The recommended Q(a) value of 6457.8 (14) keV in Audi(2003Au03) agrees with the Q(a) value of 6461.5 (25) keV, calculated by the evaluator (using program RADLST) from average radiation energies. This agreement supports the completeness and correctness of the decay scheme.

2 Nuclear Data

The Q value is from the 2003Au03 evaluation.

Level energies, have been obtained from a least-squares fit to γ-ray energies (GTOL computer code). Spin and parities are from 2003Ak06.

The measured and our evaluated ^{221}Fr half-life values are listed in Table 1. Notice that uncertainties in tables referred to the least significant digits.

Table 1 - Measured half-life values of ^{221}Fr and recommended value, in minutes

$T_{1/2}$ (min)	References	measurement method
5	1947En03	
4.8	1950Ha52	Alpha pulse analyzer
4.9 (2)	1967LoZZ	
4.79 (2)	2007Je07	From Si sample. Metallic samples(Au,W) give shorter value
4.9 (2)	2003Ak06	NDS, from 1967LoZZ
4.85 (6)		Unweighted mean of 1967LoZZ and 2007Je07
4.791 (20)		Weighted mean of 1967LoZZ and 2007Je07, χ^2=0.3
4.79 (2)	2007	Recommended value, from 2007Je07

2007Je07 measured the half-life at room temperature in different materials and obtained an improved value. As the weighted mean of 4.9 (2) min (1967LoZZ) and 4.79 (2) min (2007Je07) is very close to this most precise measurement, the value of 2007Je07 is recommended here.

2.1 g Transitions

The γ-ray transition probabilities were calculated using the γ-ray emission intensities and the relevant internal conversion coefficients.

Multipolarities and mixing ratios of γ-ray transitions are from 1968Le07 and 1995Sh01. Multipolarities in square brackets are from level scheme (they are not measured).

The internal conversion coefficients (ICC) and their associated uncertainties for γ-ray transitions have been obtained using the BrIcc computer program, which uses the “Frozen Orbital” approximation (2002Ba85).

Experimental and theoretical conversion coefficients are compared in Table 2.

Table 2 - Comparison of theoretical and measured conversion coefficients

E_g/keV	**Multipolarity**	**a(theory)**	**a(exp.)**	
			1995Sh01	1999Gr33
53.81	M1	α_T=14.17, α_L=10.79 (16)	α_L=8 (4)	
96.3	M1+E2	α_T=5.6 , α_L=4.1 (18)	α_L>2.5	α_T=25 (15)
100.25	M1	α_T=11.97, α_L=1.758 (25)	α_L=1.2 (6)	
117.82	M1	α_T=7.58		α_T=13.5 (86)
150.21	M1	α_T=3.8, α_K=3.08 (5)	α_K=2.6 (5)	α_T=3.5 (9)
171.83	E2	α_T=0.863, α_K=0.226 (4)	α_K=0.3 (1)	α_T=0.84 (2)
218.12	E2	α_T=0.367, α_K=0.1375 (20)	α_K=0.14	
324.10	M1	α_T=0.446, α_K=0.362 (5)	α_K=0.4 (2)	
359.86	M1	α_T=0.335, α_K=0.272 (4)	α_K=0.4 (1)	
382.34	M1	α_T=0.284, α_K=0.231 (4)	α_K=0.25 (10)	
410.64	E2	α_T=0.0548, α_K=0.0344 (5)	α_K=0.03 (1)	

2.2 a Transitions

Measured energies of alpha particles are listed in table 3. Our recommended values are from 1968Le07 and 2002Gr36.

Table 3 - Measured and recommended values of α-particle energies (in keV) from ^{221}Fr α decay

1967Dz02	**1968Le07**[a]	**2002Gr36**	**Recommended**
		5500 (40)	5500 (40)
		5530 (25)	5530 (25)
	5689 (3)		5689 (3)
	5697 (4)		5697 (4)
	5776 (3)		5776 (3)
	5783 (4)		5783 (4)
	5813 (3)		5813 (3)
5930 (7)	5925 (3)		5925 (3)
5940 (6)	5938.9 (20)		5938.9 (20)
5966 (6)	5965.9 (25)		5965.9 (25)
5980 (6)	5979.9 (20)		5979.9 (20)
6075 (5)	6075.9 (20)		6075.9 (20)
6125 (5)	6126.3 (15)		6126.3 (15)
6241 (6)	6243.0 (20)		6243.0 (20)
6338 (5)	6341.0 (13)		6341.0 (13)

[a]: Values were adjusted based on the calibration recommendation of 1991Ry01.

Experimental and recommended α-particle emission probabilities are listed in Table 4. Our recommended alpha particle emission probabilities are average values of measured α-particle intensities with those deduced from γ-transition probability balance at each decay scheme level.

Table 4 - Experimental, recommended α-particle emission probabilities from ^{221}Fr decay

E_a(keV)	**P_a(%)**				
	1967Dz02	**1968Le07**	**2002Gr36**	**Deduced from Pg**	**Recommended**†
5500 (40)			3.3 (9) E-4	0.000038 (10)	0.000038 (10)
5530 (25)			9.0 (20) E-4	0.00010 (2)	0.00010 (2)
5689 (3)		0.002 (1)		0.0026 (5)	0.0025 (5)
5697 (4)		~0.001		~0.004	~0.003
5776 (3)		0.06 (1)		0.065 (4)	0.064 (4)
5783 (4)		0.005(2)		0.0029 (6)	0.0031 (6)
5813 (3)		0.004 (2)		0.006 (1)	0.006 (1)
5925 (3)	0.05 (1)	0.03 (1)		0.0280 (16)	0.0285 (24)
5938.9 (20)	0.13 (1)	0.17 (3)		0.127 (3)	0.128 (3)
5965.9 (25)	0.12 (1)	0.08 (1)		0.053 (4)	0.064 (16)
5979.9 (20)	0.46 (5)	0.49 (3)		0.27 (3)	0.39 (7)
6075.9 (20)	0.13 (2)	0.15 (3)		0.30 (6)	0.15 (3)
6126.3 (15)	14.5 (7)	15.1 (2)		15.3 (3)	15.1 (2)
6243.0 (20)	1.35 (7)	1.34 (10)		0.9 (5)	1.34 (7)
6341.0 (13)	83.2 (20)	83.4 (8)		82.9 (5)	82.8 (2)*

† Weighted average of values from the first four columns, normalized to a total of 100 %.

* Value reduced by a covariance effect introduced by the normalization to 100 %.

3. Atomic data

Atomic fluorescence yields (ω_K,ϖ_L, ϖ_M, η_{KL} and η_{LM}) are from Schönfeld (1996Sc06).

The X-ray and Auger electron emission probabilities have been deduced from γ-ray and conversion electron data by using the computer code RADLST. The deduced K X-ray emission probabilities P_{KX} = 2.77 (19) % agree with the measured value of 2.23 (20) % in 1995Sh01, thus confirming the completeness of the decay scheme.

4. Electron Emissions

The conversion electron emission probabilities have been deduced from γ-ray transition data using theoretical internal conversion coefficients.

5. Photon Emissions

5.1 g-ray energy values

The experimental and our recommended γ-ray energies from ^{221}Fr α decay are listed in table 5. Unless otherwise specified the later are averages (or weighted averages) from values given in 1968Le07, 1994Ar23, 1995Sh01, and 1999Gr33. γ-rays of 809.3 and 891.9 keV reported only in 2002Gr36 have also been included here. Several γ-rays observed in 1995Bu17 and 1994Ar23 were interpreted as sum peaks in 1999Gr33. Values from 1995Bu17 have not been included in this averaging because this reference seems to be an earlier publication of 1999Gr33 (notice that only these two references reported the 201.4 - and 208.3-keV γ-rays).

Table 5 - Measured and recommended values of γ-ray energies for ^{221}Fr α decay.

1968Le07	1994Ar23	1995Bu17	1995Sh01	1999Gr33	2002Gr36	LWM	Recommended
		53.54 (18)	53.8 (1)	53.81 (3)		53.80 (28)	53.81 (3)
		68.11 (15)					
		96.12 (18	96.3 (3)	96.3 (3)		96.20 (14)	96.3 (3)
99.5	100.63 (2)	99.52 (6)	100.2 (1)	100.25 (2)		100.40 (24)	100.25 (2)
118.2 (2)	117.67 (5)	118.18 (9)	117.8 (2)	117.82 (3)		117.80 (9)	117.82 (3)
150.0 (2)	150.43 (5)	150.04 (4)	150.0 (1)	150.21 (3)		150.20 (8)	150.21 (3)
171.3	172.05 (5)	171.68 (4)	171.6 (1)	171.83 (3)		171.80 (8)	171.83 (3)
		201.44 (50)		201.4 (6)		201.4 (4)	201.4 (6)[a]
		208.3 (5)		208.3 (6)		208.3 (4)	208.3 (6)
217.99 (4)	218.30 (2)	218.14 (3)	218.0 (1)	218.12 (2)		218.20 (11)	218.12 (2)
	250.7 (2)						
	253.15 (15)						
		263.39 (14)					
	271.91 (5						
282.8	282.25 (5)	282.36 (15)	281.9 (3)	282.12 (9)		282.20 (4)	282.12 (9)
		297.11 (40)					
		299.59 (14)					
	310.20 (5)	310.14 (16)					
		314.11 (17)					
324.1	323.99	323.99 (6)	324.0 (2)	324.10 (6)		324.00 (4)	324.10 (6)
359.1	359.90 (2)	359.92 (6)	359.0 (2)	359.86 (4)		359.90 (6)	359.86 (4)
	368.17 (2)	368.18 (10)					
381.8	382.36 (2)	381.81 (4)	381.1 (2)	382.34 (4)		382.20 (15)	382.34 (4)
409.1	410.73 (2)	409.93 (7)	410.4 (2)	410.64 (5)		410.60 (16)	410.64 (5)
	435.68 (10)		437.8 (5)	437.00 (5)		436.4 (6)	437.00 (5)
		445.07 (20)	446.3 (8)	446.30 (8)		445.7 (6)	446.30 (8)
		469.6 (2)	469.0 (5)	468.3 (7)		469.40 (18)	468.3 (7)
			496.2 (10)				
	538.02 (10)	537.0 (2)	537.5 (8)	537.8 (8)		537.5 (5)	537.8 (8)
			562.3 (12)				562.3 (12)
		568.5 (3)	568.4 (10)	568.5 (3)		568.50 (21)	568.5 (3)
	577.76 (6)	576.9 (4)	577.0 (8)	576.9 (4)		577.70 (6)	576.9 (4)
				652 (2)			652 (2)
				658 (2)			658 (2)[a]
				665 (2)			665 (2)
					809.3 (2)		809.3 (2)
					891.9 (3)		891.9 (3)

[a]: not placed in level scheme.

5.2 Relative g-ray emission probabilities

Measured relative γ-ray intensities from ^{221}Fr are listed together with our recommended values in Table 6. Several γ-rays observed in 1995Bu1 7 and 1994Ar23 were interpreted as sum peaks in 1999Gr33. Thus their relative intensities may not be accurate so they have not been recommended here.

Results in 1995Sh01 are in agreement with those in 1999Gr33 within their experimental uncertainties, but they are not as complete and accurate. However, their decay scheme differs only by some weak transitions. For example, 1995Sh01 did not observe the 652 -0, 578-368 γ-ray transitions, thus it did not propose the 652 keV level. 1999Gr33 is the most precise measurement among the available experimental data. Unless otherwise specified, the present recommended values are weighted averages (LWM) from values given in 1999Gr33, 1995Sh05, 1994Ar23. 1968Le07, and two γ-rays from 2002Gr36.

Table 6 - Measured and recommended relative γ-ray emission probabilities for ^{221}Fr

E_g(keV)	**1968Le07**	**1994Ar23**	**1995Sh01**	**1999Gr33**	**2002Gr36**	**Recommended**[&]
53.81 (3)			0.15 (4)	0.116 (27)		0.127 (22)
96.3 (3)			<0.09	0.063 (27)		0.058 (23)
100.25 (2)	0.95 (34)	1.47 (9)	1.33 (18)	0.89 (27)		1.37 (11)
117.82 (3)	0.34 (17)	0.328 (17)	0.044 (18)	0.20 (12)		0.19 (14)
150.21 (3)	0.69 (26)	0.362 (17)	0.53 (9)	0.420 (18)		0.393 (21)
171.83 (3)	0.52 (26)	0.517 (17)	0.58 (11)	0.680 (18)		0.60 (8)
201.4 (6)[a]				0.0098 (9)		0.0098 (9)[†]
208.3 (6)				0.045 (9)		0.045 (9)[†]
218.12 (2)	100	100	100	100		100
282.12 (9)	0.086	0.056 (9)	0.071 (27)	0.063 (9)		0.060 (6)
324.10 (6)	0.17 (9)	0.138 (9)	0.106 (27)	0.170 (9)		0.152 (10)
359.86 (4)	0.34 (17)	0.319 (17)	0.32 (9)	0.358 (18)		0.337 (12)
382.34 (4)	0.34 (17)	0.302 (17)	0.27 (9)	0.295 (18)		0.298 (12)
410.64 (5)	1.21 (34)	1.034 (86)	0.97 (18)	1.055 (18)		1.054 (17)
437.00 (5)		0.034 (6)	~0.009	0.0083 (9)		0.0083 (9)[†]
446.30 (8)			~0.009	0.0152 (36)		0.0152 (36)[†]
468.3 (7)			0.018 (9)	0.0152 (27)		0.0154 (26)
537.8 (8)		0.034 (10)	0.018 (9)	0.0447 (45)		0.039 (7)
562.3 (12)			~0.044			~0.044
568.5 (3)			~0.009	0.0107 (36)		0.0107 (36)[†]
576.9 (4)		0.041 (6)	0.035 (9)	0.0259 (36)		0.030 (5)
652 (2)				~0.00358		~0.00358[†]
658 (2)[a]				~0.00626		~0.00626[†]
665 (2)				~0.00805		~0.00805[†]
809.3 (2)					9.0E-4 (20)	9.0E-4 (20)[*]
891.9 (3)					3.3E-4 (9)	3.3E-4 (9)[*]

[&] Deduced using the LWM statistical method, unless otherwise specified.

[a] not placed in level scheme.

† From 1999Gr33

* Reported only in 2002Gr36

5.3 Absolute g-ray emission probabilities

Measurements of the absolute γ-ray emission probability of the 218.12 keV transition from ^{221}Fr α decay are listed in Table7.

Values in 1968Le07, 1986He06 and 1995Sh01 are the only absolute independent measurements. Among these absolute measurements, the one given in 1986He06 is the most precise.

1986He06 measured the γ-ray emission probability in equilibrium with ^{229}Th. ^{229}Th α-decay emits a 218.15-keV γ-ray, therefore this contribution should be subtracted.

1987He28 and 2000Ga52 measured γ-ray emission probabilities from the α-decay of ^{229}Th to ^{225}Ra relatively to $I_\gamma = 4.3$ for the 193.5-keV transition. They obtained 0.18 (2) and 0.134 (20) for the 218.15-keV γ-ray, respectively.

The weighted average of these values is 0.146 (20) relative to I_γ(193.5) = 4.3. Using a conversion factor of 1.026 (14) as given by 1987He28, the absolute value is: 0.146 (20) × 1.026 (14) = 0.150 (20) %.

Thus, the corrected absolute γ-ray emission probability of the 218.15-keV γ-ray from ^{221}Fr α decay is 11.57 (15) - 0.150 (20) = 11.42 (15) %, which is our recommended value.

Taking into account the β- branching ratio (see §6), the normalization factor between relative and absolute emission probabilities is N = 11.42 (15) / 0.999952 (15) = 0.1142 (15).

Table 7 - Measured and recommended absolute γ-ray emission probability of 218.12 keV for ^{221}Fr

P_g (218.12 keV)	References	Experimental value and method
12.5 (4)	1968Le07	
13.44 (27)	1981Di14	Ge(Li)
11.57 (15)	1986He06	Ge(Li),Au-Si surface barrier,in equilibrium with $^{229\text{Th}}$
11.3 (10)	1995Sh01	Ge(Li),α-γ-ce coincidence
11.18 (15)	1999Gr33	Ge(Li),αγ coincidence, using I_α(6126)=15.1 (2) %
11.42 (15)	Recommended	Evaluated value, from 1986He06

[a]: value corrected using the evaluation of 1990Ak05.

The recommended absolute γ-ray emission probabilities are the recommended relative values shown in table 6 multiplied by 0.1142 (15), as given in table 8.

Table 8 - Absolute γ-ray emission probabilities from ^{221}Fr α decay.

E_g (keV)	P_g (%)		E_g (keV)	P_g (%)
53.8	0.0145 (25)		446.3	0.0017 (4)
96.3	0.007 (3)		468.3	0.0018 (3)
100.2	0.156 (13)		537.8	0.0045 (8)
117.8	0.022 (16)		562.3	0.005 (5)
150.2	0.0449 (25)		568.5	0.0012 (4)
171.8	0.069 (9)		576.9	0.0030 (6)
201.4	0.0011 (1)		652	0.0004 (4)
208.3	0.0051 (10)		658	0.0007 (7)
218.1	11.42 (15)		665	0.0009 (9)
282.12	0.0069 (7)		809.3	0.00010 (2)
324.1	0.0174 (12)		891.9	0.000038 (10)
359.9	0.0385 (15)			
382.3	0.0340 (14)			
410.6	0.1204 (25)			
437	0.0010 (1)			

6. b- Branching Ratio

Measured and recommended branching ratios for ^{221}Fr β^- decay are listed in Table 9. Our recommended β^- decay branching ratio from 1997Ch53 is $I_{\beta-}$ = 0.0048 (15) %. Thus, I_α = 99.9952 (15) %.

Table 9 - Measured and recommended branching ratio for ^{221}Fr β^- decay.

I_{b-} (%)	References
0.0011 (5)	1995Ch74
0.0048 (15)	1997Ch53
0.0048 (15)	Recommended value, from 1997Ch53

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^{222}Rn - Comments on evaluation of decay data
by V. Chisté and M. M. Bé

1 Decay Scheme

^{222}Rn disintegrates by alpha emission mainly to the ground state level of ^{218}Po. Spin and parity are from the mass-chain evaluation of Y. A. Akovali (1987El12, 1995El08 for A = 218 and 1996El01 for A = 222) and A. K. Jain (2006Ja03 for A = 218).
The calculated Q value of 5590.2 (6) keV deduced from the decay scheme data is in good agreement with the adopted value from Audi *et al.*

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).

The experimental ^{222}Rn half-life values (in days) are given in Table 1:

Table 1: Experimental values of ^{222}Rn half-life.

Reference	Experimental value (d)	Comments
W. Bothe (1923Bo**)	3.824 (4)	Ionization-chamber. Revised uncertainty by N.E. Holden (1990Ho28).
I. Curie (1924Cu**)	3.823 (2)	Ionization-chamber. Revised uncertainty by N.E. Holden (1990Ho28).
J. Tobailem (1951To25)	3.825 (5)	Ionization-chamber. Revised uncertainty by N.E. Holden (1990Ho28).
J. Robert (1956Ro31)	3.825 (4)	Calorimetry. Revised uncertainty by N.E. Holden (1990Ho28).
P. C. Marin (1956Ma64)	3.8229 (17)	Revised uncertainty by N.E. Holden (1990Ho28).
N. S. Shimanskaya (1958Sh69)	3.83 (3)	Calorimetry. Outlier
D. K. Butt (1972Bu33)	3.8235 (17)	Revised uncertainty by N.E. Holden 1990Ho28.
R. Collé (1995Co**)	3.8224 (18)	Liquid scintillator.
H. Schrader (2004Sc04)	3.8195 (30)	Ionization-chamber. Outlier
Recommended value	**3.8232 (8)**	χ^2 = 0.11

For the half-life values in references from W. Bothe (1923Bo*) to D. K. Butt (1972Bu33), the retained values take into account the uncertainty recommendations given by N. E. Holden (1990Ho28). With this data set, a weighted average was calculated using LWEIGHT computer program (version 3). Based on the Chauvenet's criterion, the Shimanskaya (1958Sh69) and Schrader's (2004Sc04) values have been shown outlier and then omitted in the final calculation.

The recommended value of ^{222}Rn half-life is the weighted average of **3.8232 days** with an internal uncertainty of **0.0008 day**. The reduced-χ^2 value is 0.11 and the critical χ^2 value is 2.8.

2.1 a Transitions and Emissions

The energies of the α-particle transitions given in Section 2.1were calculated from Q_α (2003Au03) and level energies.

The energy of the $\alpha_{0,0}$ emission given in section 4 is from A. Rytz (1991Ry01). For the $\alpha_{0,1}$ and $\alpha_{0,2}$, the emission energies are given by R. J. Walen (1958Wa16).

The α-particle emission probabilities are recommended by A. Rytz (1991Ry01). For the $\alpha_{0,1}$ emission probability, the adopted value is the measured value of R. J. Walen (1958Wa16) (0.078). Existence of the $\alpha_{0,2}$ branch is questionable.

2.2 g Transitions

The $\gamma_{(1,0)}$ transition probability was deduced from the decay-scheme balance using recommended experimental α-particle intensity value of 0.078 given by RJ. Walen (1958Wa16). (see **2.1** a **Transitions and Emissions**).
The multipolarity of the 510-keV γ-ray transition is from 2006Ja03.
510-keV γ-ray : [E2]

The internal conversion coefficients (ICC's) for this γ-ray transition have been calculated using the Br Icc computer program, which interpolates from theoretical values of I. M. Band (2002Ba85).

3 Atomic Data

Atomic values, ω_K, ϖ_L and n_{KL} and the X-ray relative probabilities are from Schönfeld and Janβen (1996Sc06).

4 a Emissions

See **2.1** a **Transitions and Emissions**.

5 Photon emissions

5.1 g-ray Emissions

The energy of the 510 keV γ-ray given in Section 5.1 was measured by L. Madansky (1956Ma28).
The intensity of 0,076 deduced from alpha intensity measurements is in agreement with the measured value of 0,07 obtained by L. Madansky (1956Ma28).

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^{223}Fr-Comments on evaluation of the decay data

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This evaluation was completed in 2008. Literature available by December 2008 was included.

1 Decay Scheme

^{223}Fr disintegrates 0.020 (4) % by α emission to levels in ^{219}At and 99.980 (4) % by β^- emission to levels in ^{223}Ra. ^{223}Fr ground state has J^π =3/2($^-$)(2001Br31).

The α decay scheme of ^{223}Fr was built based on the measurement of 2001Li44. The β^- decay scheme of ^{223}Fr was built based on the measurement of 1993Ab01.

The adopted Q(α) and Q(β^-) values of Audi(2003Au03) are in good agreement with the Q(α) and Q(β^-) values deduced from the decay scheme data.

2 Nuclear Data

The Q values are from the 2003Au03 atomic-mass adjustment.

Level energies have been deduced from a least-squares fit to γ-ray energies (GTOL computer code). Spin and parities are from 2001Br31 and 2001Li44.

The measured and our recommended ^{223}Fr half-life values are listed in Table 1.

Table 1 Measured half-life values of ^{223}Fr and recommended value, in minutes.

$T_{1/2}$ (min)	References	measurement method
22 (1)	1955Ad10	
21.8 (4)	1967Li17	G-M counter
22.00 (7)	1993Ab01	HPGe detector
22.00 (7)	2001Br31	NDS, weighted average of 1967Li17, 1993Ab01
21.93 (7)		Unweighted mean
21.99 (7)		LWM,χ^2=0.12
22.00 (7)		Recommended value, from 1993Ab01

The recommended value is from the measurement of 1993Ab01.

2.1 γ Transitions

The γ-ray transition probabilities were deduced using the γ-ray emission intensities and relevant theoretical internal conversion coefficients.

Multipolarities and mixing ratios of γ-ray transitions for β^- decay are from 2001Br31, for α decay from 2001Li44. The mixing ratio of the 29.78keV γ-ray is from the experimental data of 1990Br23, the uncertainty was assumed to be 10 %.

The internal conversion coefficients (ICC) and their associated uncertainties have been obtained using the BrIcc computer program, which applies the “Frozen Orbital” approximation (2002Ba85).

2.2 α Transitions

The measured and evaluated energies of alpha particles were listed in table 2. The recommended values are from 2001Li44.

Table 2. Measured and recommended values of α-particle energies from ^{223}Fr decay

1955Ad10	2001Li44	recommended
	5462 (3)	5462 (3)
	5403 (3)	5403 (3)
5340 (80)	5314 (4)	5314 (4)
	5291 (4)	5291 (4)
	5172 (5)	5172 (5)

The measured and evaluated alpha particle emission probabilities are listed in table 3. The recommended values are from 2001Li44.

Table 3. Measured and recommended α-particle emission probabilities from ^{223}Fr decay

E_α/keV	$P_\alpha(10^{-4})$		
	2001Li44	Calc.	recommended
5462 (3)	33 (15)	0	33 (15)
5403 (3)	44 (20)	95 (40)	44 (20)
5314 (4)	53 (23)	70 (35)	53 (23)
5291 (4)	60 (26)	60 (30)	60 (26)
5172 (5)	9 (5)	8 (5)	9 (5)

2.3 β^- transition

The maximum energies of the β^- transitions in the decay of ^{223}Fr have been deduced from the Q value (2003Au03) and the level energies.

The adopted ε and β^- transition probabilities and their associated uncertainties were deduced from the γ transition probability balance at each level of the decay scheme.

The electron capture subshell probabilities and *lg ft* values were calculated using the LOGFT program.

3. Atomic data

Atomic fluorescence yields (ω_K,ϖ_L, ϖ_M, η_{KL} and η_{LM}) are from Schönfeld (1996Sc06).

The X-ray and Auger electron emission probabilities have been deduced from γ-ray and conversion electron data using the computer code RADLST. Measured and calculated X-ray emission probabilities are compared in Table 4.

Table 4 Comparison of calculated and measured Ra X-ray emission intensities

	1982AlZL	Adopted (deduced)
$K_{\alpha1}$	2.4 (5)	2.3 (3)
$K_{\alpha2}$	**1.43 (28)**	1.44 (19)

The radium KX-ray emission probabilities, deduced from γ-ray data, agree with the measured values of 1982AlZL, thus confirming the completeness of the decay scheme.

4. Electron Emissions.

The conversion electron emission probabilities have been deduced from γ-ray emission probabilities and theoretical conversion coefficients.

5. Photon Emissions

5.1 γ-ray energy values

There is one measurement of γ-ray energies from ^{223}Fr α decay, that's 2001Li44. Our recommended γ-ray energies from ^{223}Fr α decay are from 2001Li44. The 24.14keV γ-ray, which was observed in ^{223}Fr decay was assigned by evaluators to ^{223}Fr α decay.

The measured and recommended γ-ray energies from ^{223}Fr β^- decay are listed in table 5. The recommended values are from 1993Ab01.

Table 5 Measured and recommended values of γ-ray energies from ^{223}Fr β^- decay

1964Yt01	1967MA19	1982ALZL	1993Ab01	recommended
			20.27 (5)	20.27 (5)
			27.27 (3)[b]	27.27 (3)[b]
			29.78 (4)	29.78 (4)
			31.69 (5)	31.69 (5)
			43.5 (2)	43.5 (2)
			44.0 (1)	44.0 (1)
			49.80 (5)	49.80 (5)
50 (2)	50.8 (5)	50.087 (12)	50.10 (2)	50.10 (2)
	61.0 (15)		61.43 (5)	61.43 (5)
			62.31 (6)	62.31 (6)
			73.5 (1)	73.5 (1)
80 (2)	80.0 (4)	79.651 (13)	79.65 (2)	79.65 (2)
		88.483 (11)	89.08 (10)	89.08 (10)
100 (5)			93.88 (5)	93.88 (5)
			111.05 (3)	111.05 (3)
136 (5)	134.4 (4)	134.641 (22)	134.60 (2)	134.60 (2)
			150.6 (4)[b]	150.6 (4)[b]
			155.5 (5)	155.5 (5)
167 (8)	173.1 (5)	173.393 (38)	173.35 (5)	173.35 (5)
	184.5 (5)	184.693 (38)	184.65 (5)	184.65 (5)
191 (15)			200.7 (2)	200.7 (2)
205 (5)	204.8 (4)	204.948 (15)	204.85 (5)	204.85 (5)
			205.6 (2)	205.6 (2)
			210.60 (5)	210.60 (5)
			218.80 (5)	218.80 (5)
			222.9 (3)[b]	222.9 (3)[b]
234 (3)	234.6 (4)	234.796 (10)	234.70 (5)	234.70 (5)
			236.05 (5)	236.05 (5)
	246 (1)	245.56 (21)	245.60 (5)	245.60 (5)
	250.6 (10)	250.12 (12)	250.25 (5)[a]	250.25 (5)[a]
			254.6 (2)	254.6 (2)
	256 (1)	256.09 (18)	256.18 (5)	256.18 (5)

1964Yt01	1967MA19	1982ALZL	1993Ab01	recommended
			262.9 (2)	262.9 (2)
			269.6 (3)[b]	269.6 (3)[b]
			272.8 (2)	272.8 (2)
			280.7 (5)[a]	280.7 (5)[a]
	286.0 (15)	285.9 (6)	286.0 (2)	286.0 (2)
289 (10)	289.6 (15)	289.73 (10)	289.67 (5)	289.67 (5)
			293.2 (2)[b]	293.2 (2)[b]
			296.5 (2)	296.5 (2)
	300.0 (15)	299.92 (20)	299.95 (5)	299.95 (5)
	304.2 (15)		304.40 (5)	304.40 (5)
	307.3 (15)	307.63 (20)	307.93 (5)[a]	307.93 (5)[a]
	313.3 (15)	312.7 (7)	312.65 (5)	312.65 (5)
			314.6 (2)	314.6 (2)
318 (10)	319.0 (5)	319.266 (22)	319.25 (5)	319.25 (5)
	330.0 (15)		329.80 (5)	329.80 (5)
	333.1 (15)		334.30 (6)	334.30 (6)
	338.7 (10)		339.50 (5)	339.50 (5)
	343.0 (15)		342.50 (7)	342.50 (7)
355 (12)			350.5 (2)	350.5 (2)
	369.0 (5)	369.46 (6)	369.32 (5)	369.32 (5)
			382.3 (2)[b]	382.3 (2)[b]
			434.4 (1)	434.4 (1)
			439.6 (3)	439.6 (3)
			444.5 (3)	444.5 (3)
			452.9 (2)[a]	452.9 (2)[a]
			457.5 (2)	457.5 (2)
			469.3 (2)[a]	469.3 (2)[a]
			475.4 (1)[a]	475.4 (1)[a]
			480.9 (3)	480.9 (3)
			493.4 (2)	493.4 (2)
			506.9 (2)	506.9 (2)
			516.7 (2)	516.7 (2)
			524.8 (2)	524.8 (2)
			533.1 (3)	533.1 (3)
			537.2 (2)[a]	537.2 (2)[a]
			539.8 (2)	539.8 (2)
			545.4 (4)	545.4 (4)
			552.3 (2)	552.3 (2)
			556.3 (3)	556.3 (3)
		568.85 (15)	569.03 (8)	569.03 (8)
			576.1 (4)	576.1 (4)
			581.3 (4)	581.3 (4)
			592.3 (2)	592.3 (2)
			596.9 (4)	596.9 (4)
			600.7 (4)	600.7 (4)

1964Yt01	1967MA19	1982ALZL	1993Ab01	recommended
			607.6 (3)	607.6 (3)
			613.6 (4)	613.6 (4)
			632.7 (3)	632.7 (3)
			663.7 (3)	663.7 (3)
			671.9 (4)	671.9 (4)
			682.3 (3)[b]	682.3 (3)[b]
			694.6 (3)[b]	694.6 (3)[b]
			708.3 (3)	708.3 (3)
	723 (1)	723.7 (7)	722.65 (5)	722.65 (5)
			724.15 (5)	724.15 (5)
			737.4 (3)	737.4 (3)
			742.4 (3)	742.4 (3)
	746.5 (15)	746.3 (9)	746.30 (5)	746.30 (5)
			753.65 (5)	753.65 (5)
	756 (2)		757.20 (5)	757.20 (5)
			762.6 (2)	762.6 (2)
	766.5 (20)	764.7 (7)	766.64 (5)	766.64 (5)
	776.0 (6)	776.0 (7)	775.83 (5)	775.83 (5)
781 (10)			780.8 (1)	780.8 (1)
	784 (2)		784.93 (5)	784.93 (5)
			787.6 (2)[a]	787.6 (2)[a]
	793 (2)		792.2 (3)	792.2 (3)
	797.5 (20)		796.22 (5)	796.22 (5)
		803.7 (7)	803.77 (5)	803.77 (5)
	804 (1)		806.0 (2)	806.0 (2)
	813 (2)	812.0 (10)	812.40 (6)	812.40 (6)
			816.5 (2)	816.5 (2)
	821.5 (25)		823.20 (7)	823.20 (7)
	826 (1)	826.4 (11)	825.95 (7)	825.95 (7)
	835 (2)		833.9 (2)	833.9 (2)
			837.5 (1)	837.5 (1)
	840.5 (20)	842.0 (9)	842.2 (1)	842.2 (1)
	847 (1)	847.7 (10)	846.85 (10)[a]	846.85 (10)[a]
	860 (2)		863.6 (1)	863.6 (1)
	864 (2)		867.4 (1)	867.4 (1)
	876.5 (10	876.2 (10)	876.5 (1)	876.5 (1)
			878.1 (2)	878.1 (2)
	892 (3)		893.1 (2)	893.1 (2)
	897.5 (20)	896.7 (10)	896.7 (2)	896.7 (2)
	908 (2)	907.7 (10)	907.6 (2)	907.6 (2)
			911.3 (2)	911.3 (2)
			913.6 (3)	913.6 (3)
			926.5 (3)	926.5 (3)
			941.2 (3)	941.2 (3)
			949.3 (4)	949.3 (4)

1964Yt01	1967MA19	1982ALZL	1993Ab01	recommended
			958.0 (7)	958.0 (7)
			969.2 (4)	969.2 (4)
			975.2 (5)	975.2 (5)
			978.7 (4)	978.7 (4)
			989.4 (5)	989.4 (5)
			994.3 (3)	994.3 (3)
			999.3 (5)	999.3 (5)
			1025.1 (5)	1025.1 (5)

a: multiply placed. b: not placed in level scheme.

5.2 Relative values of γ-ray intensities

The measured and recommended γ-ray emission probabilities from ^{223}Fr α decay are listed in table 6. The recommended values are from 2001Li44.

Table 6. Measured and recommended values of γ-ray energies and emission probabilities from ^{223}Fr α decay

E_γ (keV)		P_γ (10^{-4} %)	
2001Li44	recommended	2001Li44	recommended
	24.14 (3)		60 (26)[a]
58.9 (2)	58.9 (2)	8 (3)	8 (3)
150.9 (2)	150.9 (2)	56 (5)	56 (5)
145.3 (3)	145.3 (3)	2 (1)	2 (1)

[a]: (γ+ce), from intensity balance.

Measured values of the relative γ-ray intensities, the 234.7 keV being the reference line, from ^{223}Fr β^- decay are listed in Table 7. 1964Yt01 and 1967MA19 are replaced by 1993Ab01, these three references coming from the same group. There is no detailed experimental information in 1982AlZL and only the data table are given. It's noted that among 131 γ-rays, 87 γ-rays are new and observed in 1993Ab01. Compared to 1993Ab01, 1982AlZL did not provide the γ-rays with low energy; their γ-ray intensities are in agreement with those reported by 1993Ab01 for some γ-rays, and for most of the weak γ-rays quite different. Then, the present adopted values are from 1993Ab01.

Table 7 Measured and recommended relative γ-ray intensities from ^{223}Fr β^- decay.

E_γ/keV	I_γ				
	1964Yt01	1967MA19	1982ALZL	1993Ab01	recommended
20.27 (5)				53 (5)	53 (5)
27.27 (3)[b]				2.3 (4)	2.3 (4)
29.78 (4)				2.6 (4)	2.6 (4)
31.69 (5)				0.05	0.05
43.5 (2)				0.08	0.08
44.0 (1)				0.05	0.05
49.80 (5)				93 (8)	93 (8)
50.10 (2)	100	1000	1200 (80)	1224 (50)	1224 (50)
61.43 (5)		< 8		0.13	0.13

E_γ/keV	I_γ				
	1964Yt01	1967MA19	1982ALZL	1993Ab01	recommended
62.31 (6)				0.6 (2)	0.6 (2)
73.5 (1)				0.05 (3)	0.05 (3)
79.65 (2)	32.8 (3)	240 (24)	290 (20)	335 (20)	335 (20)
89.08 (10)			88 (3)	2.0 (1)	2.0 (1)
93.88 (5)			31 (1)	2.2 (3)	2.2 (3)
111.05 (3)			10.6 (4)	0.18 (4)	0.18 (4)
134.60 (2)	1.0 (1)	16.0 (16)	17.3 (10)	18.5 (5)	18.5 (5)
150.6 (4)[b]				0.10 (3)	0.10 (3)
155.5 (5)				0.1	0.1
173.35 (5)	0.6 (1)	4.0 (4)	3.35 (25)	4.26 (5)	4.26 (5)
184.65 (5)		9.0 (9)	7.7 (6)	8.27 (5)	8.27 (5)
200.7 (2)				0.10 (3)	0.10 (3)
204.85 (5)	2.1 (2)	34.0 (34)	30.9 (17)	33.7 (3)	33.7 (3)
205.6 (2)				0.22	0.22
210.60 (5)				0.36 (2)	0.36 (2)
218.80 (5)				0.32 (2)	0.32 (2)
222.9 (3)[b]				0.08 (2)	0.08 (2)
234.70 (5)	8.9 (8)	100	100.0 (35)	100	100
236.05 (5)				1.0 (2)	1.0 (2)
245.60 (5)		1.3 (4)	1.1 (4)	0.71 (3)	0.71 (3)
250.25 (5)[a]		1.3 (4)	1.0 (4)	0.11	0.11
250.25 (5)[a]				0.58	0.58
254.6 (2)				0.21 (2)	0.21 (2)
256.18 (5)		1.3 (4)	1.2 (4)	0.75 (3)	0.75 (3)
262.9 (2)				0.13 (3)	0.13 (3)
269.6 (3)[b]				0.03 (1)	0.03 (1)
272.8 (2)				0.15 (2)	0.15 (2)
280.7 (5)[a]				0.02	0.02
280.7 (5)[a]				0.02	0.02
286.0 (2)		0.52 (15)	0.2	0.17 (2)	0.17 (2)
289.67 (5)	1.4 (2)	7.2 (7)	7.6 (4)	7.7	7.7
293.2 (2)[b]				0.14 (3)	0.14 (3)
296.5 (2)				0.05 (1)	0.05 (1)
299.95 (5)		1.3 (4)	0.57 (13)	0.75 (4)	0.75 (4)
304.40 (5)		0.67 (20)		0.32 (2)	0.32 (2)
307.93 (5)[a]		0.90 (27)	0.7 (3)	0.45 (5)	0.45 (5)
307.93 (5)[a]				0.05 (5)	0.05 (5)
312.65 (5)		0.75 (22)	0.36 (18)	0.60 (5)	0.60 (5)
314.6 (2)				0.08 (2)	0.08 (2)
319.25 (5)	1.9 (3)	16.2 (16)	15.4 (8)	17.0 (5)	17.0 (5)
329.80 (5)		1.0 (3)		0.90 (5)	0.90 (5)
334.30 (6)		0.45 (13)		0.31 (2)	0.31 (2)
339.50 (5)		2.0 (4)		2.3 (2)	2.3 (2)
342.50 (7)		0.90 (27)		0.43 (4)	0.43 (4)

E_γ/keV	I_γ				
	1964Yt01	1967MA19	1982ALZL	1993Ab01	recommended
350.5 (2)	0.3 (1)			0.10 (5)	0.10 (5)
369.32 (5)		3.2 (3)	3.40 (33)	3.3 (2)	3.3 (2)
382.3 (2)[b]				0.03 (1)	0.03 (1)
434.4 (1)				0.08 (2)	0.08 (2)
439.6 (3)				0.011 (3)	0.011 (3)
444.5 (3)				0.04 (1)	0.04 (1)
452.9 (2)[a]				0.03	0.03
452.9 (2)[a]				0.03	0.03
457.5 (2)				0.03	0.03
469.3 (2)[a]				0.04	0.04
469.3 (2)[a]				0.04	0.04
475.4 (1)[a]				0.11	0.11
475.4 (1)[a]				0.1	0.1
480.9 (3)				0.05 (1)	0.05 (1)
493.4 (2)				0.09 (2)	0.09 (2)
506.9 (2)				0.08 (2)	0.08 (2)
516.7 (2)				0.12 (2)	0.12 (2)
524.8 (2)				0.16 (3)	0.16 (3)
533.1 (3)				0.07 (2)	0.07 (2)
537.2 (2)[a]				0.07	0.07
537.2 (2)[a]				0.12	0.12
539.8 (2)				0.22 (5)	0.22 (5)
545.4 (4)				0.011 (3)	0.011 (3)
552.3 (2)				0.10 (2)	0.10 (2)
556.3 (3)				0.04 (1)	0.04 (1)
569.03 (8)			1.9 (3)	1.8 (2)	1.8 (2)
576.1 (4)				0.04 (1)	0.04 (1)
581.3 (4)				0.05 (1)	0.05 (1)
592.3 (2)				0.12 (3)	0.12 (3)
596.9 (4)				0.03 (1)	0.03 (1)
600.7 (4)				0.020 (5)	0.020 (5)
607.6 (3)				0.08 (2)	0.08 (2)
613.6 (4)				0.04 (1)	0.04 (1)
632.7 (3)				0.08 (2)	0.08 (2)
663.7 (3)				0.04 (1)	0.04 (1)
671.9 (4)				0.020 (5)	0.020 (5)
682.3 (3)[b]				0.03 (1)	0.03 (1)
694.6 (3)[b]				0.03 (1)	0.03 (1)
708.3 (3)				0.05 (1)	0.05 (1)
722.65 (5)		1.5 (3)		1.4 (2)	1.4 (2)
724.15 (5)			1.9 (8)	0.52 (8)	0.52 (8)
737.4 (3)				0.033 (8)	0.033 (8)
742.4 (3)				0.04 (1)	0.04 (1)
746.30 (5)		0.70 (15)	0.7 (2)	0.74 (8)	0.74 (8)

E_γ/keV	I_γ				
	1964Yt01	1967MA19	1982ALZL	1993Ab01	recommended
753.65 (5)				0.35 (5)	0.35 (5)
757.20 (5)		0.40 (8)		0.28 (5)	0.28 (5)
762.6 (2)			0.7 (2)	0.09 (2)	0.09 (2)
766.64 (5)		0.80 (16)		0.83 (8)	0.83 (8)
775.83 (5)		12.3 (12)	15.1 (10)	16.8 (5)	16.8 (5)
780.8 (1)	1.9 (2)			0.11 (3)	0.11 (3)
784.93 (5)		0.70 (15)		0.32 (5)	0.32 (5)
787.6 (2)[a]				0.09 (2)	0.09 (2)
787.6 (2)[a]				0.01 (1)	0.01 (1)
792.2 (3)		0.40 (6)		0.020 (5)	0.020 (5)
796.22 (5)		0.30 (6)		0.40 (5)	0.40 (5)
803.77 (5)		1.70 (25)	2.4 (6)	2.2 (3)	2.2 (3)
806.0 (2)				0.05 (1)	0.05 (1)
812.40 (6)		0.60 (9)	0.66 (22)	0.78 (8))	0.78 (8)
816.5 (2)				0.05 (1)	0.05 (1)
823.20 (7)		0.30 (9)		0.26 (3)	0.26 (3)
825.95 (7)		1.4 (2)	2.3 (4)	2.0 (3)	2.0 (3)
833.9 (2)				0.05 (1)	0.05 (1)
837.5 (1)		0.20 (6)		0.36 (4)	0.36 (4)
842.2 (1)		0.20 (6)	0.5	0.18 (2)	0.18 (2)
846.85 (10)[a]		1.4 (2)	2.4 (11)	1.8 (3)	1.8 (3)
846.85 (10)[a]				0.2 (1)	0.2 (1)
863.6 (1)		0.10 (3)		0.14 (2)	0.14 (2)
867.4 (1)				0.06 (1)	0.06 (1)
876.5 (1)		1.3 (2)	1.4 (4)	1.4 (2)	1.4 (2)
878.1 (2)				0.12 (2)	0.12 (2
893.1 (2)		0.10 (3)		0.09 (2)	0.09 (2)
896.7 (2)		0.50 (8)	0.7 (3)	0.50 (5)	0.50 (5)
907.6 (2)		0.40 (7)	0.3	0.53 (5)	0.53 (5)
911.3 (2)				0.03 (l)	0.03 (l)
913.6 (3)				0.015 (5)	0.015 (5)
926.5 (3)				0.06 (1)	0.06 (1)
941.2 (3)				0.11 (2)	0.11 (2)
949.3 (4)				0.012 (3)	0.012 (3)
958.0 (7)				0.013 (3)	0.013 (3)
969.2 (4)				0.012 (3)	0.012 (3)
975.2 (5)				0.006 (2)	0.006 (2)
978.7 (4)				0.025 (5)	0.025 (5)
989.4 (5)				0.005 (1)	0.005 (1)
994.3 (3)				0.004 (1)	0.004 (1)
999.3 (5)				0.007 (2)	0.007 (2)
1025.1 (5)				0.005 (1)	0.005 (1)

[a]: multiply placed. [b]: not placed in level scheme.

5.3 Absolute values of γ-ray emission intensities

The reference gamma-ray line, in the table above, is 234.70 keV. But the measured absolute gamma-ray intensity was given for the 204.8 keV gamma-ray. So the normalization factor N is deduced from the 204.8 keV gamma-ray.

The calculation is:

The measured absolute gamma-ray intensity for the 204.8 keV line (1981Va28) is: P(204.8 keV) = 0.92 (18) %, the recommended relative gamma-ray intensity is I(204.8keV) = 33.7 (3).

So N = P(204.8 keV) / I(204.8 keV) = 0.92 (18) / 33.7 (3) = 0.027 (5).

This value is very close to that calculated with the formula $N = 100 / \sum[I(ce+\gamma)(g.s.)$ assuming $I_{\beta\text{-}}(g.s.) \leq 1$ %.

So, N has been taken from 1981Va28, that's N = 0.027 (5).

The recommended absolute γ-ray emission probabilities are equal to the relative values given in table 7 multiplied by 0.027 (5).

6. Branching Ratio

The measured and recommended total branching ratios from 223Fr decay are listed in table 8. The recommended value of %α = 0.020 (4) % is from 2001Li44. Thus, $\%\beta^-$ = 99.980 (4) %.

Table 8 Measured and recommended α-branching ratio from ^{223}Fr decay.

I_α /%	References
0.006	1955Ad10
0.020 (4)	2001Li44
0.020 (4)	Recommended value, from 2001Li44

7. References

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^{223}Ra -Comments on evaluation of decay data
by V.P. Chechev

Evaluated in December 2010 with a literature cut-off by the same date.

1. DECAY SCHEME

^{223}Ra decays 100 % to levels of ^{219}Rn by emission of α particles, with a very small branch of 6.4 (1) × 10^{-8} % by emission of ^{14}C (1991Ma16). The adopted ^{219}Rn levels populated in the ^{223}Ra α decay are based on the measurement by Sheline *et al.* (1998Sh02) and the *NDS* evaluation by Browne (2001Br31). An intense population takes place only to levels in ^{219}Rn with energy less than 500 keV (11 excited levels and ground state) and, in this part, the decay scheme is well defined, though, at some levels, there is a certain discrepancy in the P(α) values measured and deduced from probability balance.

At the same time, for a number of levels with higher energy there is disagreement between measured probabilities of alpha-transitions and the values deduced from P(γ+ce) balance. Besides, the placement of some γ-rays in the level scheme is uncertain and some observed γ-ray transitions have not been placed. Therefore, in this part the decay scheme cannot be considered as fully completed. Further measurements are needed to determine the γ-ray transitions and ^{223}Ra α decay scheme with greater precision.

The decay scheme overall consistency is verified by the comparison between Q(calc) = 6027 (133) keV, deduced from the evaluated average energies of all emissions, and Q(α) = 5978.99 (21) keV from the atomic mass evaluation of Audi *et al.* (2003Au03). Percentage deviation between Q(calc) and Q(α) is (0.8 ± 2.2) %. The deviation is not big but more than for other α decaying applied radionuclides. This indicates the need in new precise measurements of α-particle and γ-ray transitions in decay of ^{223}Ra.

2. NUCLEAR DATA

Q(α) value is from Audi *et al.* (2003Au03).

The ^{223}Ra half-life is based on the experimental results given in Table 1.

Table 1: Experimental values of ^{223}Ra half-life (in days)

Reference	Author(s)	Original value	Re-estimated	Method
1954Ha60	Hagee *et al.*	11.685 (56)		Proportional α counting
1959Ro51	Robert	11.22 (5)		Microcalorimetry
1965Ki05	Kirby *et al.*	11.4347 (11) [a]	11.4347 (44) [a]	Microcalorimetry
1965Ki05	Kirby *et al.*	11.4267 (62) [b]	11.427 (17) [b]	Proportional α counting
1967JoZX	Jordan and Blanke	11.372 (45)		Calorimetry
1987Mi10	Miller *et al.*	11.444 (46)		From α-activity following ^{227}Th decay

[a] The original value was deduced as a weighted average of the data from observations with two calorimeters: 11.4432 (57) and 11.4344 (11) days. The uncertainties are probable errors of a single observation. To take into account the contribution of possible unrecognized systematic errors associated with the method, the evaluator expanded the uncertainty to a half of the difference of the two experimental results (0.0044 day).

[b] The original value was deduced as a weighted average of the data from observations with a 2π windowless proportional counter for 10 samples. The uncertainties of the 10 measurement results include only statistical errors. To take into account the contribution of possible unrecognized systematic errors associated with the method, for the re-estimated value the evaluator used the smallest uncertainty of 0.017 d stated in the measurements.

From the six values adopted in the data analysis, the LWEIGHT computer program increased the uncertainty in the value of 11.4347 (1965Ki05) to 0.0139 to adjust weights according to the LRSW method and used a weighted average of 11.429 and an external uncertainty of 0.028 ($\chi^2/\nu = 8.05$).

The recommended value for the ^{223}Ra half-life is 11.43 (3) days.

2.1. Alpha Transitions

The energies of the alpha transitions have been obtained from the Q(α) value and ^{219}Rn level energies given in Table 2 from 2001Br31, where they were deduced from a least-squares fit to gamma-ray energies.

Table 2: ^{219}Rn levels populated in ^{223}Ra α-decay

Level	Energy (keV)	Spin and parity	Half-life	Probability of α- transition (%)
0	0.0	$5/2^+$	3.96 (1) s	1.0 (2)
1	4.47 (1)	$(9/2)^+$	15.4 (13) ns	-
2	14.37 (1)	$(7/2)^+$	875 (30) ps	0.32 (4)
3	126.77 (2)	$(11/2)^+$	402 (20) ps	10.0 (3)
4	158.64 (1)	$(7/2)^+$	42.3 (50) ps	49.6 (12)
5	269.48 (1)	$3/2^+$	14.2 (23) ps	25.8 (11)
6	338.27 (1)	$(5/2)^+$	6.1 (28) ps	10.6 (10)
7	342.78 (2)	$(5/2, 7/2)^-$		-
8	376.26 (2)	$(9/2)^+$	6.9 (38) ps	0.74 (25)
9	377.33 (6)	$(7/2, 9/2)^-$		-
10	397.1 (4)			≈ 0.008
11	445.03 (1)	$(5/2)^+$	6.2 (31) ps	1.60 (24)
12	446.82 (3)	$(5/2)^-$		0.50 (8)
13	490.92 (2)	$(5/2, 7/2, 9/2)^-$		-
14	514.5 (1)	$(9/2^+)$		≈ 0.13
15	517.7 ?			-
16	541.99 (2)	$(7/2^+)$		≈ 0.13
17	594.1 (1)	$(7/2)^-$		0.16 (4)

18	598.72 (2)	(5/2, 7/2, 9/2)$^+$		0.093
19	623.68 (4)			0.042
20	646.1 (1)			0.041
21	672.6 (5)			0.0053
22	711.3 (1)			0.026
23	732.8 (1)			0.021
24	748			≈ 0.0017
25	773			≈ 6×10^{-4}
26	800			≈ 3×10^{-4}
27	830			≈ 2×10^{-4}
28	851			≈ 4×10^{-4}
29	861			≈ 6.3×10^{-4}
30	873			≈ 4.4×10^{-4}

The recommended values of α-transition probabilities (P(α)) are based on the measurements of 1957Pi31, 1962Gi04, 1962Wa18, 1970Da08 and also on the P(α) values deduced by the evaluator from P(γ+ce) balance at the corresponding ^{219}Rn levels (Table 3).

As the lower part of the decay scheme (^{219}Rn levels with energy less than 500 keV) is reasonably complete and well defined, the probabilities of the prominent α-transitions reaching them have been deduced from P(γ+ce) balances. The uncertainties of the recommended values were expanded, where necessary, to cover the unweighted mean (UWM) of experimental P(α) values.

The probabilities of weak α-transitions (P(α) < 0.0015) have been taken mainly from the measurements of 1962Wa18 with magnetic spectrometer and also from the measurements of 1970Da08 with semiconductor detector. The P(α) values reported in 1962Wa18 have been renormalized to a sum of 100 % by 1970Da08. The uncertainties reported in 1970Da08 are only statistical (from averaging data of three measurements) and comparable with the supposed uncertainties of 1962Wa18, 1962Gi04 and 1957Pi31.

Table 3: Experimental and recommended probabilities (per 100 decays) of alpha-transitions observed in ^{223}Ra α decay

	α-particle energy	1957Pi31	1962Gi04	1962Wa18 [a]	1970Da08	UWM	Deduced from P(γ+ce) balance	**Recommended**
$\alpha_{0,0}$	5871	0.96	1.5	0.85	0.85 (4)	1.04 (16)		**1.0 (2)** [c]
$\alpha_{0,2}$	5858	0.3		0.31	0.32 (4)			**0.32 (4)** [d]
$\alpha_{0,3}$	5747	10.5	10.2	8.85 (18) [b]	9.50 (58)	9.8 (4)	10.0 (3)	**10.0 (3)** [e]
$\alpha_{0,4}$	5716	50.4	48.0	52.2 (11) [b]	52.5 (8)	50.8 (10)	49.6 (9)	**49.6 (12)** [e]
$\alpha_{0,5}$	5607	23.6	25.7	25.3 (5) [b]	24.2 (4)	24.7 (5)	25.8 (6)	**25.8 (11)** [e]
$\alpha_{0,6}$	5540	10.3	10.2	8.85 (18) [b]	9.16 (30)	9.6 (4)	10.60 (17)	**10.6 (10)** [e]
$\alpha_{0,8}$	5502	0.86	1.3	0.78	1.00 (15)	0.99 (11)	0.74 (3)	**0.74 (25)** [e]
$\alpha_{0,10}$	5481			≈ 0.008			0.0007 (4)	**≈ 0.008**
$\alpha_{0,11}+\alpha_{0,12}$	5434	2.4	2.5	2.24	2.27 (20)	2.35 (6)	2.10 (9)	**2.10 (25)** [e]

	α-particle energy	1957Pi31	1962Gi04	1962Wa18 [a]	1970Da08	UWM	Deduced from P(γ+ce) balance	**Recommended**
$\alpha_{0,14}$	5366	0.20	} Σ 0.25	0.108	≈ 0.13	0.15 (3)	0.014 (7)	**≈ 0.13** [d]
$\alpha_{0,16}$	5339	0.07		0.098	≈ 0.13	0.099 (17)	0.089 (6)	**≈ 0.13** [d]
$\alpha_{0,17}$	5287	} Σ 0.3	} Σ 0.3	0.126	≈ 0.16		0.16 (4)	**0.16 (4)** [e]
$\alpha_{0,18}$	5283			0.093				**0.093**
$\alpha_{0,19}$	5259			0.042			0.079 (8)	**0.042**
$\alpha_{0,20}$	5236			0.041			0.022 (4)	**0.041**
$\alpha_{0,21}$	5212			0.0053			0.0011 (6)	**0.0053**
$\alpha_{0,22}$	5173			0.026			0.013 (4)	**0.026**
$\alpha_{0,23}$	5152			0.021			0.0134 (27)	**0.021**
$\alpha_{0,24}$	5135			≈ 0.0017				**≈ 0.0017**
$\alpha_{0,25}$	5112			≈ 0.0006				**≈ 0.0006**
$\alpha_{0,26}$	5086			≈ 0.0003				**≈ 0.0003**
$\alpha_{0,27}$	5056			≈ 0.0002				**≈ 0.0002**
$\alpha_{0,28}$	5036			≈ 0.0004				**≈ 0.0004**
$\alpha_{0,29}$	5026			≈ 0.00063				**≈ 0.00063**
$\alpha_{0,30}$	5014			≈ 0.00044				**≈ 0.00044**

[a] Authors did not report individual uncertainties for intensity of each α-particle group but stated the relative uncertainty of 2 % for intense α-lines and 10 % for weak α-lines.

[b] Uncertainty given by Rytz (1991Ry01).

[c] Value recommended by Rytz (1991Ry01)

[d] Adopted from 1970Da08.

[e] Deduced from P(γ+ce) balance. Uncertainties were expanded to cover UWM of experimental P_α values.

The α decay hindrance factors have been calculated using the ALPHAD computer program from the ENSDF evaluation package with $r_0(^{219}\text{Rn}) = 1.543$ fm (2001Br31).

2.2. Gamma Transitions and Internal Conversion Coefficients

The recommended energies of the gamma-ray transitions are the same as those of the gamma-ray energies corrected by the minor nuclear recoil of ^{219}Rn.

The gamma-ray transition probabilities (P(γ+ce)) have been deduced from their evaluated gamma-ray emission probabilities (P(γ)) and total internal conversion coefficients (ICCs).

ICCs have been interpolated using the BrIcc computer program, version v2.2a, with the “frozen orbital” approximation (2008Ki07). Multipolarities of the gamma-ray transitions and E2/M1 mixing ratios (δ) are those deduced by 2001Br31, on the basis of measurements of conversion electrons (ce) by 1970Da08, 1970Kr01, 1972HeYM, 1974Ri05, and 1998Sh02.

P(γ+ce) values for the gamma-ray transitions $\gamma_{1,0}$ (4.4 keV), $\gamma_{9,7}$ (34.5 keV) and $\gamma_{22,18}$ (112.6 keV) have been deduced from probability balances at the ^{219}Rn ground state (level ‘0’), level ‘7’ (342.8 keV) and level ‘18’ (598.7 keV), respectively.

3. ATOMIC DATA

The fluorescence yields, X-ray energies and relative probabilities, and Auger energies and relative probabilities are from the SAISINUC software.

4. ALPHA EMISSIONS

The recommended energies of alpha particles have been deduced from the Q(α) value, taking into account the recoil energies for ^{219}Rn.

The recommended α-particle energies are compared in Table 4 with the experimental results from spectrometric measurements by 1957Pi31, 1961Ry02, 1962Wa18, 1964Wa19, 1970Da08, and 1971Gr17.

Table 4: Experimental and recommended α-particle energies (keV) in the decay of ^{223}Ra [a]

	1957Pi31	1961Ry02	1962Wa18 [b]	1964Wa19	1970Da08	1971Gr17	**Recommended**
$\alpha_{0,0}$	5870 (2)		5871.6 (10)	5869.5 (17)	5871 (3)		**5871.63 (21)**
$\alpha_{0,2}$	5856		5857.5 (10)		5857 (3)		**5857.52 (21)**
$\alpha_{0,3}$	5745 (2)	5745.5	5747.4		5747 (3)	5747.0 (4)	**5747.14 (21)**
$\alpha_{0,4}$	5715	5714.3	5716.1		5715 (3)	5716.23 (29)	**5715.84 (21)**
$\alpha_{0,5}$	5605	5605.3	5607.1		5606 (3)	5606.73 (30)	**5606.99 (21)**
$\alpha_{0,6}$	5537	5537.1	5539.6		5537 (3)	5539.8 (9)	**5539.43 (21)**
$\alpha_{0,8}$	5500		5501.6 (10)		5501 (3)		**5502.12 (21)**
$\alpha_{0,11}$	5432		5433.6 (5)		5435 (3)		**5434.59 (21)**
$\alpha_{0,14}$	5363		5365.6 (10)		5367 (3)		**5366.37 (23)**
$\alpha_{0,16}$	5337		5338.7 (10)		5339 (3)		**5339.37 (21)**
$\alpha_{0,17}$	5287		5287.3 (10)		5288 (3)		**5288.19 (23)**

[a] Authors' experimental values have been adjusted for changes in calibration energies following 1977Ma31 and 1991Ry01.

[b] Uncertainties of 1962Wa18 are the values estimated by 1977Ma31.

5. ELECTRON EMISSIONS

The energies of the conversion electrons have been obtained from the gamma-ray transition energies and the atomic electron binding energies from 1977La19. The emission probabilities of the conversion electrons have been deduced using the evaluated P(γ) and ICC values. Measurements of the ^{219}Rn conversion electrons were carried out by 1969Be67, 1970Da08, 1970Kr01, 1972HeYM, 1974Ri05, and 1998Sh02.

The total absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program (1996Sc06, 2000Sc47).

6. PHOTON EMISSIONS

6.1 X - Ray emissions

The absolute emission probabilities of Rn KX- and LX-rays were calculated using the EMISSION computer program (Table 5). In 1976Bl13 the emission probabilities of Rn KX-rays were measured relatively to Pγ ($\gamma_{5,0}$ 269.5 keV). The experimental absolute P(KX) values are given in Table 5 using the evaluated Pγ ($\gamma_{5,0}$ 269.5 keV) = 14.23 (15) %.

Table 5: Experimental (1976Bl13) and calculated absolute Rn KX-ray emission probabilities (%)

	1976Bl13	Calculated
$K\alpha_2$ (Rn)	11.5 (13)	14.86 (23)
$K\alpha_1$ (Rn)	19.4 (24)	24.5 (4)
$K\beta'_1$ (Rn)	9.4 (7)	8.50 (18)
$K\beta'_2$ (Rn)	1.71 (14)	2.72 (7)

6.2. Gamma emissions

6.2.1. Gamma-ray energies

The gamma-ray energies (E_γ) for $\gamma_{1,0}$ (4.5 keV), $\gamma_{2,1}$ (9.9 keV), $\gamma_{2,0}$ (14.4 keV), $\gamma_{4,3}$ (31.9 keV), $\gamma_{12,7}$ (104.0 keV), $\gamma_{4,2}$ (144.3 keV), $\gamma_{8,3}$ (249.5 keV), $\gamma_{7,0}$ (342.8 keV), $\gamma_{8,2}$ (361.9 keV), $\gamma_{9,1}$ (372.9 keV), $\gamma_{8,0}$ (376.3 keV), $\gamma_{16,4}$ (383.4 keV), $\gamma_{12,2}$ (432.4 keV), $\gamma_{16,0}$ (542.0 keV), and $\gamma_{19,0}$ (623.7 keV) have been deduced directly from the adopted ^{219}Rn level energies.

The remaining gamma-ray energies have been taken mainly from 2001Br31. They are weighted averages of the experimental values from 1998Sh02, 1976Bl13, 1972HeYM, 1970Da08, 1970Kr01, and 1968Br17, except as specified otherwise in footnotes of Table 6. The most precise measurements of E_γ from 1976Bl13 with Ge(Li) detector dominate the weighted averages.

Less accurate measurements of E_γ were reported in 1957Pi31, 1957Pa07, 1966Po02, 1969Be67, they were not used in the evaluation.

It should be noted that in 2001Br31 many questionable unplaced gamma-ray transitions are given from some spectrometric measurement results published in the above references, but they have not been yet confirmed by other authors. Observation of such gamma-ray transitions may be assigned to daughters of ^{223}Ra or other isotope impurities and most of these gamma-rays have not been included in the current evaluation. The criterion for their inclusion was an observation in α-γ high resolution coincidence with planar and high efficiency coaxial Ge detectors in the latest experiment by 1998Sh02.

6.2.2. Gamma-ray emission probabilities

The experimental and evaluated relative emission probabilities (I_γ) of gamma-rays in decay of ^{223}Ra are presented in Table 6. The adopted values are the weighted means of the experimental values except when noted. The statistical processing was done using the LWEIGHT computer program. The uncertainties assigned in this evaluation to the recommended values are always greater than or equal to the smallest uncertainty in any of the experimental values used in the calculation.

The normalization factor (N) was obtained from the probability balance to the ^{219}Rn ground state (level ‘0’) and excited levels ‘1’ (4.5 keV) and ‘2’ (14.4 keV):

$\Sigma(1+\alpha T)I_\gamma\ (\gamma_{i,0}\ ,\ \gamma_{j,1}\ ,\ \gamma_{k,2}) + P(\alpha_{0,0}) + P(\alpha_{0,2}) = 1$

where i = 4, 5, 6, 7, 8, 11, 16, 17, 18, 19, 20, 22, 23;

j = 3, 4, 6, 8, 9, 14, 16, 19, 20, 23;

k=4, 5, 6, 7, 8, 9, 11, 12, 14, 16, 17, 18, 19, 20, 22, 23.

N = P(γ) (269.5 keV) = 0.1423 (15).

This adopted value can be compared with the measured Pγ (269.5 keV) of 0.140 (15) (1968Br17) and the value of 0.136 (10) (1970Da08) deduced from an α-feed of the 269 keV level in ^{219}Rn.

The absolute gamma-ray emission probabilities (P(γ)) have been deduced from the evaluated relative gamma-ray emission probabilities (Table 6) using the derived normalization factor of 0.1423 (15).

P(γ) values for the gamma-ray transitions $\gamma_{2,1}$ (9.9 keV) and $\gamma_{2,0}$ (14.4 keV) have been obtained directly from probability balance at the ^{219}Rn level ‘2’ (14.4 keV) and the ratio of $P(\gamma_{2,1}$ - 9.9 keV)/$P(\gamma_{2,0}$ - 14.4 keV) = 0.86 (9) deduced from measured ratio of intensities of conversion electrons (1974Ri05) and the ratio of theoretical ICCs.

Pγ value for the gamma-ray transition $\gamma_{1,0}$ (4.5 keV) has been estimated from Pγ+ce using the total theoretical ICC α_T.

Table 6: Recommended energies (E_γ) and experimental and evaluated relative emission probabilities (I_γ) of gamma-rays in decay of ^{223}Ra

	Recommended E_γ (keV)	1968Br17	1970Kr01	1970Da08	1972HeYM	1976Bl13	1998Sh02	Evaluated I_γ
$\gamma_{1,0}$	**4.47 (1)** [a]							
$\gamma_{2,1}$	**9.90 (2)** [a]							
$\gamma_{2,0}$	**14.37 (1)** [a]							
$\gamma_{4,3}$	**31.87 (2)** [a]		0.000 74 (15)				0.001	**0.000 74 (15)**
$\gamma_{9,7}$	**34.5 (2)** [b]							
$\gamma_{12,9}$	**69.5 (1)** [b]						0.05 (2)	**0.05 (2)**
$\gamma_{15,12}$	**70.9 (2)** [b]						0.025 (8)	**0.025 (8)**
$\gamma_{11,7}$	**102.2 (2)** [b]						0.006 (3)	**0.006 (3)**
$\gamma_{17,13}$	**103.2 (2)** [b]	0.100 (14) [e]			0.12 (7) [e]		0.04 (2)	**0.04 (2)**
$\gamma_{12,7}$	**104.04 (4)** [a]					0.134 (15)	0.14 (2)	**0.136 (15)**
$\gamma_{11,6}$	**106.78 (3)**	0.164 (29)	0.14 (3)	0.16 (4)	0.19 (6)	0.157 (15)	0.17 (1)	**0.164 (10)**
$\gamma_{12,6}$	**108.5 (2)** [b]						0.04 (2)	**0.04 (2)**
$\gamma_{5,4}$	**110.856 (10)**	0.40 (6)	0.331 (29) [f]	0.41 (4)	0.21 (9) [f]	0.40 (4)	0.42 (3)	**0.41 (3)**
$\gamma_{22,18}$	**112.6** [c]							
$\gamma_{13,8}$	**114.7 (2)**				0.07 (4)		0.07 (3)	**0.07 (3)**
$\gamma_{3,1}$	**122.319 (10)**	8.2 (11)	8.75 (15)	9.8 (10)	8.7 (4)	7.5 (8)	8.7 (1)	**8.70 (10)**
$\gamma_{20,14}$	**131.6 (2)**				0.037 (22)		0.04 (2)	**0.04 (2)**
$\gamma_{14,8}$	**138.3 (3)** [b]						0.012 (5)	**0.012 (5)**
$\gamma_{4,2}$	**144.27 (2)** [a]	22.1 (21)	23.8 (5)	23.0 (24)	27.4 (18) [f]	21.6 (22)	23.5 (5)	**23.6 (5)**
$\gamma_{17,12}$	**147.2 (2)** [b]						0.04 (2)	**0.04 (2)**
$\gamma_{4,1}$	**154.208 (10)**	38.6 (29)	41.1 (8)	38 (4)	44.4 (26)	38 (4)	41 (1)	**41.0 (8)**
$\gamma_{4,0}$	**158.635 (10)**	5.0 (5)	5.02 (10)	5.6 (6)	5.3 (4)	4.6 (4)	5.0 (1)	**5.01 (10)**
$\gamma_{16,8}$	**165.8 (2)**				0.037 (22)		0.04 (2)	**0.038 (20)**

	Recommended E_γ (keV)	**1968Br17**	**1970Kr01**	**1970Da08**	**1972HeYM**	**1976Bl13**	**1998Sh02**	**Evaluated I_γ**
$\gamma_{11,5}$	**175.65 (15)**		0.10 (3)		0.15 (4)		0.14 (3)	**0.12 (3)**
$\gamma_{12,5}$	**177.3 (1)**	0.21 (7)	0.34 (3)		0.35 (6)		0.34 (3)	**0.33 (3)**
$\gamma_{6,4}$	**179.54 (6)**	1.07 (29)	1.07 (29)	1.10 (13)	1.16 (15)	1.01 (10)	1.1 (1)	**1.08 (10)**
$\gamma_{20,12}$	**199.3 (3)**				0.022 (15)		0.02 (1)	**0.021 (10)**
$\gamma_{18,9}$	**221.32 (24)**	0.25 (7)	0.22 (4)		0.25 (4)		0.26 (4)	**0.25 (4)**
$\gamma_{19,8}$	**247.2 (5)**				0.066 (22)		0.07 (2)	**0.068 (20)**
$\gamma_{8,3}$	**249.49 (3)** [a]	0.26 (7)			0.29 (13)		0.28 (7)	**0.27 (7)**
$\gamma_{17,7}$	**251.6 (3)**	0.49 (11)	0.27 (7)	0.42 (15)	0.49 (15)	0.47 (7)	0.3 (1)	**0.39 (7)**
$\gamma_{5,2}$	**255.2 (2)**	0.43 (11)		0.37 (15)	0.24 (7)	0.33 (7)	0.38 (5)	**0.34 (5)**
$\gamma_{17,6}$	**255.7 (3)**				0.037 (22)		0.04 (2)	**0.039 (20)**
$\gamma_{18,6}$	**260.4 (3)**				0.044 (22)		0.05 (2)	**0.047 (20)**
$\gamma_{5,0}$	**269.463 (10)**	100 (11)	100 (2)	100 (7)	100 (4)	100 (4)	100 (2)	**100 (2)**
$\gamma_{10,3}$	**270.3 (4)** [b]						0.005 (3)	**0.005 (3)**
$\gamma_{23,12}$	**286.0 (4)** [b]						0.008 (4)	**0.008 (4)**
$\gamma_{12,4}$	**288.18 (3)**	1.14 (14)	1.16 (5)	1.08 (12)	0.93 (13) [f]	1.07 (5)	1.15 (3)	**1.13 (3)**
$\gamma_{6,2}$	**323.871 (10)**	26.5 (29)	29.4 (6)	26.5 (26)	26.8 (11)	26.8 (13)	28.7 (5)	**28.5 (5)**
$\gamma_{7,2}$	**328.38 (3)** [a]	1.43 (14)	1.52 (7)	1.19 (24)	1.18 (18)	1.40 (8)	1.5 (5)	**1.43 (7)**
$\gamma_{6,1}$	**334.01 (6)**	0.61 (9)	0.76 (6)	0.91 (18)	0.69 (11)	0.54 (7)	0.73 (4)	**0.70 (4)**
$\gamma_{6,0}$	**338.282 (10)**	19.3 (18)	21 (5)	19.0 (20)	19.2 (7)	18.5 (9)	20.4 (4)	**20.0 (4)**
$\gamma_{7,0}$	**342.78 (2)** [a]	1.43 (14)	1.70 (9)	1.5 (4)	0.71 (16) [f]	1.49 (12)	1.6 (1)	**1.59 (9)**
$\gamma_{23,9}$	**355.5 (2)** [b]						0.03 (1)	**0.03 (1)**
$\gamma_{14,4}$	**355.7 (2)** [b]						0.02 (1)	**0.02 (1)**
$\gamma_{8,2}$	**361.89 (2)** [a]	0.29 (7)	0.34 (4)	0.37 (7)	0.24 (6)	0.298 (22)	0.20 (5)	**0.20 (5)** [g]
$\gamma_{9,2}$	**362.9 (2)** [b]						0.11 (5)	**0.11 (5)**
$\gamma_{22,7}$	**368.56 (12)**				0.06 (3)		0.06 (3)	**0.06 (3)**
$\gamma_{8,1}$	**371.676 (15)**	3.9 (4)	3.56 (7)	4.0 (6)	4.2 (4)	3.14 (16)	3.5 (1)	**3.51 (7)**

	Recommended E_γ (keV)	**1968Br17**	**1970Kr01**	**1970Da08**	**1972HeYM**	**1976Bl13**	**1998Sh02**	**Evaluated I_γ**
$\gamma_{9,1}$	**372.86 (1)** [a,b]	≈ 0.7				0.73 (8)	0.36	**0.36** [i]
$\gamma_{8,0}$	**376.26 (2)** [a]			0.088 (29)			0.09 (3)	**0.09 (3)**
$\gamma_{16,4}$	**383.35 (2)** [a]	≈ 0.04		0.11 (4)	0.029 (22)		-	**0.05 (3)**
$\gamma_{14,3}$	**387.7 (2)**				0.10 (4)		0.11 (4)	**0.11 (4)**
$\gamma_{23,7}$	**390.1 (2)**	≈ 0.05			0.022 (15)		0.05 (2)	**0.032 (15)**
$\gamma_{11,2}$	**430.6 (3)**				0.14 (4)		0.14 (4)	**0.14 (4)**
$\gamma_{12,2}$	**432.45 (3)** [a]	0.24 (3)	0.26 (4)	≈0.22	0.24 (6)	0.186 (30) [f]	0.25 (2)	**0.25 (2)**
$\gamma_{11,0}$	**445.033 (12)**	8.7 (4)	11.0 (8) [f]	9.3 (10)	9.2 (7)	8.5 (4)	9.3 (3)	**9.0 (3)**
$\gamma_{20,4}$	**487.5 (2)**	0.071 (14)	0.10 (4)	≈0.11	0.08 (4)		0.08 (1)	**0.08 (1)**
$\gamma_{-1,1}$	**490.8 (3)** [b]						0.012 (5)	**0.012 (5)**
$\gamma_{14,2}$	**500.0 (4)** [b]						0.010 (4)	**0.010 (4)**
$\gamma_{14,1}$	**510.0 (4)** [b]						0.003 (2)	**0.003 (2)**
$\gamma_{-1,2}$	**523.2 (4)** [b]						0.010 (4)	**0.010 (4)**
$\gamma_{16,2}$	**527.611 (13)**	0.50 (5)	0.54 (5)	0.51 (10)	0.47 (11)	0.410 (22) [f]	0.51 (3)	**0.51 (3)**
$\gamma_{-1,3}$	**532.9 (4)** [b]						0.010 (4)	**0.010 (4)**
$\gamma_{16,1}$	**537.6 (1)** [b]						0.015 (5)	**0.015 (5)**
$\gamma_{16,0}$	**541.99 (2)** [a,b]						0.010 (4)	**0.010 (4)**
$\gamma_{21,3}$	**545.8 (5)** [b]						0.008 (4)	**0.008 (4)**
$\gamma_{23,4}$	**574.1 (7)** [b]						0.008 (4)	**0.008 (4)**
$\gamma_{17,2}$	**579.6 (3)** [b]						0.010 (4)	**0.010 (4)**
$\gamma_{18,2}$	**584.3 (3)** [b]						0.010 (4)	**0.010 (4)**
$\gamma_{17,0}$	**594.0 (3)** [b]						0.010 (4)	**0.010 (4)**
$\gamma_{18,0}$	**598.721 (24)**	0.57 (6)	0.76 (7)	0.68 (11)	0.66 (13)	0.626 (30)	0.68 (3)	**0.65 (3)**
$\gamma_{19,2}$	**609.31 (4)**	0.36 (4)	0.54 (7)	0.46 (7)	0.30 (11)	0.373 (22)	0.41 (2)	**0.40 (2)**
$\gamma_{19,1}$	**619.1 (4)** [b]						0.025 (8)	**0.025 (8)**
$\gamma_{19,0}$	**623.68 (4)** [a]	0.057 (29)					0.06 (3)	**0.06 (3)**

	Recommended E_γ (keV)	**1968Br17**	**1970Kr01**	**1970Da08**	**1972HeYM**	**1976Bl13**	**1998Sh02**	**Evaluated I_γ**
$\gamma_{20,2}$	**631.7 (7)**			0.22 (7)			0.003 (2)	**0.003 (2)**
$\gamma_{20,1}$	**641.7 (4)** [b]						0.012 (5)	**0.012 (5)**
$\gamma_{20,0}$	**646.1 (5)** [b]						0.003 (3)	**0.003 (3)**
$\gamma_{22,2}$	**696.9 (7)** [b]						0.005 (2)	**0.005 (2)**
$\gamma_{22,0}$	**711.3 (2)** [b]	0.025 (7)					0.026 (7)	**0.026 (7)**
$\gamma_{23,2}$	**718.4 (4)** [b]						0.010 (4)	**0.010 (4)**
$\gamma_{23,1}$	**728.4 (8)** [b]						0.002 (1)	**0.002 (1)**
$\gamma_{23,0}$	**732.8 (6)** [b]						0.004 (2)	**0.004 (2)**
$\gamma_{-1,4}$	**737.2 (8)** [b]						0.002 (1)	**0.002 (1)**

[a] From the adopted ^{219}Rn level energies.

[b] From 1998Sh02; new gamma-ray transition observed.

[c] Reported only by 1998Sh02 without uncertainty in energy and without intensity value.

[d] Not reported by 1998Sh02 but observed in 1968Br37, 1970Da08, 1972HeYM, 1976Bl13.

[e] Reported γ-ray with energy of 103.7 keV that may be a sum of 103.2 keV and 104.0 keV γ-rays.

[f] Omitted on Chauvenet's criterion.

[g] Adopted from 1998Sh02 because of possible contribution of impurity Pb γ-rays in measurements of single γ-spectra.

[h] Adopted from 1998Sh02 because of contribution of unplaced 373.3 keVγ-ray observed in measurements of single γ-spectra and not observed in α-γ coincidences.

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^{224}Ra – Comments on evaluation of decay data
by A. L. Nichols

Evaluated: July/August 2001
Re-evaluated: January 2004

Evaluation Procedures

Limitation of Relative Statistical Weight Method (LWM) was applied to average numbers throughout the evaluation. The uncertainty assigned to the average value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

A relatively simple decay scheme was constructed from the alpha-particle studies of 1962Wa28, 1969Pe17, 1971So15 and 1984Bo15, and the gamma-ray measurements of 1969Pe17, 1972DaZA, 1977Ku15, 1982Sa36, 1983Sc13, 1983Va22, 1984Bo15, 1984Ge07 and 1992Li05. Only the gamma-ray studies of 1977Ku15 provide any detail beyond the 240.986 keV gamma ray; all other measurements are dedicated to the determination of the absolute emission probability of the 240.986 keV gamma ray. A weighted mean emission probability was determined for this transition, and the other emission probabilities as measured by 1977Ku15 were subsequently adjusted.

Cluster decay has been observed by 1985Pr01 and 1991Ho15, and reviewed by 1995Ar33 and 1997Tr17. ^{14}C emissions were detected with a branching fraction of 5(1)E-11. However, this decay mode has not been included in the decay-data summary section.

Nuclear Data

^{228}Th decay chain is important in quantifying the environmental impact of the decay of naturally-occurring ^{232}Th. Specific radionuclides in this decay chain are noteworthy because of their decay characteristics (^{224}Ra alpha decay to ^{220}Rn; ^{212}Bi and ^{208}Tl gamma-ray emissions).

Half-life

The recommended half-life represents the unweighted mean of two somewhat elderly studies (1962Ll02 and 1971Jo14) and a much more recent measurement (2004ScZZ). Further measurements are required to determine this half-life with greater confidence.

Reference	Half-life (d)
1962Ll02	3.62(1)
1971Jo14	3.665(38)
2004ScZZ	3.6319(23)
Recommended Value	3.627(7)

Gamma Rays

Energies

All gamma-ray transition energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 1997Ar04 were adopted, and used to determine the energies and associated uncertainties of the gamma-ray transitions between the various populated-depopulated levels.

Emission Probabilities

Absolute emission probabilities were determined from measurements of the 240.986 keV gamma ray by 1969Pe17, 1972DaZA, 1982Sa36, 1983Sc13, 1983Va22, 1984Bo15, 1984Ge07 and 1992Li05. A weighted mean value of 4.12(3)% was derived through LWEIGHT, and the uncertainty was increased slightly to the lowest measured value of ± 0.04 to give 4.12(4)% (0.0412(4)).

Only 1977Ku15 has measured the emission probabilities of other low -intensity gamma transitions identified with ^{224}Ra alpha decay; these data are reported relative to a value of 39500(1300) for the 240.986 keV gamma emission, as taken from 1969Pe17. Hence, the low -intensity emission probabilities have been subsequently adjusted on the basis of P_γ(240.986 keV) of 4.12(4)% (0.0412(4)).

Absolute Gamma-ray Emission Probabilities per 100 Disintegrations of ^{224}Ra

E_g (keV)	P_g^{abs}				
	1969Pe17	1972DaZA‡	1977Ku15†	1982Sa36	1983Sc13
240.986(6)	3.95(13)	3.9(7)	[3.95(13) → 4.12(4)]	3.9(2)	4.04(17)
292.70(11)	-	-	0.0063(7)	-	-
404.5(1)	-	-	0.0022(5)	-	-
422.04(11)	-	-	0.0030(5)	-	-
645.44(9)	-	~ 0.007	0.0054(9)	-	-

E_g (keV)	P_g^{abs} (cont.)				
	1983Va22	1984Bo15	1984Ge07	1992Li05	Recommended Values*
240.986(6)	4.05(9)	4.05(9)	4.17(4)	4.11(12)	4.12(4)
292.70(11)	-	-	-	-	0.0063(7)
404.5(1)	-	-	-	-	0.0022(5)
422.04(11)	-	-	-	-	0.0030(5)
645.44(9)	-	-	-	-	0.0054(9)

‡ Data expressed relative to P_γ(2614.511 keV) of ^{208}Tl have been adjusted.

† Data adjusted on the basis of P_γ(240.986 keV) of 4.12(4)%.

* Recommended gamma-ray emission probabilities above 241 keV taken from adjusted data of 1977Ku15.

Multipolarities and Internal Conversion Coefficients

The nuclear level scheme specified by 1997Ar04 has been used to define the multipolarities of the gamma transitions on the basis of known spins and parities. Recommended internal conversion coefficients have been interpolated from the theoretical tabulations of 1978Ro22.

Alpha-particle Emissions

Energies

All alpha-particle energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 1997Ar04 and the Q-value of 1995Au04 were used to determine the energies and uncertainties of the alpha-particle transitions to the various levels, while allowing for the significant recoil components.

Emission Probabilities

Alpha-particle emission probabilities to the first excited states of ^{220}Rn have been directly measured by 1969Pe17, 1971So15, 1984Bo15 and 1993Ba72, and these data can be used to calculate the alpha-particle emission probability directly to the ground state of ^{220}Rn:

Alpha-particle emission probability data of 1969Pe17 are effectively normalised to 94.95(5)% and 5.05(5)%,similarly for the equivalent data of 1971So15, with normalised values of 95.1(4)% and 4.9(4)%,and 1984Bo15, with normalised values of 94.94(4)% and 5.06(4)%.

1993Ba72: two alpha-particle emissions are quantified that sum to 100.03%, and the two associated uncertainties are effectively inconsistent; data adjusted so that uncertainties correspond (± 0.04%) to give:

P_α(5685.50 keV) of 95.10%, and uncertainty of ± 0.04%;
and P_α(5448.81 keV) of 4.93%, and uncertainty of ± 0.04%.

A weighted mean value of 95.00(4)% (0.9500(4)) can be determined for P_α(5685.50 keV), and matched with a value of 5.01(4)% (0.0501(4)) for P_α(5448.81 keV). Thus, a discrepancy exists between measurements of the absolute emission probability of the 240.986 keV gamma ray and measurements of the direct alpha-particle emission probability to the ground state of Rn-220:

(i) assuming that the measured gamma-ray emission probabilities are absolute (as quoted in the various references) and P_γ(240.986 keV) is 0.0412(4), NF = 1.000, P_α(5685.50 keV) of 0.9472(7) can be calculated taking into account the low-intensity gamma-ray transition probabilities populating the 240.986 keV nuclear level:

P_α(5448.81 keV) = P_γ(240.986 keV)(1 + α_{tot}(240.986 keV)) - [$\Sigma P_{\gamma i}$ (1 + α_i) populating nuclear level]= [0.0412(4) x 1.280(8)] – 0.000125(18) = 0.0526(7)

and P_α(5685.50 keV) = 0.9472(7)

(ii) if gamma-ray emission probabilities are judged to be not strictly absolute and P_α(5685.50 keV) of 0.9500(4) is adopted as the weighted mean of the alpha-particle measurements, NF = 0.947(8) and P_γ(240.986 keV) is 0.0390(3).

Although this problem cannot be resolved on the basis of the known measurements, the gamma-ray data were judged to be more reliable. Therefore, the recommended alpha-particle emission probabilities were determined from the gamma-ray data and theoretical internal conversion coefficients, rather than available alpha-particle measurements. These calculations resulted in an absolute emission probability of 0.0526(7) for the 5448.81 keV alpha particle (compared with a weighted mean value of 0.0501(4) from the alpha-particle measurements), and 0.9472(7) for the 5685.50 keV alpha particle. Further spectroscopic measurements are required to resolve the discrepancies between the alpha-particle and gamma-ray data (ie., decay-data studies involving the 240.986 keV and ground states of ^{220}Rn).

Alpha-particle Emission Probabilities per 100 Disintegrations of ^{224}Ra

E_a(keV)	P_a							
	1953As31	1962Wa28	1969Pe17	1971So15	1977Ku15[#]	1984Bo15	1993Ba72	Recommended Values[*]
5034.31(25)	-	0.0031	-	-	0.0029(5)	-	-	0.0030(5)
5051.58(24)	-	0.0072	-	-	0.0073(10)	-	-	0.0076(14)
5161.34(25)	-	0.0073	-	-	0.0069(8)	-	-	0.0074(8)
5448.81(16)	4.9	5.5	5.05(5)	4.9(4)	[5.0(16)]	5.06(4)	[4.93(4)][¶]	5.26(7)
5685.50(15)	95.1	94	[94.95(5)]	95.1(4)	94.98(16)	[94.94(4)]	[95.10(4)][¶]	94.72(7)

[#] Data were deduced from gamma-ray studies.

[¶] Relative data are quoted as 4.93(3) and 95.1(6), and have been adjusted to give consistent uncertainties.

[*] Recommended emission probabilities derived from evaluated gamma-ray emission probabilities and theoretical internal conversion coefficients.

Atomic Data

The x-ray data have been calculated using the evaluated gamma-ray data, and the atomic data from 1996Sc06, 1998ScZM and 1999ScZX.

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^{225}Ra - Comments on evaluation of decay data by Huang Xiaolong and Wang Baosong

This evaluation was completed in 2007. Literature available by May 2007 was included.

1 Decay Scheme

^{225}Ra disintegrates 100 % by β^- emission to levels in ^{225}Ac. ^{225}Ra ground state has $J^\pi = 1/2^+$ (1990Ak03).

The recommended Q(β^-) value of 356 (5) keV in Audi (2003Au03) agrees with the Q(β^-) value of 353 (8) keV, calculated by the evaluator (using program RADLST) from average radiation energies. This agreement supports the completeness and correctness of the decay scheme.

2 Nuclear Data

The Q(β-) value is from the mass adjustment in 2003Au03.
Level energies, spin and parities are from 1990Ak03.
The measured and recommended ^{225}Ra half-life values are listed in Table 1.

Table 1: Measured half-life values of ^{225}Ra and recommended value.

$T_{1/2}$ (d)	References	Measurement method
14	1947En03	
14.8 (2)	1950Ha52	Alpha pulse analyser, 10 $T_{1/2}$
15.02 (56)	1987Mi10	Solid-state detector, linear least squares fit
14.91 (11)		Unweighted mean
14.82 (19)		Weighted mean, χ^2=0.14
14.82 (19)	Recommended value	From weighted mean

The half-life weighted average has been calculated using the LWM computer program. The recommended half-life is from LWM result. Further measurements are needed to determine this value with greater precision.

2.1 β^- Transitions

The maximum energies of the β^- transitions in the decay of ^{225}Ra have been deduced from the Q(β-) value (2003Au03) and the level energies.

The adopted β^- transition probabilities and their associated uncertainties to the 40-keV level and to the ground state were deduced from P(γ) = 30.0 (7) % and α_T = 1.293 (19) for the 40-keV γ-ray. No β^- transitions to the 120.8- and 155.6- keV levels were observed. Based on Ac KX-ray intensities an upper limit of < 0.01 % for the respective β^- transitions to these levels was reported in 1984Ah01.

The *logft* values and average β^- energies have been calculated with the program LOGFT.

2.2 γ Transitions

The transition probability of the 40-keV γ-ray was calculated using its γ-ray emission intensity and the relevant total internal conversion coefficient.

The multipolarity of this γ-ray transition is from 1990Ak03.

The internal conversion coefficient (ICC) (and its associated uncertainty) for the 40-keV γ-ray transition has been interpolated from theoretical values based on the "Frozen Orbital" approximation (2002Ba85) using the BrIcc computer program (2008Ki07).

3 Atomic Data

Atomic fluorescence yields (ω_K,ϖ_L, ϖ_M, η_{KL} and η_{LM}) are from Schönfeld (1996Sc06).

The X-ray and Auger electron emission probabilities have been deduced from γ-ray and conversion electron data by using the computer code RADLST.

4 Electron emissions

The conversion electron emission probabilities have been deduced from γ-ray transition data using theoretical internal conversion coefficients.

5 Photon emissions

5.1 γ-ray energy

Measurements of the 40-keV γ-ray energy from ^{225}Ra are listed in Table 2 together with their weighted mean value. The recommended value is from the weighted mean value.

Table 2: Measured and recommended γ-ray energy from ^{225}Ra β^- decay.

1955Ma61	1955St04	1981Di14	1987Ah05	LWM	Evaluation
41 (2)	40 (1)	40.12 (5)	40.09 (5)	40.11 (4)	40.11 (4)

5.2 Absolute values of the γ-ray emission probability

The measurements of the absolute γ-ray emission probabilities from ^{225}Ra decay are listed in Table 3. The present recommended value is taken from a precise measurement in equilibrium with ^{229}Th (1986He06).

Table 3: Measured and recommended absolute γ-ray emission probability of 40.09keV for ^{225}Ra.

P_γ (40.09 keV) (%)	References	Measurement method
33	1955Ma61	Scintillation spectrometry
29	1955St04	
39.3 (12)	1981Di14	Ge(Li)
30.0 (7)	1986He06	Ge(Li) and Au-Si surface barrier, in equilibrium with ^{229}Th
30.0 (7)		Recommended value from 1986He06

6 References

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^{225}Ac - Comments on evaluation of the decay data

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This evaluation was completed in 2008. Literature available by December 2008 was included.

1 Decay Scheme

^{225}Ac disintegrates 100 % by α emission to levels in ^{221}Fr. ^{225}Ac ground state has J^{π} =(3/2$^-$) (1990Ak03).

The ^{225}Ac α decay scheme was built from the experimental conversion-electron data of 1971DzZP, 1972Dz14 and 2000Ar23, the α-γ coincidence data of 2003Ku44, the γ-γ coincidence data of 1990Ko14, and the experimental singles γ-rays data of 2000Ar23 and 2003Ku44.

The recommended Q(α) value of 5935.1 (14) keV in Audi (2003Au03) agrees with the Q(α) value of 5932.5 (16) keV, calculated by the evaluator (using program RADLST) from average radiation energies. This agreement supports the completeness and correctness of the decay scheme.

2 Nuclear Data

The Q value is from the mass adjustment in 2003Au03.

Level energies have been obtained from a least-squares fit to γ-ray energies (GTOL computer code). Spin and parities are from 1990Ak03, 2000Ar23 and 2003Ku44.

The measured and recommended ^{225}Ac half-life values are listed in Table 1.

Table 1: Measured half-life values of ^{225}Ac and recommended value, in days.

$T_{1/2}$ (d)	References	Measurement method
10	1947En03	
10.0 (1)	1950Ha52	Alpha pulse analyzer, 10 $T_{1/2}$
10.0 (1)	Recommended value	From 1950Ha52

The recommended value is taken from the measurement of 1950Ha52. Further measurements are merited to determine this value with greater confidence.

2.1 γ Transitions

The γ-ray transition probabilities were calculated using the γ-ray emission intensities and the relevant internal conversion coefficients.

Multipolarities and mixing ratios of γ-ray transitions are from 1971DzZP, 1972Dz14, 1977Vy02, 1990ArZZ and 2003Ku44. The multipolarity marked in square brackets for other γ transition are from the level scheme (they are not measured).

The internal conversion coefficients (ICC) and their associated uncertainties for γ-ray transitions have been obtained using the BrIcc computer program (2008Ki07), which uses the “Frozen Orbital” approximation (2002Ba85). Experimental and theoretical conversion coefficients are compared in Table 2.

Table 2: Comparison of theoretical and measured conversion coefficients.

E_γ (keV)	Multipolarity	α(theory)	α(exp.)
			(2003Ku44)
78.8	M1	$\alpha_T = 5.63$, $\alpha_L = 4.27$	$\alpha_T = 5.1$ (11)
87.41	M1	$\alpha_T = 4.16$, $\alpha_L = 3.16$	$\alpha_T = 2.8$ (6)
114	M1	$\alpha_T = 9.86$, $\alpha_L = 7.93$	$\alpha_T = 13.0$ (17)
139.6	M1+E2	$\alpha_T = 3.9$, $\alpha_K = 2.4$	$\alpha_T = 3.2$ (5)
145.16	(E1)	$\alpha_T = 0.191$	$\alpha_T \leq 0.1$
153.92	E1	$\alpha_T = 0.166$	$\alpha_T \leq 0.35$
197.5	E1	$\alpha_T = 0.0908$	$\alpha_T \leq 0.04$

2.2 α Transitions

The level energies of ^{221}Fr are determined from the least-squares fit to the recommended γ-ray energies. The level energies of ^{221}Fr and Q-values (2003Au03) were used to determine the energies and uncertainties of the alpha particle transitions to the various levels.

The recommended energies of alpha particles were calculated from the proposed decay scheme and listed in table 3. The recommended values are in good agreement with the measurements of 1967Dz02. Other measurements are 1964Gr11, 1967Ba51, and 1972Go29.

Table 3: Measured and recommended value of α-particle energy for ^{225}Ac (keV).

1964Gr11	1967Ba51[a]	1967Dz02[b]	1972Go29	1991Ry01	Recommended
5829 (5)	5829 (2)	5829 (2)		5829.6 (14)	5829.6 (14)
	5804 (2)				5804.2 (14)
5792 (5)	5793 (3)	5792 (3)	5792.5 (22)	5793.1 (21)	5793.1 (21)
	5791 (4)		5790.6 (22)		5791.7 (14)
5732 (5)	5731 (2)	5731 (3)		5731.9 (17)	5731.9 (17)
					5731.6 (14)
					5730.5 (14)
5724 (5)	5722.6 (25)	5723 (3)			5723.1 (14)
					5686.4 (14)
5683 (5)	5681 (2)	5681 (3)			5682.2 (14)
5638 (5)	5636.2 (20)	5637 (3)			5637.3 (14)
5610 (5)	5607.6 (30)	5608 (3)			5609.0 (14)
	5597.5 (40)				5599.3 (14)
5581 (5)	5579.1 (30)	5577 (3)			5580.5 (14)
	5561.6 (40)				5563.3 (14)
	5552.6 (40)				5555.3 (14)
	5544.1 (40)				5546.5 (14)
	5538.5 (40)	5540 (5)			5540.1 (14)
	5521.5 (70)	5526 (5)			5523.7 (14)
	5514.5 (7)	(5519)			5515.2 (14)
5494 (10)		5497 (4)			5497.4 (14)
		5489 (4)			5487.4 (14)
		(5468)			5468.4 (14)
5448 (10)	5441.1 (40)	5444 (3)			5443.3 (14)

1964Gr11	1967Ba51[a]	1967Dz02[b]	1972Go29	1991Ry01	Recommended
	5433.5 (40)	5437 (4)			5435.8 (14)
					5430.1 (14)
	5419 (7)	5427 (4)			5428.3 (14)
		5411 (4)			5414.5 (14)
5398		5391 (4)			5391.2 (14)
5367		(5377)			5379.0 (14)
		(5355)			5356.2 (14)
		(5342)			5341.9 (14)
5328 (10)	5318 (4)	5322 (3)			5321.2 (14)
5295 (10)	5285 (4)	5286 (3)			5287.6 (14)
	5266.5 (40)	5271 (4)			5269.1 (14)
	5229 (7)	5238 (4)			5239.3 (14)
5225	5209.3 (50)	5211 (3)			5210.2 (14)
	5205.5 (50)	5201 (5)			5203.3 (14)
		(5192)			5195.1 (14)
		5160 (5)			5162.1 (14)
		5130 (5)			5129.0 (14)
		5091 (4)			5094.1 (14)
					5076.8 (14)
		5066 (5)			5064.1 (14)
		(5030)			5035.5 (14)
					5025.5 (14)
		(5020)			5019.3 (14)
					4992.7 (14)
		4901 (5)			4903.6 (14)

[a]: Original energies should be increased by 1 keV due to changes in calibration energies (recommended by 1979Ry03).

[b]: Original energies should be decreased by 0.3 keV due to changes in calibration energies (recommended by 1979Ry03)

The evaluated alpha particle emission probabilities were deduced from the transition intensity balance and listed in table 4. These calculated results are in good agreement with the measured emission probabilities of the main alpha transitions. The measurements are from 1964Gr11, 1967Ba51, 1967Dz02, 1972Go29, and 2003Ku4.

Table 4: Measured and recommended α-particle emission probabilities for ^{225}Ac.

E_α (keV)	P_α					
	1964Gr11	1967Ba51	1967Dz02	1972Go29	2003Ku44	Evaluation
5829.6 (14)	52 (3)	50.65 (15)	51.6 (15)			52.4 (24)
5804.2 (14)		0.3				0.3
5793.1 (21)	28 (3)	24.3 (1)	26.7 (10)	18.1 (20)	20.2 (11)	18.9 (20)
5791.7 (14)		2.50 (1)			8.4 (5)	6.2 (9)
5731.9 (17)	12 (2)	10.10 (3)	10.0 (1)	8.6 (9)	8.5 (4)	9.0 (5)
5731.6 (14)					1.6 (2)	1.24 (10)
5730.5 (14)					1.05 (8)	1.6 (3)

E_α (keV)	P_α					
	1964Gr11	1967Ba51	1967Dz02	1972Go29	2003Ku44	Evaluation
5723.1 (14)		3.40 (1)	2.9 (5)		3.77 (19)	2.03 (23)
5686.4 (14)					0.095 (4)	0.021 (14)
5682.2 (14)	1.3 (3)	1.250 (4)	1.4 (2)		1.08 (5)	1.31 (4)
5637.3 (14)	4.2 (3)	4.350 (13)	4.5 (3)		3.7 (1)	4.16 (23)
5609.0 (14)	1.0 (3)	1.20 (1)	1.1 (1)		0.86 (3)	1.09 (5)
5599.3 (14)		0.0410 (1)			0.099 (4)	0.114 (7)
5580.5 (14)	1.0 (3)	1.20 (4)	1.2 (1)		0.89 (3)	0.95 (4)
5563.3 (14)		0.0340 (1)			0.0034 (5)	0.017 (7)
5555.3 (14)		0.1000 (3)			0.089 (4)	0.084 (10)
5546.5 (14)		0.0310 (1)			0.075 (3)	0.055 (12)
5540.1 (14)		0.0150 (5)	0.04 (1)		0.0070 (7)	0.0072 (8)
5523.7 (14)		~ 0.005	0.010 (2)			0.013 (6)
5515.2 (14)		~ 0.005	≤ 0.02			0.0052 (19)
5497.4 (14)	~ 0.02		0.003 (1)			0.0022 (7)
5487.4 (14)			0.0020 (7)			0.0020 (3)
5468.4 (14)			≤ 0.001			0.00052 (18)
5443.3 (14)	0.15 (5)	0.150 (1)	0.13 (1)		0.086 (4)	0.098 (19)
5435.8 (14)		0.0710 (2)	0.07 (2)		0.029 (2)	0.0083 (6)
5430.1 (14)						0.0028 (8)
5428.3 (14)			0.008 (3)		0.0010 (1)	0.0023 (3)
5414.5 (14)		~ 0.003	0.0020 (5)			0.0030 (4)
5391.2 (14)	~ 0.01		0.0010 (5)			0.0006 (4)
5379.0 (14)	~ 0.01		≤ 0.001			0.0020 (5)
5356.2 (14)			≤ 0.001			9.7E-5 (2)
5341.9 (14)			≤ 0.001		0.0009 (3)	0.0027 (8)
5321.2 (14)	0.07 (3)	0.080 (2)	0.068 (8)		0.054 (2)	0.007 (7)
5287.6 (14)	0.2 (1)	0.300 (1)	0.23 (1)		0.17 (1)	0.214 (10)
5269.1 (14)		0.0180 (5)	0.009 (2)		0.0086 (8)	0.048 (19)
5239.3 (14)			0.0030 (8)		0.00019 (8)	0.0026 (5)
5210.2 (14)	~ 0.02	0.0250 (1)	0.003 (3)		0.022 (2)	0.022 (1)
5203.3 (14)		0.0130 (1)	0.0020 (5)		0.0044 (6)	0.0101 (10)
5195.1 (14)			≤ 0.002			0.00015 (5)
5162.1 (14)			0.0020 (8)			0.00066 (12)
5129.0 (14)			0.0020 (8)		0.0013 (3)	0.0058 (8)
5094.1 (14)			0.006 (1)		0.0054 (15)	0.015 (7)
5076.8 (14)						0.0038 (19)
5064.1 (14)			0.003 (1)		0.0014 (2)	0.00114 (18)
5035.5 (14)			≤ 0.001			0.0021 (3)
5025.5 (14)						0.00083 (21)
5019.3 (14)			≤ 0.001		~ 0.00004	0.00015 (5)
4992.7 (14)						0.0013 (3)
4903.6 (14)			0.0020 (5)			0.0011 (4)

3. Atomic data

Atomic fluorescence yields (ω_K,ϖ_L, ϖ_M, η_{KL} and η_{LM}) are from Schönfeld (1996Sc06).

The X-ray and Auger electron emission probabilities have been deduced from γ-ray and conversion electron data by using the computer code RADLST. Measured and calculated X-ray emission probabilities are compared in Table 5.

Table 5: Comparison of the calculated and measured X-ray emission probabilities.

	1972Dz14	Adopted (deduced)
$K_{\alpha 1}$	1.5 (2)	1.64 (12)
$K_{\alpha 2}$	**1.0 (1)**	1.00 (8)

The deduced KX-ray emission probabilities agree with the measured value of 1972Dz14, thus confirming the completeness of the decay scheme.

4. Electron Emissions.

The conversion electron emission probabilities have been deduced from γ-ray transition data.

5. Photon Emissions

5.1 γ-ray energy values

There are many measured γ-ray energies of ^{225}Ac. The present evaluated values are taken from the LWM average value of 1972Dz14, 2000Ar23 and 2003Ku44. The measurements of 1990ArZZ were replaced by 2000Ar23. The experimental and our recommended γ-ray energies from ^{225}Ac α decay are listed in table 6.

Table 6: Measured and recommended value of γ-ray energy for ^{225}Ac (keV).

1972Dz14	1990ArZZ	2000Ar23	2003Ku44	LWM	Evaluation
		10.6	10.6		10.6
26.0 (1)	26.05 (10)	26.0 (1)	26.0	26.0 (1)	26.0 (1)
36.6 (1)	36.65 (3)	36.70 (3)	36.7 (1)	36.69 (3)	36.69 (3)
38.5 (1)	38.53 (3)	38.60 (4)	38.5 (1)	38.58 (4)	38.58 (4)
	46.24 (5)	46.24 (5)	46.2 (2)	46.24 (5)	46.24 (5)
49.0 (2)	49.09 (5)	49.13 (4)	49.1 (2)	49.12 (4)	49.12 (4)
		50.2			50.2
53.8 (1)		53.01 (5)		53.4 (4)	53.4 (4)
57.8 (1)	57.75 (5)	57.69 (4)	57.8 (2)	57.71 (4)	57.71 (4)
		62.6 (3)			62.6 (3)
62.90 (5)	62.95 (3)	62.96 (3)	62.9 (1)	62.94 (3)	62.94 (3)
		63.5 (3)			63.5 (3)
64.1 (1)	64.28 (5)	64.28 (3)	64.3 (1)	64.27 (3)	64.27 (3)
69.8 (1)	69.8 (2)	69.87 (5)		69.86 (5)	69.86 (5)
71.7 (1)	71.74 (3)	71.72 (4)	71.4 (3)	71.71 (4)	71.71 (4)
73.6 (1)	73.5 (1)	73.36 (20)	73.5	73.55 (9)	73.55 (9)
73.83 (5)	73.86 (2)	73.85 (4)	73.9 (1)	73.85 (3)	73.85 (3)
74.9 (2)	74.9 (2)	74.82 (5)	74.6 (4)	74.82 (5)	74.82 (5)

1972Dz14	1990ArZZ	2000Ar23	2003Ku44	LWM	Evaluation
			78.8		78.8
					82.6[ab]
87.38 (5)	87.41 (3)	87.42 (3)	87.4 (1)	87.41 (3)	87.41 (3)
94.9 (2)	94.90 (5)	94.90 (3)	94.9 (1)	94.90 (2)	94.90 (2)
96.3 (2)	96.15 (5)	96.15 (5)	96.7 (5)	96.16 (5)	96.16 (5)
99.55 (10)	99.63 (5)	99.71 (6)	99.6	99.67 (5)	99.67 (5)
99.8 (1)	99.91 (5)	100.07 (10)	99.8 (1)	99.89 (6)	99.89 (6)
100.8 (1)	100.96 (5)	100.87 (4)	100.8 (2)	100.86 (4)	100.86 (4)
	103.46 (10)	103.44 (12)	103.6 (2)	103.48 (10)	103.48 (10)
108.4 (1)	108.41 (3)	108.38 (3)	108.4 (1)	108.38 (3)	108.38 (3)
111.5 (1)	111.54 (3)	111.52 (3)	111.5 (1)	111.52 (3)	111.52 (3)
	112.8 (2)	112.8 (2)	112.8	112.8 (2)	112.8 (2)
			114		114
		119.09 (6)			119.09 (6)[b]
119.9 (1)	119.87 (5)	119.84 (3)	119.9 (1)	119.85 (3)	119.85 (3)
		121.06 (7)			121.06 (7)
123.8 (1)	123.75 (5)	123.73 (4)	123.8 (1)	123.75 (4)	123.75 (4)
124.8 (1)	124.82 (5)	124.81 (3)	124.8 (1)	124.81 (3)	124.81 (3)
	126.15 (10)	126.09 (5)	126.2 (2)	126.10 (5)	126.10 (5)
	129.2 (2)	129.22 (7)	129.2 (2)	129.22 (7)	129.22 (7)
	133.64 (5)	133.60 (4)	133.6 (1)	133.60 (3)	133.60 (3)
134.8 (1)	134.86 (5)	134.85 (3)	134.9 (1)	134.85 (3)	134.85 (3)
		137.40 (10)	137.6		137.40 (10)
					138.2[ab]
			139.6		139.6
		144.7 (2)	144.7		144.7 (2)
145.0 (2)	145.17 (5)	145.15 (3)	145.2 (1)	145.15 (3)	145.15 (3)
150.09 (5)	150.04 (2)	150.02 (4)	150.1 (1)	150.05 (3)	150.05 (3)
	152.63 (5)	152.64 (3)	152.6 (2)	152.64 (3)	152.64 (3)
154.0 (1)	153.92 (5)	153.91 (3)	153.9 (1)	153.92 (3)	153.92 (3)
157.25 (5)	157.26 (2)	157.24 (3)	157.3 (2)	157.25 (3)	157.25 (3)
		161.35 (7)			161.35 (7)
	169.1 (2)	169.18 (4)	169.1	169.18 (4)	169.18 (4)
			169.9		169.9
170.6 (1)	170.7 (2)	170.83 (6)	170.7 (2)	170.77 (5)	170.77 (5)
			173.4		173.4
	178.4 (1)	178.29 (3)	178.3 (2)	178.29 (3)	178.29 (3)
	179.8 (2)	179.78 (4)	179.8 (3)	179.78 (4)	179.78 (4)
			183		183
			186.1		186.1
186.1 (1)	186.2 (1)	186.31 (3)	186.3	186.29 (3)	186.29 (3)
			187.2		187.2
188.0 (1)	188.00 (5)	187.95 (3)	188.0 (1)	187.96 (3)	187.96 (3)
			193.2		193.2
195.69 (7)	195.78 (5)	195.74 (3)	195.8 (2)	195.74 (3)	195.74 (3)

1972Dz14	1990ArZZ	2000Ar23	2003Ku44	LWM	Evaluation
		197.50 (3)	197.4		197.50 (3)
	197.7 (1)		197.9		197.7 (1)
198.70 (7)	198.7 (1)	198.23 (8)	198.4 (3)	198.47 (23)	198.47 (23)
		205.12 (11)	204.7 (3)	205.07 (11)	205.07 (11)
	216.90 (5)	216.89 (3)	216.9 (2)	216.89 (3)	216.89 (3)
		220.43 (8)			220.43 (8)
224.56 (7)	224.64 (5)	224.58 (3)	224.7 (1)	224.59 (3)	224.59 (3)
			228.2 (4)		228.2 (4)
	231.3 (2)	231.14 (7)	231.3 (2)	231.16 (7)	231.16 (7)
			236.0 (6)		236.0 (6)
		238.64 (8)			238.64 (8)
	240.8 (1)	240.68 (3)	240.7 (2)	240.68 (3)	240.68 (3)
	243.2 (1)	243.11 (5)	243.2 (2)	243.12 (5)	243.12 (5)
	249.5 (2)	249.60 (3)	249.6 (2)	249.60 (3)	249.60 (3)
253.50 (7)	253.54 (5)	253.45 (3)	253.5 (1)	253.46 (3)	253.46 (3)
		256.0 (2)	256		256.0 (2)
	279.25 (10)	279.18 (3)	279.3 (3)	279.18 (3)	279.18 (3)
	282.1 (2)				282.1 (2)
	284.8 (1)	284.75 (3)	284.8 (3)	284.75 (3)	284.75 (3)
		298.32 (5)	298.6 (3)	298.33 (5)	298.33 (5)
		317.23 (18)	317.4		317.23 (18)
		321.77 (4)	321.8 (4)	321.77 (4)	321.77 (4)
	348.5 (1)	348.33 (4)	348.2 (4)	348.33 (4)	348.33 (4)
	354.8 (2)	354.54 (6)	354.9 (3)	354.56 (6)	354.56 (6)
			356.6		356.6
	362.5 (1)	362.38 (3)	362.2 (4)	362.38 (3)	362.38 (3)
		367.72 (12)	368.3 (6)	367.74 (12)	367.74 (12)
	375.2 (1)	374.98 (5)	375.0 (7)	374.98 (5)	374.98 (5)
		388.07 (7)			388.07 (7)
	403.1 (1)	403.1 (1)	403.4 (3)	403.13 (10)	403.13 (10)
	406.1 (1)	405.95 (3)	406.2 (3)	405.95 (3)	405.95 (3)
	418.1 (1)	417.90 (3)	417.9 (3)	417.90 (2)	417.90 (2)
		429.80 (18)			429.80 (18)
		434.81 (5)	435.0 (3)	434.82 (5)	434.82 (5)
		442.16 (8)			442.16 (8)
		443.43 (10)			443.43 (10)
		446.31 (10)			446.31 (10)
		451.04 (5)	450.1 (7)	451.04 (5)	451.04 (5)
452.4 (1)	452.4 (1)	452.21 (3)	452.4 (2)	452.23 (3)	452.23 (3)
	458.8 (2)	458.79 (8)	458.8 (4)	458.79 (8)	458.79 (8)
	462.4 (4)	462.43 (13)	462.4 (6)	462.43 (13)	462.43 (13)
	469.5 (3)	469.48 (5)	469.5 (3)	469.48 (5)	469.48 (5)
	481.05 (5)	480.84 (3)	481.1 (2)	480.85 (3)	480.85 (3)
		491.42 (10)	492.6 (6)	491.45 (10)	491.45 (10)
	496.9 (3)				496.9 (3)

1972Dz14	1990ArZZ	2000Ar23	2003Ku44	LWM	Evaluation
			498.6 (6)		498.6 (6)
			512.5 (7)		512.5 (7)
	515.40 (5)	515.12 (3)	515.3 (2)	515.13 (3)	515.13 (3)
	517.78 (5)	517.50 (3)	517.9 (2)	517.51 (3)	517.51 (3)
	522.3 (1)	522.14 (4)	522.1 (2)	522.14 (4)	522.14 (4)
	526.09 (5)	525.77 (3)	526.1 (1)	525.94 (17)	525.94 (17)
		527.29 (5)			527.29 (5)[b]
	529.9 (1)	529.59 (3)	529.7 (3)	529.59 (3)	529.59 (3)
	531.3 (1)	530.86 (4)	531.2 (3)	530.87 (4)	530.87 (4)
		532.11 (9)			532.11 (9)
	538.1 (1)				538.1 (1)
			545.8 (6)		545.8 (6)
	552.0 (1)	551.78 (3)	552.0 (2)	551.79 (3)	551.79 (3)
		564.31 (11)	565.6 (7)	564.34 (11)	564.34 (11)
		567.47 (5)	568.3 (6)	567.48 (5)	567.48 (5)
	571.0 (1)	570.68 (3)	571.0 (2)	570.69 (3)	570.69 (3)
		590.41 (5)	591.4 (7)	590.42 (5)	590.42 (5)
	594.2 (1)	593.86 (4)	594.6 (3)	593.87 (4)	593.87 (4)
	601.1 (1)	600.92 (3)	601.0 (3)	600.92 (3)	600.92 (3)
	603.3 (1)	603.09 (4)	603.5 (5)	603.09 (4)	603.09 (4)
		628.93 (10)	629.9 (7)	628.95 (10)	628.95 (10)
			637.1 (7)		637.1 (7)
		645.87 (13)	646.3 (3)	645.94 (12)	645.94 (12)
	649.2 (1)	649.01 (4)	649.5 (2)	649.03 (4)	649.03 (4)
			653.5 (4)		653.5 (4)[b]
		656.18 (11)			656.18 (11)
		657.88 (5)			657.88 (5)
		667.10 (8)	668.1 (4)	667.14 (8)	667.14 (8)
		675.51 (18)	674.3 (4)	674.9 (3)	674.9 (3)
	679.7 (1)	679.35 (6)	680.4 (6)	679.36 (6)	679.36 (6)
		697.54 (13)	698.4 (4)	697.62 (12)	697.62 (12)[b]
		702.00 (14)			702.00 (14)
	747.0 (1)	747.0 (1)	747	747.0 (1)	747.0 (1)
		752.46 (12)			752.46 (12)
	753.7 (3)	754.04 (13)	753.7	754.04 (13)	754.04 (13)
	758.7 (1)				758.7 (1)[b]
		767.6 (4)	768.4 (5)	767.9 (3)	767.9 (3)
			780.6 (6)		780.6 (6)
		808.48 (10)			808.48 (10)
			824.2 (7)		824.2 (7)

[a]: from 1969Le09.

[b]: not placed in level scheme.

5.2 Relative values of the γ-ray intensities

The results of measurements of the relative γ-ray intensities of ^{225}Ac are listed in table 7. Compared to the old measurements of 1967Le23 and 1972Dz14, recently measurements of 2000Ar23 and 2003Ku44 have better energy resolutions and higher detector efficiency. On the other hand, some measurements of 1967Le23 and 1972Dz14 have no uncertainties. Thus the recommended values are taken from the LWM average of the measured values of 2000Ar23 and 2003Ku44. The measurements of 1990ArZZ were replaced by 2000Ar23; measurements of 1994Gr20 were replaced by 2003Ku44.

Table 7: Measured and recommended relative γ-ray intensities for ^{225}Ac.

E_γ (keV)	I_γ							
	1967Le23	1972Dz14	1990ArZZ	1994Gr20	2000Ar23	2003Ku44	LWM	Evaluation
10.6								2.17 (28)*
26.0 (1)		~ 0.21	< 1.4		0.23 (3)	0.25 (8)	0.23 (3)	0.23 (3)
36.69 (3)	~ 4.1	~ 2.1	2.19 (27)	2.63 (36)	2.65 (33)	2.58 (27)	2.61 (21)	2.61 (21)
38.58 (4)		1.4	1.64 (14)	1.84 (50)	1.48 (23)	1.57 (16)	1.54 (13)	1.54 (13)
46.24 (5)			0.55 (27)		0.82 (17)	0.65 (11)	0.70 (9)	0.70 (9)
49.12 (4)		0.7	0.96 (27)	1.07 (36)	1.3 (2)	1.10 (13)	1.16 (11)	1.16 (11)
50.2					~ 0.09			~ 0.09
53.4 (4)		2.68 (56)			< 0.58			< 0.58
57.71 (4)		0.7	0.55 (27)	0.71 (36)	0.88 (19)	0.65 (14)	0.73 (11)	0.73 (11)
62.6 (3)					0.77 (17)			0.77 (17)
62.94 (3)	58 (7)	77.5 (70)	56.2 (27)	69.1 (52)	69.5 (87)	71.7 (49)	71.2 (42)	71 (4)
63.5 (3)					3.0 (4)			3.0 (4)
64.27 (3)		8.5 (28)	4.1 (4)	5.4 (5)	6.8 (7)	6.83 (75)	6.8 (5)	6.8 (5)
69.86 (5)		0.7	0.68 (27)	0.89 (36)	0.68 (17)		0.68 (17)	0.68 (17)
71.71 (4)		1.4	1.78 (14)	1.96 (48)	1.87 (20)	2.10 (43)	1.91 (18)	1.91 (18)
73.55 (9)		2.8	1.23 (27)		2.17 (72)	4.2 (12)	2.7 (6)	2.7 (6)
73.85 (3)	55 (10)	45.1 (42)	39.6 (18)	43.0 (34)	46.3 (58)	44.0 (36)	44.6 (31)	44.6 (31)
74.82 (5)		5.6	2.19 (27)		1.88 (43)	3.7 (12)	2.1 (4)	2.1 (4)
78.8				3.0 (13)		1.78 (27)		1.78 (27)
82.6$^{\times}$	21 (5)							21 (5)
87.41 (3)	< 6.8	40.8 (42)	31.9 (15)	40.5 (29)	44.9 (58)	37.7 (29)	39.1 (26)	39.1 (26)
94.90 (2)		22.5 (85)	11.9 (11)	12.5 (14)	18.8 (27)	14.0 (15)	15.1 (13)	15.1 (13)
96.16 (5)	4 (1)	4.2 (14)	3.84 (41)		< 4.3	4.7 (9)		4.7 (9)
99.67 (5)	301 (55)	95.8 (99)	78.1 (41)	243 (2)	197 (27)	117 (12)	110 (7)	110 (7)
99.89 (6)		239 (28)	127.4 (68)		38 (14)	167 (20)	156 (11)	156 (11)
100.86 (4)		7.0	8.8 (14)	10.9 (27)	17.5 (19)	12.5 (12)	13.9 (10)	13.9 (10)
103.48 (10)	~ 1.4		0.55 (27)		0.94 (27)	0.38 (9)	0.44 (9)	0.44 (9)
108.38 (3)	38 (7)	39.4 (42)	31.5 (14)	37.9 (27)	39.1 (43)	36.0 (26)	36.8 (22)	36.8 (22)
111.52 (3)	44 (7)	45.1 (42)	39.9 (18)	48.0 (36)	49.2 (58)	44.0 (32)	45.2 (28)	45.2 (28)
112.8 (2)			0.27 (13)		< 0.43	0.30 (4)		0.30 (4)
114						0.125 (18)		0.125 (18)
119.09 (6)$^{\times}$					2.6 (4)			2.6 (4)
119.85 (3)	9.6 (27)	8.5 (14)	9.3 (8)	12.1 (13)	14.0 (14)	11.0 (7)	11.6 (6)	11.6 (6)
121.06 (7)					2.5 (7)			2.5 (7)
123.75 (4)		26.8 (28)	9.0 (8)	10.9 (14)	14.2 (14)	12.0 (9)	12.6 (8)	12.6 (8)

E_γ (keV)	I_γ							
	1967Le23	1972Dz14	1990ArZZ	1994Gr20	2000Ar23	2003Ku44	LWM	Evaluation
124.81 (3)	29 (7)	7.0 (14)	3.3 (3)	4.6 (9)	4.6 (4)	4.0 (3)	4.22 (24)	4.22 (24)
126.10 (5)			0.96 (27)		1.06 (20)	1.17 (12)	1.14 (10)	1.14 (10)
129.22 (7)			0.41 (14)		0.48 (16)	0.37 (7)	0.39 (7)	0.39 (7)
133.60 (3)			1.78 (27)	2.7 (4)	13.9 (27)	2.83 (22)		2.83 (22)
134.85 (3)	5.5 (27)	5.6 (14)	3.84 (41)	5.0 (5)	4.8 (7)	4.5 (4)	4.6 (4)	4.6 (4)
137.40 (10)					0.43 (19)	0.32 (4)	0.33 (4)	0.33 (4)
138.2$^{\times}$	2.7 (14)							2.7 (14)
139.6						0.20 (3)		0.20 (3)
144.7 (2)	21 (4)				~ 0.07	0.067 (17)		0.067 (17)
145.15 (3)		18.3 (42)	18.4 (8)	21.8 (18)	21.4 (22)	21.0 (15)	21.1 (12)	21.1 (12)
150.05 (3)	100	100	100	100	100	100	100	100
152.64 (3)			2.2 (3)	2.7 (4)	2.39 (27)	3.17 (23)	2.84 (18)	2.84 (18)
153.92 (3)	23 (4)	26.8 (70)	23.6 (11)	27.7 (30)	28.2 (29)	30.3 (21)	29.6 (17)	29.6 (17)
157.25 (3)	51 (10)	43.7 (42)	45.2 (27)	55.4 (5)	50.7 (58)	53.3 (43)	52.4 (35)	52.4 (35)
161.35 (7)					0.52 (13)			0.52 (13)
169.18 (4)			2.33 (27)	2.86 (36)	2.29 (27)	1.17 (18)	1.7 (6)	1.7 (6)
169.9						2.0 (2)		2.0 (2)
170.77 (5)	5.5 (28)	1.4	0.96 (41)		1.06 (19)	2.83 (22)	1.9 (9)	1.9 (9)
173.4$^{\times}$						1.67 (19)		1.67 (19)
178.29 (3)	2.7 (14)		1.78 (14)		2.32 (26)	2.33 (20)	2.33 (16)	2.33 (16)
179.78 (4)			0.96 (27)	1.25 (36)	1.53 (19)	1.57 (13)	1.56 (11)	1.56 (11)
183$^{\times}$						1.22 (19)		1.22 (19)
186.1						1.83 (19)		1.83 (19)
186.29 (3)		2.8	2.47 (55)		2.74 (30)	0.60 (6)		0.60 (6)[b]
187.2						1.48 (9)		1.48 (9)
187.96 (3)	81 (8)	64.8 (70)	67.8 (34)	78.6 (5)	78.1 (87)	75 (5)	75.8 (44)	76 (4)
193.2$^{\times}$						0.28 (5)		0.28 (5)
195.74 (3)	19 (4)	19.7 (28)	20.5 (14)	25.2 (13)	23.4 (23)	20.5 (14)	21.3 (12)	21.3 (12)
197.50 (3)				3.6 (7)		3.83 (39)		3.8 (4)[b]
197.7 (1)			7.53 (68)	4.1 (9)	7.8 (10)	5.5 (6)		5.5 (6)[b]
198.47 (23)	4.1 (12)	2.8	3.01 (68)	3.8 (9)	2.55 (26)	2.83 (22)	2.71 (17)	2.71 (17)
205.07 (11)					0.27 (10)	0.18 (7)	0.21 (6)	0.21 (6)
216.89 (3)	47 (14)		39.7 (82)	53 (10)	47.8 (43)	45.2 (33)	46.2 (27)	46.2 (27)
220.43 (8)					0.87 (26)			0.87 (26)
224.59 (3)	15 (4)	11.3 (14)	12.1 (12)	14.8 (14)	15.6 (17)	16.3 (12)	16.1 (10)	16.1 (10)
228.2 (4)						0.67 (17)		0.67 (17)
231.16 (7)			0.27 (13)		0.30 (7)	1.10 (12)	0.7 (4)	0.7 (4)
236.0 (6)						0.25 (4)		0.25 (4)
238.64 (8)					0.14 (4)			0.14 (4)
240.68 (3)	2.7 (13)		0.96 (27)		1.71 (19)	1.67 (19)	1.69 (14)	1.69 (14)
243.12 (5)			0.16 (7)		0.39 (7)	0.50 (6)	0.45 (5)	0.45 (5)
249.60 (3)	2.7 (13)		1.51 (68)		1.9 (2)	2.0 (2)	1.95 (14)	1.95 (14)
253.46 (3)	21 (5)	14.1 (14)	15.5 (7)	18.4 (9)	18.5 (19)	19.3 (14)	19.0 (11)	19.0 (11)
256.0 (2)					0.05 (1)	0.100 (34)	0.054 (10)	0.054 (10)

E_γ (keV)	I_γ							
	1967Le23	1972Dz14	1990ArZZ	1994Gr20	2000Ar23	2003Ku44	LWM	Evaluation
279.18 (3)	4.1 (12)		2.33 (27)		4.63 (43)	4.17 (39)	4.4 (3)	4.4 (3)
282.1 (2)			0.55 (27)					0.079 (6)*
284.75 (3)	~ 1.4		0.55 (27)	0.71 (36)	1.09 (13)	1.05 (10)	1.07 (8)	1.07 (8)
298.33 (5)					0.29 (4)	0.30 (9)	0.29 (4)	0.29 (4)^{c}
317.23 (18)					0.06 (3)	> 0.018		0.06 (3)^{c}
321.77 (4)					0.46 (7)	0.50 (7)	0.48 (5)	0.48 (5)^{c}
348.33 (4)			0.41 (14)		0.46 (7)	0.42 (5)	0.43 (4)	0.43 (4)
354.56 (6)			0.21 (5)	0.25 (7)	0.19 (3)	0.38 (5)	0.29 (10)	0.29 (10)
356.6						0.037 (15)		0.037 (15)
362.38 (3)			0.82 (27)		0.9 (1)	0.70 (8)	0.78 (6)	0.78 (6)
367.74 (12)					0.05 (3)	0.10 (3)	0.075 (25)	0.075 (25)
374.98 (5)			0.41 (14)		0.027 (4)	0.28 (7)		0.28 (7)
388.07 (7)					0.18 (3)			0.18 (3)
403.13 (10)			0.18 (5)		< 0.29	0.027 (23)		0.027 (23)
405.95 (3)			0.96 (27)		1.14 (13)	1.12 (9)	1.13 (7)	1.13 (7)
417.90 (2)			0.68 (14)		0.82 (10)	0.80 (8)	0.81 (6)	0.81 (6)
429.80 (18					0.055 (27)			0.055 (27)
434.82 (5)					0.46 (7)	0.40 (5)	0.42 (4)	0.42 (4)
442.16 (8)					0.65 (10)			0.65 (10)
443.43 (10)					~ 0.014			~ 0.014^{d}
443.43 (10)					0.20 (7)			0.20 (7)^{d}
446.31 (10)					0.09 (5)			0.09 (5)
451.04 (5)					0.41 (7)	0.53 (14)	0.43 (6)	0.43 (6)
452.23 (3)	15 (5)	15.5 (14)	14.8 (12)		17.1 (19)	14.8 (11)	15.4 (10)	15.4 (10)
458.79 (8)			0.68 (27)		0.07 (2)	0.097 (37)	0.076 (18)	0.076 (18)
462.43 (13)			2.2 (11)		0.055 (16)	0.125 (45)	0.063 (15)	0.063 (15)
469.48 (5)			0.55 (14)		0.26 (10)	0.47 (6)	0.41 (5)	0.41 (5)
480.85 (3)	4.1 (12)		4.1 (4)		4.9 (6)	4.83 (41)	4.85 (34)	4.9 (3)
491.45 (10)					0.06 (2)	0.037 (23)	0.05 (2)	0.05 (2)
496.9 (3)			0.21 (10)					0.21 (10)
498.6 (6)						0.12 (3)		0.12 (3)
512.5 (7)						0.08 (3)		0.08 (3)
515.13 (3)	~ 1.4		2.47 (27)		2.95 (30)	3.17 (23)	3.09 (18)	3.09 (18)
517.51 (3)			1.78 (27)		2.1 (2)	2.5 (2)	2.30 (14)	2.30 (14)
522.14 (4)			0.21 (5)		0.30 (3)	0.30 (5)	0.30 (2)	0.30 (2)
525.94 (17)	~ 1.4		3.97 (41)		4.63 (43)	5.50 (43)	5.1 (3)	5.1 (3)
527.29 (5)$^{\times}$					0.27 (4)			0.27 (4)
529.59 (3)			0.82 (41)		1.01 (12)	1.18 (13)	1.09 (9)	1.09 (9)
530.87 (4)			0.55 (14)		0.68 (9)	0.67 (9)	0.68 (6)	0.68 (6)
532.11 (9)					0.11 (3)			0.11 (3)
538.1 (1)			0.55 (14)					0.55 (14)
545.8 (6)						0.077 (20)		0.077 (20)
551.79 (3)			0.55 (14)		0.56 (7)	0.93 (8)	0.75 (19)	0.75 (19)
564.34 (11)					~ 0.014	0.032 (13)		0.032 (13)

E_γ (keV)	I_γ							
	1967Le23	1972Dz14	1990ArZZ	1994Gr20	2000Ar23	2003Ku44	LWM	Evaluation
567.48 (5)					0.13 (2)	0.22 (5)	0.18 (5)	0.18 (5)
570.69 (3)			0.55 (14)		0.59 (7)	0.53 (9)	0.57 (6)	0.57 (6)
590.42 (5)					0.12 (2)	0.12 (3)	0.12 (2)	0.12 (2)
593.87 (4)			0.22 (11)		0.41 (4)	0.47 (10)	0.42 (4)	0.42 (4)
600.92 (3)			0.47 (14)		0.35 (6)	0.62 (15)		0.35 (6)[ad]
600.92 (3)					~ 0.87			~ 0.87[ad]
603.09 (4)			0.27 (13)		0.25 (3)	0.27 (7)	0.25 (3)	0.25 (3)
628.95 (10)					0.049 (13)	0.043 (14)	0.046 (10)	0.046 (10)
637.1 (7)						~ 0.017		~ 0.017
645.94 (12)					0.032 (10)	0.017 (7)	0.022 (6)	0.022 (6)
649.03 (4)			0.18 (5)		0.27 (3)	0.20 (5)	0.25 (3)	0.25 (3)
653.5 (4)[×]						0.025 (7)		0.025 (7)
656.18 (11)					0.07 (3)			0.07 (3)
657.88 (5)					0.20 (4)			0.20 (4)
667.14 (8)					0.56 (13)	0.040 (12)	0.30 (26)	0.30 (26)
674.9 (3)					0.019 (9)	0.012 (7)	0.015 (6)	0.015 (6)
679.36 (6)			0.11 (3)		0.09 (2)	0.102 (26)	0.095 (16)	0.095 (16)[c]
697.62 (12)[×]					0.035 (13)	0.028 (8)	0.030 (7)	0.030 (7)
702.00 (14)					0.023 (10)			0.023 (10)
747.0 (1)			0.16 (5)		< 0.29	< 0.017		0.16 (5)
752.46 (12)					0.038 (10)			0.038 (10)
754.04 (13)			0.11 (3)		0.033 (10)	< 0.017		0.033 (10)
758.7 (1)[×]			0.68 (14)					0.68 (14)
767.9 (3)					0.049 (13)	0.040 (12)	0.044 (9)	0.044 (9)
780.6 (6)						0.008 (2)		0.008 (2)
808.48 (10)					0.30 (4)			0.30 (4)
824.2 (7)						~ 0.007		~ 0.007

[a]: From 2000Ar23.
[b]: From 2003Ku44.
[c]: Multiply placed, intensity not divided.
[d]: Multiply placed, intensity suitable divided.
[*]: From intensity balance.
[×]: Not placed in level scheme.

5.3 Absolute values of the γ-ray emission probabilities

Measured absolute γ-ray emission probabilities for the 150.04 keV line for ^{225}Ac are compiled and listed in Table 8.

2000Ar23 gives the value 0.691 (16) %, which was obtained from correction of the intensity of 1986He06 using the measured value 0.053 (6) % (2000Ga52) for the 149.89 keV transition in ^{229}Th α-decay and the measured value 0.051 (10) % (1995Sh01) for the 150.14 keV transition in ^{221}Fr α-decay.

Conversely, to correct the measured intensity of 1986He06, if using the measured value 0.053 (6) % (2000Ga52) for the 149.89 keV transition in ^{229}Th α-decay and the evaluated value 0.0478 (23) % (1990Ak05) for the 150.14 keV transition in ^{221}Fr α decay, the value would be then 0.695 (13) %. These corrected values are in good agreement with the measured value in 1995Ch74.

The recommended absolute γ-ray emission probability of the 150.04 keV γ-ray is from the measurement of 1995Ch74 and adopted as the normalization factor N, with N = 0.006 93 (12). The recommended absolute γ-ray emission probabilities are the relative values evaluated in table 7 multiplied by 0.006 93 (12).

Table 8: Measured and recommended absolute γ-ray emission probability of 150.04 keV for ^{225}Ac.

P_γ (150.04 keV) (%)	References	Measurement method
0.981 (3)	1981Di14	Ge(Li)
0.796 (11)	1986He06	Ge(Li), Au-Si surface barrier, in equilibrium with ^{229}Th.
0.693 (12)	1995Ch74	Ge(Li), αγ-coincidence.
0.691 (16)	2000Ar23	From 1986He06 corrected by 2000Ga52 and 1995Sh01.
0.693 (12)		Recommended value from 1995Ch74

6. References

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^{226}Ra - Comments on evaluation of decay data
by V. Chisté and M. M. Bé

This evaluation was completed in 2006. This updated version was done in January 2007. The literature available by this date is included.

1 Decay Scheme

^{226}Ra disintegrates by alpha emissions mainly to the 186 keV level and to the ground state level of ^{222}Rn. Spin and parity are from the mass-chain evaluation of Y. A. Akovali (1996El01 and 1996Ak02).
A certain number of measurements of the 186-keV gamma intensity were carried out and the adopted data set is consistent, so the deduced intensity can be considered having a good level of confidence. Therefore, the decay scheme here was built from the gamma-ray intensity measurements.
A good agreement was found between the effective Q value (4870.5 (27) keV) calculated from the decay scheme data and the adopted and recommended value from Audi.

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).

Experimental ^{226}Ra half-life values (in years) are given in Table 1:

Table 1: Experimental values of ^{226}Ra half-life.

Reference	Experimental value (a)	Comments
S. W. Watson (1928Wa**)	1608	Not used: no uncertainty. Calorimetry.
H. J. J. Braddick (1928Br**)	1603	Not used: no uncertainty. α current.
I. Curie (1928Cu**)	1590	Not used: no uncertainty. Ion current.
F. A. B. Ward (1929Wa**)	1599	Not used: no uncertainty. Number α's emitted.
L. Meitner (1930Me**)	1590	Not used: no uncertainty. Calorimetry.
E. Gleditsch (1935Gl02)	1691	Not used: no uncertainty. Growth rate.
P. Günther (1939Gü**)	1603	Not used: no uncertainty. He production.
T. P. Kohman (1949Ko01)	1622 (13)	Number α's emitted.
W. Sebaoun (1956Se10)	1617 (12)	Number α's emitted.
G. V. Gorshkov (1959Go80)	1577 (9)	Calorimetry.
G. Martin (1959Ma12)	1602 (8)	Calorimetry.
H. Ramthun (1966Ra13)	1599 (7)	Calorimetry.
Recommended value	**1600 (7)**	$\chi^2 = 2.87$

The weighted average was calculated with LWEIGHT computer program (version 3).

The evaluators have chosen to take into account the only five experimental values with uncertainty found in the literature: 1949Ko01, 1956Se10, 1959Go80, 1959Ma12 and 1966Ra13. With this data set, the largest contribution to the weighted average comes from the value of Ramthun amounting to 33 %. The weighted average of **1600 a** and the external uncertainty of **7 a** is the half-life adopted value. The reduced-χ^2 value is 2.87.

2.1 a Transitions

The transition energies of the α-particles given in Section 2.1 were calculated from Q_α (2003Au03) and level energies.

2.2 g Transitions

The transitions probabilities were calculated using the γ-ray emission intensities and the relevant internal conversion coefficients (see **6.2 Gamma Emissions**).

Multipolarities of these γ-ray transitions are from 1996El01.

186-keV γ-ray : E2	449-keV γ-ray : [E1]
262-keV γ-ray : [E2]	600-keV γ-ray : [E1]
414-keV γ-ray : [E1]	

The internal conversion coefficients (ICC's) for these γ-ray transitions have been interpolated from theoretical values of I. M. Band (2002Ba85) using the BrIcc computer program (calculation for 'hole'). Theoretical values are compared with measured values below:

	De Pinho (1973De50)	Band (Icc99v3a computer program, no hole)[a]	BrIcc program (recommended values)
α_K	0.200 (9)	0.186 (6)	0.190 (3)
α_{L1}	0.031 (6)	0.0319 (10)	0.0321 (5)
α_{L2}	0.226 (16)	0.208 (6)	0.208 (3)
α_{L3}	0.124 (8)	0.1196 (36)	0.1196 (17)
α_L	0.380 (20)	0.360 (11)	0.360 (5)

[a] The evaluators have used a fractional uncertainty of 3 % for all Band conversion coefficients.

The results of De Pinho (1973De50) and the theoretical values calculated with two different programs (Icc99v3a (calculation for 'no hole') and BrIcc) are consistent to each other. The recommended values are the BrIcc values for the all conversion coefficients.

3 Atomic Data

Atomic values, ω_K, ϖ_L and n_{KL} and the X-ray and Auger electron relative probabilities are from Schönfeld and Janβen (1996Sc06).

4 a Emissions

The α-particle energies for the $\alpha_{0,2}$, $\alpha_{0,3}$ and $\alpha_{0,4}$ are from G. Bastin-Scoffier (1963Ba62), with uncertainties given by A. Rytz (1991Ry01). For the $\alpha_{0,0}$ and $\alpha_{0,1}$ emissions, the energies are from A. Rytz (1991Ry01).

The emission intensities of the α-particles have been deduced from the P(γ + ce) decay scheme balance at each level. In Table 2, the calculated and recommended values of the emission intensities are compared with the experimental results. For the two most important lines a slight agreement was found between the experimental results given by 2001La14 and the recommended values deduced from the decay scheme balance. For the three weak lines the calculated alpha emission intensities deduced from γ ray measurements are in good agreement with the measured values of Bastin-Scoffier.

Table 2: Experimental and recommended (deduced) values of the α-particles emission intensities.

Energy (keV)	G. Bastin-Scoffier (1963Ba62)	S. LaMont (2001La14)	Recommended values
4784.34 (25)	94.45 (5) [a]	93.84 (11)	94.038 (40)
4601 (1)	5.55 (5) [a]	6.16 (3)	5.950 (40)
4340 (1)	0.0065 (3)		0.0066 (22)
4191 (2)	0.0010 (1)		0.0008
4160 (2)	0.00027 (5)		0.0002

[a] uncertainties as given by Rytz.

5 Electron Emissions

The conversion electrons emission intensities have been calculated from γ-ray data using the EMISSION computer program.

6 Photon emissions

6.1 X-rays

The X-ray absolute intensities have been calculated from γ-ray data and ICC using the EMISSION computer program. In Table 3, the recommended values of ^{222}Rn X-ray emission intensities are compared with the experimental results.

Table 3: Experimental and recommended values of X-ray emission intensities.

	Delgado (2002De03)	Schötzig (1983Sc13)	De Pinho (1973De50)[a]	Recommended values
$K\alpha_1$	0.215 (3)			0.317 (6)
$K\alpha_2$	0.156 (39)			0.192 (4)
$K\alpha$	0.371 (39)	0.418 (21)		0.509 (7)
$K\beta_1$	0.079 (5)			0.1098 (25)
$K\beta_2$	0.020 (4)			0.0351 (10)
$K\beta$	0.099 (6)	0.145 (9)		0.1449 (27)
XK	0.47 (4)	0.563 (23)	0.693 (26)	0.654 (8)
XL1			0.0181 (25)	0.0147 (4)
XL2			0.420 (28)	0.427 (10)
XL3			0.401 (14)	0.365 (9)
XL			0.839 (43)	0.807 (13)

[a] Calculated with I_γ (186) = 3.555 (19)

The calculated recommended values and 1973De50 values, based on the assumption that I_γ (186) = 3.555 (19), are significantly greater than those measured by Delgado (2002De03) or Schötzig (1983Sc13).

The recommended data are in agreement, within the uncertainty values, with the experimental ones of 1973De50, who used a ^{226}Ra source from which the descendants were removed, since Schötzig and Delgado carried out measurements with sources in equilibrium with their daughters.

6.2 g-ray Emissions

The energies of the γ-ray emissions given in Section 6.2 are from Y. A. Akovali (1996El01).

The experimental relative γ emission intensities in ^{222}Rn are based on all available relative and absolute measurements of gamma-rays for the ^{226}Ra decay chain. The normalization factor to convert the relative emission intensities to absolute intensities is the weighted average of the measured absolute gamma -ray emission intensities (Table 4) of the most intense line in ^{226}Ra decay chain, presents in the ^{214}Bi disintegration namely the 609.3-keV line.

Table 4: Experimental 609.3 keV absolute gamma-ray emission intensities.

References	Experimental values (%)	Comments
E. W. A. Lingeman (1969Li10)	42.8 (40)	
D. G. Olson (1983Ol01)	45.0 (7)	
U. Schötzig (1983Sc13)	44.6 (5)	
W. –J. Lin (1991Li11)	46.1 (5)	
J. Morel (1998Mo14)	44.8 (6)	Superseded by 2004Mo07
J. Morel (2004Mo07)	45.57 (18)	
Recommended value	**45.49 (19)**	χ^2 = 1.45

The recommended normalization factor is the weighted average of the five experimental values: 45.49 with an external uncertainty of 0.19.

The experimental relative γ emission intensities of 186- and 262-keV given in Table 5 are relative to the ^{214}Bi 609-keV γ-ray.

Table 5: Experimental data set of the 186- and 262- keV relative γ emission intensities.

References	186-keV γ-ray	262-keV γ-ray	Comments
K. Ya. Gromov (1969Gr33)	9.5 (10)		Not used by the evaluators.
G. Wallace (1969Wa27)	9.91 (31)		Not used by the evaluators.
R.S. Mowatt (1970Mo28)	8.20 (12)		outlier
V. S. Aleksandrov (1974AlZT)	8.87 (30)		outlier
V. Zobel (1977Zo01)	9.00 (10)		Not used by the evaluators.
M. A. Farouk (1982Fa10)	9.07 (14)		Not used by the evaluators.
D. G. Olson (1983Ol01)	7.69 (11)		
U. Schötzig (1983Sc13)	7.72 (14)		
G. Mouze (1990MoZP)	8.58 (5)	0.012 (4)	outlier
W. –J. Lin (1991Li11)	7.89 (14)		
D. Sardari (2000Sa32)	7.6 (8)	0.012 (4)	
J. U. Delgado (2002De03)	7.812 (31)		
G. L. Molnar (2002MoZP)	7.85 (5)		
J. Morel (2004Mo07)	7.812 (31)		Not used by the evaluators.
Recommended values	**7.815 (25)**	**0.012 (4)**	
χ^2	0.52		

Were omitted from analysis:

a) four values: A. Hachem (1975Ha31), G. Mouze (1981Mo28), H. Akcay (1982Ak03) and O. Diallo (1993Di09), because these values comes from the same laboratory of G. Mouze (1990MoZP).
b) the sets of values from K. Ya. Gromov (1969Gr33), G. Wallace (1969Wa27) and M. A. Farouk (1982Fa10), because of lack in the articles concerning their experimental measurements.
c) the set of values from V. Zobel (1977Zo01), because these values have changed the consistency of the data set when they were introduced in the preliminary calculation with Lweight program and produced inconsistent weighted average for gamma emission intensity.

For the 186-keV γ-ray, the evaluators have chosen to take into account the nine values with associated uncertainty for the calculation. The relative γ emission intensity value given by 2004Mo07 is the same one that those measured by J. U. Delgado (2002De03). In 2004Mo07 article, the author measured the 609.3 keV absolute emission probability (Table 4) and normalized the 2002De03 data set with this value of 45.57(18), so the value given in 2004Mo07 was omitted. The weighted average of the remaining values above was calculated using LWEIGHT computer program (version 3). Based on the Chauvenet's criterion, Mowatt (1970Mo28), Aleksandrov (1974AlZT) and Mouze (1990MoZP) were shown outlier values by the Lweight program, then they have been omitted.

The adopted relative value is the weighted mean of the six remaining values: *7.815*, with an internal uncertainty of *0.025* and a reduced χ^2 of 0.52, so this data set is consistent. The largest contribution comes from the value of Delgado (2002De03), amounting to 63 %.

For the 414-, 449- and 600-keV γ-rays, the evaluators used the measured ratios of Lourens (1971Lo19): I_{414}/I_{186} = 0,00086 ; I_{449}/I_{186} = 5,5 $\times 10^{-5}$; I_{600}/I_{186} =0,00014 and the absolute value I_γ(186) = 3.555 (19) %, to determine their absolute emission intensities.

The evaluated relative and absolute γ-ray emission intensities are given in Table 6.

Table 6: Evaluated relative and absolute γ-ray emission intensities.

Energy (keV)	Relative emission intensity (%)	Absolute emission intensity (%)
186.211 (13)	7.815 (25)	3.555 (19)
262.27 (5)	0.012 (4)	0.0055 (18)
414.60 (5)		0.0003
449.37 (10)		0.0002
600.66 (5)		0.0005

6 References

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^{227}Ac – Comments on evaluation of decay data
by V. P. Chechev and N.K. Kuzmenko

This evaluation was completed in June 2008 with a literature cut off by the same date. The SAISINUC software and associated supporting computer programs were used in assembling the data following the established protocol within DDEP (2002Be).

1. Decay Scheme

The ^{227}Ac decay scheme is based on the evaluation of Browne (2001Br31). ^{227}Ac disintegrates (1,380 (4) %) by alpha transitions to the ground state and excited states of ^{223}Fr and (98,620 (4) %) by beta transitions to the ground state and excited states of ^{227}Th. The decay scheme cannot be considered well established since only approximate values are available for beta and gamma transition probabilities in the β^--decay of ^{227}Ac and the measurements of weak alpha transitions probabilities in the α-decay of ^{227}Ac are not sufficiently accurate.

2. Nuclear Data

Q(α) value is from 2003Au03.

The evaluated half-life of ^{227}Ac is based on the experimental results given in Table 1.

Table 1. Experimental values of the ^{227}Ac half-life (in years)

Reference	Author(s)	Value
1950Ho79	Hollander and Leininger	22,0 (3)
1955To07	Tobailem	21,6 (4)
1956Sh43	Shimanskaya and Yashugina	21,2 (8)
1959Ro51	Robert	21,6 (3)
1963Ei10	Eichelberger et al.	21,7714 (+56 −33)
1967JoZX	Jordan and Blanke	21,7728 (+29 −32)

The weighted mean of the 6 values is 21,772. The internal uncertainty is 0,0022, if we use the smallest uncertainties from 1963Ei10 and 1967JoZX, and 0,0028, if we use the largest uncertainties from these measurements. χ^2/ν = 0,34 and 0,33, respectively.

Our recommended value for the ^{227}Ac half-life is 21,772 (3) years.

2.1 Alpha Transitions

The energies of the alpha transitions have been obtained from Q(α) value and the level energies given in Table 2 from 2001Br31 where they were deduced from a least squares fit to gamma-ray energies.

The comparison of the adopted energies of alpha particles for most intense transitions with the measured values is shown in Table 3 (columns 3 and 4). The measured energies of the alpha particles (Table 3) have been adjusted for changes in the calibration standards (1986Ry04, 1991Ry01): +3,5 keV correction for values from 1966Ba19, +5 keV correction for values from 1959No41.

Table 2. ^{223}Fr levels populated in the ^{227}Ac α-decay

Level	Level energy, keV	Spin and parity	Half-life	a-transition energy, keV	Probability of alpha transitions (×100)
0	0	$3/2^{(-)}$	22,00 (7) min	5042,19 (14)	0,658 (14)
1	12,89 (5)	$(5/2^-)$		5029,30 (15)	0,546 (17)
2	54,97 (7)	$½^{(-)}$		4987,22 (16)	0,0015
3	82,13 (6)	$(7/2^-)$		4960,06 (15)	0,087 (7)
4	99,63 (6)	$(3/2^-)$		4942,56 (15)	} 0,08 (1)
5	101,00 (6)	$(5/2^-)$		4941,19 (15)	
6	134,51 (6)	$(3/2^+)$		4907,68 (15)	0,001
7	149,3 (3)	$(1/2^+)$			
8	160,48 (7)	$(3/2^+)$		4881,71 (16)	0,014 (7)
9	172,08 (6)	$(5/2^+)$		4870,11 (15)	0,0011
10	187,18 (10)	$(5/2^-)$		4855,01 (17)	} 0,025 (7)
11	189,10 (7)	$(7/2^-)$		4853,09 (16)	
12	219,61 (9)	$(7/2^+)$		4822,58 (17)	} 0,0012
13	222,75 (10)	$(7/2^+)$		4819,44 (17)	
14	242,63 (7)	(5/2)		4799,56 (16)	} 0,006 (3)
15	243,85 (13)	(5/2)		4798,34 (19)	
16	244,66 (15)	$(7/2^-)$		4797,53 (21)	
17	298,7 (3)	$(9/2^-)$			
18	365,47 (10)			4676,72 (17)	$\approx 3\cdot10^{-4}$
19	379 (7)			4663 (7)	$\approx 4\cdot10^{-5}$
20	449 (5)			4593 (5)	$\approx 4\cdot10^{-5}$
21	503 (7)			4539 (7)	$\approx 7\cdot10^{-5}$
22	515,20 (22)	$3/2^-$		4526,99 (26)	$\approx 7\cdot10^{-4}$
23	540,74 (25)	$(5/2^+)$		4501,45 (29)	$\approx 8\cdot10^{-5}$
24	601 (7)	$(5/2^-)$		4441,19 (16)	$\approx 4\cdot10^{-5}$

The recommended probabilities of the $\alpha_{0,i}$-transitions with i = 0, 1, 3, 4, 8, 11, 14 are from 1959No41. The remaining ones are from 1966Ba19. A comparison of the α-transition probabilities, taken directly from measurements of 1959No41, 1966Ba19 with those deduced from P(γ+ce) intensity balance, is given in Table 3. The total probability of α-transitions is from 1970Ki12 (1,3800 (36) %), see also 1974Mo05 (1,359 (14) %). The α-decay hindrance factors have been calculated using the ALPHAD computer program from the ENSDF evaluation package with $r_0 = 1,538$ fm, average of $r_0(^{222}\mathrm{Rn}) = 1,5397$ (4) fm, $r_0(^{222}\mathrm{Ra}) = 1,5383$ (8) fm and $r_0(^{224}\mathrm{Ra}) = 1,5332$ (8) fm, see 2001Br31.

Table 3. Energies and probabilities (×100) of most intense α-transitions in the ^{227}Ac decay

Level	Level energy, keV	Energies of a-particles, obtained from Q(α), keV	Measured energies of a-particles, keV	Probabilities (×100), adopted from 1959No41, 1966Ba19	Probabilities (×100), deduced from intensity balance
0	0	4953,23 (14)	4953,26 (14)	0,658 (14)	0,48 (24)
1	12,89 (5)	4940,57 (15)	4940,7 (8)	0,546 (16)	0,63 (15)
3	82,13 (6)	4872,55 (15)	4872,7 (2)	0,087 (7)	0,09 (3)
4	99,63 (6)	4855,36 (15)	4855 (2)	} 0,08 (1)	} 0,10 (6)
5	101,00 (6)	4854,01 (15)			
6	134,51 (6)	4821,09 (15)	4822 (4)	0,014 (7)	0,0090 (26)
10	187,18 (10)			} 0,025 (7)	} 0,028 (10)
11	189,10 (7)	4767,47 (15)	4768 (3)		

2.2 Beta Transitions

The energies of β^- transitions have been obtained from Q^-(^{227}Ac) and ^{227}Th level energies given in Table 4. The β^--emission probabilities per 100 β^- particles in ^{227}Ac β^--decay have been taken from 1995Li04 . The value of $\Sigma P_{\beta-}$ (i) has been obtained as (100 % - ΣPa (i)) = 98,620 (4) %. This is the total probability of beta transitions to the ground state and excited states of ^{227}Th.

Table 4. ^{227}Th levels populated in the ^{227}Ac β^--decay

Level	Level Energy, keV	Spin and Parity	Half-life	β^--emission probability per 100 β^- particles
0	0,0	1/2 +	18,68 (9) d	≈ 54
1	9,3	(5/2+)		≈ 35
2	24,5	3/2+		≈ 10
3	37,9	3/2-		0,3

2.3 Gamma Transitions and Internal Conversion Coefficients

The evaluated energies of the gamma-ray transitions are virtually the same as the gamma-ray energies because nuclear recoil is negligible.

The gamma-ray transition probabilities in ^{223}Fr have been deduced from their gamma-ray emission probabilities and the calculated total ICCs. The gamma-ray transition probabilities in ^{227}Th have been adopted from 1995Li04. ICCs have been calculated by a program supplied with the SAISINUC software (2002Be). This code uses interpolated values of Band et al. (2002Ba85). The multipolarities and mixing ratios δ of the gamma-ray transitions in ^{223}Fr and ^{227}Th have been taken from 2001Br31. The uncertainties in the ICCs for pure multipolarities have been taken as 2 %.

3. Atomic Data

The atomic data (fluorescence yields, X-ray energies and relative probabilities, Auger electrons energies and relative probabilities) were obtained using the SAISINUC software (2002Be).

4.1 Alpha Emissions

Details are given in Section 2.1.

4.2 Beta Emissions

Details are given in Section 2.2.

5. Photon Emissions

5.1 X-Ray Emissions

The absolute emission probabilities of Fr KX and LX -rays and Th LX-rays have been calculated using the EMISSION code (2000Schönfeld). An experimental Fr KX -rays intensity value of 0,0136 (16) % (from 1995Sh03) agrees well with 0,0145 (24) %, deduced by the evaluators.

5.2 Gamma-Ray Emissions

Gamma-Ray Energies

The energies of gamma-rays in ^{223}Fr have been adopted from 1995Sh03. The energies of gamma-rays $\gamma_{1,0}$ and $\gamma_{2,1}$ in ^{227}Th have been adopted from 1959No41. The energies of gamma -rays $\gamma_{2,0}$ and $\gamma_{3,1}$ in ^{227}Th have been adopted from 1997Mu08.

Gamma-Ray Emission Probabilities

The absolute emission probabilities of gamma -rays in ^{223}Fr are from 1995Sh03. The absolute emission probabilities of gamma -rays in ^{227}Th have been deduced from the absolute β^--emission probabilities in the ^{227}Ac β^--decay and α_T using the ratio of P(γ37,9-keV) / P(γ28,6-keV) = 9,0 (12) / 7,7 (10) = 1,17 (22) from ^{227}Pa EC decay (1995Li04), and the value of P(γ24,3-keV) / P(γ15,2-keV) = 20 / 0,44 = 45,5 from alpha decay of ^{231}U (2001Br31).

6. Electron Emissions

The energies of conversion electrons have been obtained from the gamma transition energies and atomic electron binding energies. The emission probabilities of conversion electrons have been deduced from the evaluated P(γ) and ICC values.

The number of K- and L- Auger electrons per 100 disintegrations has been calculated using the EMISSION code (2000Schönfeld).

Average β^- energies have been calculated using the LOGFT computer program.

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^{227}Th – Comments on evaluation of decay data
by E. Browne

1) Evaluation Procedures

The *Limitation of Relative Statistical Weight* (LWM) [1985ZiZY] method, used for averaging numbers throughout this evaluation, provided a uniform approach for the analysis of discrepant data. The uncertainty assigned in this evaluation to the recommended value is always greater than or equal to the smallest uncertainty in any of the experimental values used in the calculation. This evaluation was completed in August 2001, with minor editing done in March 2002.

2) Decay Scheme

^{227}Th decays 100% by emission of α particles, 24,2(9)% populates the ground state of ^{223}Ra. Evaluator normalized the decay scheme using measured values of the absolute emission probability of the 50.13-keV γ-ray, as described here in Section 5. There are several low-energy γ-rays, many of them with very large and not well-known conversion coefficients that have limited the accuracy of their respective total transition probabilities. For this reason the individual feedings, deduced from transition-intensity balances at each level, are also inaccurate. Thus such feedings have not been shown here. The α-particle probabilities (in percent) to individual levels presented in the decay scheme are experimental values from α-spectroscopic measurements of 1964Ba33. α-hindrance factors given in the decay scheme are from 2001Br31, calculated by using a radius parameter r_0 (^{223}Ra) = 1.536, average of r_0 (^{222}Ra) = 1.5383(8) and r_0 (^{224}Ra) = 1.5332(8) (1998Ak04). The level energies, spins, parities, as well as γ-ray multipolarities and mixing ratios shown in the decay scheme are from 2001Br31.

3) Nuclear Data

Table 1. ^{227}Th measured half-life values

Half-life (days)	Reference
18.169 (84)	1954Ha60
18.729 (48)	1963Ei10
18.7176 (52)	1967JoZX
18.738 (54)	1987Mi10

The (unpublished) value given in 1954Ha60 significantly disagrees with the other measured values. The ^{227}Th source used in 1954Ha60 contained several daughter radionuclides from the decay chain. Moreover, they used proportional counters to detect alpha particles, without any elemental discrimination. This situation may have introduced a systematic error in their half-life. Thus, the evaluator excluded this value from the statistical analysis. The recommended half-life of ^{227}Th is the weighted average (LWM) (χ^2/ν = 0.1) of the other three measured values, 18.718(5) days.

Q_α = 6146.43(15) keV is from 1995Au05.

4) Alpha Particles

Alpha particle energies and absolute probabilities presented in Section 4 are evaluated values from 2001Br31. Most α-particle energies are from 1964Ba33, increased by 1.7 keV to correct them for a systematic deviation (2001Br31). The energies of $\alpha_{(0,12)}$, $\alpha_{(0,3)}$, and $\alpha_{(0,0)}$ are from 1971Gr17, as recommended by 1991Ry01. Absolute α-particle probabilities are from 1964Ba33.

5) Gamma Rays

Energies

The recommended γ-ray energies given in Sections 2.2 and 6.2 are weighted averages (LWM) of values from 1993Ab01, 1990Br23, 1972He18, and 1969Br27, unless otherwise specified in Table 2.

Emission Probabilities

The recommended relative γ-ray emission probabilities given in Table 2 are weighted averages (LWM) of values from 1993Ab01, 1972He18, and 1969Br27, unless otherwise specified in this table.

Excepting the 304.50-keV gamma ray, all the conversion coefficients given in Section 2.2 are theoretical values from 1978Ro22 interpolated by using program ICC [1] for the recommended γ-ray energies and multipolarities. The 304.50-keV gamma ray has as E0 component, thus the conversion coefficients given here for this transition are experimental values.

The γ-ray emission (and total transition) probabilities given in Sections 6.2 and 2.2, respectively, have been normalized to an absolute scale (per 100 α decays) using a normalization factor *N = 0.126(6).* Evaluator deduced this value from I_{avg}(50.13 γ) = 8.20(17)%, weighted average of the following measured absolute γ-ray emission probabilities: I_γ(50.13) = 8.18(17)% (1990Ko40) and I_γ(50;13) = 8.4(6)% (1969Pe17).

A normalization factor *N = 0.127(11)* may be obtained by using the decay scheme and the sum of all the relative γ-ray transition probabilities (photons + electrons) to the ground state and to the first excited state at 29 keV, then equating this sum to 72.9(10)% (that is, to 100% - I_α (gs + 29-keV level) = 100% - 27.1 (10)% = 72.9(10)%). This value, although less precise, is in good agreement with the one given before, and it confirms the correctness and consistency of the decay scheme.

6) Atomic Data

X-ray and Auger (relative and absolute) electron emission probabilities given in Sections 3, 6.1 and 5, respectively, have been calculated by means of the computer code EMISSION (version 3,01, Nov. 3, 1999) [2]), which makes use of the atomic data from 1996Sc06, from reference [3], and from the evaluated γ-ray data given in Sections 2.2 and 6.2. In addition, internal conversion electron energies and absolute emission probabilities for the strongest lines are presented in Section 5. Electron energies have been calculated using electron binding energies from 1977La19, and γ-ray energies from Section 2.2. Absolute electron emission probabilities have been calculated using absolute γ-ray emission probabilities given in Section 6.2 and conversion coefficients from Section 2.2.

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Table 2. ^{227}Th Alpha Decay - Gamma-Ray Energies and Relative Emission Probabilities

1993Ab01(Eγ)	1993Ab01(Iγ)	1990Br23(Eγ)	1990Br23(Iγ)	1972He18(Eγ)	1972He18(Iγ)	1969Br27(Eγ)	1969Br27(Iγ)	Adopted Eγ [a]	Adopted Iγ [b]	χ2/ν(Eγ)	χ2/ν(Iγ)
6.5 (3)	0.7 (2)	6.3				6		6.5 (3)*	0.7 (2)*		
8.3 (2)	0.06 (2)	8				8.0 (2)		8.15 (20)	0.06 (2)*	1.1	
20.19 (5)	1.9 (2)	20.30 (5)	0.769			20.3 (2)	1.5 (5)	20.25 (5)	1.84 (20)	1.3	0.55
20.8 (2)	0.05 (2)	20.95 (5)						20.94 (5)	0.05 (2)*	0.53	
22.0 (2)	0.07 (7)							22.0 (2)*	0.07 (7)*		
24.13 (5)	0.68 (5)							24.13 (5)*	0.68 (5)*		
27.32 (5)	0.23 (4)	27.50 (10)	0.154					27.41 (9)	0.23 (4)*	1.6	
		29.60 (3)	0.046					29.60 (3)**	0.046**		
29.86 (5)	0.56 (8)	29.86 (1)	0.769			29.9 (2)	0.8 (2)	29.86 (1)	0.59 (8)	0.02	0.87
31.56 (5)	0.51 (8)	31.58 (1)	0.692			31.6 (2)	0.62 (17)	31.58 (1)	0.53 (8)	0.08	0.34
33.3 (2)	0.06 (2)	33.40 (8)	0.108					33.39 (8)	0.06 (2)*	0.22	
40.20 (3)	0.12 (3)	40.20 (10)	0.154	40.1				40.20 (3)	0.12 (3)*	0.01	
41.91 (5)	0.12 (3)	42.2 (3)	0.308	42.2 (5)	0.70 (26)	42.1 (3)	0.31 (6)	41.93 (5)	0.22 (10)	0.52	4.3
43.75 (5)	1.6 (1)	43.80 (5)	1.538	43.5 (5)	2.1 (6)	43.8 (2)	1.77 (21)	43.77 (5)	1.65 (10)	0.27	0.69
				43.8 (5)	0.43 (17)			43.8 (5)&	0.43 (17)&		
44.33 (5)	0.4 (1)	44.10 (5)	0.046	44.1	0.06 (3)	44.1		44.22 (12)	0.41 (10)	5.3	0.04
		44.40 (5)		44.3 (5)	0.11 (5)	44.4	0.15	44.40 (5)**			
		46.45 (5)						46.45 (5)**			
				48.3 (5)							
48.1 (2)	0.12 (3)	48.30 (3)	0.077	48.5 (5)	0.39 (10)	48.3	0.08 (1)	48.30 (3)	0.11 (4)	0.57	4.5
49.75 (5)	3.5 (5)	49.90 (7)	4.615	49.8 (3)	1.7 (13)	49.9	4.6 (14)	49.82 (5)	3.3 (7)	1.2	1.2
50.11 (2)	63 (2)	50.13 (1)	61.538	50.2 (2)	75.7 (52)	50.2 (2)	65 (3)	50.13 (1)	65 (3)	0.36	2.7
50.8 (2)	0.11 (5)	50.85 (5)	0.031	50.7 (5)	0.14 (6)			50.85 (5)	0.12 (5)	0.07	0.15
				51.2				51.2&			
54.1 (1)	0.05 (1)	54.20 (4)	0.008	54.2				54.19 (4)	0.05 (1)*	0.86	
		56.00 (6)	0.038	56.1	0.01 (1)	56.1	0.08 (2)	56.00 (6)**	0.038**		
56.3 (2)	0.12 (2)	56.55 (3)	0.077			56.6	0.13 (4)	56.42 (14)	0.07 (6)	0.78	10
				59.6 (5)	0.08 (3)			59.6 (5)&	0.08 (3)&		
61.42 (5)	0.70 (8)	61.44 (2)	0.846	61.5		61.5 (2)	0.69 (14)	61.44 (2)	0.70 (8)	0.12	
				62							

1993Ab01(Eγ)	1993Ab01(Iγ)	1990Br23(Eγ)	1990Br23(Iγ)	1972He18(Eγ)	1972He18(Iγ)	1969Br27(Eγ)	1969Br27(Iγ)	Adopted Eγ[a]	Adopted Iγ[b]	χ2/ν(Eγ)	χ2/ν(Iγ)
62.33 (5)	1.5 (2)	62.45 (5)	1.385	62.5 (3)	2.2 (5)	62.5 (2)	1.54 (23)	62.45 (5)	1.57 (20)	2.6	0.86
62.7 (2)	0.05 (2)	62.65 (4)	0.077	62.7 (3)	0.08 (3)			62.68 (3)	0.056 (20)	0.5	0.45
64.5 (2)	0.19 (3)	64.30 (10)	0.115	64.5 (5)	0.24 (9)			64.35 (10)	0.20 (3)	0.45	0.28
65.2 (1)	0.13 (3)	64.70 (10)	0.077					64.95 (25)	0.13 (3)*	12	
				66.2 (5)	0.05 (3)			66.2 (5)&	0.05 (3)&		
				66.4 (5)	0.06 (3)			66.4 (5)&	0.06 (3)&		
		68.70 (10)	0.046	68.7	0.01 (1)			68.70 (10)**	0.046**		
68.72 (5)	0.53 (4)	68.75 (3)	0.346	68.8 (5)	0.24 (10)	68.8 (2)	0.44 (7)	68.74 (3)	0.45 (8)	0.12	3.2
69.8 (3)	0.08 (3)			69.8 (5)	0.08 (3)			69.8 (3)	0.08 (3)		
72.85 (5)	0.32 (4)	72.80 (10)	0.231	72.9	0.03 (3)	72.9 (1)	0.22 (4)	72.85 (5)	0.19 (15)	0.25	12
73.8 (2)	0.07 (2)	73.60 (5)	0.077	73.7 (5)	0.15 (5)	73.7 (1)	0.15 (2)	73.63 (5)	0.11 (4)	0.53	4.3
75.00 (5)	0.29 (3)	75.1	0.154	75.3 (5)	0.08 (5)	75.1 (3)	0.18 (5)	75.01 (5)	0.21 (8)	0.23	7
						77.4 (4)	0.08	77.4 (4)#	0.08#		
79.66 (3)	15.1 (5)	79.72 (1)	15.385	79.7 (2)	15.7 (44)	79.8 (2)	15.4 (15)	79.69 (2)	15.1 (5)	0.78	0.04
		84									
89.17 (8)	0.03 (1)	90.0 (3)	0.031	89.9				89.6 (4)	0.03 (1)*	3.8	
93.86 (5)	11.9 (5)	93.90 (10)	10.000	94.0 (2)	11.7 (3)	94.0 (2)	10.8 (11)	93.88 (5)	11.7 (3)	0.31	0.28
94.9 (1)	0.30 (4)	94.99 (5)	0.092	95		95	0.09 (1)	94.97 (5)	0.19 (11)	0.65	14
96.02 (5)	0.6 (1)	96.1 (2)	0.462	96.1 (5)	0.39 (17)	96.1 (2)	0.54 (13)	96.03 (5)	0.54 (10)	0.1	0.57
99.5 (2)	0.20 (5)	99.60 (10)	0.100	99.5				99.58 (10)	0.20 (5)*	0.2	
		99.60 (20)	0.015	99.7				99.60 (20)**	0.1**		
100.2 (2)	0.7 (2)	100.27 (3)	0.731	100.4 (5)	0.7 (3)	100.3	0.62 (12)	100.27 (3)	0.65 (12)	0.1	0.08
		102.50 (10)	0.009	102.5				102.50 (10)**	0.009**		
106.1 (2)	0.03 (1)	105.20 (10)	0.077					105.20 (10)**	0.077**		
107.9 (2)	0.05 (2)	107.75 (7)	0.046	108	0.06 (3)	107.5 (5)	0.07 (2)	107.76 (7)	0.060 (20)	0.39	0.25
108.9 (3)	0.03 (1)	108.00 (10)	0.000	109.6 (5)	0.05 (2)			109.2 (4)	0.041 (12)	0.98	0.84
110.7 (2)	0.04 (1)	110.65 (5)	0.062	110.6	0.01 (1)			110.65 (5)	0.025 (16)	0.06	4.8
				112.6 (5)	0.07 (3)			112.6 (5)&	0.07 (3)&		
113.06 (2)	6.6 (3)	113.16 (2)	5.385	113.1 (2)	4.7 (6)	113.1 (2)	5.5 (6)	113.11 (5)[c]	5.9 (8)	4.2	3.6
117.20 (5)	1.7 (1)	117.20 (5)	1.308	117.0 (3)	1.4 (3)	117.2 (2)	1.38 (14)	117.20 (5)	1.54 (11)	0.15	1.6
		117.20 (5)	0.077	117.5 (5)	0.10 (3)			117.5 (5)&	0.10 (3)&		

1993Ab01(Eγ)	1993Ab01(Iγ)	1990Br23(Eγ)	1990Br23(Iγ)	1972He18(Eγ)	1972He18(Iγ)	1969Br27(Eγ)	1969Br27(Iγ)	Adopted Eγ [a]	Adopted Iγ [b]	χ2/ν(Eγ)	χ2/ν(Iγ)
123.6 (1)	0.14 (2)	123.5 (2)	0.154	123.6 (5)	0.07 (2)	123.6	0.08	123.58 (10)	0.11 (4)	0.1	6.1
124.4 (2)	0.04 (2)	125	0.023	124.4	0.01 (1)	124.4	0.02	124.44 (20)	0.032 (17)	0.31	0.28
				124.7 (5)	0.03 (2)						
128.02 (2)	0.025 (4)							128.02 (2)*	0.025 (4)*		
129.4 (2)	0.010 (5)							129.4 (2)*	0.010 (5)*		
134.6 (1)	0.30 (5)	134.5 (3)	0.154	134.2 (3)	0.26 (5)	134.6 (2)	0.23 (5)	134.6 (1)	0.26 (5)	0.56	0.49
138.4 (1)	0.11 (2)	138	0.018					138.4 (1)*	0.11 (2)*		
140.5 (3)	0.05 (2)	141.0 (5)	0.038	140.5 (3)	0.28 (5)			140.6 (3)	0.17 (2)	0.42	11
141.34 (5)	1.1 (1)	141.50 (5)	1.000	141.2 (3)	0.57 (13)	141.4 (2)	1.00 (15)	141.42 (5)	0.92 (18)	1.9	5.4
150.1 (2)	0.07 (3)	150.2 (2)	0.038	149.8 (5)	0.16 (3)	150.3 (5)	0.07 (2)	150.14 (20)	0.086 (24)	0.23	2.1
162.2 (1)	0.07 (2)	162.1 (3)	0.062	162.2 (5)	0.05 (2)	162.1 (5)	0.07	162.19 (10)	0.060 (20)	0.04	0.5
164.5 (1)	0.11 (2)	164.8	0.077			164.9 (5)	0.12 (3)	164.52 (10)	0.113 (20)	0.62	0.08
168.4 (1)	0.11 (2)	168.25 (15)	0.100	168.3 (3)	0.12 (3)	168.7 (5)	0.12 (3)	168.36 (10)	0.115 (20)	0.4	0.06
169.7 (2)	0.06 (2)	170.0 (1)	0.031	170.1 (5)	0.03 (2)			169.95 (10)	0.043 (17)	0.95	1.5
171.5 (2)	0.03 (1)			171.4				171.5 (2)*	0.03 (1)*		
173.45 (5)	0.16 (2)	173.40 (10)	0.123	173.4 (5)	0.10 (3)	173.5 (3)	0.12	173.45 (3)	0.135 (20)	0.09	1.5
				175.8 (3)	0.16 (3)			175.8 (3)&	0.16 (4)&		
181.1 (3)	0.02 (1)	181	0.015					181.1 (3)*	0.02 (1)*		
182.3 (2)	0.03 (1)							182.3 (2)*	0.03 (1)*		
184.65 (5)	0.29 (3)	184.65 (5)	0.262	184.7 (3)	0.23 (4)	184.7 (3)	0.31 (5)	184.65 (5)	0.28 (3)	0.02	0.73
197.5 (1)	0.07 (2)	197.60 (10)	0.077	197.6 (5)	0.09 (3)	197.8 (5)	0.12 (3)	197.56 (10)	0.10 (3)	0.25	0.4
200.5 (1)	0.17 (2)	200.5 (2)	0.154	200.5	0.02 (2)	201.0 (4)	0.25 (6)	200.50 (10)	0.10 (7)		23
201.7 (1)	0.16 (2)	201.60 (10)	0.138	201.8 (3)	0.19 (3)			201.64 (10)	0.184 (20)	1.1	0.88
				202.5 (5)	0.05 (2)			202.5 (5)&	0.05 (2)&		
204.2 (1)	1.7 (2)	204.14 (10)	1.538	204.2 (3)	2.0 (4)	204.3 (2)	1.6 (4)	204.14 (10)	1.76 (20)	0.19	0.44
204.9 (1)	1.2 (2)	205.02 (10)	0.769	205.2 (3)	1.5 (3)	205.0 (2)	1.2 (3)	204.98 (10)	1.27 (20)	0.45	0.38
206.05 (6)	1.9 (2)	206.10 (5)	1.538	206.1 (3)	2.3 (4)	206.2 (2)	1.7 (4)	206.08 (5)	1.97 (20)	0.25	0.89
		206.3	0.062	206.4	0.02 (2)			206.4&	0.02 (2)&		
210.58 (5)	9.4 (3)	210.65 (5)	8.462	210.6 (2)	11.0 (8)	210.7 (2)	8.5 (9)	210.62 (5)	9.7 (7)	0.39	2.4
212.76 (5)	0.63 (5)	212.65 (4)	0.615	212.6 (3)	0.74 (13)	212.2	0.38 (10)	212.70 (4)	0.61 (7)	1.3	1.3
				212.7 (3)	0.15 (4)	213	0.46 (12)	212.7 (3)&	0.15 (4)&		

216.0 (1)	0.002 (1)							216.0 (1)*	0.002 (1)*		
218.89 (5)	0.83 (8)	219.0 (2)	0.538	218.8 (3)	0.48 (9)	219.0 (2)	0.85 (10)	218.90 (5)	0.85 (8)	0.22	0.05
		219.0 (2)	0.231	219.0 (3)	0.39 (9)			219.0 (2)&	0.39 (9)&		
222.8 (2)	0.04 (1)	223.60 (15)	0.015					223.2 (4)*	0.04 (1)*	8	
225.9 (1)	0.07 (2)	225.5 (5)	0.015	224.7 (5)	0.13 (3)	225.5 (10)	0.03	225.5 (3)*	0.07 (2)*	1.3	
229.4 (2)	0.03 (1)	230.3 (3)	0.005	230.4				229.9 (5)*	0.03 (1)*	4.5	
234.7 (1)	3.4 (3)	234.80 (10)	3.615	234.9 (3)	5.0 (10)	234.9	3.1 (6)	234.76 (10)	3.5 (4)	0.37	1.4
235.94 (3)	100	235.97 (2)	100.000	236.0 (2)	100 (4)	236.0 (2)	100 (8)	235.96 (2)	100 (2)	0.26	
246.1 (1)	0.10 (3)	246.1 (3)	0.077	246.4 (5)	0.10 (3)	246.2 (3)	0.08 (3)	246.12 (10)	0.095 (17)	0.14	0.18
248.1 (1)	0.19 (4)							248.1 (1)*	0.19 (4)*		
				249.6 (5)	0.06 (2)			249.6 (5)&	0.06 (2)&		
250.1 (2)	0.08 (2)	250.15 (5)	3.231	250.2 (3)	2.4 (4)	250.2		250.15 (5)	0.069 (13)	0.04	0.52
250.19 (3)	4.0 (3)	250.35 (5)	1.077	250.4 (3)	0.61 (17)	250.4	3.1 (6)	250.27 (8)	3.5 (3)	2.7	1.6
252.50 (5)	0.9 (2)	252.6 (4)	0.769	252.5 (5)	1.0 (3)	252.6	0.77 (19)	252.50 (5)	0.86 (12)	0.03	0.21
254.62 (3)	5.6 (3)	254.67 (10)	5.385	254.7 (3)	7.9 (10)	254.7	3.9 (8)	254.63 (3)	5.5 (10)	0.15	4.9
256.22 (2)	54 (1)	256.25 (2)	56.154	256.2 (2)	55 (4)	256.3 (2)	57 (3)	256.23 (2)	54.3 (10)	0.42	0.46
260.6 (2)	0.04 (1)							260.6 (2)*	0.04 (1)*		
262.85 (5)	0.9 (1)	262.90 (10)	0.769	262.7 (5)	0.87 (17)	263.0 (2)	0.77 (9)	262.87 (5)	0.83 (6)	0.26	0.49
265.3 (2)	0.04 (1)							265.3 (2)*	0.04 (1)*		
267.0 (2)	0.08 (2)	267.1 (2)	0.019	267				267.05 (20)	0.08 (2)*	0.13	
267.7 (2)	0.06 (2)	268.0 (2)	0.077	267.9		268.0 (5)	0.05 (2)	267.86 (20)	0.055 (20)	0.6	0.13
				270.5							
270.6 (2)	0.16 (3)	270.5 (2)	0.062	270.7 (5)	0.28 (10)			270.56 (20)	0.22 (7)	0.1	0.72
272.90 (5)	3.9 (2)	272.90 (10)	3.846	273.0 (3)	4.3 (6)	273.0 (2)	3.9 (6)	272.91 (5)	3.94 (20)	0.11	0.2
279.7 (5)	0.35 (5)	279.7 (10)	0.462	279.7 (3)	0.78 (17)	279.8 (2)	0.38	279.80 (5)	0.42 (10)	0.03	2.7
280.4 (2)	0.02 (1)	281.0 (2)	0.054	281				280.7 (3)	0.02 (1)*	4.5	
281.42 (5)	1.4 (1)	281.40 (10)	1.231	281.4 (3)	1.3 (3)	281.4 (2)	1.3 (3)	281.42 (5)	1.38 (9)	0.01	0.09
284.2 (1)	0.4 (1)	284.4 (2)	0.385	284.3	0.22 (10)			284.24 (10)	0.31 (10)	0.8	1.6
285.6 (2)	0.25 (5)	285.50 (10)	0.385	285.6 (3)	0.48 (9)	285.4 (3)	0.38 (10)	285.52 (10)	0.34 (9)	0.14	2.2
286.06(2)	15 (1)	286.12 (2)	11.538	286.2 (2)	14.3 (7)	286.2 (2)	12.3 (6)	286.09 (2)	13.5 (12)	1.7	3.8
289.6 (1)	15 (3)	289.5 (3)	0.054	289.6	0.02 (2)			289.59 (10)	15 (3)*	0.1	

1993Ab01(Eγ)	1993Ab01(Iγ)	1990Br23(Eγ)	1990Br23(Iγ)	1972He18(Eγ)	1972He18(Iγ)	1969Br27(Eγ)	1969Br27(Iγ)	Adopted Eγ [a]	Adopted Iγ [b]	χ2/ν(Eγ)	χ2/ν(Iγ)
289.8 (1)	0.15 (3)	289.5 (3)	0.012					289.77 (10)	0.15 (3)*	0.9	
292.41 (5)	0.52 (6)	292.40 (10)	0.538	292.3 (5)	0.48 (10)	292.5 (3)	0.54 (13)	292.41 (5)	0.51 (6)	0.05	0.08
296.50 (5)	3.3 (3)	296.50 (5)	3.769	296.6 (3)	3.4 (6)	296.6 (2)	3.7 (5)	296.50 (5)	3.4 (3)	0.12	0.24
299.95 (3)	17.3 (5)	300.00 (3)	16.923	300.0 (2)	16.4 (12)	300.0 (2)	16.9 (17)	299.98 (3)	17.1 (5)	0.47	0.25
300.8 (2)	0.11 (2)	300.35 (3)	0.846	300.3 (3)	2.4 (4)			300.50 (16)	0.11 (2)*	1.8	
304.47 (3)	8.6 (5)	304.52 (2)	7.692	304.4 (3)	12 (1)	304.5 (2)	7.7 (8)	304.50 (2)	8.9 (10)	0.68	5.2
306.1 (3)	0.08 (3)							306.1 (3)*	0.08 (3)*		
308.40 (5)	0.14 (2)	308.40 (10)	0.108	308.5 (5)	0.13 (3)	308.4 (3)	0.11 (3)	308.40 (3)	0.131 (20)	0.01	0.35
312.69 (3)	4.0 (3)	312.70 (10)	3.846	312.6 (3)	4.5 (9)	312.7 (2)	3.9 (6)	312.69 (3)	4.0 (3)	0.03	0.16
		314.75 (10)	0.269	314.8 (5)	0.22 (9)			314.75 (10)	0.27**	0.01	
314.85 (4)	3.7 (3)	314.85 (10)	3.385	314.8 (3)	4.7 (9)	314.9 (2)	3.6 (5)	314.85 (4)	3.8 (3)	0.03	0.62
		318.4 (2)	0.046	318.8 (5)	0.05 (2)			318.46 (20)	0.052 (17)&	0.55	
319.24 (5)	0.30 (3)	319.2 (2)	0.231	319.2 (5)	0.16 (4)	319.2 (2)	0.26 (3)	319.24 (5)	0.25 (5)	0.03	4
324.8 (2)	0.08 (2)	324.9 (2)	0.046					324.88 (20)	0.08 (2)*	0.29	
325.7 (3)	0.07 (3)	326.10 (10)	0.231	325.2 (5)	0.04 (2)			325.99 (18)	0.049 (20)	0.89	0.69
326.7				326.2	0.01 (1)	326.4 (5)	0.23				
329.85 (2)	21.7 (5)	329.85 (3)	21.538	329.9 (2)	25.2 (14)	329.9 (2)	21.5 (19)	329.85 (2)	22.8 (12)	0.04	2.2
332.2 (2)	0.013							332.2 (2)*	0.013 (4)*		
334.36 (2)	8.2 (3)	334.38 (2)	8.462	334.4 (3)	10.0 (9)	334.5 (2)	8.5 (11)	334.37 (2)	8.8 (6)	0.31	1.3
339.6 (2)	0.03 (1)	339.80 (10)	0.012	339.8				339.76 (10)	0.03 (1)*	0.8	
342.56 (4)	3.4 (1)	342.50 (10)	3.231	342.5 (3)	1.7 (4)	342.5 (2)	3.2 (6)	342.55 (4)	2.7 (7)	0.13	9.3
346.48 (5)	0.10 (1)	346.45 (1)	0.077	346.3 (5)	0.07 (2)	346.5 (5)	0.08 (3)	346.45 (1)	0.093 (10)	0.15	1
				348.5 (5)	0.05 (2)			348.5 (5)&	0.052 (17)&		
350.66 (2)	0.9 (2)	350.40 (10)	0.923	350.5 (3)	0.70 (17)	350.5 (2)	0.92 (14)	350.54 (7)	0.85 (14)	1.3	0.54
		352.60 (10)	0.100	352.6 (5)	0.08 (2)	352.7 (3)	0.10 (3)	352.61 (10)	0.078 (17)&	0.01	
362.7 (1)	0.04 (1)	362.4 (2)	0.038	362.5 (5)	0.03 (2)	362.6 (2)	0.04 (1)	362.63 (10)	0.393 (10)	0.63	0.04
369.5 (5)	0.05 (1)	369.35 (5)	0.046	369.4 (5)	0.03 (2)	369.4	0.05 (1)	369.35 (5)	0.048 (10)	0.05	0.33
371.0 (1)	0.06 (2)	370.85 (5)	0.054	370.9	0.01 (1)	370.9	0.05 (1)	370.93 (8)	0.031 (21)	1.1	5.8
		374.8 (2)	0.012	375.1		374.5 (1)	0.01	374.8 (2)**	0.012**		
376.0 (3)	0.04 (1)	376.30 (10)	0.005					376.27 (10)	0.04 (1)*	0.9	
379.4 (1)	0.08 (2)							379.4 (1)*	0.08 (2)*		

1993Ab01(Eγ)	1993Ab01(Iγ)	1990Br23(Eγ)	1990Br23(Iγ)	1972He18(Eγ)	1972He18(Iγ)	1969Br27(Eγ)	1969Br27(Iγ)	Adopted Eγ [a]	Adopted Iγ [b]	χ2/ν(Eγ)	χ2/ν(Iγ)
381.9 (1)	0.05 (1)	382.4 (6)	0.046	382.4 (5)	0.05 (2)	382.5 (1)	0.05	382.2 (3)	0.050 (10)	6.1	
383.51 (4)	0.37 (5)	383.50 (10)	0.385	383.6	0.01 (1)	383.6 (2)	0.38 (8)	383.51 (4)	0.19 (18)	0.11	
				392.4 (5)	0.08 (2)			392.4 (5)&	0.078 (17)&		
398.2 (2)	0.011 (3)	399.0 (4)	0.015			399.0 (15)	0.02	398.6 (3)	0.011 (3)**	1.1	
401.9 (1)	0.10 (3)	402.50 (10)	0.092	402.5	0.02 (2)	402.6 (3)	0.09 (3)	402.2 (3)	0.06 (4)	9.8	3.4
415.1 (1)	0.016 (3)	415.1 (2)	0.014	415.2		415.2 (3)	0.01	415.11 (10)	0.011 (5)	0.05	3
432.4 (5)	0.030 (4)	432.30 (10)	0.038	432.5 (5)	0.03 (2)	432.4 (2)	0.04 (1)	432.33 (10)	0.032 (4)	0.12	0.45
						442.5 (10)	0.00046	442.5 (10)#	0.00046#		
						445	0.0039 (39)	445#	0.004 (4)#		
						448.0 (6)	0.00115	448.0 (6)#	0.0011#		
452.9 (3)	0.002 (5)					452.7 (6)	0.00077	452.9 (3)	0.002 (5)*	0.09	
						457.5 (1)	0.00054	457.5 (1)#	0.00054#		
						462 (1)	0.00038	462 (1)#	0.00038#		
466.8 (2)	0.004 (2)					466.5 (10)	0.00038	466.8 (2)	0.004 (2)*	0.09	
469.0 (2)	0.007 (2)							469.0 (2)*	0.007 (2)*		
						480 (1)	0.0023 (7)	480 (1)#	0.0023 (7)#		
						482 (1)	0.0011 (3)	482 (1)#	0.0011 (3)#		
						493.1 (2)	0.0042 (6)	493.1 (2)#	0.0042 (6)#		
507.5 (1)	0.007 (2)					507.4 (3)	0.0031 (6)	507.5 (1)	0.0051 (20)	0.1	1.9
516.7 (3)	0.003 (1)					516.4 (3)	0.0013 (3)	516.6 (3)	0.0022 (8)	0.5	1.3
521.8 (3)	0.003 (1)							521.8 (3)*	0.003 (1)*		
524.7 (4)	0.0018 (4)					524.3 (4)	0.00115 (23)	524.5 (4)	0.0015 (3)	0.5	1.3
534.5 (4)	0.001					535.0 (12)	0.00077 (23)	534.6 (4)	0.00077 (23)#	0.16	
536.9 (1)	0.013 (2)					537.0 (3)	0.085 (12)	536.9 (1)	0.0085 (13)#	0.1	
540.2 (3)	0.002 (1)							540.2 (3)*	0.002 (1)*		
						552.4 (5)	0.0018 (3)	552.4 (5)#	0.0018 (4)#		
556.0 (2)	0.004 (1)					556.5 (5)	0.0017 (3)	556.1 (2)	0.0029 (12)	0.86	2.7
565.4 (1)	0.011 (2)							565.4 (1)*	0.011 (2)*		
569.4 (5)	0.010 (2)					569.0 (3)	0.0046 (7)	569.1 (3)	0.0046 (7)#	0.47	
576.0 (2)	0.004 (1)					575.7 (7)	0.0010 (2)	576.0 (2)	0.0025 (15)	0.31	4.5

1993Ab01($E\gamma$)	1993Ab01($I\gamma$)	1990Br23($E\gamma$)	1990Br23($I\gamma$)	1972He18($E\gamma$)	1972He18($I\gamma$)	1969Br27($E\gamma$)	1969Br27($I\gamma$)	Adopted $E\gamma$ [a]	Adopted $I\gamma$ [b]	$\chi2/\nu(E\gamma)$	$\chi2/\nu(I\gamma)$
579.0 (2)	0.006 (2)					578.5 (7)	0.0010 (2)	579.0 (2)	0.0035 (25)	0.47	3.1
585.8 (1)	0.007 (2)							585.8 (1)*	0.007 (2)*		
						589.0 (6)	0.00046 (12)	589.0 (6)#	0.00046 (12)#		
						596 (1)	0.00008	596 (1)#	0.00008#		
598.9 (2)	0.005 (1)							598.9 (2)*	0.005 (1)*		
607.8 (3)	0.002 (1)					607.5 (4)	0.0014 (3)	607.7 (3)	0.0014 (3)	0.36	0.33
						621.4 (5)	0.00046 (12)	621.4 (5)#	0.00046 (12)#		
623.8 (5)	0.002 (1)					623.8 (5)	0.0012 (3)	623.8 (5)	0.0013 (3)		0.59
						632.3 (7)	0.00108 (22)	632.3 (7)#	0.0011 (2)#		
						641.0 (5)	0.00015 (5)	641.0 (5)#	0.00015 (5)#		
644.3 (3)	0.0010 (3)					644.2 (5)	0.00038 (12)	644.3 (3)	0.0007 (3)	0.03	2.1
						648.5 (5)	0.00046 (14)	648.5 (5)#	0.00015 (5)#		
662.5 (3)	0.003 (1)					663.1 (5)	0.00046 (14)	662.8 (4)	0.00046 (14)#	0.72	
						692.0 (7)	0.00031 (9)	692.0 (7)#	0.00031 (9)#		
						704.3 (5)	0.00062 (12)	704.3 (5)#	0.00062 (12)#		
						707.2 (7)	0.00031 (9)	707.2 (7)#	0.00031 (9)#		
						718.5 (10)	0.00023 (9)	718.5 (10)#	0.00023 (9)#		
						722.1 (6)	0.0029 (9)	722.1 (6)#	0.0029 (9)#		
723.5 (1)	0.008 (2)					723.6 (6)	0.0029 (9)	723.5 (1)	0.0021 (8)#	0.03	
						734.4 (5)	0.0008 (3)	734.4 (5)#	0.0008 (3)#		
735.4 (2)	0.002 (1)					735.5 (5)	0.0012 (4)	735.4 (2)	0.0013 (4)	0.03	0.55
						738.4 (10)	0.00054 (13)	738.4 (10)#	0.00054 (13)#		
						746.4 (7)	0.0008 (3)	746.4 (7)#	0.0008 (3)#		
749.2 (1)	0.004 (1)					748.5 (5)	0.0023 (5)	748.8 (4)	0.0032 (9)	0.98	1.4
754.1 (2)	0.003 (1)					754.0 (6)	0.00077 (19)	754.1 (2)	0.0019 (11)	0.02	2.5
						756.9 (2)	0.0015 (4)	756.9 (2)#	0.0015 (4)#		
757.7 (1)	0.010 (2)					756.9 (2)	0.0062 (15)	757.3 (4)	0.0081 (19)	8	1.8
763.1 (2)	0.003 (1)					762.2 (5)	0.0020 (4)	762.6 (5)	0.0021 (4)	1.6	0.86
						766.3 (5)	0.0023 (5)	766.3 (5)#	0.0023 (5)#		
773.5 (4)	0.0013 (3)					773.0 (8)	0.0010 (4)	773.4 (4)	0.0012 (3)	0.31	0.36
776.3 (1)	0.013 (2)					775.3 (2)	0.0115 (12)	775.8 (5)	0.012 (1)	13	0.2

1993Ab01(Eγ)	1993Ab01(Iγ)	1990Br23(Eγ)	1990Br23(Iγ)	1972He18(Eγ)	1972He18(Iγ)	1969Br27(Eγ)	1969Br27(Iγ)	Adopted Eγ [a]	Adopted Iγ [b]	χ2/ν(Eγ)	χ2/ν(Iγ)
781.5 (2)	0.0025 (8)					780.5 (3)	0.0025 (5)	781.0 (5)	0.0025 (5)	5.6	
						784.2 (5)	0.00077 (19)	784.2 (5)#	0.00077 (19)#		
787.7 (5)	0.0011 (3)					787.4 (5)	0.00069 (17)	787.6 (5)	0.00089 (21)	0.18	0.9
						787.4 (5)	0.00031 (8)	787.4 (5)#	0.00031 (8)#		
						792.6 (6)	0.00031 (8)	792.6 (6)#	0.00031 (8)#		
						792.6 (6)	0.00023 (6)	792.6 (6)#	0.00023 (6)#		
797.7 (1)	0.008 (1)					796.8 (2)	0.0062 (6)	797.3 (5)	0.0071 (9)	10	1.6
804.2 (1)	0.009 (1)					803.5 (2)	0.0075 (8)	803.9 (4)	0.005 (4)	6.1	34
808.6 (4)	0.0006 (2)					807.5	0.00038	808.6 (4)#	0.0006 (2)#		
813.0 (1)	0.024 (5)					812.2 (2)	0.0208 (21)	812.6 (4)	0.013 (2)	8	9.6
818.1 (2)	0.0019 (5)					818.0 (10)	0.00077 (23)	818.1 (2)	0.0013 (6)	0.01	2.6
						818.0 (10)	0.00023 (9)	818.0 (10)#	0.00023 (9)#		
823.8 (1)	0.024 (5)					823.1 (2)	0.0192 (19)	823.4 (4)	0.020 (2)	6.1	0.86
826.9 (5)	0.0012 (4)					826.0 (10)	0.0015 (5)	826.7 (5)	0.0013 (4)	0.65	0.22
						828.5 (5)	0.0015 (4)	828.5 (5)#	0.0015 (4)#		
829.0 (2)	0.0060 (2)					828.5 (5)	0.00008 (3)	828.9 (2)	0.0060 (2)*	0.86	
838.2 (2)	0.005 (1)					837.3 (3)	0.0031 (3)	837.8 (5)	0.0041 (9)	4.5	1.8
842.8 (1)	0.007 (1)					842.2 (3)	0.0046 (5)	842.5 (3)	0.0069 (10)	2	0.15
						846.7 (5)	0.00115 (23)	846.7 (5)#	0.00115 (23)#		
847.8 (3)	0.003 (1)					848.7 (5)	0.00046 (14)	848.3 (6)	0.0021 (9)	0.4	1.6
						854.3 (5)	0.00054 (11)	854.3 (5)#	0.00054 (11)#		
						857.3 (7)	0.00046 (14)	857.3 (7)#	0.00046 (14)#		
858.9 (2)	0.003 (1)					858.8 (3)	0.0019 (3)	858.9 (2)	0.0020 (3)	0.08	1.1
						863 (1)	0.00015 (6)	863 (1)#	0.00015 (6)#		
867.1 (5)	0.004 (1)					867.5 (5)	0.00054 (11)	867.3 (5)	0.0023 (17)	0.32	6
876.5 (5)	0.0023 (6)					876.2 (4)	0.0012 (4)	876.3 (4)	0.0018 (6)	0.22	1.7
878.2 (4)	0.0015 (5)					878.2 (4)	0.0009 (3)	878.2 (4)	0.0011 (3)		1.1
						891 (1)	0.00015 (5)	891 (1)#	0.00015 (5)#		
						893 (1)	0.00010 (3)	893 (1)#	0.00010 (3)#		
						896.1 (5)	0.00085 (21)	896.1 (5)#	0.00085 (21)#		
908.9 (1)	0.021 (2)					908.2 (2)	0.0161 (24)	908.6 (4)	0.0185 (25)	6.1	3.1

1993Ab01(Eγ)	1993Ab01(Iγ)	1990Br23(Eγ)	1990Br23(Iγ)	1972He18(Eγ)	1972He18(Iγ)	1969Br27(Eγ)	1969Br27(Iγ)	Adopted Eγ [a]	Adopted Iγ [b]	χ2/ν(Eγ)	χ2/ν(Iγ)
						910 (1)	0.00012 (5)	910 (1)#	0.00012 (5)#		
						920.0 (5)	0.00009 (2)	920.0 (5)#	0.00009 (2)#		
						927 (1)	0.00005 (2)	927 (1)#	0.00005 (2)#		
						938.0 (8)	0.00008 (3)	938.0 (8)#	0.00008 (3)#		
						941.6 (3)	0.00055 (8)	941.6 (3)#	0.00055 (8)#		
						958.7 (3)	0.00048 (10)	958.7 (3)#	0.00048 (10)#		
970.3 (2)	0.0020 (5)					970.0 (4)	0.00023 (5)	970.2 (2)	0.0011 (9)		6.3
						971.7 (10)	0.00008 (4)	971.7 (10)#	0.00008 (4)#		
						988 (1)					
						990.0 (7)	0.00027 (7)	990.0 (7)#	0.00027 (7)#		
						995 (1)	0.00005	995 (1)#	0.00005 (3)#		
						999.8 (5)	0.00023 (6)	999.8 (5)#	0.00023 (6)#		
						1015.2 (7)	0.00012 (3)	1015.2 (7)#	0.00012 (3)#		
						1020 (1)	0.00015 (5)	1020 (1)#	0.00015 (5)#		
						1025 (1)	0.00012 (3)	1025 (1)#	0.00012 (3)#		
* From 93Ab01											
** From 90Br23											
& From 72He18											
# From 69Br27											
a Weighted average (LWM) of values from 93Ab01, 90Br23, 72He18, 69Br27, unless otherwise specified.											
b Weighted average (LWM) of values from 93Ab01, 72He18, 69Br27, unless otherwise specified.											
c Double											

^{228}Ra – Comments on Evaluation of Decay Data
by A. Luca

This evaluation was completed in June 2009. The literature available by December 31st, 2008 was included.

1. Evaluation Procedures

The Limitation of Relative Statistical Weight (LWM) method was applied for averaging numbers throughout this evaluation; this method was implemented by using the computer code LWEIGHT, ver. 4 (designed for Excel, MS Office). The uncertainty assigned to an average value in this evaluation is never lower than the lowest uncertainty of any of the experimental input values.

2. Decay Scheme

^{228}Ra decays 100 % by beta minus particle emissions, populating the ^{228}Ac excited states. The decay scheme was studied by a few authors (1961To10, 1972HeYY, 1995So11). The most recent evaluation of the ^{228}Ra nuclear structure and decay data, published in Nuclear Data Sheets, was made by A. Artna-Cohen (1997). In the present evaluation, the spin, parity and energy of the ^{228}Ac excited levels, and the multipolarities of the γ-ray transitions, have been adopted from the above mentioned A=228 ENSDF mass-chain evaluation (1997Ar08).

3. Nuclear Data

The adopted beta decay energy value Q(β)=45.8 (7) keV, is from 2003Au03. This value is in very good agreement with the effective Q(β) value of 46 keV (with an uncertainty of 6 keV), calculated from the decay scheme data, by using the SAISINUC software, version 2008 April.

3.1. Half-life

In the literature, only two measured ^{228}Ra half-life ($T_{1/2}$) values are reported; both measurements are very old (the most recent is from 1962), so new half-life measurements are needed to improve the quality of the evaluation. The half-life values and their uncertainties are presented in Table 1; the value recommended by Curie et al. (1931), with an estimated uncertainty added by the evaluator, was also included. A critical review of the half-life computation (weighted average of 7 values) from reference 1962Ma58, was done by using the computer code LWEIGHT, ver.4. The set of data is consistent and the recommended value, 5.75 years, with an uncertainty of 0.04 years, is the weighted average (LWM, χ^2_ν=4.6) of the three input values. The references are expressed as NSR (Nuclear Science References) type keynumbers.

Table 1: ^{228}Ra Half-life values

$T_{1/2}$ (years)	Uncertainty of $T_{1/2}$ (years)	Reference
6.7	1	1931Cu01
5.7	0.2	1960Du11
5.75	0.04	1962Ma58

3.2. Beta transitions and emissions

In the literature, the most complete reference reporting measurements of energy and emission intensities for ^{228}Ra beta minus transitions is 1995So11.

For this evaluation, the beta transitions energies were calculated from Q(β-) and the energies of the decay scheme levels. The intensities of the beta branches were deduced from γ-ray transition intensity balance at each level (using also the corresponding total ICC values, computed as described below, in section 3.3), with the exception of the lowest energy branch (12.7 keV maximum energy) which was adopted from the measurements reported by 1995So11; also, the intensity ratio of the two highest energy beta branches, 39.1 keV and 39.5 keV, was adopted from the same reference (the uncertainty of this ratio, not mentioned in 1995So11, was neglected in present computations).
The intensity balance equations – including the normalization for the ground state of ^{228}Ac, together with the experimental data mentioned above and below in section 3.3, were assembled in a linear system of nine equations with nine unknown parameters to be determined. The system of equations is the following (the numbers between round parentheses associated to Iβ, Iγ and α_T correspond to the energy values of the beta minus/gamma-ray emissions/transitions, expressed in keV):

$$
\begin{aligned}
&I\beta(12.7)=[1+\alpha_T(12.88)]\cdot I\gamma(12.88)+[1+\alpha_T(26.40)]\cdot I\gamma(26.40)\\
&I\beta(25.6)+[1+\alpha_T(12.88)]\cdot I\gamma(12.88)=[1+\alpha_T(13.52)]\cdot I\gamma(13.52)\\
&I\beta(39.1)+[1+\alpha_T(13.52)]\cdot I\gamma(13.52)+[1+\alpha_T(26.40)]\cdot I\gamma(26.40)=[1+\alpha_T(6.67)]\cdot I\gamma(6.67)\\
&I\beta(39.5)=[1+\alpha_T(6.28)]\cdot I\gamma(6.28)\\
&[1+\alpha_T(6.28)]\cdot I\gamma(6.28)+[1+\alpha_T(6.67)]\cdot I\gamma(6.67)=100\ \%\\
&I\beta(12.7)=30\ (10)\ \%\\
&I\beta(39.1)/I\beta(39.5)=4\\
&I\gamma(13.52)=1.6\ (1)\ \%\\
&I\gamma(12.88)=0.30\ (6)\ \%
\end{aligned}
$$

Using the gamma-ray emission probabilities for the 13.52 keV and 12.88 keV photons measured by 1995So11, a new intensity value of the 25.6 keV beta branch was computed by the evaluator (see Table 2); this was done because the 20 % beta intensity gives a negative gamma-ray emission probability for the 12.88 keV photons, according to the intensity balance of the 20.19 keV ^{228}Ac excited level. The normalization condition of the beta emissions (the sum of the all the beta transitions intensities must be 100 %) was checked. The adopted energy and intensity values of the beta transitions, as well as their Log ft values are shown in Table 2.

Table 2: ^{228}Ra β^- Energies and Emission Probabilities

$E_{\beta-}$ (keV)	Uncertainty $E_{\beta-}$ (keV)	Emission probability (%)	Emission probability (%), from 1995So11	Log ft
12.7	0.7	30 (10)	30 (10)	5.11
25.6	0.7	8.7 (9)	20 (6)	6.2
39.1	0.7	49 (10)	40 (10)	6.45
39.5	0.7	12 (10)	10	7.07

3.3. γ- transitions: γ rays and internal conversion electrons

The single paper reporting measurements of the γ-ray energies and some emission intensities following the ^{228}Ra decay (only for 13.52 keV and 12.88 keV) is 1995So11. Using the measured 13.52 keV gamma-ray emission probability of 1.6 % (with a 0.1 % estimated uncertainty, added by the evaluator), the 12.88 keV photons measured emission probability of 0.30 (6) % and the internal conversion coefficients, the corresponding absolute gamma-ray emission probabilities and their uncertainties were computed for all the γ rays, by solving the linear system of equations from section 3.2; the obtained data are given below in Table 3. The internal conversion coefficients were computed with the program BrIcc, version 2.2b/20-Jan-2009, using the “Frozen Orbitals” approximation.

Other possible gamma-ray transitions observed only by Sood et al. (1995), but not placed in the level scheme, are: 15.15 keV, 15.5 keV, 16.2 keV and 30.6 keV.

Table 3: ^{228}Ra γ-ray Energies and Absolute Emission Probabilities

E_γ (keV)	Uncertainty E_γ (keV)	Absolute Emission Probability (%)	Uncertainty of absolute emission probability (%)	Total ICC (α_T) and uncertainty
6.28	0.03	$1.8 \cdot 10^{-6}$	$1.5 \cdot 10^{-6}$	$6.68\ (19) \cdot 10^{6}$
6.67	0.02	$5.7 \cdot 10^{-5}$	$0.9 \cdot 10^{-5}$	$1.560\ (40) \cdot 10^{6}$
12.88	0.11	0.30	0.06	6.67 (18)
13.52	0.04	1.6	0.1	5.86 (10)
26.40	0.11	0.14	0.05	201 (4)

4. Atomic data

The mean L-shell fluorescence yield (ϖ_L) and the relative probabilities of vacancies in the L-shell were given by the computer program EMISSION v.3.10, 28-Jan-2003.

4.1. Auger electrons and X-rays

Because the decay energy, Q, is very low, there are no electron emissions from the ^{228}Ac K-shell (Auger electrons or internal conversion electrons).

The emission intensity of the L Auger electrons (energy from 0.1 keV to 19.69 keV), was computed using the EMISSION computer program: 12 (5) %.

The absolute emission intensity values of the different groups of L X-rays (L_L, L_α, L_η, L_β and L_γ) were determined using the EMISSION program; the total L X-rays emission intensity is 9.6 (19) %, for an energy range between 10.87 keV and 18.92 keV. Neither measurements of X-ray energies nor of emission intensities were found in the literature, in order to compare them with the results of this evaluation.

5. Main production mode

The main production mode of ^{228}Ra is by alpha-particle decay of the ^{232}Th nuclei (^{228}Ra is the daughter of ^{232}Th), present in important quantities in many natural ores.

6. References

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^{228}Ac - Comments on Evaluation Decay Data
By Andy Pearce

This evaluation was completed in September 2009 drawing in part from the mass-chain evaluation of Artna-Cohen[1]. The literature available up until January 2009 was included. There is some evidence the decay scheme is not complete based upon the calculated beta emissions.

1 Decay Scheme

^{228}Ac decays almost entirely by beta- decay to excited states in ^{228}Th. The decay scheme (energies, half lives, spins and parities of levels in ^{228}Th) are based upon the adopted levels and gammas from Artna-Cohen[1], which in turn are largely derived from the work of Dalmasso et al[2]. The assignments of gammas to levels are also largely derived from Dalmasso et al.

Baltzer et al[3] place gammas at 56.8 keV and 137.4 keV originating from a 1588 keV 4- level in ^{228}Pa decay. Gamma emissions of similar energies have been observed in ^{228}Ac decay but not placed, and it is assumed these are the same transitions. Inserting this level in the ^{228}Ac decay allows for alternative placement of the 356 keV gamma, for which the predicted multipolarity (E2) did not match the measured conversion coefficient[4] (α=0.3-4). Placement from the 1945 keV level to the 1588 keV level indicates a multipolarity of E1+M2; the mixing ratio has been tentatively estimated at δ=0.5 giving α_T=0.35.

Decay via alpha emission to ^{224}Fr has been reported[5] with a probability of $(5.5 \pm 2.2) \times 10^{-6}$ per 100 decays, but this is unconfirmed.

2 Nuclear Data

For the purposes of this evaluation it is assumed ^{228}Ac decays entirely to ^{228}Th and any alpha branching present is negligibly small. The Q-value of beta decay is taken from Audi, Wapstra & Thibault[6] and is 2123.8 (27) keV. The effective Q-value calculated from the individual decay rates and energies calculated with the RADLST[7] program is 2010 (100) keV; this is low compared with the value from Audi, Wapstra & Thibault and serves to confirm that the decay scheme is incomplete.

There have been only two measurements of the half life reported in the open literature, Hahn and Erbacher[8] at 6.13 hours (quoted in Curie[9], however the corresponding publication could not be identified) and Skanemarg & Skalberg[10] at 6.15 (3) hours. No uncertainty is given for the value of Hahn & Erbacher, but it serves to give confidence in the recommended value of 6.15 (3) hours taken from Skanemarg and Skalberg. From an evaluators' point of view more data are required to provide a definitive half life, however in practice this radionuclide will generally be encountered in secular equilibrium with either the ^{228}Ra or ^{232}Th decay parents, and the exact value of the half life will likely be of no great concern to the user.

3 Atomic Data

All values of atomic data (ω_K, ω_L, η_{KL}, relative probabilities of X-ray and Auger emissions) were derived from Schönfeld and Janßen[11].

4 Gamma-ray Transitions and Internal Conversion Coefficients

Gamma-ray transition energies are calculated from the differences in level energies from Artna-Cohen[1].

Internal conversion coefficients have been determined using the BrIcc code[12], with the gamma-ray multipolarities and mixing ratios from the evaluation of Artna-Cohen[1]. For many emissions the multipolarity is undetermined, and no conversion coefficients could be calculated. Where a multipolarity is available but no mixing ratio given, a default value of 1 is assumed and the uncertainty of the derived conversion coefficients is increased accordingly.

Internal conversion coefficients have been measured by Herment and Vieu[4] and Mahajan and Bidarkundi[13] and these are compared in table 3 with the recommended values calculated with BrIcc. The agreement of the total conversion coefficients for the K and L shells is generally good. The 204 keV transition has been reassigned to M2 based upon the measured K conversion coefficient in 1982Ma52; the authors assign 96 % M2 + 4% E1 however the theoretical coefficients calculated using BrIcc for pure M2 are very close to the measured values.

Devare and Devare[24] have measured accurately the L_{II}/L_I conversion ratios for the 184 keV transition from the 1153 keV level and have assigned the multipolarity as predominantly E0 + M1 with a mixing ratio of $\delta \approx 0.3$. It is not possible with BrIcc to calculate conversion coefficients of mixed type transitions incorporating an E0 element, therefore the K-shell conversion coefficient has been estimated at 80 (30) from the measured data as the median of values measured by Herment and Vieu and Mahajan and Bidarkundi and the total coefficient of 100 (40) calculated from the calculated K/total ratio derived from BrIcc with the multipolarity and mixing ratio as above.

5 Electron Emissions

5.1 Beta-particle Emissions

There are no published measurements of the beta emissions in the open literature. Beta-particle transition energies have therefore been determined from the Q-value and level energies, and the emission probabilities from the balance of the decay scheme using the program ‘GTOL’[14].

A normalisation factor for the gamma emission probabilities of 0.0454 (11) has been used to determine absolute gamma emission intensities; however, applying this same value when deriving level feedings implies a ~7 % feeding direct to the ground state. Such a transition would be a 2nd forbidden unique decay and such a high branching seems unreasonable. By assuming negligible feeding to the ground state leads a normalisation factor of 0.0475 (11) is calculated, and this value is used to calculate beta particle emission intensities with GTOL. There is therefore an unexplained ~7 % discrepancy between the beta and gamma emissions in this decay; Artna-Cohen[1] suggests there are missing gammas in the decay scheme. Given the available data it seems such gammas would need to decay direct to the ground state and be of such character as to be difficult to detect, for example low energy or E0 transitions. Further measurements of the gamma data, particularly at low energy, would be of benefit, as would coincidence studies to validate the placement of gammas in the level scheme.

The Q-value coupled with the presence of a level in the decay scheme at 2123.1 (3) keV implies a beta emission with an end-point energy of 0.7 keV; it seems unlikely such a low energy emission could have a significant emission probability. This may indicate a deficiency in either the placement of gammas in the decay scheme or in the Q-value.

5.2 Auger & Conversion Electron Emissions

Auger and conversion electron emissions per 100 decays were calculated from the gamma-ray data and conversion coefficients according to the method of Schönfeld and Janßen[11] using version 3.10 of the code EMISSION.

6 Photon Emissions

6.1 X-ray Emissions

The X-ray intensities per 100 decays have been calculated from the gamma-ray data and conversion coefficients using version 3.10 of the code EMISSION. No measurements of the X-ray emissions have been published so it is not possible to make a comparison of calculated and measured data. A comparison with values in the NUDAT database is given in table 4.

6.2 Gamma-ray Emissions

The gamma-ray emission energies have been taken from Helmer[15] where possible, in which precise measurements were made by measuring energy differences against accepted calibration standards. Only the directly measured values have been taken, as the decay scheme used to derive further values was incomplete. These values have been adjusted to reflect the updated calibration standards given in Helmer and van der Leun[16]. Where gamma-ray lines are not present in Helmer[15], weighted means of the values in Herment and Vieu[4], Taylor[17], Kurcewicz et al[18], Borner et al[19], Dalmasso et al[2] and Baltzer et al[3] were taken. The uncertainties of Borner et al were expanded based upon the detector resolution stated in the publication. The values in these publications were first rescaled by a least-squares fit to be compatible with Helmer[15]. In most cases the energy shift incurred by doing so was very small.

Gamma emission probabilities were determined by a weighted mean of values in Arnoux and Gizon[20], Herment and Vieu[4], Mahajan and Bidarkundi[13], Sadasivan and Raghunath[21], Schötzig and Debertin[22], Dalmasso et al[2], Lin and Harbottle[23] and Baltzer et al[3]. Uncertainties were expanded to match the minimum input uncertainty where appropriate. Values were first renormalised to 100 for the 463 keV emission. Baltzer et al relates to ^{228}Pa decay, however additional information could be obtained from this publication for relative gamma emission probabilities originating from the 1431 keV level. Measured and evaluated relative emission probabilities are compared in appendices II and III. While there are several publications covering some of the emissions the intensities of many transitions have been derived solely from Dalmasso et al; where alternative data exists the agreement is often poor.

Several of the gamma emission probabilities measured by Mahajan and Bidarkundi have been rejected on technical grounds. The radionuclides used for calibration stated by the authors were ^{152}Eu, ^{160}Tb and ^{192}Ir. The lowest energy of any gamma line which could reliably be used for efficiency calibration belongs to ^{152}Eu at 122 keV; therefore, gamma emission intensities reported below this energy were rejected. Furthermore, in the energy region 321 keV to 338 keV there seems to be a consistent high bias to the data (see appendix I); two out of three measurements were rejected by Chauvenet’s criterion. The remaining measurement passed Chauvenet’s criterion but appears high and was rejected due to the obvious trend.

It is not clear that the data in Arnoux and Gizon[20] and Herment and Vieu[4] are independent; in many cases, the data are numerically identical, and appear to correspond to the work of the same research group. In cases where the same emission has been reported by both authors, only the data from the latter publication have been used in the analysis.

Absolute gamma emissions were measured by Schötzig and Debertin[22] and Lin and Harbottle[23]. The intensities of the 463 keV emissions were used to derive normalisation factors and these values are 0.0450 (12) and 0.0441 (11) respectively. The weighted mean of these two values at 0.0445 (11) was used to convert relative intensities into absolute intensities. However, this value is not consistent with expected beta decay characteristics (see section 5.1), suggesting deficiencies in either the adopted decay scheme or the measured data.

There are twenty gammas which cannot be placed in the level scheme. The total intensity is less than 0.25 % (accounting for some internal conversion). These are listed in table 2. The intensity of these gamma emissions is insufficient to account for the discrepancies observed in the decay scheme.

The 18.4 keV gamma has been observed but the probability not directly measured in ^{228}Ac decay; a nominal value of 0.14 (3) for the total transition probability has been derived based upon coincidence measurements on ^{228}Pa[16]. This implies a gamma emission probability of 0.019 (4).

Several doublets have been reported in ^{228}Ac decay. The measured gamma emission intensities have been divided between the components where possible by comparing with ^{228}Pa decay[3]:

168.53 (12) keV

The 1344 keV level has not being reported in ^{228}Pa decay, therefore the intensity of the 168 keV emission from the 1928 keV level was derived from the ratio of the 168 keV emission to the 1741 keV and 1870 keV emissions in ^{228}Pa:

Intensity 168 keV (^{228}Ac, 1928 keV) = intensity 168 keV ^{228}Pa / intensity 1741 keV ^{228}Pa × intensity 1741 keV ^{228}Ac

and:

Intensity 168 keV (^{228}Ac, 1928 keV) = intensity 168 keV ^{228}Pa / intensity 1870 keV ^{228}Pa × intensity 1870 keV ^{228}Ac

The calculated values are 0.0715 (18) and 0.0407 (43) respectively; these are not consistent so a median of the two values is taken, with an uncertainty large enough to cover the difference.

The assigned relative intensities are 0.056 (15) from the 1928 keV level and 0.25 (6) from the 1344 keV keV level. The absolute intensities are therefore 0.0025 (7) and 0.0111 (27) respectively.

278.80 (15) keV

The total relative intensity is 5.28 (28) determined by LRSW weighted mean of the measured data[2,13,20]. The intensity has been split between transitions from the 1153 keV and 1431 keV levels by comparing the emission intensities in ^{228}Ac decay and ^{228}Pa decay. The relative intensities are therefore 4.6 (5) and 0.69 (7) for transitions from the 1153 keV and 1431 keV levels respectively.

649.02 (12) keV

The measured relative intensity is 0.94 (10) from Dalmasso et al[2]. The intensity has been split between transitions from the 1168 keV and 1617 keV levels by comparing the emission intensities in ^{228}Ac decay and ^{228}Pa decay. The relative intensities are therefore 0.75 (8) and 0.189 (20) for transitions from the 1168 keV and 1617 keV levels respectively.

666.451 (46) keV

The measured relative intensity is 2.4 (2) from Dalmasso et al[2]. The intensity has been split between transitions from the 1645 keV and 1892 keV levels by comparing the emission intensities in ^{228}Ac decay and ^{228}Pa decay. The relative intensities are therefore 2.27 (23) and 0.128 (13) for transitions from the 1645 keV and 1892 keV levels respectively.

688.117 (42) keV

Dalmasso et al[2] suggests this emission originates from the 874 keV level; Baltzer et al[4] suggest dual placement from the 874 keV and 1016 keV levels. The measured relative intensity is 1.58 (14) from Dalmasso et al. The intensity has been split by comparing the emission intensities in ^{228}Ac decay and ^{228}Pa decay. The relative intensities are therefore 0.161 (16) and 1.42 (14) for transitions from the 1645 keV and 1892 keV levels respectively.

791.43 (8) keV

The measured relative intensity is 0.54 (17) from Dalmasso et al[2]. The intensity has been split between transitions from the 1760 keV and 1944 keV levels by comparing the emission intensities in ^{228}Ac decay and ^{228}Pa decay. The relative intensities are therefore 0.23 (7) and 0.31 (10) for transitions from the 1760 keV and 1944 keV levels respectively.

853.96 (8) keV

Artna-Cohen[1] indicates a doublet between an unplaced transition and a transition originating from the 1944 keV level. The energy measured by Dalmasso et al[2] is 853.19 (10) keV however a transition of this energy does not readily fit in to the level scheme as it stands. In the absence of confirmatory measurements it is assumed this transition is the same as that observed at 853.96 keV by Baltzer et al[4] in ^{228}Pa decay. The entire measured intensity of 0.0124 (20) is assigned to the 1944 keV level, and the energy is determined from ^{228}Pa decay.

921.87 (12) keV

Artna-Cohen indicates a doublet between the 979 keV and 1925 keV levels. However, the transition from the 1925 keV level was reported separately by Baltzer et al[4] in ^{228}Pa decay at an energy of 922.5 keV. Based upon the reported energy, it is assumed the transition measured in ^{228}Ac decay is predominantly from the 979 keV level. This emission has therefore been assigned in it’s entirety to decay from the 979 keV level.

930.99 (6) keV

The total measured intensity is 0.0129 (20) from 1987Da28. The intensity has been split between transitions from the 1450 keV and 1899 keV levels by comparing the emission intensities in ^{228}Ac decay and ^{228}Pa decay. The absolute intensities are therefore 0.0040 (10) and 0.0025 (23) for transitions from the 1760 keV and 1944 keV levels respectively.

1016.44 (8) keV

Observed in both ^{228}Ac and ^{228}Pa decay. Dalmasso et al[2] suggests a multiple placing, originating from both the 1016 keV and 1344 keV levels of ^{228}Th. Baltzer et al[4] gives only a “less than” value for the 1016 keV transition. The 1344 keV level is not indicated as being fed in ^{228}Pa decay, and assuming the intensity in ^{228}Pa decay is half the “less than” value gives a branching ratio very similar to that observed in ^{228}Ac decay. The intensity has therefore been assigned in its entirety to the transition from the 1016 keV level.

1110.604 (9) keV

The total measured intensity is 0.311 (24) from a weighted mean of Arnoux and Gizon[20] and Dalmasso et al[2]. The intensity has been split between transitions from the 1168 keV and 1297 keV levels by comparing the emission intensities in ^{228}Ac decay and ^{228}Pa decay (1995Ba42). The relative intensities are therefore 6.4 (5) and 0.60 (5) for transitions from the 1168 keV and 1297 keV levels respectively.

Table 1. Comparison of beta transition probabilities calculated using the gamma normalisation factor derived from measurements using a normalisation factor of 0.0445 (11) [A] and from assuming zero feeding to the ground state with a normalisation factor of 0.0474 (11) [B]. Where the calculated beta transition probability is within one standard deviation of zero, a “less than” value is stated. In these cases the emission is not assumed to occur with significant probability. The values calculated assuming zero feeding to the ground state have been recommended.

Level energy /keV	Beta endpoint energy /keV	Feeding /per 100 decays		log *ft*	Transition type
		[A]	[B]		
ground state	2123.8 (27)	7 (3)	<6	-	2nd forbidden unique
57.759 (4)	2066.0 (27)	6 (4)	6 (4)	9.0 (4)	allowed
186.823 (4)	1937.0 (27)	0.6 (5)	0.6 (5)	10 (4)	allowed
328.003 (4)	1795.8 (27)	0.67 (22)	0.72 (23)	10.65 (20)	1st forbidden unique
378.179 (10)	1745.6 (27)	0.138 (19)	0.147 (21)	12.29 (16)	2nd forbidden unique
396.078 (5)	1727.7 (27)	11.6 (5)	12.4 (5)	8.40 (15)	1st forbidden unique
519.192 (6)	1604.6 (27)	<0.07	<0.07	-	1st forbidden unique
831.823 (10)	1292.0 (27)	<0.01	<0.05	-	1st forbidden unique
874.473 (18)	1249.3 (27)	0.16 (10)	0.17 (10)	9.7 (3)	allowed
938.58 (7)	1185.2 (27)	<0.01	<0.01	-	2nd forbidden unique
944.196 (13)	1179.6 (27)	0.081 (15)	0.087 (16)	9.95 (17)	allowed /1t forbidden
968.369 (20)	1155.4 (27)	0.17 (3)	0.18 (3)	9.60 (16)	1st forbidden
968.968 (5)	1154.8 (27)	29 (3)	31 (4)	7.37 (16)	allowed
979.499 (14)	1144.3 (27)	0.224 (19)	0.238 (20)	9.47 (15)	allowed
1016.406 (21)	1107.4 (27)	0.36 (6)	0.39 (6)	9.20 (16)	allowed/1st forbidden
1022.527 (6)	1101.3 (27)	2.8 (4)	3.0 (4)	8.31 (16)	allowed
1059.93 (3)	1063.9 (27)	0.093 (11)	0.099 (11)	9.74 (15)	1st forbidden
1091.017 (8)	1032.8 (27)	0.16 (7)	0.16 (7)	9.48 (24)	allowed
1122.951 (6)	1000.8 (27)	6.27 (17)	6.67 (18)	7.81 (15)	1st forbidden
1153.467 (10)	970.3 (27)	6 (3)	6 (3)	7.8 (3)	allowed
1168.375 (5)	955.4 (27)	3.18 (11)	3.39 (11)	8.04 (15)	1st forbidden
1174.508 (18)	949.3 (27)	<	<		allowed
1175.39 (5)	948.4 (27)	0.155 (18)	0.166 (19)	9.34 (15)	allowed
1226.565 (7)	897.2 (27)	0.63 (7)	0.67 (8)	8.65 (15)	1st forbidden
1297.423 (10)	826.4 (27)	1.37 (10)	1.46 (11)	8.18 (15)	1st forbidden unique
1344.078 (11)	779.7 (27)	0.208 (18)	0.208 (18)	8.94 (15)	1st forbidden
1416.11 (6)	707.7 (27)	0.060 (8)	0.060 (8)	9.34 (16)	allowed /1st forbidden
1431.979 (6)	691.8 (27)	1.6 (5)	1.6 (5)	7.88 (20)	allowed
1450.394 (10)	673.4 (27)	0.25 (8)	0.26 (9)	8.63 (21)	1st forbidden
1531.474 (6)	592.3 (27)	<3	<3	-	allowed
1539.21 (9)	584.6 (27)	<0.01	0.030 (6)	9.36 (17)	allowed
1588.335 (14)	535.5 (27)	8.2 (22)	8.8 (23)	6.77 (19)	1st forbidden
1617.78 (7)	506.0 (27)	0.067 (10)	0.071 (10)	8.78 (16)	allowed
1638.284 (9)	485.5 (27)	1.16 (6)	1.23 (6)	7.48 (15)	allowed
1643.125 (15)	480.7 (27)	0.82 (3)	0.82 (3)	7.64 (15)	1st forbidden
1645.954 (12)	477.8 (27)	4.12 (20)	4.12 (20)	6.94 (15)	allowed
1682.81 (3)	441.0 (27)	1.21 (4)	1.21 (4)	7.35 (15)	allowed
1683.82 (5)	440.0 (27)	0.20 (3)	0.20 (3)	8.13 (16)	1st forbidden
1688.394 (11)	435.4 (27)	2.50 (16)	2.50 (16)	7.02 (15)	allowed
1724.283 (6)	399.5 (27)	1.81 (8)	1.93 (8)	7.01 (15)	allowed
1735.45 (25)	388.4 (27)	0.140 (10)	0.149 (11)	8.08 (15)	allowed
1743.89 (3)	379.9 (27)	0.355 (15)	0.378 (16)	7.65 (15)	allowed
1758.24 (12)	365.6 (27)	0.056 (8)	0.06 (8)	8.39 (16)	allowed
1760.218 (24)	363.6 (27)	0.130 (11)	0.139 (12)	8.02 (15)	allowed
1795.90 (10)	327.9 (27)	0.033 (5)	0.035 (6)	8.48 (16)	allowed
1797.65 (8)	326.2 (27)	0.048 (8)	0.051 (8)	8.30 (16)	allowed
1892.996 (17)	230.8 (27)	0.102 (8)	0.109 (8)	7.50 (15)	allowed
1899.95 (4)	223.9 (27)	0.064 (7)	0.069 (8)	7.65 (15)	allowed

Level energy /keV	Beta endpoint energy /keV	Feeding /per 100 decays		log *ft*	Transition type
		[A]	[B]		
1906.64 (10)	217.2 (27)	0.023 (5)	0.025 (5)	8.05 (17)	allowed
1928.57 (6)	195.2 (27)	0.057 (7)	0.061 (7)	7.52 (16)	allowed
1937.16 (9)	186.6 (27)	0.050 (6)	0.053 (6)	7.52 (15)	allowed
1944.895 (11)	178.9 (27)	0.289 (20)	0.307 (22)	6.70 (15)	allowed
1958.72 (22)	165.1 (27)	0.0035 (8)	0.0038 (8)	8.50 (17)	allowed
1964.98 (7)	158.8 (27)	0.0124 (13)	0.0132 (14)	7.91 (15)	allowed
1987.46 (10)	136.3 (27)	0.07 (4)	0.07 (4)	7.0 (3)	allowed
2010.11 (5)	113.7 (27)	0.224 (14)	0.238 (15)	6.20 (15)	allowed
2013.6 (3)	110.2 (27)	0.0030 (9)	0.0032 (10)	8.03 (20)	allowed
2022.84 (10)	101.0 (27)	0.057 (6)	0.061 (6)	6.64 (16)	allowed/1st forbidden
2029.84 (16)	94.0 (27)	0.024 (4)	0.026 (4)	6.91 (16)	allowed
2036.99 (17)	86.8 (27)	0.0065 (11)	0.0069 (10)	7.38 (17)	allowed
2123.1 (3)	0.7 (27)	0.0044 (10)	0.0047 (11)	≤3.3	allowed

Table 2. Unplaced gamma emissions. The following gamma emissions have not been unambiguously placed in the level scheme. The energy lost from the decay scheme is insufficient to explain the deviation in Q_{eff} and the total probability is insufficient to explain the anomalous feeding to the ground state.

Energy /keV	Emission probability per 100 decays	Observed in	Comments
466.40 (10)	0.0299 (34)	1987Da28	-
481.5 (5)	0.024 (5)	1987Da28, 1995Ba42	Placed at 1450 keV level by 1995Ba42, however unreasonable multipolarity of M2 or E3 results (from Artna-Cohen).
634.18 (10)	0.0111 (22)	1987Da28	-
1337.33 (20)	0.0051 (16)	1987Da28	-
1378.23 (10)	0.0062 (19)	1987Da28	-
1385.39 (10)	0.0111 (22)	1987Da28	-
1434.22 (15)	0.0084 (25)	1987Da28	-
1438.01 (10)	0.0062 (17)	1987Da28	-
1480.38 (15)	0.0170 (34)	1987Da28, 1995Ba42	-
1529.01 (34)	0.059 (6)	1969Ar16, 1987Da28, 1995Ba42	Assigned by 1995Ba42 to 1925 keV level, this level not listed in ^{228}Ac decay. If present 1738 keV may be multiply placed.
1671.67 (15)	0.0043 (14)	1987Da28	-
1684.04 (20)	0.0154 (49)	1987Da28	-
1721.49 (30)	0.0059 (19)	1987Da28	-
1745.32 (20)	0.0067 (9)	1987Da28	-
1784.40 (30)	0.0062 (11)	1987Da28, 1995Ba42	-
1787.20 (20)	0.0013 (5)	1987Da28	May correspond to transition placed from 1974 keV level in ^{228}Pa decay
1916.34 (33)	0.00081 (27)	1987Da28, 1995Ba42	May correspond to transition placed from 1974 keV level in ^{228}Pa decay
1919.54 (30)	0.0022 (6)	1987Da28, 1995Ba42	-
1944.24 (20)	0.0022 (6)	1987Da28	-
2001.0 (5)	0.00108 (28)	1987Da28	-
Total Intensity	0.22 (7)		

Table 3. Comparison of experimental and calculated conversion coefficients for selected gamma transitions.

Transition energy /keV	Multipolarity	Subshell	Publication	Measured conversion coefficient	Calculated (BrIcc)
57.759 (4)	E2	L_I+L_{II}	1982Ma52	50 (4)	61.8 (9)
		L_{III}	1982Ma52	35 (3)	50.4 (7)
		L-total	1971He23	117 (6)	112.2 (16)
99.495 (8)	M1	L_I	1982Ma52	1.9 (1)	2.58 (4)
		L_{II}	1982Ma52	0.12 (1)	0.305 (5)
		L_{III}	1982Ma52	0.17 (3)	0.01646 (20)
		L-total	1971He23	2.8 (1)	2.90 (4)
129.064 (6)	E2	L_I	1982Ma52	0.17 (3)	0.1025 (15)
		L_{II}	1982Ma52	1.6 (1)	1.494 (21)
		L_{III}	1982Ma52	~0.97	0.943 (14)
		L-total	1971He23	2.45 (15)	2.54 (4)
137.941 (17)	M1	K	1971He23	4.1 (14)	6.00 (9)
		L-total	1971He23	0.8 (4)	1.146 (16)
204.038 (9)	M2	K	1982Ma52	7.5 (8)	7.26 (11)

Table 4 Comparison of X-rays calculated using EMISSION with those in the NUDAT database. Note X-ray emission probabilities for this evaluation are generally within uncertainties of, but consistently higher than the NUDAT values.

Transition	**NUDAT**		**DDEP**	
	Energy /keV	**Probability /%**	**Energy /keV**	**Probability /%**
K-α1	93.35	3.1 (4)	93.351	4.0 (11)
K-α2	89.957	1.9 (3)	89.954	2.5 (7)
L-total	~13.0	33.7 (21)	11.1-19.5	37 (4)

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Appendix I. Tables of gamma emission energies

Energies have been taken from 1979He10[15] where possible, adjusted using the later reference energies of Helmer[16]. All other energies have been taken from a weighted mean of data from 1971He23[4], 1973Ta25[17], 1977Ku01[18], 1979Bo30[19], 1987Da28[2] and 1995Ba42[5]. All energies have been adjusted to be on the same energy scale as 1979He10[15] before taking means. Nominal energies given in table headings are taken from the evaluation of Artna-Cohen[1].

Nominal Energy /keV	**42.46**	**56.86**	**57.766**	**77.34**	**99.509**
1979He10	-	-	57.752 (13)	-	99.505 (12)
1971He23	-	-	57.74 (8)	-	99.49 (11)
1973Ta25	-	-	57.78 (6)	-	99.45 (8)
1977Ku01	-	-	57.77 (7)	-	-
1979Bo30	-	-	-	-	-
1987Da28	42.457 (50)	56.96 (5)	57.761 (6)	77.338 (30)	99.497 (6)
1995Ba42	42.46 (10)	56.852 (32)	57.752 (22)	77.35 (10)	99.461 (61)
LWEIGHT4	42.46 (5)	56.88 (5)	57.760 (13)	77.340 (30)	99.496 (6)
Adopted	**42.46 (5)**	**56.88 (5)**	**57.752 (13)**	**77.34 (3)**	**99.505 (12)**
Comments	wtd mean	wtd mean	1979He10	wtd mean	1979He10

Nominal Energy /keV	**100.41**	**114.54**	**129.065**	**135.51**	**137.95**
1979He10	-	-	129.0652 (30)	-	-
1971He23	100.39 (11)	-	129.09 (11)	135.49 (20)	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	129.07 (7)	-	-
1979Bo30	-	-	129.07 (16)	-	-
1987Da28	100.408 (30)	114.56 (7)	129.067 (7)	135.539 (50)	137.91 (5)
1995Ba42	100.41 (10)	-	129.051 (22)	135.501 (22)	137.941 (22)
LWEIGHT4	100.410 (30)	-	129.071 (8)	135.507 (20)	137.936 (22)
Adopted	**100.41 (3)**	**114.56 (7)**	**129.065 (3)**	**135.507 (22)**	**137.936 (22)**
Comments	wtd mean	1987Da28	1979He10	wtd mean	wtd mean

Nominal Energy /keV	**141.01**	**145.849**	**153.977**	**168.65**	**173.964**
1979He10	-	-	-	-	173.964 (26)
1971He23	140.89 (20)	146.19 (20)	153.99 (20)	-	174.00 (20)
1973Ta25	-	-	-	-	-
1977Ku01	141.0 (5)	-	-	-	-
1979Bo30	-	-	153.956 (19)	-	-
1987Da28	141.019 (30)	145.848 (11)	153.977 (11)	168.650 (11)	173.980 (10)
1995Ba42	140.991 (22)	145.811 (22)	153.941 (22)	168.41 (9)	174.011 (41)
LWEIGHT4	140.999 (20)	145.842 (20)	153.967 (8)	168.53 (12)	173.995 (28)
Adopted	**140.999 (20)**	**145.842 (20)**	**153.967 (11)**	**168.53 (12)**	**173.96 (3)**
Comments	wtd mean	wtd mean	wtd mean	wtd mean	wtd mean

Nominal Energy /keV	**184.54**	**191.353**	**199.407**	**204.026**	**209.253**
1979He10	-	-	-	-	-
1971He23	184.50 (11)	192.10 (30)	-	-	209.20 (20)
1973Ta25	-	-	-	-	-
1977Ku01	-	190.99 (20)	-	-	209.50 (50)
1979Bo30	-	-	-	-	209.238 (21)
1987Da28	184.540 (20)	191.353 (11)	199.408 (15)	204.027 (11)	209.254 (7)
1995Ba42	184.60 (5)	191.341 (21)	199.391 (21)	204.041 (21)	209.251 (21)
LWEIGHT4	184.547 (19)	191.351 (17)	199.402 (12)	204.029 (9)	209.248 (5)
Adopted	**184.547 (19)**	**191.351 (17)**	**199.402 (15)**	**204.029 (11)**	**209.248 (7)**
Comments	wtd mean	wtd mean	wtd mean	wtd mean	wtd mean

Nominal Energy /keV	**214.85**	**223.8**	**231.42**	**257.7**	**263.62**
1979He10	-	-	-	-	-
1971He23	-	223.70	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	214.85 (10)	223.85 (10)	231.42 (10)	257.52 (10)	263.58 (10)
1995Ba42	214.92 (10)	223.791 (21)	231.49 (5)	257.481 (21)	-
LWEIGHT4	214.89 (7)	223.793 (21)	231.477 (45)	257.482 (21)	-
Adopted	**214.89 (10)**	**223.793 (21)**	**231.42 (10)**	**257.482 (21)**	**263.58 (10)**
Comments	wtd mean	wtd mean	1987Da28	wtd mean	1987Da28

The value of 231.49 (5) keV line observed by 1995Ba42 is believed to relate to a separate gamma transition and has not been used.

Nominal Energy /keV	**270.245**	**278.95**	**282.0**	**321.646**	**326.04**
1979He10	270.245 (7)	-	282.022 (40)	321.646 (8)	-
1971He23	270.20 (50)	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	270.19 (21)	-	-	-	-
1979Bo30	270.235 (14)	-	-	-	-
1987Da28	270.245 (7)	278.952 (50)	281.922 (50)	321.653 (50)	326.04 (20)
1995Ba42	270.241 (21)	278.651 (21)	282.001 (21)	321.701 (31)	-
LWEIGHT4	270.255 (7)	278.80 (15)	281.989 (28)	321.688 (26)	-
Adopted	**270.245 (7)**	**278.80 (15)**	**282.02 (4)**	**321.646 (8)**	**326.04 (20)**
Comments	1979He10	wtd mean	1979He10	1979He10	1987Da28

Nominal Energy /keV	**327.44**	**328.00**	**332.37**	**338.32**	**340.98**
1979He10	-	-	332.371 (6)	338.320 (5)	-
1971He23	-	-	-	338.31 (40)	-
1973Ta25	-	-	-	-	-
1977Ku01	-	327.89 (22)	332.29 (10)	338.09 (22)	-
1979Bo30	-	328.003 (11)	-	338.321 (10)	-
1987Da28	-	328.004 (7)	332.374 (50)	338.324 (6)	340.964 (50)
1995Ba42	327.45 (4)	328.02 (4)	332.360 (21)	338.310 (21)	340.970 (21)
LWEIGHT4	-	328.004 (7)	332.366 (35)	338.342 (18)	340.969 (19)
Adopted	**-**	**328.004 (7)**	**332.371 (6)**	**338.320 (5)**	**340.969 (21)**
Comments	not used	wtd mean	1979He10	1979He10	wtd mean

The 327.44 keV line is listed in Artna-Cohen based upon expected presence inferred from ^{228}Pa EC decay. However, only lines directly observed in ^{228}Ac decay are considered here.

Nominal Energy /keV	**356.94**	**372.57**	**377.99**	**384.47**	**389.12**
1979He10	-	-	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	356.94 (10)	372.57 (20)	377.99 (10)	384.63 (20)	389.12 (15)
1995Ba42	356.35 (10)	372.590 (31)	377.98 (10)	384.43 (10)	389.40 (10)
LWEIGHT4	356.65 (30)	372.590 (30)	377.99 (7)	384.47 (9)	389.32 (13)
Adopted	**356.7 (3)**	**372.59 (3)**	**377.99 (10)**	**384.47 (9)**	**389.32 (13)**
Comments	wtd mean	wtd mean	wtd mean	wtd mean	wtd mean

Nominal Energy /keV	**397.94**	**399.62**	**409.462**	**416.3**	**419.4**
1979He10	-	-	409.460 (13)	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	409.487 (33)	-	-
1987Da28	397.95 (10)	399.63 (10)	409.456 (10)	416.31 (20)	419.43 (10)
1995Ba42	-	399.93 (7)	409.440 (21)	415.90 (8)	419.34 (10)
LWEIGHT4	-	399.83 (14)	409.464 (25)	415.96 (14)	419.38 (7)
Adopted	**397.95 (10)**	**399.83 (14)**	**409.460 (13)**	**415.96 (14)**	**419.38 (7)**
Comments	1987Da28	wtd mean	1979He10	wtd mean	wtd mean

Nominal Energy /keV	**440.44**	**449.21**	**452.51**	**457.35**	**463.004**
1979He10	440.450 (24)	449.11 (6)	-	-	463.002 (6)
1971He23	-	-	-	-	463.33 (41)
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	463.002 (13)
1987Da28	440.446 (50)	449.26 (10)	452.47 (10)	457.18 (15)	463.023 (10)
1995Ba42	440.390 (40)	449.22 (30)	452.51 (6)	-	463.01 (50)
LWEIGHT4	440.418 (35)	449.24 (7)	452.50 (5)	-	463.048 (15)
Adopted	**440.450 (24)**	**449.11 (6)**	**452.50 (6)**	**457.18 (15)**	**463.002 (6)**
Comments	1979He10	1979He10	wtd mean	1987Da28	wtd mean

Nominal Energy /keV	**466.4**	**470.2**	**471.76**	**474.79**	**478.4**
1979He10	-	-	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	478 (1)
1979Bo30	-	-	-	-	-
1987Da28	466.40 (10)	470.26 (20)	471.77 (15)	474.76 (10)	478.337 (50)
1995Ba42	-	469.89 (50)	-	475.09 (30)	478.440 (40)
LWEIGHT4	-	470.21 (19)	-	474.79 (10)	478.399 (37)
Adopted	**466.40 (10)**	**470.21 (20)**	**471.77 (15)**	**474.79 (10)**	**478.40 (5)**
Comments	1987Da28	wtd mean	1987Da28	wtd mean	wtd mean

Nominal Energy /keV	**480.94**	**490.33**	**492.37**	**497.64**	**503.823**
1979He10	-	-	-	-	503.819 (23)
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	503.60 (33)
1979Bo30	-	-	-	-	-
1987Da28	480.95 (20)	490.33 (15)	492.38 (10)	497.50 (15)	503.83 (50)
1995Ba42	482.03 (5)	-	492.21 (10)	497.70 (10)	503.69 (20)
LWEIGHT4	481.5 (5)	-	492.29 (8)	497.64 (9)	503.67 (18)
Adopted	**481.5 (5)**	**490.33 (15)**	**492.29 (8)**	**497.64 (10)**	**503.819 (23)**
Comments	wtd mean	1987Da28	wtd mean	wtd mean	1979He10

Nominal Energy /keV	**508.959**	**515.06**	**520.151**	**523.131**	**540.76**
1979He10	508.955 (13)	-	520.16 (3)	523.129 (22)	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	508.968 (50)	515.07 (10)	520.18 (5)	523.118 (50)	540.77 (10)
1995Ba42	509.12 (8)	515.19 (11)	520.16 (8)	523.15 (11)	540.650 (50)
LWEIGHT4	509.04 (8)	515.12 (7)	520.17 (6)	523.13 (8)	540.674 (48)
Adopted	**508.955 (13)**	**515.12 (7)**	**520.16 (3)**	**523.129 (22)**	**540.67 (5)**
Comments	1979He10	wtd mean	1979He10	1979He10	wtd mean

Nominal Energy /keV	**546.45**	**548.73**	**555.12**	**562.5**	**570.91**
1979He10	-	-	-	562.496 (7)	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	547 (1)	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	546.479 (50)	548.74 (15)	555.13 (10)	562.529 (30)	570.91 (10)
1995Ba42	546.440 (21)	548.73 (11)	554.59 (30)	562.490 (40)	570.870 (40)
LWEIGHT4	546.445 (19)	548.73 (9)	555.07 (16)	562.509 (29)	570.876 (37)
Adopted	**546.445 (21)**	**548.73 (11)**	**555.07 (16)**	**562.496 (7)**	**570.88 (4)**
Comments	wtd mean	wtd mean	wtd mean	1979He10	wtd mean

Nominal Energy /keV	**572.14**	**583.41**	**590.4**	**610.64**	**616.2**
1979He10	572.10 (5)	-	-	-	616.212 (30)
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	572.30 (10)	583.419 (50)	-	610.65 (10)	616.27 (10)
1995Ba42	572.290 (21)	583.390 (10)	590.64 (11)	-	616.139 (50)
LWEIGHT4	572.290 (20)	583.391 (10)	-	-	616.20 (7)
Adopted	**572.10 (5)**	**583.391 (10)**	**-**	**610.65 (10)**	**616.21 (3)**
Comments	1979He10	wtd mean	not used	wtd mean	1979He10

Nominal Energy /keV	**620.38**	**623.27**	**627.23**	**629.4**	**634.18**
1979He10	-	-	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	620.390 (50)	623.27 (20)	627.24 (20)	629.410 (50)	634.18 (10)
1995Ba42	620.259 (50)	623.7 (2)	626.69 (10)	629.39 (20)	-
LWEIGHT4	620.32 (7)	623.48 (22)	626.80 (22)	629.409 (49)	-
Adopted	**620.32 (7)**	**623.48 (22)**	**626.80 (22)**	**629.41 (5)**	**634.18 (10)**
Comments	wtd mean	wtd mean	wtd mean	wtd mean	1987Da28

Nominal Energy /keV	**640.34**	**648.84**	**651.5**	**660.1**	**663.88**
1979He10	640.317 (37)	-	651.526 (28)	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	640.371 (50)	648.85 (10)	651.461 (50)	660.11 (30)	663.83 (10)
1995Ba42	640.319 (50)	649.11 (7)	651.49 (20)	660.17 (30)	663.91 (8)
LWEIGHT4	640.345 (36)	649.02 (12)	651.48 (14)	660.14 (21)	663.88 (6)
Adopted	**640.32 (4)**	**649.02 (12)**	**651.53 (3)**	**660.1 (3)**	**663.88 (8)**
Comments	1979He10	wtd mean	1979He10	wtd mean	wtd mean

Nominal Energy /keV	**666.47**	**672.0**	**674.76**	**677.07**	**684.0**
1979He10	666.451 (46)	-	674.625 (40)	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	666.46 (10)	672.01 (15)	674.61 (10)	677.12 (10)	-
1995Ba42	666.459 (40)	671.93 (10)	674.76 (10)	676.89 (20)	683.99 (30)
LWEIGHT4	666.46 (7)	671.95 (8)	674.69 (7)	677.08 (9)	-
Adopted	**666.45 (5)**	**671.95 (8)**	**674.63 (4)**	**677.08 (10)**	**-**
Comments	1979He10	wtd mean	1979He10	wtd mean	not used

Nomina Energy /keV	**688.11**	**692.47**	**699.08**	**701.747**	**707.41**
1979He10	-	-	-	701.742 (15)	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	688.112 (50)	-	699.09 (15)	701.752 (50)	707.422 (50)
1995Ba42	688.13 (8)	692.46 (7)	698.94 (10)	701.709 (40)	707.39 (30)
LWEIGHT4	688.117 (42)	-	698.99 (8)	701.731 (35)	707.421 (49)
Adopted	**688.12 (4)**	**-**	**698.99 (10)**	**701.742 (15)**	**707.42 (5)**
Comments	wtd mean	not used	wtd mean	1979He10	wtd mean

Nominal Energy /keV	**718.48**	**726.863**	**737.72**	**755.315**	**770.2**
1979He10	-	727.317 (15)	-	755.313 (9)	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	718.49 (15)	726.876 (15)	737.733 (50)	755.325 (15)	-
1995Ba42	718.299 (21)	726.89 (10)	737.79 (20)	755.309 (21)	770.2 (2)
LWEIGHT4	718.303 (26)	726.88 (7)	737.736 (49)	755.317 (15)	-
Adopted	**718.30 (3)**	**726.88 (10)**	**737.74 (5)**	**755.313 (9)**	**-**
Comments	wtd mean	wtd mean	wtd mean	1979He10	not used

The 684 keV, 692 keV and 770 keV emissions have not been observed directly in ^{228}Ac decay and are not included in this evaluation.

There is a considerable discrepancy between data measured for the 727 keV line by 1979He10 and the mean of values measured by 1987Da28 and 1995Ba42. The value measured by 1979He10 is not consistent with the decay scheme; this is possibly due to interference from the ^{212}Bi decay daughter. The weighted mean of 1987Da28 and 1995Ba42 is used instead.

Nominal Energy /keV	**772.291**	**774.1**	**776.52**	**778.1**	**782.142**
1979He10	772.291 (7)	-	-	-	782.140 (6)
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	772.294 (10)	774.11 (20)	776.57 (10)	-	782.154 (50)
1995Ba42	772.269 (21)	774.06 (10)	776.509 (30)	778.09 (20)	782.09 (20)
LWEIGHT4	772.282 (25)	774.07 (9)	776.514 (29)	-	782.12 (14)
Adopted	**772.291 (7)**	**774.07 (10)**	**776.51 (3)**	**-**	**782.140 (6)**
Comments	1979He10	wtd mean	wtd mean	not used	1979He10

Nominal Energy /keV	**791.44**	**792.8**	**794.947**	**813.77**	**816.62**
1979He10	-	-	794.942 (14)	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	817 (1)
1979Bo30	-	-	794.94 (14)	-	-
1987Da28	791.50 (25)	792.8 (10)	794.940 (10)	813.78 (15)	816.71 (10)
1995Ba42	791.42 (9)	792.69 (10)	794.959 (20)	813.92 (10)	816.92 (10)
LWEIGHT4	791.43 (8)	792.69 (10)	794.951 (14)	813.88 (8)	816.82 (7)
Adopted	**791.43 (9)**	**792.69 (10)**	**794.942 (14)**	**813.88 (10)**	**816.82 (10)**
Comments	wtd mean	wtd mean	1979He10	wtd mean	wtd mean

Nominal Energy /keV	**824.934**	**830.486**	**835.71**	**840.377**	**853.17**
1979He10	824.931 (25)	830.481 (8)	835.704 (8)	840.372 (9)	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	824.87 (10)	830.476 (20)	835.708 (20)	840.370 (20)	853.19 (10)
1995Ba42	-	830.469 (30)	835.639 (21)	840.349 (40)	853.96 (8)
LWEIGHT4	-	830.472 (22)	835.674 (35)	840.366 (18)	-
Adopted	**824.931 (25)**	**830.481 (8)**	**835.704 (8)**	**840.372 (9)**	**853.96 (8)**
Comments	1979He10	1979He10	1979He10	1979He10	1995Ba42

The values of the 853 keV line from 1987Da28 and 1995Ba42 are clearly discrepant; the value of 1995Ba42 has been preferred as it better fits the level scheme.

Nominal Energy /keV	**870.45**	**873.11**	**874.45**	**877.39**	**880.76**
1979He10	870.47 (7)	-	874.45 (8)	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	870.456 (50)	873.17 (15)	874.41 (15)	877.48 (10)	880.76 (10)
1995Ba42	870.438 (21)	872.99 (20)	874.49 (20)	877.34 (7)	-
LWEIGHT4	870.441 (19)	873.10 (12)	874.44 (12)	877.38 (6)	-
Adopted	**870.47 (7)**	**873.10 (15)**	**874.45 (8)**	**877.38 (7)**	**880.76 (10)**
Comments	1979He10	wtd mean	1979He10	wtd mean	1987Da28

Nominal Energy /keV	**887.33**	**901.26**	**904.19**	**911.204**	**919.01**
1979He10	-	-	904.20 (5)	911.196 (6)	-
1971He23	-	-	-	911.27 (25)	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	911.166 (40)	-
1987Da28	887.34 (10)	901.25 (15)	904.197 (50)	911.233 (11)	918.99 (10)
1995Ba42	887.18 (10)	90.388 (31)	904.178 (31)	911.188 (21)	919.39 (30)
LWEIGHT4	887.26 (8)	901.383 (30)	904.183 (26)	911.221 (13)	919.03 (12)
Adopted	**887.26 (10)**	**901.38 (3)**	**904.20 (5)**	**911.196 (6)**	**919.03 (12)**
Comments	wtd mean	wtd mean	1979He10	1979He10	wtd mean

Nominal Energy /keV	**921.98**	**924.03**	**930.93**	**939.87**	**944.196**
1979He10	-	-	-	-	944.191 (30)
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	922.00 (10)	-	930.95 (10)	939.89 (15)	944.178 (50)
1995Ba42	921.75 (10)	924.29 (20)	931.01 (7)	-	944.30 (6)
LWEIGHT4	921.87 (12)	-	930.99 (6)	-	944.23 (6)
Adopted	**921.87 (12)**	**-**	**930.99 (7)**	**939.89 (15)**	**944.19 (3)**
Comments	wtd mean	not used	wtd mean	1987Da28	1979He10

Nominal Energy /keV	**947.982**	**958.61**	**964.766**	**968.971**	**975.98**
1979He10	947.976 (24)	958.591 (38)	964.786 (8)	968.960 (9)	-
1971He23	-	-	964.48 (43)	968.88 (34)	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	964.68 (9)	969.161 (34)	-
1987Da28	947.968 (50)	958.638 (50)	964.783 (11)	968.989 (11)	975.978 (50)
1995Ba42	-	958.68 (11)	964.788 (21)	968.668 (21)	975.987 (50)
LWEIGHT4	-	958.645 (46)	964.783 (36)	968.90 (10)	975.983 (36)
Adopted	**947.976 (24)**	**958.59 (4)**	**964.786 (8)**	**968.960 (9)**	**975.98 (5)**
Comments	1979He10	1979He10	1979He10	1979He10	wtd mean

Nominal Energy /keV	**979.48**	**987.88**	**988.63**	**1000.69**	**1013.58**
1979He10	-	-	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	979.50 (10)	987.73 (10)	988.65 (20)	1000.71 (15)	1013.60 (20)
1995Ba42	979.39 (40)	987.91 (10)	-	1000.67 (10)	1013.53 (13)
LWEIGHT4	979.49 (10)	987.87 (9)	-	1000.68 (8)	1013.55 (11)
Adopted	**979.49 (10)**	**987.87 (10)**	**988.65 (20)**	**1000.68 (10)**	**1013.55 (13)**
Comments	wtd mean	wtd mean	1987Da28	wtd mean	wtd mean

Nominal Energy /keV	**1016.44**	**1017.92**	**1019.86**	**1033.248**	**1039.84**
1979He10	-	-	-	1033.244 (23)	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1016.46 (15)	1017.94 (20)	1019.88 (10)	1033.240 (20)	1039.67 (15)
1995Ba42	1016.4 (10)	-	-	1033.26 (7)	1039.86 (6)
LWEIGHT4	1016.44 (8)	-	-	1033.241 (19)	1039.83 (7)
Adopted	**1016.44 (10)**	**1017.94 (20)**	**1019.88 (10)**	**1033.244 (23)**	**1039.83 (7)**
Comments	wtd mean	1987Da28	1987Da28	1979He10	wtd mean

Nominal Energy /keV	**1040.92**	**1053.09**	**1054.22**	**1062.55**	**1065.19**
1979He10	-	-	-	-	1065.168 (15)
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1040.94 (15)	1053.11 (20)	1054.13 (20)	1062.57 (15)	1065.200 (50)
1995Ba42	-	-	-	-	1065.20 (7)
LWEIGHT4	-	-	-	-	1065.200 (41)
Adopted	**1040.94 (15)**	**1053.11 (20)**	**1054.13 (20)**	**1062.57 (15)**	**1065.168 (15)**
Comments	1987Da28	1987Da28	1987Da28	1987Da28	1979He10

Nominal Energy /keV	**1074.71**	**1088.18**	**1095.679**	**1103.43**	**1110.61**
1979He10	-	-	1095.671 (23)	-	1110.604 (9)
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1074.73 (15)	1088.20 (15)	1095.711 (50)	1103.43 (10)	-
1995Ba42	-	-	1095.73 (14)	-	1110.537 (51)
LWEIGHT4	-	-	1095.713 (47)	-	-
Adopted	**1074.73 (15)**	**1088.20 (15)**	**1095.671 (23)**	**1103.43 (10)**	**1110.604 (9)**
Comments	1987Da28	1987Da28	1979He10	1987Da28	1979He10

201Nominal Energy /keV	**1117.63**	**1135.24**	**1142.85**	**1148.16**	**1153.52**
1979He10	-	-	-	-	1153.266 (35)
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1117.65 (10)	1135.26 (15)	1142.87 (15)	1148.14 (15)	1153.502 (50)
1995Ba42	-	1135.4 (10)	1142.8 (10)	1148.19 (14)	1153.59 (30)
LWEIGHT4	-	1135.26 (15)	1142.87 (15)	1148.17 (10)	1153.505 (50)
Adopted	**1117.65 (10)**	**1135.26 (15)**	**1142.87 (15)**	**1148.17 (14)**	**1153.27 (4)**
Comments	1987Da28	wtd mean	wtd mean	wtd mean	1979He10

Nominal Energy /keV	**1157.14**	**1164.55**	**1175.31**	**1190.83**	**1217.03**
1979He10	-	-	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1157.16 (15)	1164.52 (7)	1175.33 (10)	1190.83 (20)	1217.03 (10)
1995Ba42	-	1164.57 (7)	-	1190.9 (10)	-
LWEIGHT4	-	1164.55 (7)	-	1190.83 (20)	-
Adopted	**1157.16 (15)**	**1164.55 (7)**	**1175.33 (10)**	**1190.83 (20)**	**1217.03 (10)**
Comments	1987Da28	wtd mean	1987Da28	wtd mean	1987Da28

Nominal Energy /keV	**1229.4**	**1245.16**	**1247.08**	**1250.04**	**1276.69**
1979He10	-	-	1247.10 (5)	1250.062 (44)	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1229.42 (15)	1245.07 (20)	1247.065 (50)	1249.77 (15)	1276.72 (10)
1995Ba42	-	1245.16 (6)	1247.056 (51)	1249.69 (20)	-
LWEIGHT4	-	1245.15 (6)	1247.061 (36)	1249.74 (12)	-
Adopted	**1229.42 (15)**	**1245.15 (6)**	**1247.10 (5)**	**1250.06 (5)**	**1276.72 (10)**
Comments	1987Da28	wtd mean	1979He10	1979He10	1987Da28

Nominal Energy /keV	**1286.27**	**1287.78**	**1309.71**	**1315.31**	**1337.33**
1979He10	-	-	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1286.30 (20)	1287.71 (20)	1309.74 (20)	1315.37 (10)	1337.33 (20)
1995Ba42	1286.29 (30)	1287.78 (8)	1310.2 (10)	1315.19 (20)	-
LWEIGHT4	1286.29 (17)	1287.77 (7)	1309.76 (20)	1315.33 (10)	-
Adopted	**1286.29 (20)**	**1287.77 (8)**	**1309.76 (20)**	**1315.33 (10)**	**1337.33 (20)**
Comments	wtd mean	wtd mean	wtd mean	wtd mean	1987Da28

Nominal Energy /keV	**1344.59**	**1347.5**	**1357.78**	**1365.71**	**1374.24**
1979He10	-	-	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1344.62 (15)	1347.50 (15)	1357.81 (15)	1365.73 (15)	1374.24 (7)
1995Ba42	1344.6 (10)	-	-	1365.71 (12)	1374.25 (7)
LWEIGHT4	1344.62 (15)	-	-	1365.71 (12)	1374.24 (6)
Adopted	**1344.62 (15)**	**1347.50 (15)**	**1357.81 (15)**	**1365.71 (12)**	**1374.24 (7)**
Comments	wtd mean	1987Da28	1987Da28	wtd mean	1987Da28

Nominal Energy /keV	**1378.23**	**1385.39**	**1401.49**	**1415.55**	**1430.95**
1979He10	-	-	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1378.23 (10)	1385.39 (10)	1401.52 (10)	1415.69 (10)	1430.98 (10)
1995Ba42	-	-	-	1415.41 (10)	1432.0 (10)
LWEIGHT4	-	-	-	1415.55 (14)	1430.99 (10)
Adopted	**1378.23 (10)**	**1385.39 (10)**	**1401.52 (10)**	**1415.55 (14)**	**1430.99 (10)**
Comments	1987Da28	1987Da28	1987Da28	wtd mean	wtd mean

Nominal Energy /keV	**1434.22**	**1438.01**	**1451.4**	**1459.138**	**1469.71**
1979He10	-	-	-	1459.131 (22)	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1434.22 (15)	1438.01 (10)	1451.43 (15)	1459.15 (15)	1469.74 (15)
1995Ba42	-	-	1451.4 (10)	1459.19 (20)	-
LWEIGHT4	-	-	1451.43 (15)	1459.16 (12)	-
Adopted	**1434.22 (15)**	**1438.01 (10)**	**1451.43 (15)**	**1459.131 (22)**	**1469.74 (15)**
Comments	1987Da28	1987Da28	wtd mean	1979He10	1987Da28

Nominal Energy /keV	**1480.37**	**1495.93**	**1501.57**	**1529.02**	**1537.87**
1979He10	-	1495.904 (16)	-	1529.010 (34)	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1480.37 (15)	1495.80 (5)	1501.600 (51)	-	1537.92 (10)
1995Ba42	1480.4 (3)	1496.14 (6)	1501.49 (20)	1529.01 (6)	1537.79 (20)
LWEIGHT4	1480.38 (15)	1495.97 (17)	1501.59 (5)	-	1537.89 (10)
Adopted	**1480.38 (15)**	**1495.904 (16)**	**1501.59 (5)**	**1529.01 (4)**	**1537.89 (10)**
Comments	wtd mean	1979He10	wtd mean	1979He10	wtd mean

Nominal Energy /keV	**1548.65**	**1557.1**	**1559.78**	**1571.52**	**1573.26**
1979He10	1548.65 (6)	1557.13 (7)	-	-	1573.23 (8)
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1548.64 (10)	1557.102 (51)	1559.88 (20)	1571.55 (20)	1573.39 (10)
1995Ba42	-	1557.05 (6)	-	-	1573.29 (30)
LWEIGHT4	-	1557.079 (39)	-	-	1573.38 (10)
Adopted	**1548.65 (6)**	**1557.13 (7)**	**1559.88 (20)**	**1571.55 (20)**	**1573.23 (8)**
Comments	1979He10	1979He10	1987Da28	1987Da28	1979He10

Nominal Energy /keV	**1580.53**	**1588.19**	**1609.41**	**1625.06**	**1630.627**
1979He10	1580.531 (25)	1588.200 (25)	-	1625.092 (35)	1630.618 (20)
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1580.522 (51)	1588.202 (51)	1609.44 (15)	1625.023 (51)	1630.663 (51)
1995Ba42	1580.49 (30)	1588.136 (52)	-	1624.99 (20)	1630.62 (6)
LWEIGHT4	1580.52 (5)	1588.170 (36)	-	1625.021 (49)	1630.644 (39)
Adopted	**1580.531 (25)**	**1588.200 (25)**	**1609.44 (15)**	**1625.09 (4)**	**1630.618 (20)**
Comments	1979He10	1979He10	1987Da28	1979He10	1979He10

Nominal Energy /keV	**1638.281**	**1666.523**	**1671.64**	**1677.67**	**1684.01**
1979He10	1638.272 (23)	1666.514 (13)	-	1677.66 (6)	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1638.304 (51)	1666.55 (51)	1671.67 (15)	1677.704 (51)	1684.04 (20)
1995Ba42	1638.29 (7)	1666.52 (6)	-	-	-
LWEIGHT4	1638.297 (41)	1666.52 (6)	-	-	-
Adopted	**1638.272 (23)**	**1666.514 (13)**	**1671.67 (15)**	**1677.66 (6)**	**1684.04 (20)**
Comments	1979He10	1979He10	1987Da28	1979He10	1987Da28

Nominal Energy /keV	**1686.12**	**1700.59**	**1702.44**	**1706.17**	**1713.49**
1979He10	1686.22 (11)	-	1702.40 (8)	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1686.095 (51)	1700.62 (20)	1702.57 (10)	1706.23 (10)	1713.51 (20)
1995Ba42	1686.14 (7)	-	1702.59 (30)	1706.15 (7)	1713.1 (10)
LWEIGHT4	1686.11 (4)	-	1702.57 (10)	1706.17 (6)	1713.49 (20)
Adopted	**1686.22 (11)**	**1700.62 (20)**	**1702.40 (8)**	**1706.17 (7)**	**1713.49 (20)**
Comments	1979He10	1987Da28	1979He10	wtd mean	wtd mean

Nominal Energy /keV	**1721.4**	**1724.2**	**1738.22**	**1740.4**	**1742.09**
1979He10	-	1724.188 (43)	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1721.49 (30)	1724.28 (10)	1738.26 (25)	1740.46 (30)	1742.09 (30)
1995Ba42	-	1723.99 (20)	1738.465 (52)	-	-
LWEIGHT4	-	1724.22 (12)	1738.46 (5)	-	-
Adopted	**1721.5 (3)**	**1724.19 (5)**	**1738.46 (5)**	**1740.5 (3)**	**1742.1 (3)**
Comments	1987Da28	1979He10	wtd mean	1987Da28	1987Da28

Nominal Energy /keV	**1745.28**	**1750.54**	**1758.11**	**1772.2**	**1784.4**
1979He10	-	-	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1745.32 (20)	1750.58 (20)	1758.15 (10)	1772.22 (30)	1784.40 (30)
1995Ba42	-	-	1758.095 (53)	-	-
LWEIGHT4	-	-	1758.106 (47)	-	-
Adopted	**1745.32 (20)**	**1750.58 (20)**	**1758.11 (5)**	**1772.2 (3)**	**1784.4 (3)**
Comments	1987Da28	1987Da28	wtd mean	1987Da28	1987Da28

Nominal Energy /keV	**1787.2**	**1795.15**	**1797.5**	**1800.86**	**1823.21**
1979He10	-	-	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1787.30 (50)	1795.14 (50)	1797.50 (50)	1800.90 (20)	1823.26 (10)
1995Ba42	1787.18 (20)	1795.13 (6)	-	-	1823.17 (10)
LWEIGHT4	1787.20 (20)	1795.13 (6)	-	-	1823.22 (7)
Adopted	**1787.20 (20)**	**1795.13 (6)**	**1797.5 (5)**	**1800.90 (20)**	**1823.22 (10)**
Comments	wtd mean	wtd mean	1987Da28	1987Da28	wtd mean

Nominal Energy /keV	**1826.7**	**1835.29**	**1842.14**	**1850.13**	**1870.81**
1979He10	-	-	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1826.78 (30)	1835.47 (10)	1842.17 (10)	1850.17 (20)	1870.87 (9)
1995Ba42	-	1835.244 (53)	1842.13 (8)	-	1870.78 (9)
LWEIGHT4	-	1835.29 (9)	1842.15 (6)	-	1870.82 (7)
Adopted	**1826.8 (3)**	**1835.29 (10)**	**1842.15 (8)**	**1850.17 (20)**	**1870.82 (9)**
Comments	1987Da28	wtd mean	wtd mean	1987Da28	wtd mean

Nominal Energy /keV	**1879.6**	**1887.12**	**1900.14**	**1907.13**	**1916.6**
1979He10	-	-	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1879.60 (30)	1887.139 (51)	1900.11 (20)	1907.22 (20)	1915.94 (40)
1995Ba42	-	1887.113 (53)	1900.28 (30)	1907.11 (11)	1916.58 (30)
LWEIGHT4	-	1887.127 (37)	1900.16 (17)	1907.14 (10)	1916.34 (33)
Adopted	**1879.6 (3)**	**1887.13 (5)**	**1900.16 (20)**	**1907.14 (11)**	**1916.3 (4)**
Comments	1987Da28	wtd mean	wtd mean	wtd mean	wtd mean

Nominal Energy /keV	**1919.5**	**1929.78**	**1936.2**	**1944.2**	**1952.37**
1979He10	-	-	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1919.54 (30)	1929.78 (20)	1936.34 (30)	1944.24 (20)	1952.37 (15)
1995Ba42	-	-	-	-	1952.37 (10)
LWEIGHT4	-	-	-	-	1952.37 (8)
Adopted	**1919.5 (3)**	**1929.78 (20)**	**1936.3 (3)**	**1944.24 (20)**	**1952.37 (10)**
Comments	1987Da28	1987Da28	1987Da28	1987Da28	wtd mean

Nominal Energy /keV	**1955.9**	**1958.4**	**1965.22**	**1971.9**	**1979.3**
1979He10	-	-	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1955.94 (50)	1958.41 (30)	1965.28 (20)	1971.96 (30)	1979.32 (30)
1995Ba42	-	-	1965.20 (12)	-	-
LWEIGHT4	-	-	1965.22 (10)	-	-
Adopted	**1955.9 (5)**	**1958.4 (3)**	**1965.22 (12)**	**1972.0 (3)**	**1979.3 (3)**
Comments	1987Da28	1987Da28	wtd mean	1987Da28	1987Da28

Nominal Energy /keV	**2000.9**	**2029.4**
1979He10	-	-
1971He23	-	-
1973Ta25	-	-
1977Ku01	-	-
1979Bo30	-	-
1987Da28	2000.98 (50)	2029.39 (50)
1995Ba42	-	-
LWEIGHT4	-	-
Adopted	**2001.0 (5)**	**2029.4 (5)**
Comments	1987Da28	1987Da28

Appendix II. Relative emission probabilities

Normalised to 100 for the 463 keV emission. Values marked with an asterisk (*) have been rejected from the weighted mean based on statistical evidence or on technical grounds. Where multiplets occur, the intensity is listed here once (in italics) and is the total measured intensity. Normalised values are also given - note the normalisation factor of 0.0445 (11) has been applied before rounding.

Nominal Energy /keV	**18.4**	**42.46**	**56.88**	**57.752**	**77.34**	**99.505**
1969Ar16	-	-	-	10.5 (5)*	-	30.6 (5)*
1971He23	-	-	-	10.5 (3)	-	28.3 (3)
1982Ma52	-	-	-	6.2 (4)*	-	36.5 (8)*
1982Sa36	-	-	-	11.4 (9)	-	31.0 (22)
1983Sc13	-		-	-	-	-
1987Da28	-	0.212 (61)	0.454 (94)	10.2 (11)	0.60 (12)	26.7 (33)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	-	10.57 (28)	-	28.33 (30)
Adopted	**calc.**	**0.21 (6)**	**0.45 (9)**	**10.6 (3)**	**0.60 (12)**	**28.3 (3)**
Normalised	-	0.009 (3)	0.020 (5)	0.470 (17)	0.027 (6)	1.26 (4)
Comments	no data	1987Da28	1987Da28	wtd mean	1987Da28	wtd mean

Nominal Energy /keV	**100.41**	**114.56**	**129.065**	**135.507**	**137.936**	**141.000**
1969Ar16	-	-	56.4 (4)*	-	-	0.80 (20)
1971He23	2.60 (10)	-	56.4 (4)	0.70 (10)	0.70 (10)	0.80 (20)
1982Ma52	-	-	54.1 (11)	-	-	-
1982Sa36	-	-	64.3 (56)	-	-	-
1983Sc13	-	-	49.6 (34)	-	-	-
1987Da28	2.18 (32)	0.23 (5)	61.2 (67)	0.41 (9)	0.55 (11)	1.18 (19)
1992Li05	-	-	55.3 (43)	-	-	~0.94
1995Ba42	-	-	-	-	-	-
LWEIGHT4	2.56 (12)	-	56.1 (5)	0.54 (14)	0.63 (10)	1.00 (19)
Adopted	**2.56 (12)**	**0.23 (5)**	**56.1 (5)**	**0.54 (14)**	**0.63 (10)**	**1.00 (19)**
Normalised	0.114 (6)	0.0102 (22)	2.50 (7)	0.024 (6)	0.028 (4)	0.045 (9)
Comments	wtd mean	1987Da28	wtd mean	wtd mean	wtd mean	wtd mean

Nominal Energy /keV	**145.82**	**153.967**	***168.53***	**173.964**	**184.547**	**191.351**
1969Ar16	3.6 (3)*	18.5 (4)*	-	-	2.2 (10)	3.9 (7)
1971He23	3.80 (10)	17.1 (4)	-	0.80 (20)	1.9 (6)	3.1 (3)
1982Ma52	-	17.1 (4)	-	-	0.70 (20)	-
1982Sa36	3.81 (30)	18.8 (15)	-	-	-	2.86 (27)
1983Sc13	-	15.6 (8)	-	-	-	-
1987Da28	3.6 (4)	18.2 (20)	*0.30 (6)*	0.82 (13)	1.64 (20)	3.03 (34)
1992Li05	-	15.8 (13)	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	3.79 (9)	16.94 (40)	-	0.81 (11)	1.21 (43)	2.98 (27)
Adopted	**3.79 (10)**	**16.9 (4)**	***0.30 (6)***	**0.81 (13)**	**1.2 (4)**	**3.0 (3)**
Normalised	0.169 (6)	0.754 (23)	-	0.036 (5)	0.054 (19)	0.133 (8)
Comments	wtd mean	wtd mean	*1987Da28*	wtd mean	wtd mean	wtd mean

Nominal Energy /keV	**199.402**	**204.029**	**209.248**	**214.890**	**223.793**	**231.477**
1969Ar16	6.0 (5)	3.0 (5)	93 (4)	-	1.6 (5)	-
1971He23	-	-	93 (4)*	-	-	-
1982Ma52	-	2.4 (2)	-	-	-	-
1982Sa36	7.4 (6)	2.38 (26)	93 (6)	-	-	-
1983Sc13	-	-	84.7 (34)	-	-	-
1987Da28	7.4 (8)	3.09 (34)	98 (9)	0.69 (11)	1.27 (14)	0.58 (9)
1992Li05	-	-	89.1 (35)	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	6.7 (5)	2.56 (17)	89.3 (19)	-	1.30 (13)	-
Adopted	**6.7 (5)**	**2.56 (20)**	**89 (4)**	**0.69 (11)**	**1.30 (14)**	**0.58 (9)**
Normalised	0.299 (23)	0.114 (8)	3.97 (13)	0.031 (5)	0.058 (6)	0.026 (4)
Comments	wtd mean	wtd mean	wtd mean	1987Da28	wtd mean	1987Da28

Nominal Energy /keV	**257.482**	**263.580**	**270.245**	***278.80***	**282.022**	**321.646**
1969Ar16	-	-	76.0 (40)	*5.6 (5)*	-	5.0 (10)
1971He23	-	-	78.0 (40)	-	-	-
1982Ma52	-	-	82.3 (20)	*6.0 (4)*	-	7.9 (5)
1982Sa36	-	-	79 (6)	-	2.62 (27)	5.24 (54)
1983Sc13	-	-	76.4 (29)	-	-	5.44 (53)
1987Da28	0.70 (8)	0.94 (11)	78 (7)	*4.49 (37)*	1.46 (14)	5.09 (44)
1992Li05	-	-	80.0 (27)	-	-	6.08 (12)
1995Ba42	0.626 (44)	0.97 (7)	-	-	-	-
LWEIGHT4	0.642 (39)	0.96 (6)	79.9 (13)	*5.28 (49)*	2.0 (6)	5.22 (28)
Adopted	**0.64 (5)**	**0.96 (7)**	**79.9 (20)**	***5.3 (5)***	**2.0 (6)**	**5.2 (5)**
Normalised	0.0286 (19)	0.043 (3)	3.55 (10)	*0.235 (22)*	0.09 (3)	0.232 (14)
Comments	wtd mean	wtd mean	wtd mean	*wtd mean*	wtd mean	wtd mean

Nominal Energy /keV	**326.040**	**328.004**	**332.370**	**338.320**	**340.969**	**356.65**
1969Ar16	-	68.0 (20)	7.2 (5)	250 (5)	10 (4)	-
1971He23	-	-	-	255 (5)	-	-
1982Ma52	-	78.3 (20)	-	282 (6)	-	-
1982Sa36	-	69.0 (58)	9.3 (11)	255 (17)	9.0 (10)	-
1983Sc13	-	-	6.2 (7)	250 (9)	9.0 (6)	-
1987Da28	0.78 (13)	69.7 (50)	9.8 (8)	256 (18)	7.7 (7)	0.400 (47)
1992Li05	-	-	10.57 (56)	260 (9)	9.8 (18)	-
1995Ba42	-	-	-	-	9.2 (6)	-
LWEIGHT4	-	68.3 (18)	8.4 (12)	255.1 (38)	9.09 (39)	-
Adopted	**0.78 (13)**	**68.3 (20)**	**8.4 (12)**	**255 (5)**	**9.1 (6)**	**0.40 (5)**
Normalised	0.035 (6)	3.04 (11)	0.37 (6)	11.4 (4)	0.405 (20)	0.0178 (21)
Comments	1987Da28	wtd mean	wtd mean	wtd mean	wtd mean	1987Da28

Nominal Energy /keV	**372.590**	**377.99**	**384.47**	**389.32**	**397.95**	**399.83**
1969Ar16	-	-	-	-	-	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	0.158 (37)	0.576 (67)	0.158 (37)	0.242 (38)	0.642 (68)	0.691 (75)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	-	-	-	-
Adopted	**0.16 (4)**	**0.58 (7)**	**0.16 (4)**	**0.24 (4)**	**0.64 (7)**	**0.69 (8)**
Normalised	0.0070 (17)	0.026 (3)	0.0070 (17)	0.0108 (17)	0.029 (3)	0.031 (4)
Comments	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28

Nominal Energy /keV	**409.46**	**415.96**	**419.38**	**440.45**	**449.11**	**452.50**
1969Ar16	44 (2)	-	-	3.0 (5)	-	-
1971He23	-	-	-	-	-	-
1982Ma52	46.5 (10)	-	-	-	-	-
1982Sa36	42.9 (31)	-	-	-	-	-
1983Sc13	43.3 (19)	-	-	-	-	-
1987Da28	44.8 (33)	0.309 (51)	0.48 (8)	2.85 (23)	1.12 (13)	0.36 (12)
1992Li05	45.1 (23)	-	-	-	-	-
1995Ba42	44.7 (32)	-	-	-	-	0.456 (42)
LWEIGHT4	45.3 (7)	-	-	2.87 (21)	-	0.466 (40)
Adopted	**45.3 (10)**	**0.31 (5)**	**0.48 (8)**	**2.87 (23)**	**1.12 (13)**	**0.47 (4)**
Normalised	2.02 (6)	0.0138 (23)	0.022 (3)	0.128 (10)	0.050 (6)	0.0199 (19)
Comments	wtd mean	1987Da28	1987Da28	wtd mean	wtd mean	wtd mean

Nominal Energy /keV	**457.18**	**466.40**	**470.21**	**471.77**	**474.79**
1969Ar16	-	-	-	-	-
1971He23	-	-	-	-	-
1982Ma52	-	-	-	-	-
1982Sa36	-	-	-	-	-
1983Sc13	-	-	-	-	-
1987Da28	0.352 (57)	0.67 (8)	0.30 (6)	0.76 (8)	0.52 (8)
1992Li05	-	-	-	-	-
1995Ba42	-	-	-	-	-
LWEIGHT4	-	-	-	-	-
Adopted	**0.35 (6)**	**0.67 (8)**	**0.30 (6)**	**0.76 (8)**	**0.52 (8)**
Normalised	0.016 (3)	0.30 (4)	0.014 (3)	0.034 (4)	0.023 (4)
Comments	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28

Nominal Energy /keV	**478.399**	**481.50**	**490.34**	**492.29**	**497.64**	**503.819**	**508.955**
1969Ar16	5.7 (10)	-	-	-	-	3.0 (5)	12.0 (10)
1971He23	-	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	4.2 (9)	-
1987Da28	4.91 (44)	0.55 (11)	0.261 (56)	0.552 (61)	0.139 (43)	4.24 (37)	10.7 (12)
1992Li05	-	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-	-
LWEIGHT4	5.04 (40)	-	-	-	-	3.85 (41)	11.5 (8)
Adopted	**5.0 (5)**	**0.55 (11)**	**0.26 (6)**	**0.55 (6)**	**0.14 (4)**	**3.9 (4)**	**11.5 (10)**
Normalised	0.224 (19)	0.024 (5)	0.0116 (25)	0.025 (3)	0.0062 (19)	0.171 (19)	0.51 (4)
Comments	wtd mean	wtd mean	1987Da28	1987Da28	1987Da28	wtd mean	wtd mean

Nominal Energy /keV	**515.12**	**520.159**	**523.129**	**540.674**	**546.445**	**548.73**	**555.07**
1969Ar16	-	-	3.0 (1)	-	4.0 (5)	-	-
1971He23	-	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-	-
1987Da28	1.14 (13)	1.58 (14)	2.42 (22)	0.61 (7)	4.73 (38)	0.54 (8)	1.08 (12)
1992Li05	-	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-	-
LWEIGHT4	-	-	2.90 (22)	-	4.46 (35)	-	-
Adopted	**1.13 (13)**	**1.58 (14)**	**2.90 (22)**	**0.61 (7)**	**4.5 (4)**	**0.54 (8)**	**1.08 (12)**
Normalised	0.051 (6)	0.070 (7)	0.129 (10)	0.027 (3)	0.199 (16)	0.024 (4)	0.048 (6)
Comments	1987Da28	1987Da28	wtd mean	wtd mean	wtd mean	wtd mean	1987Da28

Nominal Energy /keV	**562.496**	**570.876**	**572.10**	**583.391**	**610.65**	**616.212**
1969Ar16	21 (2)	6.5 (10)	-	3.0 (5)	-	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	21.4 (26)	-	-	-	-	-
1983Sc13	19.8 (12)	-	-	-	-	-
1987Da28	18.8 (15)	3.82 (41)	3.52 (40)	2.61 (27)	0.54 (11)	1.88 (15)
1992Li05	20.3 (10)	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	20.0 (6)	4.2 (9)	-	2.70 (24)	-	-
Adopted	**20.0 (10)**	**4.2 (9)**	**3.5 (4)**	**2.7 (3)**	**0.54 (11)**	**1.88 (15)**
Normalised	0.89 (4)	0.19 (5)	0.156 (18)	0.120 (11)	0.024 (5)	0.084 (7)
Comments	wtd mean	wtd mean	1987Da28	wtd mean	1987Da28	1987Da28

Nominal Energy /keV	**620.32**	**623.48**	**626.80**	**629.409**	**634.18**	**640.317**
1969Ar16	-	-	-	-	-	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	1.88 (15)	0.26 (6)	0.33 (7)	1.06 (12)	0.248 (50)	1.27 (14)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	-	-	-	-
Adopted	**1.88 (15)**	**0.26 (6)**	**0.33 (7)**	**1.06 (12)**	**0.25 (5)**	**1.27 (14)**
Normalised	0.084 (7)	0.012 (3)	0.015 (3)	0.047 (5)	0.0111 (22)	0.057 (6)
Comments	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28

Nominal Energy /keV	***649.02***	**651.526**	**660.14**	**663.88**	***666.451***	**671.95**
1969Ar16	-	-	-	-	-	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	*0.94 (10)*	2.12 (21)	0.121 (6)	0.66 (14)	*1.45 (14)*	0.61 (18)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	-	-	-	-
Adopted	***0.94 (10)***	**2.12 (21)**	**0.121 (6)**	**0.66 (14)**	***1.45 (14)***	**0.61 (18)**
Normalised	*0.042 (5)*	0.094 (10)	0.0054 (3)	0.029 (6)	*0.065 (6)*	0.027 (8)
Comments	*1987Da28*	1987Da28	1987Da28	1987Da28	*1987Da28*	1987Da28

Nominal Energy /keV	**674.625**	**677.08**	***688.117***	**698.99**	**701.742**	**707.421**
1969Ar16	~3	-	-	-	~2.7	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	2.36 (22)	1.45 (14)	*1.58 (14)*	0.86 (13)	4.06 (31)	3.64 (40)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	-	-	-	-
Adopted	**2.36 (22)**	**1.45 (14)**	***1.58 (14)***	**0.86 (13)**	**4.1 (3)**	**3.6 (4)**
Normalised	0.105 (10)	0.065 (6)	*0.070 (7)*	0.038 (6)	0.181 (15)	0.162 (18)
Comments	1987Da28	1987Da28	*1987Da28*	1987Da28	1987Da28	1987Da28

Nominal Energy /keV	**718.303**	**727.317**	**737.736**	**755.313**	**772.291**	**774.07**
1969Ar16	-	18 (4)	-	22 (3)	40 (4)	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	23.8 (26)	38.1 (30)	-
1983Sc13	-	-	-	23.6 (15)	32.2 (16)	-
1987Da28	0.44 (9)	14.5 (20)	0.87 (9)	21.8 (16)	33.9 (25)	1.39 (7)
1992Li05	-	-	-	23.4 (11)	34.0 (12)	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	15.2 (18)	-	23.1 (7)	34.1 (10)	-
Adopted	**0.44 (9)**	**15.2 (20)**	**0.87 (9)**	**23.1 (11)**	**34.1 (12)**	**1.39 (7)**
Normalised	0.019 (4)	0.68 (8)	0.039 (5)	1.03 (4)	1.52 (6)	0.062 (4)
Comments	1987Da28	wtd mean	1987Da28	wtd mean	wtd mean	1987Da28

Nominal Energy /keV	**776.514**	**782.14**	***791.43***	**792.69**	**794.942**	**813.88**
1969Ar16	-	17 (3)	-	-	105 (10)	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	100 (7)	-
1983Sc13	-	10.7 (14)	-	-	96.4 (35)	-
1987Da28	0.44 (14)	11.3 (8)	*0.54 (17)*	1.82 (9)	98 (7)	0.164 (37)
1992Li05	-	10.8 (13)	-	-	95.2 (34)	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	11.3 (7)	-	-	96.9 (22)	-
Adopted	**0.44 (14)**	**11.3 (8)**	***0.54 (17)***	**1.82 (9)**	**97 (4)**	**0.16 (4)**
Normalised	0.020 (6)	0.50 (4)	*0.024 (7)*	0.081 (5)	4.31 (14)	0.0073 (17)
Comments	1987Da28	1987Da28	*1987Da28*	1987Da28	wtd mean	wtd mean

Nominal Energy /keV	**816.82**	**824.931**	**830.481**	**835.481**	**840.372**	***853.57***
1969Ar16	-	-	16.5 (10)	39.5 (10)	23.0 (10)	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	15.0 (20)	42.9 (31)	22.1 (20)	-
1983Sc13	-	-	11.1 (12)	34.0 (22)	21.6 (13)	-
1987Da28	0.70 (8)	1.18 (13)	12.7 (9)	37.6 (26)	20.0 (16)	*0.279 (45)*
1992Li05	-	-	-	35.4 (20)	18.6 (24)	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	13.7 (12)	38.3 (12)	21.7 (7)	-
Adopted	**0.70 (8)**	**1.18 (13)**	**13.7 (12)**	**38.3 (12)**	**21.7 (10)**	***0.28 (5)***
Normalised	0.031 (4)	0.053 (6)	0.61 (6)	1.70 (7)	0.97 (4)	*0.0124 (20)*
Comments	1987Da28	1987Da28	wtd mean	wtd mean	wtd mean	*wtd mean*

Nominal Energy /keV	**870.47**	**872.99**	**874.45**	**877.38**	**880.76**	**887.26**
1969Ar16	-	-	-	-	-	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	1.03 (11)	0.73 (15)	1.12 (25)	0.32 (6)	0.145 (43)	0.64 (7)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	-	-	-	-
Adopted	**1.03 (11)**	**0.73 (15)**	**1.12 (25)**	**0.32 (6)**	**0.15 (5)**	**0.64 (7)**
Normalised	0.046 (5)	0.032 (7)	0.050 (11)	0.014 (3)	0.0065 (19)	0.029 (3)
Comments	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28

Nominal Energy /keV	**901.383**	**904.2**	**911.196**	**919.03**	***921.87***	***930.99***
1969Ar16	-	-	590 (30)	-	-	-
1971He23	-	-	580 (20)	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	19.0 (25)	605 (42)	-	-	-
1983Sc13	-	17.6 (10)	591 (22)	-	-	-
1987Da28	0.38 (8)	17.0 (15)	606 (29)	0.64 (7)	*0.345 (51)*	*0.291 (45)*
1992Li05	-	-	573 (20)	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	17.5 (8)	588 (12)	-	-	-
Adopted	**0.38 (8)**	**17.5 (10)**	**588 (20)**	**0.64 (7)**	***0.35 (5)***	***0.29 (5)***
Normalised	0.017 (4)	0.78 (4)	26.2 (8)	0.028 (3)	*0.0154 (23)*	*0.0129 (20)*
Comments	1987Da28	wtd mean	wtd mean	wtd mean	*1987Da28*	*1987Da28*

Nominal Energy /keV	**939.89**	**944.191**	**947.976**	**958.591**	**964.786**	**968.96**
1969Ar16	-	-	-	-	100 (10)	360 (20)
1971He23	-	-	-	-	100 (10)	350 (10)
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	3.8 (14)	124 (9)	360 (26)
1983Sc13	-	-	-	-	112.2 (43)	361 (13)
1987Da28	0.21 (6)	2.24 (21)	2.49 (22)	6.8 (6)	118 (8)	372 (26)
1992Li05	-	-	-	-	110.4 (42)	349 (13)
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	-	6.4 (11)	112.1 (26)	357 (7)
Adopted	**0.21 (6)**	**2.24 (21)**	**2.49 (22)**	**6.4 (11)**	**112 (5)**	**357 (10)**
Normalised	0.009 (3)	0.100 (10)	0.111 (10)	0.29 (5)	4.99 (17)	15.9 (5)
Comments	1987Da28	1987Da28	1987Da28	wtd mean	wtd mean	wtd mean

Nominal Energy /keV	**975.983**	**979.49**	**987.87**	**988.65**	**1000.68**	**1013.55**
1969Ar16	-	-	4.3 (3)	-	-	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	1.16 (13)	0.62 (7)	1.82 (32)	1.82 (32)	0.121 (6)	0.109 (31)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	3.1 (12)	-	-	-
Adopted	**1.16 (13)**	**0.62 (7)**	**3.1 (12)**	**1.8 (4)**	**0.121 (6)**	**0.11 (3)**
Normalised	0.052 (6)	0.028 (3)	0.14 (6)	0.081 (14)	0.0054 (3)	0.0049 (14)
Comments	1987Da28	1987Da28	wtd mean	1987Da28	1987Da28	1987Da28

Nominal Energy /keV	**1016.44**	**1017.94**	**1019.88**	**1033.244**	**1039.83**	**1040.94**
1969Ar16	-	1.3 (3)	-	4.5 (3)	2.0 (4)	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	0.44 (6)	0.133 (31)	0.49 (10)	4.73 (38)	1.05 (22)	1.05 (22)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	-	-	1.27 (40)	-
Adopted	**0.44 (6)**	**0.7 (6)**	**0.49 (10)**	**4.59 (24)**	**1.3 (4)**	**1.05 (22)**
Normalised	0.019 (3)	0.03 (3)	0.022 (5)	0.204 (12)	0.056 (18)	0.047 (10)
Comments	1987Da28	wtd mean	1987Da28	wtd mean	wtd mean	1987Da28

Nominal Energy /keV	**1053.11**	**1054.13**	**1062.57**	**1065.168**	**1074.73**	**1088.20**
1969Ar16	~1	-	-	3.0 (2)	-	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	0.32 (9)	0.42 (13)	0.24 (7)	3.09 (29)	0.24 (7)	0.139 (31)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	-	3.03 (16)	-	-
Adopted	**0.32 (9)**	**0.42 (13)**	**0.24 (7)**	**3.03 (20)**	**0.24 (7)**	**0.14 (3)**
Normalised	0.014 (4)	0.019 (6)	0.011 (4)	0.135 (8)	0.011 (4)	0.0062 (14)
Comments	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28

Nominal Energy /keV	**1095.671**	**1103.43**	**1110.604**	**1117.65**	**1135.26**	**1142.87**
1969Ar16	2.6 (3)	-	6.5 (10)	1.6 (3)	-	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	3.03 (28)	0.35 (6)	7.2 (6)	1.27 (19)	0.230 (38)	0.242 (50)
1992Li05	-	-	-	-	-	-
1995Ba42	-	0.224 (11)	-	-	-	-
LWEIGHT4	2.83 (22)	0.228 (24)	6.98 (51)	1.37 (16)	-	-
Adopted	**2.8 (3)**	**0.228 (24)**	**7.0 (6)**	**1.37 (19)**	**0.23 (4)**	**0.24 (5)**
Normalised	0.126 (10)	0.0102 (11)	0.311 (24)	0.061 (7)	0.0102 (17)	0.0108 (22)
Comments	wtd mean	wtd mean	wtd mean	wtd mean	1987Da28	1987Da28

Nominal Energy /keV	**1148.17**	**1153.266**	**1157.16**	**1164.55**	**1175.33**	**1190.83**
1969Ar16	-	4.0 (10)	-	~1.5	-	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	0.139 (31)	3.27 (29)	0.164 (31)	1.52 (14)	0.56 (8)	0.146 (37)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	3.33 (28)	-	-	-	-
Adopted	**0.14 (3)**	**3.3 (3)**	**0.16 (3)**	**1.52 (14)**	**0.56 (8)**	**0.15 (4)**
Normalised	0.0062 (14)	0.148 (13)	0.0073 (14)	0.067 (7)	0.025 (4)	0.0065 (17)
Comments	1987Da28	wtd mean	1987Da28	1987Da28	1987Da28	1987Da28

Nominal Energy /keV	**1217.03**	**1229.42**	**1245.15**	**1247.10**	**1250.062**	**1276.72**
1969Ar16	-	-	-	-	-	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	0.50 (8)	0.176 (55)	2.24 (44)	11.21 (55)	1.46 (14)	0.33 (7)
1992Li05	-	-	-	11.5 (14)	-	-
1995Ba42	-	-	2.50 (18)	-	-	-
LWEIGHT4	-	-	2.46 (17)	11.78 (46)	-	-
Adopted	**0.50 (8)**	**0.18 (6)**	**2.46 (18)**	**11.8 (5)**	**1.46 (14)**	**0.33 (7)**
Normalised	0.022 (4)	0.0078 (25)	0.110 (8)	0.524 (24)	0.065 (6)	0.015 (3)
Comments	1987Da28	1987Da28	wtd mean	wtd mean	1987Da28	1987Da28

Nominal Energy /keV	**1286.29**	**1287.77**	**1309.76**	**1315.33**	**1337.33**	**1344.62**
1969Ar16	-	3.0 (2)	-	-	-	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	1.17 (24)	1.88 (38)	0.44 (15)	0.35 (7)	0.115 (37)	0.212 (44)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	2.44 (56)	-	-	-	-
Adopted	**1.17 (24)**	**2.4 (6)**	**0.44 (15)**	**0.35 (7)**	**0.12 (4)**	**0.21 (5)**
Normalised	0.052 (11)	0.109 (25)	0.020 (7)	0.015 (3)	0.0051 (16)	0.0094 (20)
Comments	1987Da28	wtd mean	1987Da28	1987Da28	1987Da28	1987Da28

Nominal Energy /keV	**1347.50**	**1357.81**	**1365.71**	**1374.24**	**1378.23**	**1385.39**
1969Ar16	-	-	-	-	-	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	0.36 (8)	0.48 (10)	0.32 (7)	0.32 (9)	0.139 (43)	0.248 (50)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	0.447 (22)	-	-
LWEIGHT4	-	-	-	0.440 (29)	-	-
Adopted	**0.36 (8)**	**0.48 (10)**	**0.32 (7)**	**0.44 (3)**	**0.14 (5)**	**0.25 (5)**
Normalised	0.016 (4)	0.021 (5)	0.014 (3)	0.0196 (14)	0.0062 (19)	0.0111 (22)
Comments	1987Da28	1987Da28	1987Da28	wtd mean	1987Da28	1987Da28

Nominal Energy /keV	**1401.52**	**1415.55**	**1430.99**	**1434.22**	**1438.01**	**1451.43**
1969Ar16	-	-	-	-	-	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	0.29 (6)	0.50 (10)	0.82 (17)	0.188 (55)	0.139 (37)	0.248 (50)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	-	-	-	-
Adopted	**0.29 (6)**	**0.50 (10)**	**0.82 (17)**	**0.19 (6)**	**0.14 (4)**	**0.25 (5)**
Normalised	0.013 (3)	0.022 (5)	0.037 (8)	0.0084 (25)	0.0062 (17)	0.0111 (22)
Comments	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28

Nominal Energy /keV	**1459.131**	**1469.74**	**1480.38**	**1495.904**	**1501.59**	**1529.01**
1969Ar16	20.0 (5)	-	-	21.0 (4)	11.6 (2)	~1
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	17.3 (10)	-	-	18.7 (16)	9.6 (11)	-
1987Da28	18.8 (15)	0.47 (9)	0.38 (8)	21.2 (16)	11.2 (10)	1.33 (14)
1992Li05	24.3 (17)	-	-	18.9 (13)	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	19.5 (11)	-	-	20.73 (43)	11.53 (25)	-
Adopted	**19.5 (11)**	**0.47 (9)**	**0.38 (8)**	**20.7 (5)**	**11.53 (25)**	**1.33 (14)**
Normalised	0.87 (5)	0.021 (5)	0.017 (4)	0.92 (3)	0.513 (17)	0.059 (6)
Comments	wtd mean	1987Da28	1987Da28	wtd mean	wtd mean	1987Da28

Nominal Energy /keV	**1537.89**	**1548.65**	**1557.13**	**1559.88**	**1571.55**	**1573.23**
1969Ar16	~0.8	~0.7	3.8 (2)	-	-	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	1.10 (12)	0.89 (10)	4.18 (37)	0.48 (10)	0.133 (37)	0.77 (9)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	3.89 (18)	-	-	-
Adopted	**1.10 (12)**	**0.89 (10)**	**3.89 (20)**	**0.48 (10)**	**0.13 (4)**	**0.77 (9)**
Normalised	0.049 (6)	0.040 (5)	0.173 (9)	0.021 (5)	0.0059 (17)	0.034 (4)
Comments	1987Da28	1987Da28	wtd mean	1987Da28	1987Da28	1987Da28

Nominal Energy /keV	**1580.531**	**1588.20**	**1609.44**	**1625.092**	**1630.618**	**1638.272**
1969Ar16	17 (3)	71 (3)	-	7.0 (20)	33.0 (20)	10.0 (10)
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	11.6 (20)	72.4 (29)	-	-	34.0 (22)	10.2 (9)
1987Da28	14.5 (14)	76.4 (52)	0.182 (37)	6.00 (51)	38.8 (31)	11.0 (10)
1992Li05	13.7 (14)	66.0 (17)	-	-	33.8 (12)	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	13.9 (9)	68.8 (20)	-	6.06 (50)	34.1 (9)	10.43 (55)
Adopted	**13.9 (14)**	**68.8 (20)**	**0.182 (37)**	**6.1 (5)**	**34.1 (12)**	**10.4 (9)**
Normalised	0.62 (4)	3.06 (12)	0.0081 (17)	0.270 (23)	1.52 (6)	0.46 (3)
Comments	wtd mean	1987Da28	1987Da28	wtd mean	wtd mean	wtd mean

Nominal Energy /keV	**1666.514**	**1671.67**	**1677.66**	**1684.04**	**1686.22**	**1700.62**
1969Ar16	3.8 (2)	-	~1.2	-	2.0 (2)	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	4.18 (37)	0.091 (31)	1.27 (14)	0.35 (11)	2.24 (21)	0.236 (56)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	3.89 (18)	-	-	-	2.11 (15)	-
Adopted	**3.89 (20)**	**0.9 (3)**	**1.27 (14)**	**0.35 (11)**	**2.11 (20)**	**0.24 (6)**
Normalised	0.173 (9)	0.0043 (14)	0.057 (6)	0.015 (5)	0.094 (7)	0.0105 (25)
Comments	wtd mean	1987Da28	1987Da28	1987Da28	wtd mean	1987Da28

Nominal Energy /keV	**1702.40**	**1706.17**	**1713.49**	**1721.49**	**1724.188**	**1738.46**
1969Ar16	1.5 (2)	-	-	-	~0.5	~0.6
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	1.13 (12)	0.200 (26)	0.127 (25)	0.133 (43)	0.68 (8)	0.41 (9)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	1.23 (17)	-	-	-	-	-
Adopted	**1.23 (17)**	**0.20 (3)**	**0.127 (25)**	**0.13 (5)**	**0.68 (8)**	**0.41 (9)**
Normalised	0.055 (7)	0.0089 (12)	0.0057 (11)	0.0059 (19)	0.030 (4)	0.018 (4)
Comments	wtd mean	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28

Nominal Energy /keV	**1740.46**	**1742.09**	**1745.32**	**1750.58**	**1758.11**	**1772.22**
1969Ar16	-	~0.5	-	-	~0.8	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	0.26 (8)	0.188 (55)	0.152 (20)	0.188 (20)	0.81 (9)	0.042 (12)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	-	-	-	-
Adopted	**0.26 (8)**	**0.19 (6)**	**0.152 (20)**	**0.188 (20)**	**0.81 (9)**	**0.042 (12)**
Normalised	0.011 (4)	0.0084 (25)	0.0067 (9)	0.0084 (9)	0.036 (4)	0.0019 (5)
Comments	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28

Nominal Energy /keV	**1784.40**	**1787.20**	**1795.13**	**1797.50**	**1800.90**	**1823.22**
1969Ar16	-	-	-	-	-	1.00 (10)
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	0.139 (25)	0.030 (12)	0.048 (18)	0.048 (18)	0.103 (19)	1.03 (12)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	-	-	-	1.01 (8)
Adopted	**0.139 (25)**	**0.030 (12)**	**0.048 (18)**	**0.048 (18)**	**0.103 (19)**	**1.01 (10)**
Normalised	0.0062 (11)	0.0013 (5)	0.0022 (8)	0.0022 (8)	0.0046 (8)	0.046 (5)
Comments	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28	wtd mean

Nominal Energy /keV	**1826.78**	**1835.29**	**1842.15**	**1850.17**	**1870.82**	**1879.60**
1969Ar16	-	0.80 (10)	0.70 (10)	-	0.60 (10)	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	0.048 (18)	0.89 (10)	0.98 (11)	0.103 (19)	0.57 (6)	0.030 (12)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	0.84 (7)	0.83 (14)	-	0.578 (52)	-
Adopted	**0.048 (18)**	**0.84 (10)**	**0.83 (14)**	**0.103 (19)**	**0.58 (5)**	**0.030 (12)**
Normalised	0.0022 (8)	0.038 (4)	0.037 (6)	0.0046 (8)	0.0257 (24)	0.0013 (5)
Comments	1987Da28	wtd mean	wtd mean	wtd mean	wtd mean	1987Da28

Nominal Energy /keV	**1887.13**	**1900.16**	**1907.14**	**1916.34**	**1919.54**	**1929.78**
1969Ar16	2.1 (2)	-	~0.3	-	-	~0.4
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	2.12 (21)	0.067 (13)	0.279 (28)	0.018 (6)	0.048 (12)	0.467 (54)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	2.11 (14)	-	-	-	-	-
Adopted	**2.11 (20)**	**0.067 (13)**	**0.28 (3)**	**0.018 (6)**	**0.048(12)**	**0.47 (6)**
Normalised	0.094 (7)	0.0030 (6)	0.0124 (13)	0.008 (3)	0.0022 (6)	0.0208 (24)
Comments	wtd mean	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28

Nominal Energy /keV	**1936.34**	**1944.24**	**1952.37**	**1955.90**	**1958.41**	**1965.22**
1969Ar16	-	-	1.4 (2)	-	-	0.60 (10)
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	0.048 (12)	0.048 (12)	1.39 (14)	0.018 (6)	0.036 (12)	0.478 (48)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	1.40 (11)	-	-	0.502 (48)
Adopted	**0.048 (12)**	**0.048 (12)**	**1.40 (14)**	**0.018 (6)**	**0.036 (12)**	**0.50 (5)**
Normalised	0.0022 (6)	0.0022 (6)	0.062 (5)	0.008 (3)	0.0016 (5)	0.0223 (22)
Comments	1987Da28	1987Da28	wtd mean	1987Da28	1987Da28	wtd mean

Nominal Energy /keV	**1971.96**	**1979.32**	**2001.0**	**2029.4**
1969Ar16	-	-	-	-
1971He23	-	-	-	-
1982Ma52	-	-	-	-
1982Sa36	-	-	-	-
1983Sc13	-	-	-	-
1987Da28	0.085 (19)	0.042 (12)	0.024 (6)	0.042 (12)
1992Li05	-	-	-	-
1995Ba42	-	-	-	-
LWEIGHT4	-	-	-	-
Adopted	**0.085 (19)**	**0.042 (12)**	**0.024 (6)**	**0.042 (12)**
Normalised	0.0038 (8)	0.0019 (5)	0.0011 (3)	0.0019 (5)
Comments	1987Da28	1987Da28	1987Da28	1987Da28

^{228}Th – Comments on evaluation of decay data
by A. L. Nichols

Evaluated: July/August 2001
Re-evaluated: January 2004 and April 2010

Evaluation Procedures

Limitation of Relative Statistical Weight Method (LWM) was applied to average numbers throughout the evaluation. The uncertainty assigned to the average value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

^{228}Th ($T_{½}$ = 698.6 days) decays 100 % by alpha-particle emission ($Q(\alpha)$ = 5520.08 (22) keV) to various excited levels and the ground state of ^{224}Ra ($T_{½}$ = 3.631 days). A reasonably well-defined decay scheme was derived from the alpha-particle studies of 1969Pe17, 1970Ba20, 1976BaZZ and 1993Ba72, and the gamma-ray measurements of 1977Ku15 and 1984Ge07. An additional gamma transition was added to the proposed decay scheme from equivalent studies of ^{224}Fr decay by 1981Ku02: 908.28-keV gamma ray depopulating the 992.65-keV nuclear level of ^{224}Ra. Weighted mean relative emission probabilities were calculated for the 131.612-, 166.410-, 205.99- and 215.985-keV gamma rays, while equivalent data for the other gamma transitions were adopted from the measurements of 1977Ku15; all of these relative emission probabilities were defined in terms of the 84.373-keV gamma ray (100 %).

^{20}O cluster decay has been observed by 1993Bo20 to be 1.13 (22) E-13. Subsequent reviews by 1995Ar33 and 1997Tr17 list a cluster-decay branching fraction of 1.13 (22) E-13 and 1.1 (2) E-13, respectively, based primarily on the earlier measurement.

Nuclear Data

The ^{228}Th decay chain is important in quantifying the environmental impact of the decay of naturally-occurring ^{232}Th. Certain radionuclides in this decay chain are noteworthy because of their decay characteristics: ^{224}Ra alpha decay to ^{220}Rn; ^{212}Bi and ^{208}Tl gamma-ray emissions. ^{208}Tl in particular emits high-energy gamma rays that represent a well-defined spectroscopic signature for this decay chain.

Half-life

The measurements of 1956Ki16, 1962Ma57, 1971Jo14 and 2002Un02 were adopted to give a least-squares weighted mean half-life of 698.55 (32) days. ^{228}Th half-life quoted in 2002Un02 is also listed within 1992Un01. Woods has recommended a half-life of 698.60 (23) days (2007BeZP), but without due consideration of the calculated uncertainty with respect to the measured values, see relevant footnotes.

Reference	Half-life (d)*
1918Me01	695.8 [1.905 a]†
1956Ki16	697.6 (7) [1.910 (2) a]
1962Ma57	696.9 (15) [1.908 (4) a]
1962Ma57	703 (7) [1.924 (20) a]‡
1971Jo14	698.77 (32)
2002Un02	698.60 (36)
Recommended value	698.55 (32)§ or 1.9126 (9) a

* Conversion factor: 1 tropical year ≡ 365.2422 days.
† Uncertainty not specified – not included in weighted mean analysis of the data set.
‡ Defined as an outlier.
§ Recommended uncertainty adjusted from ± 0.22 to ± 0.32, in alignment with the smallest uncertainty of the values used to calculate the average value.

Alpha Particles

Energies

All alpha-particle energies were derived from the structural details of the proposed decay scheme. While the energies of the main alpha-particle emissions have been directly measured by 1953As31, 1970Ba20, 1971Gr07, 1976BaZZ and 1991Ry01, the nuclear level energies of 1997Ar05 and evaluated Q-value of 5520.08 (22) keV (2003Au03) were used to determine the recommended energies and uncertainties of the alpha-particle emissions, while allowing for the significant recoil components.

Adopted nuclear levels of ^{224}Ra: J$^{\pi}$ and origins (1997Ar05).

Nuclear level	Nuclear level energy (keV)	J$^{\pi}$	Origins
0	0.0	0 +	^{224}Fr β^- decay, ^{224}Ac EC decay, **^{228}Th α decay**, ^{226}Ra(p,t), ^{226}Ra(α,α'2nγ), ^{226}Ra(^{58}Ni,^{60}Ni)
1	84.373 ± 0.003	2 +	^{224}Fr β^- decay, ^{224}Ac EC decay, **^{228}Th α decay**, ^{226}Ra(p,t), ^{226}Ra(α,α'2nγ), ^{226}Ra(^{58}Ni,^{60}Ni)
2	215.985 ± 0.004	1 –	^{224}Fr β^- decay, ^{224}Ac EC decay, **^{228}Th α decay**, ^{226}Ra(p,t), ^{226}Ra(α,α'2nγ), ^{226}Ra(^{58}Ni,^{60}Ni)
3	250.783 ± 0.005	4 +	^{224}Fr β^- decay, ^{224}Ac EC decay, **^{228}Th α decay**, ^{226}Ra(α,α'2nγ), ^{226}Ra(^{58}Ni,^{60}Ni)
4	290.36 ± 0.04	(3) –	^{224}Fr β^- decay, ^{224}Ac EC decay, **^{228}Th α decay**, ^{226}Ra(α,α'2nγ), ^{226}Ra(^{58}Ni,^{60}Ni)
5	433.07 ± 0.10	(5) –	^{224}Fr β^- decay, **^{228}Th α decay**, ^{226}Ra(α,α'2nγ), ^{226}Ra(^{58}Ni,^{60}Ni)
6	479.20 ± 0.18	(6 +)	**^{228}Th α decay**, ^{226}Ra(p,t), ^{226}Ra(α,α'2nγ), ^{226}Ra(^{58}Ni,^{60}Ni)
7	916.34 ± 0.07	0 +	^{224}Fr β^- decay, **^{228}Th α decay**, ^{226}Ra(p,t)
8	992.65 ± 0.06	(2 +)	^{224}Fr β^- decay, **^{228}Th α decay**

Measured and recommended energies of the main alpha-particle emissions of ^{228}Th.

	E$_{\alpha}$ (keV)					
	1953As31	**1970Ba20**	**1971Gr07**	**1976BaZZ**	**1991Ry01**	**Recommended value***
$\alpha_{0,8}$	–	–	–	–	–	4448.00 (23)
$\alpha_{0,7}$	–	–	–	–	–	4522.97 (23)
$\alpha_{0,6}$	–	–	–	–	–	4952.5 (3)
$\alpha_{0,5}$	–	–	–	–	–	4997.76 (24)
$\alpha_{0,4}$	–	5136.1	–	–	–	5137.97 (22)
$\alpha_{0,3}$	5173	5171.5	–	–	–	5176.86 (22)
$\alpha_{0,2}$	5208	5208.9	–	–	–	5211.05 (22)
$\alpha_{0,1}$	5388.5 (10)	5338.6	5340.54 (15)	5339.2 (10)	5340.36 (15)	5340.35 (22)
$\alpha_{0,0}$	5421 (1)	5420.0	5423.33 (22)	5420.6 (10)	5423.15 (22)	5423.24 (22)

* Determined from the nuclear level energies of 1997Ar05 and evaluated Q-value of 5520.08 (22) keV (2003Au03).

Emission Probabilities

An alpha-particle emission probability of 73.4 (5) % was derived for alpha decay directly to the ground state of ^{224}Ra, based on the various alpha-particle studies. This value and the gamma-ray data were used in conjunction with the theoretical internal conversion coefficients to determine a normalisation factor of 0.0119 (3) per 100 disintegrations for the relative emission probabilities of the gamma rays (see below).

Published alpha-particle emission probabilities per 100 disintegrations of ^{228}Th.

E$_{\alpha}$(keV)	**P$_{\alpha}$**				
	1953As31	**1969Pe17**	**1970Ba20**	**1976BaZZ**	**1993Ba72**
4448.00 (23)	-	-	-	-	-
4522.97 (23)	-	-	-	-	-
4952.5 (3)	-	-	-	-	-
4997.76 (24)	-	-	-	-	-
5137.97 (22)	-	-	~ 0.05	-	-
5176.86 (22)	0.2	-	0.18	-	-
5211.05 (22)	0.4	-	0.36	-	-
5340.35 (22)	28	26.7 (2)	26.7	26.6 (5)	26.0 (8)
5423.24 (22)	71	[73.3 (2)]	72.7	72.4 (10)	74.0 (6)

Alpha-particle emission probability data of 1969Pe17 are effectively normalised to 73.3 (2) % and 26.7 (2) %.

1976BaZZ measurements require re-normalisation to (100 – 0.36 – 0.18 – 0.05) = 99.41 %
(72.4 + 26.6) N = 99.41
N = 1.00414 to give P_α(5423.24 keV) of 72.7 %, and uncertainty of ± 1.0;
and P_α(5340.35 keV) of 26.7 %, and uncertainty of ± 0.5.

1993Ba72 studies also require re-normalisation to give P_α(5423.24 keV) of 73.6 % and uncertainty of ± 0.6; and P_α(5340.35 keV) of 25.8 %, and uncertainty of ± 0.8.

A weighted mean value of 73.4 (5) % (0.734 (5)) was determined for P_α(5423.24 keV) from the data of 1976BaZZ and 1993Ba72, which has been matched against a value of 26.0 (5) % (0.260 (5)) for P_α(5340.35 keV).

The absolute emission probabilities of the majority of the other alpha particles were calculated from population-depopulation of the nuclear level of ^{224}Ra and the gamma-ray normalisation factor. Although a consistent decay scheme was derived, further detailed alpha-particle measurements are required to develop and support the overall correctness of the proposed decay scheme. A hindrance factor (HF) of 1.000 for the 5423.24-keV alpha-particle emission yields r_0(^{224}Ra) of 1.5339 (3) fm, whereas the recommended value is 1.5332 (8) fm (1998Ak04).

Adjusted alpha-particle emission probabilities per 100 disintegrations of ^{228}Th, and hindrance factors.

E_α(keV)	P_α						HF
	1953As31	**1969Pe17**	**1970Ba20**	**1976BaZZ**	**1993Ba72**	**Recommended value**[*]	
4448.00 (23)	-	-	-	-	-	4.5 (7) x 10^{-6}	7.2
4522.97 (23)	-	-	-	-	-	1.7 (3) x 10^{-5}	7.0
4952.5 (3)	-	-	-	-	-	2.4 (5) x 10^{-5}	4600
4997.76 (24)	-	-	-	-	-	1.0 (2) x 10^{-5}	21400
5137.97 (22)	-	-	~ 0.05	-	-	0.036 (6)	44
5176.86 (22)	0.2	-	0.18	-	-	0.218 (4)	12.5
5211.05 (22)	0.4	-	0.36	-	-	0.408 (7)	10.7
5340.35 (22)	28	26.7 (2)	26.7	26.7 (5)	25.8 (8)	26.0 (5)	0.958
5423.24 (22)	71	[73.3 (2)]	72.7	72.7 (10)	73.6 (6)	73.4 (5)[‡]	1.000
						Σ100.1 (7)	

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[*] Recommended emission probabilities of the low-intensity α transitions were derived from the evaluated gamma-ray emission probabilities and theoretical internal conversion coefficients.

[‡] P_α(5423.24 keV) of 73.4 (5) % is effectively the weighted mean of the re-normalised studies (1976BaZZ, 1993Ba72), which has been subsequently matched with P_α(5340.35 keV) of 26.0 (5) %.

Gamma Rays

Energies

Although energies of the gamma-ray emissions have been measured by 1968Da21 and 1997Ku15 in particular, the well-defined nuclear level energies of 1997Aro5 were used to determine the recommended energies and associated uncertainties of the gamma-ray emissions between the various populated-depopulated levels because of their more extensive origins.

Measured and recommended gamma-ray energies.

E_γ (keV)			
1968Da21	**1977Ku15**	**1977Ku25**	**Recommended value**[*]
-	74.4 (1)[‡]	-	74.38 (4)
-	84.371 (3)[†]	84.371 (3)	84.373 (3)
131.6 (8)	131.610 (4)[†]	131.610 (4)	131.612 (5)
-	142.0 (5)[‡]	-	142.71 (11)
166.5 (8)	166.407 (4)[†]	166.407 (4)	166.410 (6)
-	182.2 (2)[‡]	-	182.29 (10)
-	205.93 (5)	-	205.99 (4)
216.1 (6)	215.979 (5)[†]	215.979 (5)	215.985 (4)
-	228.5 (2)	-	228.42 (18)
-	700.5 (5)[‡]	-	700.36 (7)
-	742.2 (5)	-	741.87 (6)
-	832.0 (2)	-	831.97 (7)
-	-	-	908.28 (6)
-	992.9 (10)	-	992.65 (6)

[†] Identical value and uncertainty also reported by 1977Ku25.
[‡] Data derived from coincidence measurements.
[*] Determined from the nuclear level energies of 1997Ar05.

Emission Probabilities

Gamma-ray emission probabilities have been partially or fully determined in the measurements of 1977Ku15, 1982Sa36 and 1984Ge07. However, the data derived by 1982Sa36 are significantly lower by 20 % to 30 % compared with the equivalent values measured by 1977Ku15 and 1984Ge07, and therefore they were set aside from in the weighted mean analysis. Weighted mean relative emission probabilities were calculated for the 131.612-, 166.410-, 205.99- and 215.985-keV gamma rays, while equivalent data for the other gamma emissions were directly adopted from the measurements of 1977Ku15. An additional gamma transition was added to the proposed decay scheme from the equivalent studies of ^{224}Fr decay by 1981Ku02 as a 908.28-keV gamma ray depopulating the 992.65-keV nuclear level of ^{224}Ra - this gamma transition may have been observed in the α decay of ^{228}Th by 1977Ku15, but was adjudged by them to be background radiation (within the 911.2-keV peak). All of these relative emission probabilities were defined in terms of the emission probability of the 84.373-keV gamma ray (100.0 %).

Published gamma-ray emission probabilities.

E_γ (keV)	P_γ			
	1969Pe17[*]	**1977Ku15**[†]	**1982Sa36**[‡]	**1984Ge07**[§]
74.38 (4)	-	4.0 (14)	-	-
84.373 (3)	1.21(6)	12100 (600)	1.9 (1)	100.0 (16)
131.612 (5)	-	1240 (60)	0.17 (2)	10.70 (15)
142.71 (11)	-	0.013 (4)	-	-
166.410 (6)	-	960 (50)	0.13 (1)	8.49 (12)
182.29 (10)	-	0.052 (18)	-	-
205.99 (4)	-	184 (9)	-	-
215.985 (4)	-	2390 (130)	0.30 (2)	1.61 (5)
228.42 (18)	-	0.18(3)	-	20.78 (25)
700.36 (7)	-	~ 0.03	-	-
741.87 (6)	-	0.014 (4)	-	-
831.97 (7)	-	0.14 (2)	-	-
908.28 (6)	-	-	-	-
992.65 (6)	-	~ 0.015	-	-

[*] Emission probability expressed in terms of photons per 100 disintegrations.
[†] Emission probabilities expressed in terms of photons per 10^6 disintegrations.
[‡] Emission probabilities published relative to Pγ(238.63 keV) for ^{212}Pb of 43.0 %.
[§] Emission probabilities published relative to Pγ(84.373 keV) of 100.0 %.

Measured and recommended gamma-ray emission probabilities relative to Pγ(84.373 keV) of 100 %.

E_γ (keV)	P_γ^{rel}			
	1977Ku15	**1982Sa36**	**1984Ge07**	**Recommended value**[*]
74.38 (4)	0.033 (12)	-	-	0.033 (12)
84.373 (3)	100 (5)	100 (5)	100.0 (16)	100.0 (16)
131.612 (5)	10.25 (50)	8.9 (10)[†]	10.70 (15)	10.7 (2)
142.71 (11)	0.000 11 (3)	-	-	0.000 11 (3)
166.410 (6)	7.9 (4)	6.8 (5)[†]	8.49 (12)	8.44 (12)
182.29 (10)	0.000 43 (15)	-	-	0.000 43 (15)
205.99 (4)	1.52 (7)	-	1.61 (5)	1.58 (4)
215.985 (4)	19.8 (11)	15.8 (11)[†]	20.78 (25)	20.7 (3)
228.42 (18)	0.001 5 (3)	-	-	0.001 5 (3)
700.36 (7)	~ 0.000 25	-	-	0.000 25 (8)
741.87 (6)	0.000 12 (3)	-	-	0.000 12 (3)
831.97 (7)	0.001 2 (2)	-	-	0.001 2 (2)
908.28 (6)	-	-	-	0.000 14 (4)
992.65 (6)	~ 0.000 12	-	-	0.000 12 (3)

[*] Weighted mean values adopted when judged appropriate.

[†] Significantly lower than equivalent data of 1977Ku15 and 1984Ge07 by 20 % to 30 %; judged to be an outlier, and therefore not considered in any weighted mean analysis.

Multipolarities and Internal Conversion Coefficients

The nuclear level scheme specified by Artna-Cohen has been used to define the multipolarities of the gamma transitions on the basis of known spins and polarities (1997Ar05). Limited studies of the internal conversion coefficients support the proposed transition types: E2 for both the 84.373- and 166.410-keV gamma rays (1953As31, 1966Co40, 1968Du06, 1969Pe17 and 1970SpZW).

Internal conversion coefficients as determined by measurement.

Reference	E_γ (keV)	α					Measurement technique
		α_L	α_{L2}	α_{L3}	α_{M+}	α_{total}	
1953As31	84.373 (3)	-	-	-	-	16	deduced from measured P_γ and P_α populating 84.37-keV nuclear level of ^{224}Ra
	166.410 (4)	-	-	-	-	1.2	deduced from measured P_γ and P_α populating 251-keV nuclear level of ^{224}Ra
1966Co40	84.373 (3)	14 (3)	7.6	6.3	3.8 (9)	18 (4)	P_{ce} measured by means of photographic emulsion technique
1968Du06	84.373 (3)	-	-	-	-	19.6 (14)	deduced from α-gated γ-ray spectra
1969Pe17	84.373 (3)	-	-	-	-	21.4 (9)	deduced from α-gated γ-ray spectra

Conversion electron spectra: Measurements of L- and M-subshell internal conversion ratios (1970SpZW).

E_γ (keV)	L_1/L_2	L_1/L_3	L_2/L_3	M_1/M_2	M_1/M_3	M_2/M_3
84.373 (3)	0.0388 (19)	0.0519 (21)	1.343 (10)	0.0471 (46)	0.0571 (57)	1.2187 (85)

The 908.28-keV gamma ray was identified as the only mixed multipolarity (M1 + E2), and was arbitrarily assigned a mixing ratio of 1.0 with an uncertainty of ± 0.2. Recommended internal conversion coefficients have been determined from the frozen orbital approximation of Kibédi *et al*. (2008Ki07), based on the theoretical model of Band *et al*. (2002Ba85, 2002Ra45). Uncertainties of ± 1.5 % were adopted for all of the E1 and E2 gamma transitions (with minor upward adjustments associated with the significant figures for α_L and α_{M+}).

Gamma-ray emissions: multipolarities and theoretical internal conversion coefficients (frozen orbital approximation).

E_γ (keV)	Multipolarity	α_K	α_L	α_{M+}	α_{total}
74.38 (4)	[E2]	–	28.3 (4)	10.3	38.6 (6)
84.373 (3)	E2	–	15.57 (22)	5.63	21.2 (3)
131.612 (5)	E1	0.194 (3)	0.0406 (6)	0.0124	0.247 (4)
142.71 (11)	[E2]	0.279 (4)	1.368 (20)	0.493	2.14 (3)
166.410 (6)	E2	0.225 (4)	0.691 (10)	0.248	1.164 (17)
182.29 (10)	[E1]	0.089 4 (13)	0.017 57 (25)	0.005 63	0.112 6 (16)
205.99 (4)	(E1)	0.067 1 (10)	0.012 92 (18)	0.004 08	0.084 1 (12)
215.985 (4)	E1	0.060 0 (9)	0.011 48 (16)	0.003 72	0.075 2 (11)
228.42 (18)	[E2]	0.124 4 (18)	0.178 (3)	0.063 6	0.366 (6)
700.36 (7)	E1	0.005 02 (7)	0.000 834 (12)	0.000 256	0.006 11 (9)
741.87 (6)	[E2]	0.011 96 (17)	0.003 22 (5)	0.001 07	0.016 25 (23)
831.97 (7)	E2	0.009 70 (14)	0.002 40 (4)	0.000 79	0.012 89 (18)
908.28 (6)	[50%M1 + 50%E2] δ = 1.0 (2)	0.019 0 (24)	0.003 6 (4)	0.001 4	0.024 (3)
992.65 (6)	[E2]	0.007 05 (10)	0.001 569 (22)	0.000 511	0.009 13 (13)

The normalisation factor was calculated for the gamma-ray emission probabilities by averaging the values determined by three different routes:

(i) direct population of the ^{224}Ra ground state

$[\Sigma P_{\gamma i} (1 + \alpha_i)$ to ground state$]$ NF + 0.734 (5) = 1.00
NF = 0.000 119 (3)

(ii) population/depopulation of the 84.373-keV nuclear level of ^{224}Ra

$[P_\gamma(84.373\text{ keV})(1 + \alpha(84.373\text{ keV})) - \Sigma P_{\gamma i} (1 + \alpha_i)$ to 84.373-keV level$]$ NF = 0.260 (5)
NF = 0.000 119 (3)

(iii) all α emissions

ΣP_α NF = 1.00, and adopting α-particle emission probability to ^{224}Ra ground state of 0.734 (5) (see section on alpha-particle emissions)
NF = 0.000 119 (3)

Thus, a normalization factor of 0.000 119 (3) has been adopted in the determination of the absolute gamma-ray emission probabilities.

Atomic Data

The x-ray and Auger-electron data have been calculated using the evaluated gamma-ray data, and atomic data from 1996Sc06, 1998ScZM and 1999ScZX. Both the x-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.01, 28 January 2003). This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

K and L X-ray emission probabilities per 100 disintegrations of ^{228}Th.

			Energy (keV)	Photons per 100 disint.
XL		(Ra)	10.622 – 18.412	8.6 (4)
	XL_l	(Ra)	10.622	0.166 (6)
	XL_α	(Ra)	12.196 – 12.339	2.86 (9)
	XL_η	(Ra)	13.662	0.109 (4)
	XL_β	(Ra)	14.236 – 15.447	4.67 (15)
	XL_γ	(Ra)	17.848 – 18.412	1.09 (4)
XK_α	$XK_{\alpha2}$	(Ra)	85.43	0.018 0 (3)
	$XK_{\alpha1}$	(Ra)	88.47	0.029 5 (5)
$XK'_{\beta1}$	$XK_{\beta3}$	(Ra)	99.432	) 0.010 34 (21)
	$XK_{\beta1}$	(Ra)	100.13	)
	$XK''_{\beta5}$	(Ra)	100.738	)
$XK'_{\beta2}$	$XK_{\beta2}$	(Ra)	102.89	) 0.003 39 (9)
	$XK_{\beta4}$	(Ra)	103.295	)
	$XKO_{2,3}$	(Ra)	103.74	)

Electron energies were determined from electron binding energies tabulated by Larkins (1977La19) and the evaluated gamma-ray energies. Absolute electron emission probabilities were calculated from the evaluated absolute gamma-ray emission probabilities and associated internal conversion coefficients.

Data Consistency

A Q_α-value of 5520.08 (22) keV has been adopted from the atomic mass evaluation of Audi *et al.* (2003Au03) while in the course of formulating the decay scheme of ^{228}Th. This value has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{228}Th alpha-decay process (i.e. α, electron, γ, etc.):

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 5523\ (40)\ \text{keV}$$

Percentage deviation from the Q-value of Audi *et al.* is − (0.1 ± 0.7) %, which supports the derivation of a highly consistent decay scheme with a significant variant.

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^{231}Th -Comments on evaluation of decay data
by Huang Xiaolong , Wang Baosong

This evaluation was completed in 2007. Literature available by May 2007 was included.

1 Decay Scheme

^{231}Th disintegrates 100 % by β^- emission to levels in ^{231}Pa.

^{231}Th ground state has $J^\pi = 5/2^+$(2001Br31).

The adopted Q(β^-) value of 391.6 (15) keV from Audi(2003Au03) is good in agreement with the Q(β^-) value of 372 (59) keV, calculated by the evaluator (using program RADLST) from average radiation energies and decay scheme data.

2 Nuclear Data

The Q value is from the 2003Au03 evaluation.

Level energies, spin and parities are from 2001Br31.

Measured and evaluated ^{231}Th half-life values are listed in Table 1.

Table 1: Measured half-life values of ^{231}Th and recommended value.

$T_{1/2}$ (h)	References	Measurement method
25.51 (23)	1949Kn09	Geiger counters, weighted average of 5 samples, 10 $T_{1/2}$
25.64 (10)	1951Ja17	G-M tube, unweighted average of 2 samples, 6 $T_{1/2}$
25.52 (1)	1958Ca19	$4\pi\beta$ counter, unweighted average of 18 sources, 4 $T_{1/2}$
25.7 (2)	1971Ko48	Ge(Li), γ-rays
25.76 (21)	1983Ch06	Ge(Li), 84keV γ-ray, 6 $T_{1/2}$
25.63 (5)		Unweighted mean
25.522 (10)		Weighted mean with all experimental values, χ^2=0.88
25.522 (10)	Recommended value	Weighted mean

The weighted half-life average has been calculated using the LWM program.

2.1 β^- transitions

The maximum energies of the β^- transitions in the decay of ^{231}Th have been deduced from the Q value (2003Au03) and the level energies.

The adopted β^- transition probabilities and their associated uncertainties were deduced from the γ transition probability balance at each level of the decay scheme, using a normalization factor N = 0.0670 (7) (See Section 5.3). The $I_{\beta-}$(g.s. + 9.2 keV) = 0.022 (7) and $I_{\beta-}$(58.6 keV) < 0.33 are the experimental values from a β^- Kurie plot (1975Ho14). Measured and recommended β^- transition probabilities are given in Table 2.

Table 2: Measured and recommended β^- transition probabilities (%).

Level energy/keV	1975Ho14	Adopted value
0	0.022 (7)	0.022 (7)
58.6	< 0.33	< 0.33
77.7	< 0.33	0.43 (2)
84.2		29 (18)
101.4		41 (16)
102.3		13 (8)
174.2		1.36 (24)
183.5		12.2 (15)
218.2		0.31 (23)
247.3		2.7 (4)
318		0.00078 (5)
320.2		0.066 (2)
351.8		0.0032 (2)

The values of *lg ft* and average β^- energies have been calculated with the program LOGFT.

2.2 γ-Ray Transitions

The γ-ray transition probabilities were calculated using the γ-ray emission intensities and the relevant internal conversion coefficients.

Multipolarities and mixing ratios of γ-ray transitions are from 1975Ho14 and 2001Br31.

The internal conversion coefficients (ICC) and their associated uncertainties for γ-ray transitions have been obtained using the BrIcc computer program (2008Ki07), which uses the “Frozen Orbital” approximation (2002Ba85). The mixing ratios of the 18- and 63-keV gamma transitions have asymmetric uncertainties, $\delta = 0.14\ (+12, -4)$ and 0.52 (+20, -32), respectively. The ICC of the 84.214 keV γ-ray has been taken from a measurement of 1975Ho14 because it has an anomalous conversion coefficient. Experimental and theoretical conversion coefficients are compared in Table 3.

Table 3: Comparison of theoretical and measured conversion coefficients.

E_γ (keV)	Multipolarity	α(theory)	α(exp.)	
			1960As02	1975Ho14
18.07	M1+E2	$\alpha_T = 757$		$\alpha_{M3} > 9$
25.64	E1	$\alpha_T = 4.37$, $\alpha_L = 3.26$, $\alpha_M = 0.84$	$\alpha_T = 4.8\ (10)$	$\alpha_{L3} = 1.6\ (3)$, $\alpha_M = 0.96\ (9)$
58.57	E2	$\alpha_T = 155.5$, $\alpha_L = 113.6$, $\alpha_M = 31.3$		$\alpha_L = 115.9$, $\alpha_M = 29.9\ (30)$
63.86	M1+E2	$\alpha_T = 34$, $\alpha_L = 25$, $\alpha_M = 7$		$\alpha_{L1} = 9.1\ (16)$
68.5	E2	$\alpha_T = 73.3$, $\alpha_L = 53.5$, $\alpha_M = 14.8$		$\alpha_L = 57\ (11)$
81.228	M1(+E2)	$\alpha_T = 8.1$, $\alpha_L = 6.1$, $\alpha_M = 1.5$		$\alpha_{L1} = 4.7\ (8)$, $\alpha_M = 1.3\ (3)$
82.087	M1(+E2)	$\alpha_T = 7.9$, $\alpha_L = 5.9$, $\alpha_M = 1.4$		$\alpha_{L1+L3} = 5.7\ (11)$, $\alpha_M = 1.6\ (4)$
84.214	E1	$\alpha_T = 0.19$, $\alpha_L = 0.14$	$\alpha_T = 2.8\ (4)$	$\alpha_T = 2.50\ (25)$, $\alpha_M = 0.57\ (10)$
99.278	M1+E2	$\alpha_T = 6$, $\alpha_L = 4.4$, $\alpha_M = 1.1$		$\alpha_M = 1.13\ (14)$, $\alpha_N = 0.35\ (10)$
135.664	M1(+E2)	$\alpha_T = 8$, $\alpha_K = 6.1$, $\alpha_L = 1.4$		$\alpha_K = 6.5\ (11)$, $\alpha_L = 1.1\ (3)$
145.94	M1+E2	$\alpha_T = 5.1$, $\alpha_K = 3.4$, $\alpha_L = 1.3$		$\alpha_K = 3.6\ (8)$, $\alpha_L = 0.8\ (3)$
163.101	M1(+E2)	$\alpha_T = 4.9$, $\alpha_K = 3.9$, $\alpha_L = 0.78$		$\alpha_K = 4.1\ (5)$, $\alpha_L = 0.6\ (1)$
217.94	E1	$\alpha_T = 0.079$, $\alpha_K = 0.062$, $\alpha_L = 0.01$		$\alpha_K < 0.12$, $\alpha_L < 0.09$
311	M1+E2	$\alpha_T = 0.6$, $\alpha_K = 0.5$, $\alpha_L = 0.1$		$\alpha_L = 0.11\ (3)$, $\alpha_M = 0.04\ (1)$

3. Atomic data

Atomic fluorescence yields (ω_K,ϖ_L, ϖ_M, η_{KL} and η_{LM}) are from Schönfeld (1996Sc06).

The X-ray and Auger electron emission probabilities have been deduced from γ-ray and conversion electron data by using the computer code RADLST. Measured and calculated X-ray emission probabilities are compared in Table 4.

Table 4: Comparison of the calculated and measured X-ray emission probabilities.

	1973Br12	1999Ch12	Recommended (deduced)
$K_{\alpha 1}$	0.69 (8)	0.64 (4)	0.59 (7)
$K_{\alpha 2}$	0.40 (5)	0.376 (24)	0.37 (4)
K_{β}	0.332 (25)	0.310 (14)	0.28 (3)

The deduced KX-ray emission probabilities agree with the measured values of 1999Ch12 and 1973Br12, thus confirming the completeness of the decay scheme.

4. Electron Emissions.

The conversion electron emission probabilities have been deduced from γ-ray transition data using theoretical internal conversion coefficients.

5. Photon Emissions

5.1 γ-ray energy values

Measurements of γ-ray energy values from ^{231}Th β^- decay are listed in Table 5. The recommended values are taken from the measurements of 1975Ho14 and 1979Bo30, except as noted in Table 5.

It should be noticed that some uncertain weak γ-rays: 26.55, 29.30, 32.73, 33.32, 38.90, 41.55, 42.22, 45.34, 85.80, 97.55, 106.85, 173.0, 224.1 and 237.8 keV, were observed only by 1977Ba72. These γ-rays have not been considered in the present evaluation.

Table 5: Measured and recommended γ-ray energies for ^{231}Th.

1973Br12	1973Te06	1975Ho14	1977Ba72	1979Bo30	Recommended
					9.2[a]
					10.25[a]
		17.2	17.21		17.2
		18.07	18.05		18.07
(25.65)		25.64 (2)	25.64 (5)		25.64 (2)
42.80 (6)		42.86 (7)	42.22 (5)		42.86 (7)
44.1 (3)		44.08 (17)	45.34 (5)		44.08 (17)
58.47 (5)		58.57 (2)	58.54 (5)	58.5700 (24)	58.5700 (24)[b]
63.7 (2)		63.86 (3)	63.65 (5)		63.86 (3)
		68.5 (1)	68.55		68.5 (1)
72.66 (6)	72.74 (5)	72.78 (2)	72.70 (5)	72.7510 (25)	72.7510 (25)[b]
			76		77.69[c]
81.18 (5)	81.20 (6)	81.24 (2)	81.16 (5)	81.2280 (14)	81.2280 (14)[b]
82.02 (6)	82.06 (7)	82.11 (2)	82.02 (5)	82.0870 (14)	82.0870 (14)[b]
(84.17)	84.20	84.21 (2)	84.16 (5)	84.2140 (13)	84.2140 (13)[b]
89.94 (5)	89.95 (4)	89.95 (2)	89.94 (5)		89.95 (2)

1973Br12	1973Te06	1975Ho14	1977Ba72	1979Bo30	Recommended
93.0 (1)	92.91 (10)	93.02 (4)			93.02 (4)
99.30 (5)	99.33 (5)	99.28 (2)	99.33 (5)	99.278 (3)	99.278 (3)[b]
102.30 (5)	102.32 (4)	102.27 (2)	102.23 (5)	102.2700 (13)	102.2700 (13)[b]
105.73 (10)	105.74 (10)	105.81 (3)			105.81 (3)
106.58 (10)	106.66 (8)	106.61 (3)	106.65 (10)		106.61 (3)
115.5 (2)		115.63 (3)	115.83 (10)		115.63 (3)
116.91 (5)		116.82 (2)	116.80 (10)		116.82 (2)
125.10 (5)		124.93 (2)	125.00 (10)	124.914 (17)	124.914 (17)[b]
134.14 (8)		134.03 (2)	134.00 (5)		134.03 (2)
135.77 (6)		135.68 (2)	135.66 (5)	135.664 (11)	135.664 (11)[b]
136.78 (20)		136.75 (7)			136.75 (7)
		140.54 (4)			140.54 (4)
145.15 (30)		145.06 (4)			145.06 (4)
146.00 (7)		145.94 (2)	145.90 (5)		145.94 (2)
163.16 (6)		163.12 (2)	163.15 (5)	163.101 (4)	163.101 (4)[b]
164.94 (10)		165.00 (5)	164.70 (10)		165.00 (5)
169.58 (10)		169.66 (3)			169.66 (3)
174.19 (8)		174.15 (2)	174.1 (10)		174.15 (2)
					177.66
183.47 (7)		183.50 (2)	183.4 (10)	183.480 (25)	183.480 (25)[b]
188.77 (20)		188.76 (2)	188.7 (10)		188.76 (2)
218.00 (7)		217.94 (3)	218.0 (5)		217.94 (3)
236.17 (7)		236.01 (3)	236.l (10)		236.01 (3)
240.4 (2)		240.27 (5)			240.27 (5)
242.6 (1)		242.50 (4)			242.50 (4)
249.8 (3)		249.60 (7)	249.8		249.60 (7)
250.5 (3)		250.45 (7)			250.45 (7)
267.80 (7)		267.62 (8)	267.8		267.62 (8)
		274.10 (10)			274.10 (10)
308.9 (3)		308.78 (7)			308.78 (7)
311.0 (1)		311.00 (5)	312.3 (25)		311.00 (5)
318.0 (4)		317.87 (8)			317.87 (8)
320.2 (3)		320.15 (8)			320.15 (8)
		351.80 (10)			351.80 (10)

a: Expected but as yet unobserved.

b: From 1979Bo30 curved crystal.

c: From 1999Ch12.

5.2 Relative γ-ray intensities

Experimental γ-ray intensities from ^{231}Th β^- decay are listed in Table 6. The recommended values are from a LWM average of values reported in 1999Ch12, 1983BaZZ, 1975Ho14, 1973Te06 and 1973Br12.

1977Ba72 observed some uncertain weak γ-rays with measured relative γ-ray intensities different from those given in other measurements. These relative intensities may not be accurate and thus have not been considered here.

Table 6: Measured and evaluated relative γ-ray intensities for ^{231}Th.

E_γ (keV)	I_γ									
	1953 Fr37	1971 Ko48	1973 Br12	1973 Te06	1975 Ho14	1977 Ba72	1983 BaZZ	1999 Ch12	LWM	Evaluation
(9.2)										7.44[a]
(10.25)										11.0[a]
17.2										680 (230)[b]
18.07					≤ 5.1					310 (110)[b]
25.64	170	119 (25)	202 (20)		228 (15)	331.92 (56)	230 (16)	210 (10)	217 (7)	207 (10)[c]
42.86			0.87 (10)		0.89 (6)	0.469 (19)		0.89 (2)	0.89 (2)	0.89 (2)
44.08			0.06 (4)		0.011 (3)	0.527 (20)			0.011 (3)	0.011 (3)
58.5700		8.4 (6)	7.2 (7)		7.4 (3)	8.748 (82)	6.8 (6)	6.8 (2)	6.98 (16)	7.17 (22)[c]
63.86	< 40		0.68 (14)		0.35 (3)			0.29 (5)	0.35 (3)	0.35 (3)
68.5					0.088 (22)			0.088 (4)	0.088 (2)	0.088 (2)
72.7510		4.4 (4)	4.0 (4)	3.8 (2)	3.86 (23)	4.046 (59)	7.8 (8)	3.8 (1)	3.88 (24)	3.88 (24)
77.69								0.063 (10)	0.063 (10)	0.063 (10)
81.2280		1.03 (3)	14.2 (14)	13.5 (9)	13.7 (8)	11.69 (10)	13.2 (5)	13.5 (5)	13.5 (3)	13.5 (3)
82.0870		21.5 (13)	7.2 (7)	6.8 (4)	6.2 (5)	4.675 (67)	6.0 (3)	6.0 (3)	6.24 (17)	6.24 (17)
84.2140	100	100	100	100	100	100	100	100	100	100
89.95		13.9 (13)	15.3 (15)	15.3 (8)	14.5 (9)	13.25 (12)		15.0 (5)	15.0 (4)	15.0 (4)
93.02			0.50 (5)	0.9 (2)	0.69 (8)			0.71 (8)	0.60 (4)	0.60 (4)
99.278		1.03 (10)	2.1 (2)	2.2 (2)	1.85 (11)	1.555 (43)		2.0 (1)	2.05 (8)	2.05 (8)
102.2700		4.6 (4)	6.7 (7)	6.8 (4)	6.3 (5)	5.424 (82)	6.5 (3)	6.6 (2)	6.58 (14)	6.58 (14)
105.81	6 (5)		0.14 (2)	0.13 (8)	0.11 (1)			0.12 (1)	0.118 (7)	0.118 (7)
106.61		3.04 (25)	0.34 (4)	0.33 (10)	0.262 (15)	0.482 (25)		0.264 (11)	0.267 (9)	0.267 (9)
115.63			0.04 (1)		0.015 (3)	0.267 (20)		0.015 (4)	0.0164 (23)	0.0164 (23)
116.82			0.39 (4)		0.318 (20)	0.367 (21)		0.34 (2)	0.336 (13)	0.336 (13)
124.914	2		0.95 (9)		0.86 (5)	1.014 (43)	0.89 (12)	0.88 (2)	0.88 (2)	0.88 (2)
134.03			0.42 (5)		0.37 (2)	0.562 (24)	0.29 (14)	0.38 (1)	0.38 (1)	0.38 (1)
135.664			1.3 (1)		1.20 (8)	1.704 (28)	1.30 (23)	1.17 (4)	1.19 (3)	1.19 (3)
136.75			0.09 (3)		0.065 (3)			0.067 (3)	0.066 (2)	0.066 (2)
140.54					0.011 (1)			0.011 (1)	0.011 (1)	0.011 (1)
145.06			0.12 (3)		0.089 (6)			0.084 (6)	0.087 (4)	0.087 (4)
145.94			0.58 (6)		0.49 (3)	0.571 (25)		0.47 (2)	0.484 (16)	0.484 (16)
163.101	1.8		2.6 (3)		2.38 (14)	2.754 (64)		2.30 (8)	2.33 (7)	2.33 (7)
165.00			0.06 (3)		0.060 (6)	0.200 (11)		0.051 (2)	0.052 (2)	0.052 (2)
169.66			0.03 (1)		0.0185 (15)			0.021 (1)	0.021 (1)	0.021 (1)
174.15			0.31 (3)		0.278 (17)	0.704 (21)		0.26 (1)	0.268 (8)	0.268 (8)
177.66[×]								0.00095 (20)	0.00095 (20)	0.00095 (20)
183.480			0.57 (6)		0.506 (20)	1.005 (26)		0.49 (2)	0.50 (1)	0.50 (1)
188.76			0.08 (1)		0.049 (3)	0.084 (8)		0.049 (1)	0.050 (4)	0.050 (4)
217.94	0.3		0.67 (7)		0.62 (5)	0.960 (29)	0.57 (2)	0.60 (1)	0.60 (1)	0.60 (1)
236.01	0.1		0.18 (2)		0.14 (1)	1.465 (28)		0.138 (5)	0.140 (4)	0.140 (4)
240.27			0.0050 (5)		0.0043 (5)			0.0040 (5)	0.0043 (6)	0.0043 (6)

E_γ (keV)	I_γ									
	1953 Fr37	1971 Ko48	1973 Br12	1973 Te06	1975 Ho14	1977 Ba72	1983 BaZZ	1999 Ch12	LWM	Evaluation
242.50			0.0130 (6)		0.013 (1)			0.011 (1)	0.0123 (6)	0.0123 (6)
249.60			0.010 (2)		0.012 (1)			0.012 (1)	0.012 (1)	0.012 (1)
250.45			0.011 (2)		0.010 (1)			0.010 (1)	0.010 (1)	0.010 (1)
267.62			0.0230 (6)		0.018 (2)			0.019 (1)	0.021 (2)	0.021 (2)
274.10					0.00046 (15)			0.0006 (2)	0.0005 (2)	0.0005 (2)
308.78			0.008 (1)		0.0060 (6)			0.0053 (2)	0.0054 (2)	0.0054 (2)
311.00			0.054 (5)		0.045 (3)			0.046 (2)	0.047 (2)	0.047 (2)
317.87			0.0020 (2)		0.00123 (15)			0.0013 (2)	0.0015 (2)	0.0015 (2)
320.15			0.0035 (3)		0.0017 (2)			0.0020 (2)	0.0022 (4)	0.0022 (4)
351.80					0.0011 (2)			0.0010 (2)	0.0010 (2)	0.0010 (2)

a: I(γ+ce), from γ-ray transition intensity balance.

b: I(γ+ce), from ce measurements(1975Ho14).

c: Adjusted value from intensity balance.

×: Not placed in level scheme.

5.3 Absolute values γ-ray emission probabilities

Measurements of the absolute emission probability of the 84.21keV γ-ray from ^{231}Th β^- decay and the LWM results are listed in Table 7. The measurement of 1973Br12 is an average of two α-γ coincidence measurements (6.7 (5) and 7.3 (4)). This value and the measurement of 1960As02 are higher than other measurements and not adopted in the calculation.

The recommended absolute γ-ray emission probability of the 84.21keV γ-ray is from the LWM calculation, and has been used here to produce a recommended normalization factor N = 0.0670 (7).

Table 7: Measured and recommended absolute γ-ray emission probability of 84.21keV for ^{231}Th.

P_γ (84.21 keV) (%)	References	measurement method
7.2 (1)	1960As02	Not used
7.9 (5)	1971Ko48	Ge(Li). Replaced by 1999Ch12
7.0 (3)	1973Br12	Ge(Li). Not used
6.5 (4)	1975Ho14	Ge(Li)
6.6 (3)	1982Va04	Si(Li). Weighted average of 3 sources
6.52 (13)	1983BaZZ	
7.25 (41)	1983Ch06	Ge(Li). Replaced by 1999Ch12
6.84 (10)	1984He12	Ge detector. Weighted average of 5 measurements
6.60 (25)	1999Ch12	LEPS. Secular equilibrium with ^{235}U
6.71 (10)	1986LoZT	CRP evaluation in 1986
6.89 (31)		LWM of all measurements
6.70 (7)		LWM, χ^2=1.1
6.70 (7)		**Recommended value**

The recommended absolute γ-ray emission probabilities are the relative values evaluated in Table 6 multiplied by 0.0670 (7).

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^{231}Pa – Comments on evaluation of decay data

A. Arinc

Evaluation completed: February 2010
Literature cut-off date: June 2009

Evaluation procedure

Weighted mean analyses were applied to determine recommended values throughout the evaluation when the data were in statistical agreement. When the data were not in statistical agreement, the Limitation of Relative Statistical Weights (LRSW) was used. Uncertainties were expanded to match the minimum input uncertainty where appropriate.

1. Decay scheme

^{231}Pa disintegrates by alpha emission to various excited levels and the ground state of ^{227}Ac. The spin, parity, half-life of first excited state, multipolarities, mixing ratios and level energies of ^{227}Ac are based on the mass-chain evaluation of Browne (2001Br31).

A lack of experimental data for low-energy gamma transitions and imprecise alpha spectrometry measurements has adversely affected the construction of the decay scheme. The strongest transition of the decay scheme $\gamma_{1,0}$ at 27.370 (10) keV has a transition probability with an uncertainty of 12 %. Further measurements are required in order to build a more reliable decay scheme.

2. Nuclear data

The Q(α) value of 5149.9 (8) keV is taken from the evaluation of Audi et al (2003Au03). The Q-value calculated with Saisinuc is 5100 (120) keV.

% Deviation = [Q(Audi *et al.*) – Q(calculated) / Q(Audi *et al.*)] × 100

= [5149.9 (8) – 5100 (120) / 5149.9 (8)] x 100
= [(49.9 ± 120.0) / (5149.9 ± 0.8)] x 100 = (1.0 ± 2.3) %

The experimental half-life values used for calculating the mean are given in Table 1. The half-life value of 32 000 (3 200) years from Van Grosse (1932Grosse) was omitted from the analysis due to its inaccuracy. The published values from 1969Ro33 and 1961Ki05 were adjusted by 2001Br31 to take into account the change in the adopted decay scheme.
The AveTool computer code was used to calculate the average using three statistical methods: Limitation of Relative Statistical Weights (LRSW), Normalised Residual Methods (NRM) and the Rajeval Technique (RT).

Table 1: Experimental half-life values of ^{231}Pa.

Reference	Half-life (years)	Comments
1949Va02	34 300 (300)	
1961Ki05	32 643 (260)	
1968Br04	32 340 (115)	
1969Ro33	32 765 (110)	
LRSW	32 670 (260)	
NRM	32 705 (93)	reduced-χ^2 = 2.40
RT	32 718 (97)	reduced-χ^2 = 1.09
Recommended value	**32 670 (260)**	

The data set is discrepant with a reduced-χ^2 = 12.84 on the LRSW which is larger than the critical reduced-χ^2 = 3.78 (99 % confidence level). Although the value from 1949Va02 is not in good agreement with the other three values it was not excluded by Chauvenet's criterion. The published uncertainty of 300 years of 1949Va02 was adjusted to 800 years by NRM and to 1300 years by RT, while the published uncertainty of 115 years of 1968Br04 was adjusted to 400 years by RT. The recommended value is the LRSW mean of 32 670 (260) years. This value was chosen as it includes the two most precise values.

Overall the half-life data set is unsatisfactory and there is a strong need for new half-life measurements.

3. Atomic data

The values of ω_K, ω_L, n_{KL} and relative probabilities of the X-ray and Auger emissions were derived from Schönfeld and Janßen (1996Sc06).

The energies and relative emission probabilities of the X-ray and Auger electrons have been calculated using the computer code EMISSION. A summary of the results is given in Tables 2 and 3. The calculated L X-ray and K X-ray subshell ratios were in good agreement with the published data from De Pinho (1974De11).

Table 2: Calculated L X-ray emission energies and probabilities.

L X-ray	Energy (keV)	Calculated value
Ll	10.87	1.10 (4)
Lα	12.50 – 12.65	18.7 (7)
Lη	14.08	0.303 (19)
Lβ	14.60 – 16.63	19.7 (7)
Lγ	17.81 – 18.92	4.45 (16)
LX total		44.3 (13)

Table 3: Calculated K X-ray emission energies and probabilities.

K X-ray	Energy (keV)	Calculated value
$K\alpha_2$	87.768	0.715 (23)
$K\alpha_1$	90.885	1.16 (4)
$K\beta_1$’	102.10 – 103.46	0.410 (15)
$K\beta_2$’	105.68 – 106.56	0.136 (6)
KX total		2.42 (8)

4. Alpha particles

4.1 Alpha particle energies

The alpha transition energies have been calculated from the Q(α) value (2003Au03), and the level energies were adopted from Browne (2001Br31) and are given in Table 4.

Adopted alpha emission energies have been calculated from the transition energies taking into account the recoil energy of the daughter nucleus. The theoretically calculated values were compared to the published data where available (Table 5). The data from 1961Ba42, 1968Ba25 and 1976BaZZ are from the same main author (Baranov). Experimental alpha emission energies were taken from the compilation of 1991Ry01 when available; otherwise primarily from 1976BaZZ and then from 1961Ba42.

Alpha hindrance factors were calculated using the ALPHAD computer program. The radius parameter of r_0 (^{227}Ac) = 1.5323 (14) was calculated as the average of r_0 (^{226}Ra) = 1.5331 (13), r_0 (^{226}Th) = 1.531 (5), r_0 (^{228}Th) = 1.5289 (5) and r_0 (^{228}Ra) = 1.5361 (22) from 1998Ak04. A summary of the adopted levels and theoretical and experimental alpha emission values is presented in Table 6.

Table 4: Adopted nuclear levels of ^{227}Ac.

Nuclear level number	Nuclear level energy (keV)	Spin and parity	Half-life
0	0.0	3/2-	21.772 (3) a
1	27.37 (1)	3/2+	38.3 (3) ns
2	29.98 (1)	5/2-	
3	46.35 (1)	5/2+	
4	74.14 (1)	(7/2)-	
5	84.55 (1)	(7/2)+	
6	109.94 (2)	(9/2)+	
7	126.86 (2)	(9/2)-	
8	160 (2)		
9	187.32 (3)	(11/2+)	
10	198.71 (4)	(11/2-)	
11	210.78 (5)	(13/2+)	
12	271.29 (6)	(13/2-)	
13	273.14 (3)	(5/2)-	
14	304.73 (5)	(5/2+)	
15	330.04 (1)	3/2-	<70 ps
16	354.50 (4)	1/2-	
17	387.23 (2)	7/2-	

Nuclear level number	Nuclear level energy (keV)	Spin and parity	Half-life
18	425.59 (3)	5/2+	
19	435.19 (2)	(1/2)+	
20	437.96 (4)	(5/2-)	
21	469.24 (6)	(9/2+)	
22	501.28 (7)	(3/2-,5/2-)	
23	537.0 (1)	(3/2+)	
24	562.8 (1)	(3/2+,5/2+)	
25	656.4 (3)	(7/2+)	

Table 5: Experimental alpha emission energies (keV).

Transition	1961Ba42[1]	1966Ba04	1968Ba25[2]	1976BaZZ	1991Ry01
$\alpha_{0,0}$	5058.9 (21)	5058.5 (15)	5057.5 (10)	5058.1 (10)	5058.6 (15)
$\alpha_{0,1}$	5032.0 (21)	-	5030.8	-	-
$\alpha_{0,2}$	5029.9 (21)	-	5028.3	-	5028.4 (10)
$\alpha_{0,3}$	5012.7 (20)	5013.5 (15)	5012.7	5013.3 (10)	5013.8 (14)
$\alpha_{0,4}$	4985.5 (20)	-	4985.8 (10)	4986.4 (10)	-
$\alpha_{0,5}$	4974.8 (20)	-	-	-	-
$\alpha_{0,6}$	4951.2 (20)	4951.0 (15)	4950.3 (10)	4950.9 (10)	4951.3 (14)
$\alpha_{0,7}$	4933.8 (21)	-	-	-	-
$\alpha_{0,8}$	4900.0 (21)	-	-	-	-
$\alpha_{0,9}$	-	-	-	-	-
$\alpha_{0,10}$	-	-	-	-	-
$\alpha_{0,11}$	4852.2 (21)	-	-	-	-
$\alpha_{0,12}$	4794.3 (22)	-	-	-	-
$\alpha_{0,13}$	-	-	-	-	-
$\alpha_{0,14}$	-	-	-	-	-
$\alpha_{0,15}$	4736.4 (23)	4733.5 (15)		4736.1 (10)	4736.0 (8)
$\alpha_{0,16}$	4712.0 (24)	-	-	-	-
$\alpha_{0,17}$	4679.7 (24)	-	-	-	-
$\alpha_{0,18}$	4642.2 (25)	-	-	-	-
$\alpha_{0,19}$	-	-	-	-	-
$\alpha_{0,20}$	4631 (3)	-	-	-	-
$\alpha_{0,21}$	4598 (3)	-	-	-	-
$\alpha_{0,22}$	4565 (3)	-	-	-	-
$\alpha_{0,23}$	-	-	-	-	-
$\alpha_{0,24}$	4506 (3)	-	-	-	-
$\alpha_{0,25}$	-	-	-	-	-

[1] Published value was adjusted to recommended values by 1991Ry01 and 4986.4 (10) keV by 1976BaZZ due to changes in calibration energy.

[2] Additional values, which were not placed in the decay scheme, were reported at 5026.6 keV (population of 32-keV energy level of ^{227}Ac) and at 5009.0 keV (population of 49-keV energy level of ^{227}Ac).

Table 6: Adopted levels, theoretical and experimental alpha particle emission energies and hindrance factors.

Transition	Level energy (keV)	Theoretical alpha emission energy[1] (keV)	Experimental alpha emission energy (keV)	HF
$\alpha_{0,0}$	0.0	5060.7 (8)	5058.6 (15)	250
$\alpha_{0,1}$	27.37 (1)	5033.8 (8)	5032.0 (21)	707
$\alpha_{0,2}$	29.98 (1)	5031.2 (8)	5028.4 (10)	95
$\alpha_{0,3}$	46.35 (1)	5015.1 (8)	5013.8 (14)	59.5
$\alpha_{0,4}$	74.14 (1)	4987.8 (8)	4986.4 (10)	629
$\alpha_{0,5}$	84.55 (1)	4977.6 (8)	4974.8 (20)	2 160
$\alpha_{0,6}$	109.94 (2)	4952.6 (8)	4951.3 (14)	26.5
$\alpha_{0,7}$	126.86 (2)	4936.0 (8)	4933.8 (21)	160
$\alpha_{0,8}$	160 (2)	4903.4 (22)	4900.0 (21)	141 000
$\alpha_{0,9}$	187.32 (3)	4876.6 (8)	-	-
$\alpha_{0,10}$	198.71 (4)	4865.4 (8)	-	-
$\alpha_{0,11}$	210.78 (5)	4853.5 (8)	4852.2 (21)	94
$\alpha_{0,12}$	271.29 (6)	4794.1 (8)	4794.3 (22)	1 300
$\alpha_{0,13}$	273.14 (3)	4792.3 (8)	-	-
$\alpha_{0,14}$	304.73 (5)	4761.2 (8)	-	9 600
$\alpha_{0,15}$	330.04 (1)	4736.3 (8)	4736.0 (8)	2.46
$\alpha_{0,16}$	354.50 (4)	4712.3 (8)	4712.0 (24)	11.7
$\alpha_{0,17}$	387.23 (2)	4680.1 (8)	4679.7 (24)	4.6
$\alpha_{0,18}$	425.59 (3)	4642.5 (8)	4642.2 (25)	56
$\alpha_{0,19}$	435.19 (2)	4633.0 (8)	-	75.8
$\alpha_{0,20}$	437.96 (4)	4630.3 (8)	4631 (3)	47
$\alpha_{0,21}$	469.24 (6)	4599.6 (8)	4598 (3)	146
$\alpha_{0,22}$	501.28 (7)	4568.1 (8)	4565 (3)	160
$\alpha_{0,23}$	537.0 (1)	4533.0 (8)	-	930
$\alpha_{0,24}$	562.8 (1)	4507.6 (8)	4506 (3)	126
$\alpha_{0,25}$	656.4 (3)	4415.6 (9)	-	43

[1] Calculated from alpha transition energy, taking into account the recoil energy of the daughter nucleus.

4.2 Alpha particle emission probabilities

The alpha emission probabilities have been determined from published data measurements when available; otherwise they are calculated from the balance of the decay scheme. All available experimental measurements were derived from magnetic spectrometers (1956Hu96, 1961Ba42 and 1976BaZZ). Data from Baranov (1961Ba42 and 1976BaZZ) and Hummel (1956Hu96) are in good agreement, with the exception of the $\alpha_{0,15}$ emission. For the recommended alpha emission probabilities, the evaluator has used values with uncertainties when available, adjusting the uncertainty as necessary. Otherwise the average of the values from Baranov (1961Ba42) and Hummel (1956Hu96) was used, with the uncertainty being estimated on the basis of the decay scheme and individual values.

The theoretical emission probabilities were calculated from the P(γ+ce) balances using the GTOL software. There are large uncertainties associated with the theoretical calculations at the lower energy levels (see Table 7). These large uncertainties arise as a consequence of the incomplete decay scheme, which in turn is due to the difficulties experienced in measuring low-energy gamma transitions.

There is a discrepancy between the alpha particle and gamma ray feeding and the gamma ray depopulating the first excited state. This is very probably due to the dominant $\gamma_{1,0}$ transition for which the emission probability and ICC value are not very well known.

Weak alpha particle emissions to levels 14, 19, 23 and 25 were expected, but not observed experimentally. These emissions were added to the decay scheme.

Table 7: Alpha particle emission energies, published and recommended probabilities.

Transition	**Adopted emission energy (keV)**	**1961Ba42**	**1956Hu96**	**1976BaZZ^1**	**Calculated^2 emission probability**	**Adopted emission probability**
$\alpha_{0,0}$	5060.7 (8)	11.0	10	11.7 (1)	11 (8)	11.7 (5)
$\alpha_{0,1}$	5033.8 (8)	~ 2.5	} 23	-	10 (8)	2.8 (3)
$\alpha_{0,2}$	5031.2 (8)	≤ 20.0		-	16 (4)	20 (2)
$\alpha_{0,3}$	5015.1 (8)	25.4	24	25.3 (2)	26 (5)	25.3 (5)
$\alpha_{0,4}$	4987.8 (8)	1.4	} 2.3	1.60 (5)	0.97 (20)	1.60 (20)
$\alpha_{0,5}$	4977.6 (8)	0.4			-1 (4)	0.4 (1)
$\alpha_{0,6}$	4952.6 (8)	22.8	22	22.5 (2)	21.4 (14)	22.5 (5)
$\alpha_{0,7}$	4936.0 (8)	3.0	2.8		2.51 (12)	2.9 (3)
$\alpha_{0,8}$	4903.4 (22)	0.002	-	-	0	0.002 (1)
$\alpha_{0,9}$	4876.6 (8)	-	-	-	-0.46 (16)	-
$\alpha_{0,10}$	4865.4 (8)	-	-	-	0.012 (10)	-
$\alpha_{0,11}$	4853.5 (8)	1.4	1.4	-	1.41 (15)	1.40 (15)
$\alpha_{0,12}$	4794.1 (8)	0.04	-	-	0.066 (8)	0.040 (15)
$\alpha_{0,13}$	4792.3 (8)	-	-	-	0.00 (5)	-
$\alpha_{0,14}$	4761.2 (8)	-	-	-	0.003 2 (9)	0.003 2 (9)
$\alpha_{0,15}$	4736.3 (8)	8.4	11	8.35 (8)	9.1 (5)	8.4 (4)
$\alpha_{0,16}$	4712.3 (8)	~ 1	1.4	-	1.20 (22)	1.20 (22)
$\alpha_{0,17}$	4680.1 (8)	1.5	2.1	-	1.8 (4)	1.8 (3)
$\alpha_{0,18}$	4642.5 (8)	~ 0.1	-	-	0.080 (6)	0.080 (6)
$\alpha_{0,19}$	4633.0 (8)	-	-	-	0.050 4 (11)	0.050 4 (11)
$\alpha_{0,20}$	4630.3 (8)	~ 0.1	-	-	0.078 (21)	0.078 (21)
$\alpha_{0,21}$	4599.6 (8)	0.015	-	-	0.003 65 (22)	0.015 (7)
$\alpha_{0,22}$	4568.1 (8)	0.008	-	-	0.001 5 (5)	0.008 (4)
$\alpha_{0,23}$	4533.0 (8)	-	-	-	0.000 76 (20)	0.000 76 (20)
$\alpha_{0,24}$	4507.6 (8)	0.003	-	-	0.003 6 (3)	0.003 6 (3)
$\alpha_{0,25}$	4415.6 (9)	-	-	-	0.002 1 (5)	0.002 1 (5)

[1] Authors have reported only type A uncertainties.
[2] Emission probabilities calculated from balance of the decay scheme.

5. Gamma rays

5.1 Gamma-ray transitions and internal conversion coefficients

All gamma-ray transition energies were calculated from the differences in level energies as adopted from Browne (2001Br31).

Theoretical internal conversion coefficients (ICCs) were calculated using the BrIcc code (Kibédi et al., 2008Ki07) with the “frozen orbital” approximation, which uses interpolated values of Band et al. (2002Ba85).

The agreement between theoretical and measured ICC values was poor for $\gamma_{1,0}$ – under these circumstances, the experimental ICC data was adopted.

ICCs for some low-energy gamma transitions

$\gamma_{3,2}$: 16.370 (14) keV

The transition energy for this gamma ray is within 1 keV of the L3 shell binding energy of 15.971 keV. Since the model may be inaccurate close to the binding energy, the BrIcc code cannot be used to calculate theoretical ICCs. Therefore, the theoretical ICCs were calculated by Kibédi using the RAINE code, resulting in a value of 5.06 (7) for the L3 shell conversion and a total conversion coefficient of 8.58 (12) for this transition.

$\gamma_{1,0}$: 27.370 (10) keV

Disagreement between theoretically derived and experimentally measured data has been observed for this low-energy E1 transition (Table 8).

Table 8: Experimental and calculated values of α_L for the $\gamma_{1,0}$ transition of 27.370 (10) keV and E1 multipolarity.

Reference	α_L	Comments
1960As02	2.8 (3)	
1961Ba42	3.6 (4)	
1970De19	3.0 (3)	Not used - same author as 1974De11
1974De11	3.7 (3)	
Experimental mean	3.3 (4)	Weighted mean of 3 values
BrIcc code	2.66 (4)	

Asaro et al. suggest that the disagreement observed for this E1 transition can be explained by a small M2 contribution (1960As02). Assuming a multipolarity of E1+M2, the mixing ratio that agrees with the recommended value of α_L = 3.3 (4) is δ= 0.007.

$\gamma_{2,0}$: 29.980 (10) keV

The mixing ratio of 0.22 (2) from the evaluation of Browne (2001Br31) was derived from the measurements of De Pinho (1974De11). De Pinho derives the mixing ratio from an experimental value of α_L = 220 (20); the author suggests that a value of δ^2 from approximately 0.042 to 0.053 can explain the experimental α_L coefficients observed. Changing the mixing ratio value within the limits indicated above varies the $\gamma_{2,0}$ transition probability significantly from 24.4 to 27.6. More precise measurements are necessary to clarify the decay scheme at this level.

Summary of ICCs

A summary of the ICCs for the low-energy gamma-ray transitions is given in Table 9.

Table 9: Energies, multipolarities and internal conversion coefficients for low-energy gamma-ray transitions. Data within square parentheses [] are unconfirmed.

Transition	**Transition energy (keV)**	**Multipolarity**	**Mixing ratio**	α_T	α_L	α_M
$\gamma_{3,2}$	16.370 (14)	[E1]	-	8.58 (12)	5.06 (7)	2.68 (4)
$\gamma_{3,1}$	18.980 (14)	[M1]	-	113.2 (16)	2.35 (4)	82.7 (12)
$\gamma_{11,9}$	23.46 (6)	[M1]	-	241 (4)	182 (3)	44.1 (7)
$\gamma_{16,15}$	24.46 (4)	[M1]	-	214 (4)	161.3 (24)	39.0 (6)
$\gamma_{6,5}$	25.390 (22)	[M1]	-	191 (3)	144.6 (21)	34.9 (5)
$\gamma_{1,0}$	27.370 (10)	E1 [+M2]	[0.007]	4.5 (6)	3.3 (4)	0.87 (13)
$\gamma_{2,0}$	29.980 (10)	M1+E2	0.22 (2)	270 (30)	202 (21)	52 (6)
$\gamma_{6,4}$	35.800 (22)	[E1]	-	1.746 (25)	1.313 (19)	0.327 (5)
$\gamma_{5,3}$	38.200 (14)	M1+E2	0.18 (5)	89 (19)	66 (14)	17 (4)
$\gamma_{4,2}$	44.160 (14)	[M1]	-	37.4 (6)	28.3 (4)	6.79 (10)
$\gamma_{3,0}$	46.350 (10)	[E1]	-	0.879 (13)	0.663 (10)	0.1634 (23)
$\gamma_{20,17}$	50.73 (5)	[M1]	-	24.9 (4)	18.8 (3)	4.52 (7)
$\gamma_{7,4}$	52.720 (22)	[M1]	-	22.2 (4)	16.81 (24)	4.03 (6)
$\gamma_{5,2}$	54.570 (14)	[E1]	-	0.569 (8)	0.430 (6)	0.1053 (15)
$\gamma_{15,13}$	56.90 (3)	[M1+E2]	[0.41 (7)]	37 (6)	28 (5)	7.1 (12)
$\gamma_{5,1}$	57.180 (14)	E2	-	148.1 (21)	108.6 (16)	29.6 (5)
$\gamma_{17,15}$	57.190 (22)	E2	-	148.0 (21)	108.5 (16)	29.6 (5)
$\gamma_{9,7}$	60.46 (4)	[E1]	-	0.433 (7)	0.327 (5)	0.0800 (12)
$\gamma_{6,3}$	63.590 (22)	E2	-	88.8 (13)	65.1 (10)	17.8 (3)
$\gamma_{10,7}$	71.85 (5)	[M1]	-	8.98 (13)	6.79 (10)	1.630 (23)
$\gamma_{12,10}$	72.58 (7)	[M1]	-	8.71 (13)	6.59 (10)	1.582 (23)
$\gamma_{4,0}$	74.140 (10)	[E2]	-	42.6 (6)	31.2 (5)	8.53 (12)
$\gamma_{9,6}$	77.38 (4)	[M1]	-	7.23 (11)	5.47 (8)	1.313 (19)
$\gamma_{7,2}$	96.880 (22)	E2	-	12.02 (17)	8.81 (13)	2.41 (4)
$\gamma_{11,6}$	100.84 (5)	[E2]	-	9.97 (15)	7.30 (11)	2.00 (3)
$\gamma_{9,5}$	102.77 (3)	[E2]	-	9.12 (13)	6.69 (10)	1.83 (3)

5.2 Gamma-ray emission energies

There are a total of 9 sets of measurements for the gamma-ray emission energies. The recommended values were calculated from the differences in level energies as adopted from Browne (2001Br31) and were compared to the experimental values calculated from the weighted means (calculated with LWEIGHT4 code) of Lange (1969La04), De Pinho (1970De19), Leang (1970Le11), Börner (1979Bo30) and Teoh (1979Te02). The measurements from Falk-Vairant (1953Fa08), Foucher (1960Fo05), Baranov (1961Ba42) and Abou-Leila (1963Ab04) were not taken into account as they either do not have uncertainties, or are imprecise (uncertainties of a few keV). Experimental results and recommended values can be seen in Table 1 of Appendix 1.

Unplaced gamma rays

Below 45 keV

In the region 30-45 keV, various authors have reported 7 unplaced gamma rays. See Table 10 below for the reported energies.

Table 10: Experimental gamma-ray emission energies for unplaced gamma rays below 45 keV.

Reference	1961Ba42	1969La04	1970De19	1979Te02
Energy (keV)		30.7 (5)	31.00 (5)	30.87 (4)
			31.54 (4)	31.55 (5)
	34.0			
		39.6 (5)	39.57 (4)	39.73 (3)
			39.97 (2)	40.00 (3)
			42.48 (5)	42.41 (4)
			43.05 (5)	43.08 (4)

Baranov (1961Ba42), De Pinho (1970De19), Teoh (1970Te02) and Banham (1983Banham) have reported gamma-ray emission probabilities for these energies.

De Pinho et al. mention in their later paper (1974De19) that the six transitions reported in their earlier paper (1970De19) were not confirmed by later measurements and were the result of X-ray summing effects.

The evaluator has decided not to include these 7 transitions in the final table of evaluated gamma rays because their genuine existence is questionable.

Above 45 keV

With the exception of the 59.4 keV and 512.2 keV gamma-ray emissions reported by Lange (1969La04), the 318.1 keV gamma ray reported by Leang (1970Le11) and the 536.6 keV gamma ray reported by Teoh (1979Te02), the other unplaced gamma rays have been listed in the table.

The unplaced gamma-ray transition at 56.78 (4) keV detected by De Pinho (1970De19) and Teoh (1979Te02) was placed in the decay scheme based on the energy difference that constitutes the $\gamma_{15,13}$ transition. The energy for $\gamma_{15,13}$ calculated from the difference in level energies is 56.90 (3) keV which is in good agreement with the experimental value. If this gamma transition was absent, the balance of the decay scheme at level 13 would result in an alpha emission ($\alpha_{0,13}$) with an intensity of 0.19 (4) %; since weaker alpha emissions were detected in this region, it seems unlikely such an emission could be missed, which lends support to the placement of $\gamma_{15,13}$. With a transition from level 3/2- to level 5/2- and assuming a probability for $\alpha_{0,13}$ = 0, a multipolarity M1+E2 with a mixing ratio of δ = 0.41 (7) has been tentatively deduced.

5.3 Gamma-ray emission probabilities

There are a total of 9 sets of measurements for the gamma-ray emission probabilities. Four of the authors (1970De19, 1970Le11, 1979Te02 and 1983Banham) have measured over a wide energy range. Two of the publications are from the same authors (1970De19 and 1974De11); the later publication was favoured for emissions reported in both papers. Values were first normalised such that the intensity of the 283.7 keV peak was set to be 100. The scaling factor used for the two data sets from De Pinho et al. was derived from their most recent publication.

The recommended values are the weighted mean of De Pinho (1970De19, 1974De11), Leang (1970Le11), Teoh (1979Te02), Aničin (1982An02) and Banham (1983Banham, 1984BAYS). The measurements from Foucher (1960Fo05), Baranov (1961Ba42) and Lange (1969La04) were not taken into account as they have no reported uncertainties. The experimental results and recommended values can be seen in Table 2 of Appendix 1.

Normalisation factor

Two experimental values were reported:
0.016 49 (27) from Banham (1984BAYS)
0.016 (2) from Leang (1970Le11)

The theoretical value obtained from the balance of the decay scheme to the ground state is 0.016 3 (14), which is in good agreement with the experimental values. As the theoretical normalisation factor is strongly influenced by the dominant $\gamma_{1,0}$ transition for which the theoretical and experimental ICC values do not agree, the evaluator has decided to use the experimental normalisation factor of 0.016 5 (3) derived from Banham (1984BAYS).

Low-energy gamma-ray emission probabilities

The emission probabilities for many of the gamma-ray transitions of 25 keV and below were either missing or imprecise, and had to be calculated using the balance of the decay scheme.

$\gamma_{3,2}$ *: 16.370 (14) keV*

One measured value of I$\gamma_{3,2}$ =13.4 (5) from Banham (1984BAYS) is available and was adopted as the recommended value. De Pinho (1974De11) has measured a transition ratio between Iγ+ce(19 keV)/ Iγ+ce(16.4 keV) ≈ 18 (5). Calculating the same ratio with the evaluated data gives 20.1 (15) which is in good agreement with the value of De Pinho et al.

$\gamma_{3,1}$ *: 18.980 (14) keV*

The lack of coherent experimental data reported for this transition, due to the intense L X-rays observed in this part of the spectrum, made it impossible to calculate a weighted mean. This transition was calculated from the balance of the decay scheme at level 3. The resulting relative emission probability is I$\gamma_{3,1}$ = 22.2 (16).

$\gamma_{11,9}$ *: 23.46 (6) keV*

No values have been reported for this transition, and the emission probability has been calculated from the balance of the decay scheme to level 11. The resulting gamma-ray emission probability is I$\gamma_{11,9}$ = 0.288 (35).

$\gamma_{16,15}$ *: 24.46 (4) keV*

Two measurements are available for this gamma ray: 0.7 (3) from Teoh (1979Te02), and ~ 0.59 from De Pinho (1970De19). Neither of these values is very precise, and therefore the evaluator decided to evaluate this gamma-ray emission probability by means of the balance of the decay scheme to level 16. The resulting relative emission probability is I$\gamma_{16,15}$ = 0.30 (6).

$\gamma_{6,5}$: 25.390 (22) keV

There are four reported measurements for this transition. The measurements are not in very good agreement and fall into two ranges. Measurements of 7.6 (12) from De Pinho (1974De11) and 6.9 (10) from Teoh (1979Te02) contrast with the equivalent data from Leang (1970Le11) and Banham (1984BAYS) of 18.75 and 16.5 (9), respectively. The evaluator has decided to calculate the gamma-ray emission probability using the mean value of the balance of the decay scheme to levels 5 and 6 to give I$\gamma_{6,5}$ = 5.8 (4). This value is in agreement with the lower set of values from De Pinho and Teoh.

Multiple placement - doublets

The gamma-ray transitions $\gamma_{15,1}$ (302.7 keV) and $\gamma_{17,5}$ (302.7 keV), $\gamma_{5,1}$ (52.7 keV) and $\gamma_{17,15}$ (52.7 keV) have been placed twice in the decay scheme; their individual emission probabilities have been suitably divided as follows.

$\gamma_{15,1}$ and $\gamma_{17,5}$: 302.7 keV

The combined evaluated relative probability for this gamma ray is 149.4 (12). Two authors have reported values for the separated doublet and the agreement between authors is poor:

Transition	1979Te02	1982An02
$\gamma_{15,1}$	100 (10)	138 (20)
$\gamma_{17,5}$	40 (5)	10.6 (26)

Only $\gamma_{15,1}$ is observed in the decay of ^{227}Ra, so using the ratios between this transition and $\gamma_{15,0}$, $\gamma_{15,2}$ and $\gamma_{15,3}$ the expected transition probability for the doublet in the ^{231}Pa decay was calculated:

^{27}Ra transition	Calculated $\gamma_{15,1}$ in ^{231}Pa decay
$\gamma_{15,0}$	132 (16)
$\gamma_{15,2}$	137 (16)
$\gamma_{15,3}$	141 (16)
Unweighted mean	137 (16)

The recommended emission probability for $\gamma_{15,1}$ is 137 (16), and therefore the calculated $\gamma_{17,5}$ probability is 13 (6).

These values are in good agreement with the value of $\gamma_{15,1}$=138 (20) and $\gamma_{17,5}$=10.6 (26) from Aničin (1982An02).

$\gamma_{5,1}$ and $\gamma_{17,15}$: 57.2 keV

The combined evaluated relative probability for this gamma ray is 2.16 (14). One author (1979Te02) has reported values for the separated doublet. The calculated values using the balance of the decay scheme at level 17 are as follows:

Transitions	1979Te02	Calculated
$\gamma_{5,1}$	1.58 (16)	1.88 (19)
$\gamma_{17,15}$	0.96 (10)	0.28 (13)

The agreement between the calculated and measured values is poor for I$\gamma_{17,15}$. The evaluator has decided to adopt the calculated values.

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Appendix 1: Experimental and recommended gamma-ray emission energies and probabilities.

Table 1. Experimental and recommended gamma-ray emission energies (keV).

	1969La04	1970De17	1970Le11	1979Bo30 [a]	1979Te02	Calculated from experimental data	Recommended values
$\gamma_{3,2}$	-	16.5 (1)	-	-	-	16.5 (1)	16.370 (14)
$\gamma_{3,1}$	-	18.88 [b]	-	-	-	18.88	18.980 (14)
$\gamma_{11,9}$	-	-	-	-	-	-	23.46 (6)
$\gamma_{16,15}$	-	24.5 (1)	-	-	24.6 (5)	24.50 (10)	24.46 (4)
$\gamma_{6,5}$	25.3 (5)	25.54 (6)	25.2 (2)	-	25.36 (8)	25.46 (6)	25.390 (22)
$\gamma_{1,0}$	27.3 (5)	27.35 (2)	27.3 (2)	-	27.38 (2)	27.365 (20)	27.370 (10)
$\gamma_{2,0}$	29.8 (5)	29.95 (2)	29.9 (2)	-	30.01 (3)	29.968 (20)	29.980 (10)
$\gamma_{6,4}$	35.6 (5)	35.82 (3)	35.8 (3)	-	35.86 (4)	35.834 (30)	35.800 (22)
$\gamma_{5,3}$	38.0 (5)	38.20 (2)	38.1 (2)	-	38.19 (2)	38.194 (20)	38.200 (14)
$\gamma_{4,2}$	43.9 (5)	44.16 (2)	44.1 (2)	-	44.13 (2)	44.145 (20)	44.160 (14)
$\gamma_{3,0}$	46.1 (5)	46.37 (2)	46.2 (2)	-	46.32 (2)	46.344 (20)	46.350 (10)
$\gamma_{20,17}$	-	50.98 (5)	-	-	50.68 (6)	50.83 (15)	50.73 (5)
$\gamma_{7,4}$	52.4 (5)	52.74 (2)	52.6 (2)	-	52.66 (3)	52.658 (30)	52.720 (22)
$\gamma_{5,2}$	54.8 (5)	54.61 (2)	54.5 (2)	-	54.56 (3)	54.594 (20)	54.570 (14)
$\gamma_{15,13}$	-	56.76 (4)		-	56.79 (4)	56.78 (4)	56.90 (3)
$\gamma_{5,1}$	-	57.19 (3)	57.0 (2)	-	57.19 (3)	57.188 (30)	57.180 (14)
$\gamma_{17,15}$	-	57.19 (3)	57.0 (2)	-	57.19 (3)	57.188 (30)	57.190 (22)
$\gamma_{9,7}$	-	60.50 (3)	60.2 (3)	-	60.47 (8)	60.494 (30)	60.46 (4)
$\gamma_{6,3}$	63.3 (5)	63.67 (3)	63.5 (2)	-	63.60 (4)	63.642 (30)	63.590 (22)
$\gamma_{-1,1}$	-	70.50 (5)	-	-	70.45 (8)	70.49 (5)	70.49 (5) [c]

	1969La04	1970De17	1970Le11	1979Bo30 [a]	1979Te02	Calculated from experimental data	Recommended values
$\gamma_{10,7}$	-	71.9 (1)	-	-	71.9 (1)	71.9 (1)	71.85 (5)
$\gamma_{12,10}$	-	72.5 (1)	-	-	72.78 (8)	72.67 (14)	72.58 (7)
$\gamma_{4,0}$	-	74.18 (4)	74.1 (3)	-	74.08 (6)	74.15 (4)	74.140 (10)
$\gamma_{9,6}$	77.1 (5)	77.36 (3)	77.2 (2)	-	77.30 (4)	77.336 (30)	77.38 (4)
$\gamma_{7,2}$	-	96.88 (3)	96.7 (2)	-	96.80 (3)	96.838 (30)	96.880 (22)
$\gamma_{11,6}$	-	100.92 (4)	100.5 (5)	-	100.77 (4)	100.84 (5)	100.84 (5)
$\gamma_{9,5}$	102.5 (5)	-	102.5 (4)	-	102.6 (5)	102.5 (4)	102.77 (3)
$\gamma_{10,4}$	-	124.6 (1)	124.4 (5)	-	124.56 (8)	124.57 (8)	124.57 (4)
$\gamma_{12,7}$	-	144.5 (1)	144.4 (5)	-	144.33 (8)	144.40 (8)	144.43 (6)
$\gamma_{13,4}$	-	199 (1)	198.7 (6)	-	198.89 (10)	198.89 (10)	199.00 (3)
$\gamma_{14,4}$	-	-	-	-	230.0 (10)	230.0 (10)	230.59 (5)
$\gamma_{-1,2}$	-	242.2 (1)	-	-	242.16 (8)	242.18 (8)	242.18 (8) [c]
$\gamma_{13,2}$	243.0 (5)	243.0 (1)	242.9 (4)	-	243.15 (9)	243.08 (9)	243.16 (3)
$\gamma_{15,5}$	-	245.4 (1)	245.3 (5)	-	245.77 (9)	245.60 (13)	245.490 (14)
$\gamma_{13,1}$	-	246.0 (2)	-	-	246.05 (9)	246.04 (9)	245.77 (3)
$\gamma_{15,4}$	256.1 (5)	255.78 (7)	255.9 (3)	-	255.76 (8)	255.78 (7)	255.900 (14)
$\gamma_{14,3}$	-	258.4 (1)	-	-	258.54 (15)	258.44 (10)	258.38 (5)
$\gamma_{17,7}$	260.2 (5)	260.14 (8)	260.2 (3)	-	260.23 (8)	260.19 (8)	260.37 (3)
$\gamma_{13,0}$	273.5 (5)	273.08 (9)	273.2 (3)	273.237 (117)	273.15 (9)	273.14 (9)	273.14 (3)
$\gamma_{17,6}$	277.7 (5)	276.99 (9)	277.2 (3)	277.322 (15)	277.10 (9)	277.19 (7)	277.29 (3)
$\gamma_{15,3}$	283.9 (5)	283.56 (6)	283.7 (3)	283.690 (16)	283.65 (5)	283.679 (16)	283.690 (14)

	1969La04	1970De17	1970Le11	1979Bo30 [a]	1979Te02	Calculated from experimental data	Recommended values
$\gamma_{-1,3}$	-	286.55 (10)	-	-	286.60 (10)	286.58 (10)	286.58 (10) [c]
$\gamma_{15,2}$	300.5 (5)	299.94 (6)	300.1 (2)	300.069 (12)	300.02 (5)	300.062 (15)	300.060 (14)
$\gamma_{15,1}$	303.2 (5)	302.52 (6)	302.7 (2)	302.669 (11)	302.65 (5)	302.664 (15)	302.670 (14)
$\gamma_{17,5}$	303.2 (5)	302.52 (6)	302.7 (2)	302.669 (11)	302.65 (5)	302.664 (15)	302.680 (22)
$\gamma_{-1,4}$	-	310.0 (1)	-	-	310.0 (5)	310.0 (1)	310.0 (1) [c]
$\gamma_{17,4}$	313.0 (5)	312.88 (8)	312.9 (3)	-	312.94 (5)	312.92 (5)	313.090 (22)
$\gamma_{16,1}$	-	327.02 (10)	327.2 (4)	327.130 (188)	327.26 (10)	327.14 (10)	327.13 (4)
$\gamma_{15,0}$	330.2 (5)	329.89 (6)	330.0 (2)	330.057 (18)	330.06 (5)	330.045 (22)	330.040 (10)
$\gamma_{17,3}$	341.0 (5)	340.61 (7)	340.8 (2)	-	340.77 (6)	340.71 (6)	340.880 (22)
$\gamma_{18,4}$	-	351.4 (1)	-	-	351.6 (1)	351.50 (10)	351.45 (3)
$\gamma_{16,0}$	-	354.38 (8)	354.6 (2)	354.474 (76)	354.57 (8)	354.48 (8)	354.50 (4)
$\gamma_{17,2}$	356.6 (5)	356.96 (7)	357.2 (2)	-	357.21 (6)	357.10 (7)	357.250 (22)
$\gamma_{17,1}$	-	359.25 (10)	358.6 (4)	-	359.57 (10)	359.39 (15)	359.860 (22)
$\gamma_{20,4}$	364.2 (5)	363.74 (10)	363.9 (4)	-	363.93 (10)	363.84 (10)	363.82 (4)
$\gamma_{-1,5}$	-	374.9 (1)	374.9 (4)	-	375.01 (10)	374.95 (10)	374.95 (10) [c]
$\gamma_{18,3}$	379.5 (5)	379.09 (8)	379.2 (3)	-	379.41 (6)	379.29 (9)	379.24 (3)
$\gamma_{21,5}$	-	384.7 (1)	384.8 (3)	-	384.7 (1)	384.71 (10)	384.69 (6)
$\gamma_{17,0}$	-	387.0 (1)	-	-	-	387.0 (1)	387.230 (20)
$\gamma_{20,3}$	392.5 (5)	391.5 (1)	391.7 (3)	-	391.67 (9)	391.61 (9)	391.61 (4)
$\gamma_{18,2}$	-	395.5 (1)	395.7 (4)	-	395.49 (10)	395.50 (10)	395.61 (3)
$\gamma_{18,1}$	398.4 (5)	398.10 (8)	398.1 (3)	-	398.19 (9)	398.14 (8)	398.22 (3)

	1969La04	1970De17	1970Le11	1979Bo30 [a]	1979Te02	Calculated from experimental data	Recommended values
$\gamma_{19,1}$	408.1 (5)	407.71 (6)	407.7 (3)	407.829 (31)	407.80 (5)	407.802 (31)	407.820 (22)
$\gamma_{20,1}$	410.5 (5)	410.5 (1)	410.3 (10)	-	410.1 (1)	410.30 (12)	410.59 (4)
$\gamma_{22,4}$	-	-	-	-	427.0 (10)	427.0 (10)	427.14 (7)
$\gamma_{19,0}$	-	435.1 (1)	434.9 (8)	-	435.0 (1)	435.05 (10)	435.190 (20)
$\gamma_{20,0}$	437.9 (5)	437.9 (1)	437.9 (8)	-	438.10 (9)	438.01 (9)	437.96 (4)
$\gamma_{-1,6}$	-	438.7 (1)	-	-	438.8 (2)	438.72 (10)	438.72 (10) [c]
$\gamma_{24,4}$	487.2 (5)	486.7 (3)	486.6 (10)	486.827 (27)	486.8 (10)	486.826 (27)	488.66 (10)
$\gamma_{23,3}$	-	491.0 (6)	491 (2)	-	491.0 (10)	491.0 (6)	490.65 (10)
$\gamma_{22,0}$	-	501.6 (5)	501 (1)	-	501.0 (10)	501.4 (5)	501.28 (7)
$\gamma_{23,1}$	-	509 (1)	510 (1)	-	510.0 (10)	509.7 (10)	509.63 (10)
$\gamma_{24,3}$	516.2 (5)	516.2 (6)	516 (1)	-	516.1 (10)	516.2 (5)	516.45 (10)
$\gamma_{24,1}$	-	535.3 (7)	535 (1)	-	-	535.2 (7)	535.43 (10)
$\gamma_{25,6}$	-	546.6 (7)	546 (1)	-	546.6 (10)	546.5 (7)	546.5 (3)
$\gamma_{25,5}$	-	572.1 (8)	571 (2)	-	571.0 (10)	571.6 (8)	571.9 (3)
$\gamma_{25,4}$	-	-	583 (2)	-	-	583 (2)	582.3 (3)
$\gamma_{25,3}$	-	-	609 (2)	-	-	609 (2)	610.1 (3)

a) Uncertainty on energy calibration of detectors was added to published data

b) Obtained from private communication.

c) Unplaced gamma.

Table 2. Experimental and recommended relative gamma-ray emission probabilities.

	E_γ(keV)	P_γ^{rel}					
		1970De19 [a]	**1970Le11**	**1974De11** [a]	**1979Te02**	**1984BAYS** [b]	**Recommended values**
$\gamma_{3,2}$	16.370 (14)	-	-	-	-	13.4 (5)	13.4 (5)
$\gamma_{3,1}$	18.980 (14)	-	-	-	-	76.7 (15)	22.2 (16) [c]
$\gamma_{11,9}$	23.46 (6)	-	-	-	-	-	0.29 (4) [c]
$\gamma_{16,15}$	24.46 (4)	~ 0.59	-	-	0.7 (3)	-	0.30 (6) [c]
$\gamma_{6,5}$	25.390 (22)	~ 5.9	~ 18.75	7.6 (12)	6.9 (10)	16.5 (9)	5.8 (4) [c]
$\gamma_{1,0}$	27.370 (10)	588 (28)	440 (130)	588 (28)	640 (50)	673 (13)	655 (22)
$\gamma_{2,0}$	29.980 (10)	5.8 (5)	6.3 (19)	5.88 (24)	6.5 (5)	5.63 (30)	5.87 (24)
$\gamma_{6,4}$	35.800 (22)	1.00 (12)	0.94 (31)	1.15 (9)	0.94 (5)	-	0.99 (6)
$\gamma_{5,3}$	38.200 (14)	9.4 (9)	6.3 (19)	8.6 (6)	9.4 (5)	8.59 (33)	8.8 (4)
$\gamma_{4,2}$	44.160 (14)	3.8 (4)	2.8 (9)	3.41 (24)	3.77 (40)	2.7 (5)	3.36 (24)
$\gamma_{3,0}$	46.350 (10)	13.18 (12)	8.1 (25)	11.1 (5)	12.97 (64)	10.6 (7)	11.5 (6)
$\gamma_{20,17}$	50.73 (5)	0.09 (4)	-	0.12 (3)	0.3 (1)	-	0.14 (5)
$\gamma_{7,4}$	52.720 (22)	5.4 (5)	3.8 (13)	4.41 (22)	4.85 (34)	5.4 (6)	4.60 (22)
$\gamma_{5,2}$	54.570 (14)	5.1 (5)	3.8 (13)	4.12 (19)	4.33 (35)	4.44 (32)	4.22 (19)
$\gamma_{15,13}$	56.90 (3)	0.35 (6)	-	0.31 (5)	0.27 (4)	-	0.29 (4)
$\gamma_{5,1}$	57.180 (14)	2.47 (24)	1.9 (6)	1.94 (11)	1.58 (16)	2.34 (15)	2.16 (14)
$\gamma_{17,15}$	57.190 (22)				0.96 (10)		
$\gamma_{9,7}$	60.46 (4)	0.41 (6)	0.19 (13)	0.36 (4)	0.3 (1)	0.29 (5)	0.32 (4)
$\gamma_{6,3}$	63.590 (22)	3.2 (3)	1.9 (6)	2.82 (21)	2.7 (3)	2.70 (9)	2.70 (9)
$\gamma_{-1,1}$	70.49 (5)	0.41 (6)	-	0.29 (6)	0.6 (2)	0.30 (5)	0.31 (5)
$\gamma_{10,7}$	71.85 (5)	0.12 (6)	-	0.12 (4)	0.1 (1)	-	0.12 (4)

		P_γ^{rel}						
	E_γ(keV)	**1970De19 [a]**	**1970Le11**	**1974De11 [a]**	**1979Te02**	**1982An02**	**1984BAYS [b]**	**Recommended values**
$\gamma_{12,10}$	72.58 (7)	0.24 (12)	-	0.18 (4)	0.2 (1)	-	-	0.18 (4)
$\gamma_{4,0}$	74.140 (10)	1.59 (18)	1.25 (44)	1.41 (12)	1.24 (20)	-	1.35 (5)	1.35 (5)
$\gamma_{9,6}$	77.38 (4)	4.3 (5)	2.5 (6)	3.53 (24)	4.31 (20)	-	3.45 (7)	3.67 (25)
$\gamma_{7,2}$	96.880 (22)	5.6 (6)	4.1 (9)	5.5 (4)	5.62 (28)	-	5.00 (10)	5.08 (14)
$\gamma_{11,6}$	100.84 (5)	2.0 (3)	0.75 (31)	1.35 (12)	1.66 (25)	-	1.38 (4)	1.37 (5)
$\gamma_{9,5}$	102.77 (3)	~ 1.2	2.8 (9)	1.35 (24)	<0.8	-	0.9 (2)	1.13 (25)
$\gamma_{10,4}$	124.57 (4)	0.29 (12)	0.13 (6)	-	0.29 (9)	0.23 (13)	0.259 (24)	0.261 (24)
$\gamma_{12,7}$	144.43 (6)	0.76 (24)	0.25 (13)	-	0.64 (30)	0.70 (6)	0.69 (5)	0.70 (5)
$\gamma_{13,4}$	199.00 (3)	0.35 (12)	0.06 (3)	-	0.23 (10)	0.28 (5)	0.246 (29)	0.18 (7)
$\gamma_{14,4}$	230.59 (5)	-	-	-	0.10 (5)	-	-	0.10 (5)
$\gamma_{-1,2}$	242.18 (8)	0.53 (6)	-	-	0.5 (2)	0.44 (8)	0.70 (4)	0.60 (6)
$\gamma_{13,2}$	243.16 (3)	2.18 (18)	2.5 (6)	-	2.97 (24)	2.51 (43)	1.87 (4)	2.2 (3)
$\gamma_{15,5}$	245.490 (14)	0.47 (6)	0.44 (13)	-	0.48 (12)	0.44 (8)	0.382 (31)	0.41 (3)
$\gamma_{13,1}$	245.77 (3)	-	-	-	0.7 (2)	0.70 (20)	-	0.70 (20)
$\gamma_{15,4}$	255.900 (14)	6.4 (4)	8.1 (13)	-	6.34 (41)	7.00 (48)	6.41 (6)	6.42 (6)
$\gamma_{14,3}$	258.38 (5)	0.15 (4)	-	-	0.15 (5)	0.13 (4)	0.06 (2)	0.093 (24)
$\gamma_{17,7}$	260.37 (3)	10.9 (6)	11.3 (19)	-	11.39 (57)	11.03 (14)	10.97 (10)	11.00 (10)
$\gamma_{13,0}$	273.14 (3)	3.65 (18)	4.4 (9)	-	3.48 (24)	3.48 (18)	3.50 (4)	3.51 (4)
$\gamma_{17,6}$	277.29 (3)	4.24 (24)	5.0 (9)	-	3.88 (25)	4.59 (58)	4.12 (5)	4.12 (5)

		P_{γ}^{rel}						
	E_{γ}(keV)	**1970De19** [a]	**1970Le11**	**1974De11** [a]	**1979Te02**	**1982An02**	**1984BAYS** [b]	**Recommended values**
$\gamma_{15,3}$	283.690 (14)	100.0	100.0	100.0	100.0	100.0	100.0 (8)	100.0
$\gamma_{-1,3}$	286.58 (10)	0.59 (6)	-	-	0.8 (3)	0.68 (10)	0.632 (30)	0.63 (3)
$\gamma_{15,2}$	300.060 (14)	144 (8)	144 (13)	} 294 (8)	149.6 (75)	143.2 (55)	146.3 (13)	146.2 (13)
$\gamma_{15,1}$	302.670 (14)	} 148 (8)	} 144 (13)		100 (10)	138 (20)	} 149.6 (12)	} 149.4 (12)
$\gamma_{17,5}$	302.680 (22)				40 (5)	10.6 (26)		
$\gamma_{-1,4}$	310.0 (1)	0.088 (29)	-	-	0.07 (3)	0.03 (2)	0.058 (12)	0.056 (12)
$\gamma_{17,4}$	313.090 (22)	6.0 (4)	6.9 (13)	-	7.05 (56)	5.93 (17)	5.97 (5)	5.98 (5)
$\gamma_{16,1}$	327.13 (4)	1.88 (12)	2.5 (13)	-	2.27 (28)	2.19 (44)	2.22 (4)	2.19 (5)
$\gamma_{15,0}$	330.040 (10)	82.4 (41)	81 (13)	82.4 (29)	81.9 (65)	82.1 (12)	82.4 (7)	82.3 (7)
$\gamma_{17,3}$	340.880 (22)	10.5 (5)	10.0 (25)	-	10.9 (13)	10.62 (16)	10.80 (9)	10.75 (9)
$\gamma_{18,4}$	351.45 (3)	0.224 (24)	-	-	0.15 (6)	0.44 (7)	0.102 (4)	0.17 (7)
$\gamma_{16,0}$	354.50 (4)	6.00 (35)	6.3 (13)	-	5.07 (56)	5.92 (16)	5.81 (6)	5.83 (6)
$\gamma_{17,2}$	357.250 (22)	10.9 (6)	9.4 (19)	-	9.67 (82)	10.35 (46)	10.14 (9)	10.16 (9)
$\gamma_{17,1}$	359.860 (22)	0.57 (5)	0.38 (19)	-	0.41 (18)	0.42 (8)	0.512 (14)	0.512 (14)
$\gamma_{20,4}$	363.82 (4)	0.47 (4)	0.38 (19)	-	0.42 (15)	0.45 (5)	0.488 (14)	0.483 (14)
$\gamma_{-1,5}$	374.95 (10)	0.294 (24)	0.19 (6)	-	0.24 (10)	0.21 (3)	0.282 (15)	0.270 (16)
$\gamma_{18,3}$	379.24 (3)	3.12 (24)	2.5 (9)	-	2.89 (23)	2.96 (10)	3.03 (4)	3.02 (4)
$\gamma_{21,5}$	384.69 (6)	0.259 (24)	0.13 (6)	-	0.18 (4)	0.18 (5)	0.221 (12)	0.221 (13)
$\gamma_{17,0}$	387.230 (20)	0.029 (12)	-	-	-	0.01 (1)	0.018 (6)	0.018 (6)

		P_γ^{rel}					
	E_γ(keV)	**1970De19** [a]	**1970Le11**	**1979Te02**	**1982An02**	**1984BAYS** [b]	**Recommended values**
$\gamma_{20,3}$	391.61 (4)	0.43 (4)	0.31 (13)	0.52 (8)	0.35 (5)	0.408 (11)	0.408 (11)
$\gamma_{18,2}$	395.61 (3)	0.165 (18)	0.06 (3)	0.11 (2)	0.12 (2)	0.148 (10)	0.137 (13)
$\gamma_{18,1}$	398.22 (3)	0.59 (5)	0.44 (19)	0.49 (9)	0.49 (12)	0.574 (14)	0.572 (14)
$\gamma_{19,1}$	407.820 (22)	2.29 (18)	1.3 (6)	2.13 (18)	2.07 (16)	2.156 (24)	2.160 (24)
$\gamma_{20,1}$	410.59 (4)	0.118 (12)	0.06 (3)	0.19 (4)	0.21 (6)	0.099 (11)	0.109 (13)
$\gamma_{22,4}$	427.14 (7)	-	-	0.04 (2)	-	-	0.04 (2)
$\gamma_{19,0}$	435.190 (20)	0.212 (24)	0.125 (60)	0.12 (3)	0.18 (1)	0.177 (10)	0.178 (10)
$\gamma_{20,0}$	437.96 (4)	0.259 (24)	0.25 (13)	0.20 (6)	0.28 (3)	0.283 (16)	0.273 (16)
$\gamma_{-1,6}$	438.72 (10)	0.094 (24)	-	0.07 (2)	-	-	0.080 (20)
$\gamma_{24,4}$	488.66 (10)	0.112 (24)	0.063 (30)	0.15 (5)	0.10 (3)	0.091 (9)	0.100 (10)
$\gamma_{23,3}$	490.65 (10)	0.0294	0.006	< 0.04	0.04 (2)	0.023 (6)	0.024 (6)
$\gamma_{22,0}$	501.28 (7)	0.035 (12)	0.0125	0.05 (2)	0.07 (7)	0.053 (11)	0.046 (11)
$\gamma_{23,1}$	509.63 (10)	0.018 (6)	0.031	0.05 (2)	0.10 (4)	-	0.022 (10)
$\gamma_{24,3}$	516.45 (10)	0.082 (18)	0.050	0.06 (2)	0.06 (2)	0.093 (9)	0.083 (9)
$\gamma_{24,1}$	535.43 (10)	0.029 (12)	0.031	0.05 (2)	0.04 (2)	0.038 (7)	0.037 (6)
$\gamma_{25,6}$	546.5 (3)	0.035 (12)	0.025	0.04 (2)	0.06 (2)	0.056 (8)	0.050 (8)
$\gamma_{25,5}$	571.9 (3)	0.029 (12)	0.019	0.04 (2)	0.02 (2)	-	0.029 (12)
$\gamma_{25,4}$	582.3 (3)	-	0.019	-	0.26 (1)	-	0.019 (10) [d]
$\gamma_{25,3}$	610.1 (3)	-	0.031	-	0.43 (2)	-	0.031 (20) [d]

a) Same author for both publications - data from (1974De11) used when available.

b) Data originally published as 1983Banham, then as private communication (1984BAYS) within 1986LoZT.

c) Calculated from balance of decay scheme.

d) Values taken from 1970Le11; uncertainties were evaluated.

^{232}Th – Comments on evaluation of decay data
by A. Arinc

This evaluation was completed in September 2008 and has a literature cut off date of April 2008. The weighted mean was applied to determine recommended values throughout the evaluation where the data were in statistical agreement. Where the data were not in statistical agreement, the Limitation of Relative Statistical Weights (LRSW) was used.

1. Decay Scheme

The nuclide ^{232}Th disintegrates by alpha emission to two excited levels and to the ground state of ^{228}Ra. The spin, parity, half-life of first excited state, multipolarities and level energies of ^{228}Ra are based on the mass-chain evaluation of A. Artna-Cohen (1997Ar08).

Spontaneous fission and cluster decay of $^{24-26}$Ne have been observed by R. Bonetti (1995Bo18) with a partial half-life of 1.22 10^{21} years for the spontaneous fission and a partial half-life greater than 5.04 10^{21} years for the cluster decay. However, these decay modes were not taken into account in this evaluation.

2. Nuclear data

The Q(a) value of 4081.6 (14) keV is taken from the evaluation of Audi *et al.* (2003Au03). The effective Q-value calculated from decay scheme data is 4070 (70) keV.

The experimental half-life values are given in table 1.

Table 1. Experimental half-life values of ^{232}Th

Reference	**Half-life (10^{10} years)**	**Comments**
1963Le21	1.401 (7)	
1960Fa07	1.410 (14)	
1956Ma43	1.45 (5)	Rejected by Chauvenet's criterion
1956Pi42	1.39 (3)	
1956Se17	1.42 (7)	
1938Ko01	1.39 (3)	
Recommended value	**1.402 (6)**	

The value of R. Macklin (1956Ma43) was excluded from the data analysis by Chauvenet's criterion. The data set is consistent and the recommended value, which is the weighted average of 5 remaining values, is 1.402 (6) 10^{10} years. The reduced chi-square value is 0.18 which is smaller than the critical value 3.32.

2.1 Alpha Transitions and emissions

The alpha transition and emission energies have been determined from the Q-value and level energies. Published alpha emission energies are given in table 2.

Table 2. Published alpha emission energies (keV)

Transition	$a_{0,0}$	$a_{0,1}$	$a_{0,2}$
1954Philbert[1]	4014 (20)	3939 (20)	
1957Ha08[2]	4012.3 (50)		
1961Ko11[2]	4013.6 (50)[4]	3950 (8)	3825 (10)
1962Ko12[2]	4013.4 (50)		
1989Sa01	4012.3 (14)	3947.2 (20)	
Mean experimental emission values	4012.4 (14)	3947.3 (20)	3825 (10)
Calculated values[3]	4011.2 (14)	3948.5 (14)	3810.0 (14)
Recommended Values	**4011.2 (14)**	**3948.5 (14)**	**3810.0 (14)**

[1] The values were adjusted by the evaluator for changes in the calibration energy.

[2] The values were adjusted as suggested by A. Rytz (1991Ry01)

[3] Calculated from alpha transition energies taking into account the recoil of the alpha particle

[4] For the $a_{0,0}$ transition, the value from 1961Ko11 was not taken into account as the same author published an updated value in 1962Ko12

Alpha hindrance factors were calculated using the ALPHAD computer program. A summary of the adopted level, alpha transition and emission values is presented in table 3.

Table 3. Adopted level, alpha particle transition and emission energies

Transition	**Level Energy (keV)**	**Alpha Transition Energy (keV)**	**Alpha Emission Energy (keV)**	**HF**
$a_{0,0}$	0.0	4081.6 (14)	4011.2 (14)	1.000
$a_{0,1}$	63.823 (20)	4017.8 (14)	3948.5 (14)	1.02 (7)
$a_{0,2}$	204.68 (3)	3876.9 (14)	3810.0 (14)	16 (5)

2.2 Gamma Transitions and Internal Conversion Coefficients

The recommended $\gamma_{1,0}$ transition energy of 63.811 (10) keV was calculated by taking the weighted mean of 63.81 (7) keV (1973Ta25), 63.81 (1) keV (1983Mi30) and 63.84 (6) keV (1989Sa01). The recommended $\gamma_{2,1}$ transition energy of 140.880 (10) keV was calculated by taking the weighted mean of 140.88 (1) keV (1983Mi30) and 140.83 (15) keV (1989Sa01).

Internal conversion coefficients were calculated using the BrIcc code (T.Kibédi, 2005KiZW), which uses interpolated values of Band *et al.* (2002Ba85).

The γ-ray transition energies, multipolarities and electron internal conversion coefficients are presented in table 4.

Table 4. Energies, multipolarities and electron internal conversion coefficients for gamma transitions

Transition	**Transition Energy (keV)**	**Multipolarity**	a_T	a_K	a_L	a_M
$g_{1,0}$	63.811 (10)	E2	80.4 (12)	-	59.1 (9)	16.05 (23)
$g_{2,1}$	140.880 (10)	E2	2.26 (4)	0.283 (4)	1.450 (21)	0.394 (6)

3. Alpha particle emissions

The alpha particle emission intensities were deduced from the decay scheme and can be viewed in table 5.

Table 5. Alpha particle emission energies and probabilities

Transition	Emission Energy (keV)	Emission intensity (%)
$a_{0,0}$	4012.4 (14)	78.9 (13)
$a_{0,1}$	3947.3 (20)	21.0 (13)
$a_{0,2}$	3810.0 (14)	0.068 (20)

The values calculated using the balancing of the decay scheme are in good agreement with the experimental values (table 6) but the former values have been used as they are more precise.

Table 6: Reported values on alpha particle emission intensities

Reference	$a_{0,0}$	$a_{0,1}$	$a_{0,2}$	Comments
1952Du12		24 (3)		See note 1)
1956Al30		22 (2)		See note 1)
1959Ko58		23 (3)	0.20 (8)	See note 2)
1961Ko11	77	23	0.2	No uncertainties. See note 2)
1983Mi30	77 (3)	23 (2)	0.066 (7)	See 3)
1989Sa01	100	33 (5)		

Notes:

1) The values found in the publications of D. Dunlavey (1952Du12) and G. Albouy (1956Al30) represent the percentage of conversion electron accompanying alpha decays ($a_{0,1}$ and $a_{0,2}$).
2) The values published by G. Kocharov in 1959Ko58 and 1961Ko11 appear to be from the same experiment.
3) The values from T. Mitsugashira (1983Mi30) are deduced by the author from the gamma emission probabilities measured by the author.

4. Gamma-ray emissions

The published data for the gamma-ray emissions can be viewed in table 7.

Table 7: Experimental data on gamma-ray emission probabilities

Reference	Absolute values (%)		Ratio of
	63 keV	140 keV	140 keV/63 keV
1982Sa36	0.29[1] (2)		
1983Mi30	0.24 (3)	0.018 (2)	0.075 (13)
1983Ro23	0.247[2] (15)		0.102 (9)
1989Sa01			0.055 (10)

[1] Value recalculated using the new DDEP recommended value for $\gamma_{1,0}$(84 keV) of ^{228}Th decay.
[2] Value recalculated using the new DDEP recommended value for $\gamma_{2,0}$(238 keV) of ^{212}Pb decay.

The recommended 63 keV emission intensity of 0.259 (15) % was calculated by taking the weighted mean of 0.29 (2) % (1982Sa36), 0.24 (3) % (1983Mi30) and 0.247 (15) % (1983Ro23).
The recommended ratio 140 keV/63 keV of 0.080 (22) was calculated by taking the weighted mean of 0.075 (13) (1983Mi30), 0.102 (9) (1983Ro23) and 0.055 (10) (1989Sa01). The spread in the results is

quite significant and the reduced chi -square is larger than the critical chi -square. This may be due to the low probability of the gamma combined with the low specific activity of ^{232}Th. The recommended emission probability for the 140 keV line, calculated from the above ratio and the 63 keV emission probability, is 0.021 (6) %.

Transition	**Recommended Values**	**Gamma-ray emission intensity (%)**	**a_T**
$g_{1,0}$	63.811 (10)	0.259 (15)	80.4 (12)
$g_{2,1}$	140.880 (10)	0.021 (6)	2.26 (4)

5. Atomic data

The values of ω_K, ω_L and n_{KL} relative probabilities of the X-ray and Auger emissions are from Schönfeld and Janßen (1996Sc06).

The energies and relative emission probabilities of the X-ray and Auger electrons have been calculated by using the computer code EMISSION.

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^{232}U - Comments on Evaluation of Decay Data
by Andy Pearce

This evaluation was completed in August 2008 drawing in part on the mass-chain evaluation of Artna-Cohen[1]. Some references not in the NSR database were identified by cross-referencing with the evaluation of Nichols[2]. The literature available up until January 2008 was included.

1 Decay Scheme

The decay scheme (nuclear level energies, half lives and spins of ^{228}Th) are based upon the adopted levels and gammas from Artna-Cohen[1].

2 Nuclear Data

Uranium-232 decays primarily by alpha decay to excited states in ^{228}Th. A small branching of exotic decay via ^{24}Ne emission and a smaller branching of spontaneous fission have been reported [3-5]. The Q-value for alpha decay is taken from Audi, Wapstra and Thibault[6-7]. The alpha decay branching is reported as essentially 100 %.

Seven published values of the half life were found in literature from which three independent values with uncertainties were used for analysis. The value of 1964Ch05 [8] determined by calorimetry has been adjusted taking into account the Q-values of Audi, Wapstra and Thibault [6-7]. The authors of 1979Ag04 [9] measured the half life by two methods and both are stated here, although an arithmetic mean of the two has been used in analysis. Similarly the authors of 1964Ch05 [8] performed measurements by two methods and an arithmetic mean is taken for subsequent analysis. Sufficient experimental details were published in 1964Ch05 to allow the values to be recalculated using, for example, current values of Q, however doing so has no significant effect on the data. The adopted value has been determined by a LRSW weighted mean of the values from 1954Se26 [10], 1964Ch05[8] and 1979Ag04[9]. Overall the data are not consistent, however no valid reason could be found to exclude or prefer any of the three values. The discrepancies probably reflect the difficulties in measuring half lives of the order of several decades, and the uncertainty of the adopted value is large. The available data are presented in table 1.

There have been several publications on the spontaneous fission/cluster decay of ^{232}U[3-5] suggesting that ^{24}Ne cluster decay has been misidentified in earlier work as spontaneous fission. This leads to significantly lower values for branching to spontaneous fission than in previous evaluations. The value quoted here for spontaneous fission is that from 1990Bo16 [4] and that for cluster decay is a weighted mean of the values from 1985Ba18 [3] and 1990Bo16[4]. The earlier data from Jaffey and Hirsh[10] has not been published in open literature. Analysis of their data in the light of recent work would appear to confirm the cluster decay branching ratio at approximately 2×10^{-10} per 100 decays. The available data are presented in table 2.

Table 1. Measured half lives of alpha decay of ^{232}U. The reports 1949Go01 and 1949Ja01 were not used in analysis as they were presented without uncertainties.

Reference	Value (days)	Uncertainty (days)	Method
1949Go01[11]	10 957	-	Ingrowth from ^{232}Pa
1949Ja01[12]	25 567	-	Ingrowth from ^{236}Pu
1954Se26	26 880	370	Isotope dilution mass spec and proportional counting
1964Ch05 [A]	26 080	110	Calorimetry
1964Ch05 [B]	26 330	110	Alpha counting
1964Ch05 [mean]	26 130	110	-
1979Ag04 [A]	25 200	150	Isotope dilution mass spec and LS/proportional counting
1979Ag04 [B]	25 170	140	Relative activity vs. ^{233}U
1979Ag04 [mean]	25 090	140	-
1986Ag01	25 170	140	Relative activity vs. ^{233}U; same data as half of 1979Ag01, republished
LRSW/expanded	25 800	390	-
Median (all values)	25 600	400	
Adopted	**25 800**	**400**	**LWM/expanded**

Table 2. Branching ratios for cluster decay and spontaneous fission, calculated where necessary from the partial decay constants using the recommended half life. The cluster decay value of Jaffey and Hirsh has been calculated by doubling the spontaneous fission value (in cluster decay one fragment will be detected compared with two in spontaneous fission).

Reference	Spontaneous Fission (%)	Cluster Decay (^{24}Ne) (%)
2000Bo46	$2.8\ (6) \times 10^{-12}$	-
1990Bo16	$<10^{-12}$	$8.7\ (8) \times 10^{-10}$
1985Ba18	-	$2.0\ (5) \times 10^{-10}$
Jaffey & Hirsh (unpublished)	$9\ (3) \times 10^{-11}$	$1.8\ (12) \times 10^{-10}$
Adopted	**2.8 (6) ´ 10^{-12}**	**5 (3) ´ 10^{-10}**

2.1 Alpha-particleTransitions

The energies of the alpha-particle transitions have been determined from the Q-value and the adopted levels from Artna-Cohen[1]. Alpha-particle hindrance factors were calculated using ALPHAD [13]. The values so obtained are presented in table 3.

Table 3. Adopted level and alpha-particle transition energies

Transition	Level Energy (keV)	Transition Energy (keV)	Alpha-particle Emission Energy (keV)	HF
a_{0}	0	5413.63 (9)	5320.24 (9)	1
a_{58}	57.759 (4)	5355.87 (9)	5263.48 (9)	1.04 (3)
a_{187}	186.823 (4)	5226.81 (9)	5136.64 (9)	16.4 (4)
a_{328}	328.003 (4)	5085.63 (9)	4997.90 (9)	112.0 (24)
a_{378}	378.179 (10)	5035.45 (9)	4948.59 (9)	6490 (80)
a_{396}	396.078 (5)	5017.55 (9)	4931.00 (9)	5270 (50)
a_{519}	519.192 (6)	4894.44 (9)	4810.01 (9)	710 (50)
a_{831}	831.823 (10)	4581.81 (9)	4502.77 (9)	10.6 (8)
a_{874}	874.473 (18)	4539.16 (9)	4460.86 (9)	33 (9)

2.2 Gamma-ray Transitions and Internal Conversion Coefficients

Gamma-ray transition energies (Table 5) are calculated from the differences in level energies from Artna-Cohen[1]. Transition energies calculated from the level scheme are compared with those derived from measured values in table 6. No precise measurements have been reported for the energy of the 831 keV E0 transition.

Table 5. Recommended gamma -ray emission energies, rescaled to be compatible with the values of 1971He23. Values from 1971He23 have been recalculated based on improved calibration standards from 2000He14. The uncertainties of the recalculated values have been increased to be not less than those in the original publication.

Nominal energy (keV)	**57**	**129**	**141**	**191**	**209**	**270**	**328**
1971He23	57.78 (6)	129.1 (1)	-	-	-	270.2 (5)	-
1973Ta25	57.78 (6)	-	-	-	-	-	-
1977Ku15	57.77 (6)	129.07 (6)	-	-	-	270.2 (2)	-
1979Bo30	-	129.070 (16)	-	-	209.238 (21)	270.235 (21)	328.004 (11)
1979He10	57.752 (13)	129.065 (3)	-	-	-	270.245 (7)	-
1987Da28	57.758 (7)	129.067 (7)	141.02 (3)	191.353 (11)	209.254 (7)	270.245 (8)	328.004 (7)
1995Ba42	57.75 (2)	129.05 (2)	140.99 (2)	191.34 (2)	209.25 (2)	270.24 (2)	328.02 (4)
LWEIGHT4	57.757 (6)	129.0655 (27)	140.999 (17)	191.351 (9)	209.252 (6)	270.2441 (13)	328.004 (6)
Adopted	57.752 (13)	129.065 (3)	140.999 (20)	191.351 (11)	209.252 (6)	270.245 (7)	328.004 (7)
Comments	From 1979He10	From 1979He10	LWEIGHT, uncert inc.	LWEIGHT, uncert inc.	LWEIGHT	From 1979He10	LWEIGHT

Table 5 (Cont.)

Nominal energy (keV)	**332**	**338**	**478**	**503**	**546**	**773**	**817**
1971He23	-	338.3 (4)	-	-	-	-	-
1973Ta25	-	-	-	-	-	-	-
1977Ku15	332.3 (3)	338.1 (2)	-	503.6 (3)	-	773.4 (5)	817 (1)
1979Bo30	-	338.321(10)	-	-	-	-	-
1979He10	332.371 (6)	338.320 (5)	-	503.819(23)	-	-	-
1987Da28	332.37 (5)	338.324 (7)	478.34 (5)	503.83 (5)	546.48 (5)	774.1 (2)	816.7 (1)
1995Ba42	332.36 (2)	338.31 (2)	478.45 (4)	503.69 (20)	546.45 (2)	774.06 (10)	816.49 (12)
LWEIGHT4	332.370 (6)	338.3209 (37)	478.41 (5)	503.818 (21)	546.454 (19)	774.05 (9)	816.62 (7)
Adopted	332.371 (6)	338.320 (5)	478.41 (5)	503.819 (23)	546.454 (21)	774.05 (9)	816.62 (7)
Comments	From 1979He10	From 1979He10	LWEIGHT	From 1979He10	LWEIGHT, uncert. inc.	LWEIGHT, uncert inc.	LWEIGHT, uncert inc.

Table 6. Recommended gamma -ray transition energies and internal conversion coefficients. Measured transition energies are those obtained from gamma -ray emission energies via the recoil correction, whereas derived transition energies are those determined from the level scheme.

Measured Energy (keV)	**Transition Energy (keV)**		**Multi-polarity from ENSDF**	**Conversion Coefficients**			
	Measured	**Derived**		a_K	a_L	a_{M+}	a_T
57.752 (13)	57.752 (13)	57.759 (4)	E2	-	112.2 (16)	41.1 (5)	153.2 (22)
129.065 (3)	129.065 (3)	129.064 (6)	E2	0.264 (4)	2.54 (4)	0.933 (41)	3.74 (6)
140.999 (20)	140.999 (20)	141.013 (12)	E1	0.1689 (24)	0.0362 (5)	0.01169 (14)	0.217 (3)
191.351 (11)	191.350 (11)	191.356 (11)	E2	0.1710 (24)	0.443 (7)	0.162 (7)	0.776 (11)
209.252 (6)	209.252 (6)	209.255 (7)	E1	0.0672 (10)	0.01333 (19)	0.00429 (5)	0.0848 (12)
270.245 (7)	270.245 (7)	270.244 (6)	E1	0.0376 (6)	0.00716 (10)	0.002297 (25)	0.0470 (7)
328.004 (7)	328.005 (7)	328.003 (4)	E1	0.0245 (4)	0.00455 (7)	0.001458 (16)	0.0305 (5)
332.371 (6)	332.372 (6)	332.369 (7)	E1	0.0238 (4)	0.00441 (7)	0.001414 (16)	0.0297 (5)
338.320 (5)	338.321 (5)	338.319 (7)	E1	0.0229 (4)	0.00424 (6)	0.001358 (16)	0.0285 (4)
478.41 (5)	478.41 (5)	478.395 (18)	E1	0.01118 (16)	0.0198 (3)	0.000631 (7)	0.01379 (20)
503.819 (23)	503.820 (23)	503.820 (11)	E1	0.01009 (15)	0.001775 (25)	0.000565 (6)	0.01243 (18)
546.454 (21)	546.455 (21)	546.470 (18)	E1	0.00861 (12)	0.001500 (21)	0.000478 (5)	0.01058 (15)
774.05 (9)	774.05 (9)	774.064 (11)	E2	0.01204 (17)	0.00333 (5)	0.001199 (13)	0.01649 (23)
816.62 (7)	816.62 (7)	816.714 (18)	M1+E2 (d=1)	0.028 (18)	0.006 (3)	0.0019 (7)	0.036 (21)
-	-	831.823 (10)	E0	-	-	-	-

Internal conversion coefficients have been determined using the BrIcc code [14], using the gamma -ray multipolarities and mixing ratios from the evaluation of Artna -Cohen[1]. No mixing ratio could be found in literature for the 817 keV transition and a mixing ratio of 1 has been assumed. Measured and adopted conversion coefficients are compared in table 9.

Table 9. Comparison of available measured conversion coefficients with the values calculated with the BrIcc code. Adopted values are from the BrIcc code in all cases.

Energy (keV)	BrIcc		1971He23[25]		1982Ma52[35]	
	a_K	a_L	a_K	a_L	a_K	a_L
57.752 (13)	-	112.2 (16)	-	117 (3)	-	85 (5)
129.065 (3)	0.264 (4)	2.54 (4)	0.23 (1)	2.45 (8)		2.74 (12)
140.999 (20)	0.1689 (24)	0.0362 (5)	0.11 (5)	-	-	-
191.350 (11)	0.1710 (24)	0.443 (7)	0.20 (2)	-	-	-
209.252 (6)	0.0672 (10)	0.01333 (19)	0.058 (1)	-	-	-
270.245 (7)	0.0376 (6)	0.00716 (10)	0.025 (3)	-	0.042 (3)	-
338.320 (5)	0.0229 (4)	0.00424 (6)	0.008 (1)	-	0.030 (2)	

3 Atomic Data

All values of atomic data (ω_K, ω_L, n_{KL}, relative probabilities of the X-ray and Auger emissions) were derived from Schönfeld and Janßen[15].

4 Alpha-particle Emissions

The alpha-particle emission probabilities were calculated from the balance of the gamma -ray decay scheme using GTOL[16]. The adopted emission probabilities of the three strongest transitions a_{0}, a_{58} & a_{187} are in good agreement with a weighted mean of the available measured data [17-21], and those of a_{328} & a_{831} are in agreement with the measured values of 1964Le17 [19]. However, there are significant unexplained differences between the recommended values and the values measured by Baranov [21] for the emission probabilities of a_{328}, a_{381} and a_{396}. Further measurements of the weak alpha -particle and gamma -ray transitions would be necessary to fully resolve these issues.

Table 4. Alpha -particle emission probabilities. Note the value quoted in the table may not match the published value exactly, as the values have been adjusted to a common scale (by dividing by the probability of the most intense emission) to take into account undetected alpha-particle emissions.

Trans.	**Alpha-particle emissions per 100 decays**							**Adopted values (%)**
	1955As28	**1955Go32**	**1963Le17**	**1965Be15**	**1966Ba49**	**LWEIGHT**	**GTOL**	
a_{0}	68 (1)	68.0	-	67.8 (7)	68.6 (6)	68.0 (4)	69.1 (6)	69.1 (6)
a_{58}	32 (1)	34.1	-	32.2 (3)	31.2 (4)	31.7 (7)	30.6 (6)	30.6 (6)
a_{187}	0.32 (3)	-	-	0.30 (9)	0.28 (2)	0.294 (23)	0.325 (6)	0.325 (6)
a_{328}	-	-	6 (2) $\times 10^{-3}$	-	2.9 (2) $\times 10^{-4}$	6 (2) $\times 10^{-3}$	6.22 (9) $\times 10^{-3}$	6.22 (9) $\times 10^{-3}$
a_{378}	-	-	-	-	1.7 (3) $\times 10^{-4}$	1.7 (4) $\times 10^{-4}$	5.1 (6) $\times 10^{-5}$	5.1 (6) $\times 10^{-5}$
a_{396}	-	-	-	-	2.1 (3) $\times 10^{-4}$	2.1 (4) $\times 10^{-4}$	4.8 (4) $\times 10^{-5}$	4.8 (4) $\times 10^{-5}$
a_{519}	-	-	-	-	-	-	5.4 (4) $\times 10^{-5}$	5.4 (4) $\times 10^{-5}$
a_{831}	-	-	2.4 (7) $\times 10^{-5}$	-	-	2.4 (7) $\times 10^{-5}$	2.14 (16) $\times 10^{-5}$	2.14 (16) $\times 10^{-5}$
a_{874}	-	-	-	-	-	-	3.3 (9) $\times 10^{-6}$	3.3 (9) $\times 10^{-6}$

5 Electron Emissions

Auger and conversion electron emissions per 100 decays were calculated from the gamma -ray data and conversion coefficients according to the method of Schönfeld and Janßen [22] using version 3.10 of the code EMISSION.

6 Photon Emissions

6.1 X-ray Emissions

The X-ray intensities per 100 decays have been calculated from the gamma -ray data and conversion coefficients using version 3.10 of the code EMISSION.

6.2 Gamma-ray Emissions

The gamma-ray emission energies have been taken from 1979He10 [23] where possible, in which precise measurements were made by measuring energy differences against accepted calibration standards. Only the directly measured values have been taken as the decay scheme used to derive further values was incomplete. These values have been adjusted to reflect the updated calibration standards given in 2000He14[24]. Where gamma-ray lines are not present in 1979He10, weighted means of the values in 1971He23[25], 1973Ta25[26], 1977Ku15[27], 1979Bo30[28], 1987Da28[29] and 1995Ba42[30] were taken. The values in these publications were first rescaled by a least-squares fit to be compatible with 1979He10. In most cases the energy shift incurred by doing so was very small.

Relative gamma-ray emission probabilities were determined by a weighted mean of values in 1966Ah02[31], 1977Ku15[27], 1984Ge07[32] and Banham & McChrohon [33]. Data for many of the less intense gamma-ray emissions have only been reported in 1977Ku15. In determining means, values were normalised to the 129 keV gamma-ray transition rather than the most intense 60 keV transition due to the experimental difficulties in measuring gamma-ray emissions below 100 keV. There were three absolute emission probability measurements, two by 1984Ge07 [32] and one by Banham & McChrohon [34]. The reference value of the normalisation factor was determined from the weighted mean of the absolute values of the 129 keV line and is 6.86 (7) × 10^{-4} per 100 decays. The normalisation factor was also calculated with the code GABS[34] and by balance of the feeding to the 1st excited state and the figures thus obtained were 7.0 (3) × 10^{-4} per 100 decays and 7.08 (16) ×10^{-4} per 100 decays respectively. These values are statistically compatible with the reference value.

The intensity of the 831 keV E0 transition is given by 1963Le17 as 2 (1) × 10^{-6} per 100 decays. The 831 keV transition is E0, thus, it emits only electrons.

Table 7. Relative gamma-ray emission probabilities, normalised to 100 emissions for the 129 keV line. Note one additional significant figure is quoted in columns 2-6 over that which would normally be quoted; this is intentional to allow statistics to be calculated. The 817 keV line is quoted by 1977Ku15 as ~0.0011; the uncertainty assumed is a relative uncertainty of ±100 % at 3 s, giving a relative emission probability of 0.0011 ± 0.0004.

Energy (keV)	**Gamma-ray emissions per 100 emissions at 129 keV**				
	1966Ah02	**1977Ku15**	**1984Ge07**	**Banham 1986**	**Adopted**
57.752 (13)	256 (26)	298.9 (118)	291.5 (65)	292.5 (42)	292 (4)
129.065 (3)	100	100	100	100	100
140.999 (20)	-	0.00453 (189)	-	-	0.0045 (19)
191.351 (11)	-	0.0453 (40)	-	-	0.0453 (40)
209.252 (6)	-	0.0155 (38)	-	-	0.0155 (38)
270.245 (7)	4.62 (90)	4.264 (198)	-	4.660 (68)	4.62 (9)
328.004 (7)	4.10 (88)	3.774 (161)	-	4.168 (62)	4.12 (9)
332.371 (6)	-	0.0717 (44)	-	-	0.0717 (44)
338.320 (5)	-	0.05396 (249)	-	-	0.0540 (25)
478.41 (5)	-	0.00208 (80)	-	-	0.0021 (8)
503.819 (23)	-	0.02113 (130)	-	-	0.0211 (13)
546.454 (21)	-	0.00147 (91)	-	-	0.0015 (9)
774.05 (9)	-	0.00679 (115)	-	-	0.0068 (12)
816.62 (7)	-	~0.0011	-	-	0.0011 (4)
831.823 (10)	-	E0	-	-	E0

Table 8. Recommended gamma-ray emission probabilities.

Energy (keV)	Multipolarity	Gamma-ray Emission Probability per 100 decays
57.752 (13)	E2	0.200 (4)
129.065 (3)	E2	0.0686 (7)
140.999 (20)	E1	$3.1\ (13) \times 10^{-6}$
191.351 (11)	E2	$3.1\ (3) \times 10^{-5}$
209.252 (6)	E1	$1.1\ (3) \times 10^{-5}$
270.245 (7)	E1	0.00317 (7)
328.004 (7)	E1	0.00283 (7)
332.371 (6)	E1	$4.9\ (3) \times 10^{-5}$
338.320 (5)	E1	$3.70\ (18) \times 10^{-5}$
478.41 (5)	E1	$1.4\ (6) \times 10^{-6}$
503.819 (23)	E1	$1.45\ (9) \times 10^{-5}$
546.454 (21)	E1	$1.0\ (6) \times 10^{-6}$
774.05 (9)	E2	$4.7\ (8) \times 10^{-6}$
816.62 (7)	M1+E2 (d=1)	$8\ (3) \times 10^{-7}$
831.823 (10)	E0	0 [TI $2\ (1) \times 10^{-6}$]

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^{233}Th– Comments on evaluation of decay data

by V.P.Chechev and N.K.Kuzmenko

This evaluation was done originally in 2004 and then updated and revised in January 2009 with a literature cut-off by the same date.

1. DECAY SCHEME

The decay scheme is based on 2005Si15. Some gamma-ray transitions were not observed directly in ^{233}Th decay but have been adopted from ^{237}Np α-decay. There are no precise measurements of beta transitions from the decay of ^{233}Th available. Data on gamma-ray emission probabilities have been taken mainly from measurements in 2008De31.

Several unplaced gamma rays were observed. These gamma rays carry ≤ 3 % of the total intensity of all the gamma rays placed in the decay scheme.

2. NUCLEAR DATA

Q^- value is from 2003Au03.

The recommended half-life of ^{233}Th is based on the experimental results given in Table 1.

Table 1. Experimental values of ^{233}Th half-life (in minutes)

Reference	Author(s)	Original value	Re-estimated	Measurement method
1952Ru10	Rutledge et al.	23,6 (6)		β-counting
1955Je26	Jenkins	22,12 (5) [a]	22,12 (7)	β-counting, good purification of the thorium sample
1957Dr46	Dropesky and Langer	22,4 (1)		β-counting
1969HoZY	Hoekstra	22,3 (1)		Gamma-ray counting
1989Ab05	Abzouzi et al.	22,30 (2) [b]	22,30 (10)	Gamma-ray counting
1998Us01	Usman et al.	21,83 (4) [c]	21,83 (10)	Gamma-ray counting
2008De31	DeVries and Griffin	21,99 (5) [d]	21,99 (9)	Liquid scintillation counting, multiple purifications of the thorium sample

[a] Original value was deduced as the mean value from two experiments with the same result of 22,12 (7) min. As these experiments were correlated the evaluators used the value of 22,12 (7) min.

[b] Uncertainty may include only statistical errors. The evaluators have taken into account the contribution of possible systematic errors associated with the gamma-ray counting method (see below).

[c] Possible systematic errors associated to the gamma-ray counting method may have been caused by the use of a different shape of pulser and gamma-ray peaks, and by contamination of the gamma-ray spectrum with ^{233}Pa and other radionuclides. Based on data scattering in three experiments for the strongest 459 keV and 669 keV gamma ray peaks (with a half-life ranging from 21,748 to 21,945 min) the evaluators have estimated the overall uncertainty of 0.10 min, which includes possible systematic errors.

[d] Authors reported only statistical errors ≤ (0,2 – 0,3) %. Assuming possible systematic errors of the same order of magnitude (~ 0,3 %), the evaluators have estimated an overall uncertainty of 0,09 min.

The value from 1952Ru10 has been omitted because it is an outlier. The unweighted mean of the 6 remaining values from Table 1 is 22,16 (9), the weighted mean is 22,15, the internal uncertainty is 0,037, the external uncertainty is 0,082. The LWEIGHT computer program recommended the weighted mean and its external uncertainty. Therefore, the recommended value of ^{233}Th half-life is 22,15 (8) minutes.

2.1. Beta-transitions

The energies of β^- transitions have been obtained from the Q^- value and the ^{233}Pa level energies given in Table 2, taken mainly from 2005Si15. The adopted level energies include also available data from ^{237}Np alpha-decay. The energies of the levels ”5”, ”10” and “12” have been obtained directly from the energies of the $\gamma_{5,0}$ (94,65 keV), $\gamma_{10,0}$ (237,86 keV) and $\gamma_{12,0}$ (447,762 keV) gamma rays, respectively.

The comparison of measured and recommended energies of β^- transitions is given in Table 3.

The emission probabilities of β^- transitions have been deduced from the P(γ+ce) balance at each level of ^{233}Pa. The accurate combined β^- intensity of the $\beta_{0,0}$ and $\beta_{0,1}$ transitions is 84,0 (5) %, using 100 % for the total intensity of the beta decay from ^{233}Th.

Table 2. ^{233}Pa levels populated in ^{233}Th decay

Level	Energy (keV)	Spin and Parity	Half-life	Probabilities of β^--transitions (%)
0	0	$3/2^-$	26,98 (2) d	34 (6)
1	6,65 (5)	$1/2^-$		50 (6)
2	57,10 (2)	$7/2^-$		-
3	70,49 (10)	$5/2^-$		-
4	86,477 (10)	$5/2^+$		-
5	94,65 (5)	$3/2^+$		10,4 (4)
6	103,8 (1)	$7/2^+$		-
7	169,159 (10)	$1/2^+$		0,692 (12)
8	201,62 (5)	$3/2^+$		0,074 (8)
9	212,34 (5)	$5/2^+$		-
10	237,86 (6)	$5/2^+$		-
11	257,30 (15)	$5/2^-$		0,60 (3)
12	447,762 (20)	$3/2^-$		0,821 (14)
13	454,40 (7)	$3/2^+$		0,217 (13)
14	553,88 (6)	$1/2^+$, $3/2^+$		1,23 (3)
15	585,50 (5)	$3/2^+$		0,15 (3)
16	669,9 (5)	($3/2^-$)		0,0174 (22)
17	764,55 (6)	$1/2^+$, $3/2^+$		1,19 (3)
18	811,6 (2)	($3/2^+$)		0,385 (4)
19	984,8 (5)	($3/2^+$)		0,205 (2)
20	1018,7 (5)	(3/2)		0,0434 (9)

Table 3. Measured and recommended energies of β^- -transitions

	1957Dr46	1957Fr55	Recommended
$\beta_{0,0}$	1230 (10)	1245 (3)	1243,1 (14)
$\beta_{0,5}$		1158	1148,4 (14)
$\beta_{0,7}$		1073	1073,9 (14)
$\beta_{0,11}$		880	985,8 (14)
$\beta_{0,12}$		790	795,3 (14)
$\beta_{0,13}$			788,7 (14)
$\beta_{0,14}$			689,2 (14)
$\beta_{0,15}$			657,6 (14)
$\beta_{0,16}$		580	573,2 (14)
$\beta_{0,17}$			478,5 (14)
$\beta_{0,18}$			431,5 (14)

2.2. Gamma Transitions and Internal Conversion Coefficients

The recommended energies of gamma-ray transitions are virtually the same as the gamma-ray energies because nuclear recoil is negligible for 233Pa.

The gamma-ray transition probabilities [P(γ+ce)] have been obtained using the gamma-ray emission probabilities and total conversion coefficients (ICC). The ICC have been interpolated using the BrIcc package with the so called "*Frozen Orbital*" approximation (2008Ki07). The uncertainties in the ICC for pure multipolarities have been taken as 2 %.

P(γ+ce)(8,22 keV) has been obtained from the intensity imbalance at the level "4" (86,477 keV) assuming negligible beta transition probability to this level [$P(\beta_{0,4}) = 0$]. The obtained value of P(γ+ce)(8,22 keV)=12,3 (4) % differs from ≈ 19 % estimated in 2005Si15 using the intensity of N conversion electrons measured in 1976JeZU. It should be noted that the E2/M1 mixing ratio for the 8,22 keV gamma ray transition has not been measured. However, the experimental P_{ce} (N2) ≈ P_{ce} (N3) indicates a large contribution of E2 multipolarity for this transition.

The ICC for the anomalous E1 gamma-ray transition $\gamma_{4,0}$ (86,477 keV) has been taken from 1988Wo01. The value of the total internal conversion coefficient of 1,43 (8) measured in 1988Wo01 agrees well with the theoretical assessment of 1,49 (18) (which includes the effect of nuclear penetration) obtained in 2008Go10 for this anomalous E1 gamma-ray transition.

The conversion electron data of 1988Wo01 indicate that the gamma-transition $\gamma_{4,2}$ (29,37 keV) also may be an anomalous E1. However, the evaluators have been adopted (following 2005Si15) the theoretical ICC for this transition since the detector efficiency was not completely reliable for energies lower than 50 keV, as pointed out in 1988Wo01.

Multipolarities and E2/M1 mixing ratios have been adopted from conversion electron measurements of 1972SeZI, 1976JeZU, and from data on ^{237}Np alpha-decay (see 2005Si15).

3. ATOMIC DATA

The atomic data (fluorescence yields, X-ray energies and relative probabilities, and Auger electrons energies and relative probabilities) have been deduced by using the SAISINUC software (2002Be).

4. ELECTRON EMISSIONS

The energies of the conversion electrons have been obtained from the gamma-ray transition energies and the electron binding energies.

The absolute emission probabilities of conversion electrons have been obtained using the recommended P_γ and ICC.

The absolute emission probabilities of K- and L- Auger electrons have been deduced from the emission probabilities of KX- and LX- rays measured in 2008De31. Their values, given in Table 4, are compared to the results of calculations using the evaluated $P_{\gamma,}$ ICC with the EMISSION computer program.

Table 4. Absolute emission probabilities of K- and L- Auger electrons from the decay of ^{233}Th

	Calculated using recommended $P_{\gamma\,,}$ ICC (EMISSION code)	Deduced from absolute intensities of LX-, KX- rays measured in 2008De31	Recommended
e_{AL} (Pa)	6,71 (26)	8,6 (10)	8,6 (10)
e_{AK} (Pa)	0,037 (6)	0,041 (5)	0,041 (5)
KLL	0,022 (4)	0,024 (3)	0,024 (3)
KLX	0,013 (2)	0,014 (2)	0,014 (2)
KXY	0,0020 (3)	0,0021 (3)	0,0021 (3)

β^- average energies have been obtained using the LOGFT computer program.

5. PHOTON EMISSIONS

5.1. X-Ray Emissions

The recommended absolute emission probabilities of Pa KX- and LX- rays are from the measurements of 2008De31, which include a contribution from possible systematic errors in the uncertainties of photon intensities (see section 5.2).

In Tables 5 and 6, a comparison of measured and calculated emission probabilities for specific groups of Pa KX- and LX- rays is given. The calculated values have been obtained with the EMISSION computer program using the adopted atomic data for Pa and the recommended total absolute emission probabilities of K- and L- conversion electrons from ^{233}Th→^{233}Pa decay.

Table 5. Experimental and calculated values of absolute Pa KX- ray emission probabilities in the decay of ^{233}Th

	Energy (keV)	1969HoZY (measured)	2008De31 (measured)	Calculated	Recommended
$K\alpha_2$	92,288	0,54 (7)	0,39 (1)	0,357 (20)	0,39 (1)
$K\alpha_1$	95,869	1,01 (7)	0,615 (10)	0,57 (4)	0,615 (13)
$K\beta'_1$	107,60-109,07	0,28	0,235 (5)	0,206 (12)	0,235 (6)
$K\beta'_2$	111,40-112,38	0,09	0,079 (3)	0,070 (5)	0,079 (3)

Table 6. Experimental and calculated values of absolute Pa LX- ray emission probabilities in the decay of ^{233}Th

	Energy (keV)	2008De31 (measured)	Calculated	Recommended
Ll	11,366	0,14 (2)	0,151 (5)	0,14 (2)
Lα	13,122 – 13,291	2,84 (32)	2,48 (7)	2,84 (32)
Lη	14,946	4,3 (5)	0,0626 (20)	4,3 (5)
Lβ	15,3 – 16,7		3,07 (8)	
Lγ	19,9 – 21,6	0,95 (11)	0,706 (17)	0,95 (11)

5. 2. Gamma-Ray Emissions

The energies of the gamma-rays $\gamma_{7,5}$ (74 keV), $\gamma_{9,6}$ (109 keV), $\gamma_{8,4}$ (115 keV), $\gamma_{11,6}$ (153 keV), $\gamma_{17,15}$ (179 keV), $\gamma_{10,2}$ (181 keV), $\gamma_{11,3}$ (187 keV), $\gamma_{8,1}$ (195 keV), $\gamma_{17,14}$ (211 keV), $\gamma_{13,10}$ (216 keV), $\gamma_{12,8}$ (246 keV), $\gamma_{11,1}$ (251 keV), $\gamma_{13,8}$ (253 keV), $\gamma_{13,7}$ (285 keV), $\gamma_{15,10}$ (348 keV), $\gamma_{12,4}$ (361 keV), $\gamma_{13,4}$ (368 keV), $\gamma_{12,3}$ (377 keV), $\gamma_{14,4}$ (467 keV), $\gamma_{17,10}$ (527 keV), $\gamma_{17,9}$ (552 keV), $\gamma_{7,8}$ (563 keV), $\gamma_{17,7}$ (595 keV), $\gamma_{18,9}$ (599 keV), $\gamma_{18,7}$ (642 keV), $\gamma_{16,0}$ (670 keV), $\gamma_{17,4}$ (678 keV), $\gamma_{18,6}$ (708 keV), $\gamma_{18,5}$ (717 keV), $\gamma_{18,4}$ (725 keV), $\gamma_{18,3}$ (741 keV), $\gamma_{17,1}$ (758 keV), $\gamma_{19,8}$ (783 keV), $\gamma_{18,1}$ (805 keV), $\gamma_{20,7}$ (849 keV), $\gamma_{19,4}$ (898 keV), $\gamma_{20,3}$ (948 keV), $\gamma_{19,1}$ (978 keV) have been deduced from the adopted ^{233}Pa level energies (Table 2).

The energies of the gamma-rays $\gamma_{7,1}$ (162 keV), $\gamma_{7,0}$ (169 keV), $\gamma_{12,11}$ (190 keV), $\gamma_{13,5}$ (360 keV), $\gamma_{12,1}$ (441 keV), $\gamma_{12,0}$ (448 keV), $\gamma_{14,5}$ (459 keV), $\gamma_{15,5}$ (491 keV), $\gamma_{17,5}$ (670 keV) are from precise measurements performed with a crystal spectrometer (1979Bo30).

The following gamma-rays, $\gamma_{6,2}$ (46 keV), $\gamma_{3,0}$ (70 keV), $\gamma_{8,4}$ (115 keV), $\gamma_{10,6}$ (134 keV), $\gamma_{9,3}$ (141 keV), $\gamma_{9,2}$ (155 keV), $\gamma_{10,2}$ (181 keV), $\gamma_{9,0}$ (212 keV), $\gamma_{10,0}$ (238 keV) have not been observed in ^{233}Th decay. These gamma-rays have been adopted from the decay scheme on the basis of the available data on ^{237}Np α-decay.

In Table 7 various experimental energies for a number of prominent gamma-rays in the decay of ^{233}Th are compared with evaluated results.

The recommended energies of the remaining gamma-rays are from 1969HoZY, 1972SeZI, 1972Vo08 following the evaluation by 2005Si15. See also 1968Br25, 1968Da24, 1969Va06, 1970Se06 and 1972De67.

Table 7. Experimental and evaluated gamma-ray energies in the decay of ^{233}Th

	1976Sk01	1979Bo30	1979Go12	1988Wo01 (Ge detector)	1988Wo01 (LEPS detector)	Evaluated (recommended)
$\gamma_{4,2}$	29,373 (10)		29,374 (20)	29,5 (17)	29,18 (21)	29,373 (10)
$\gamma_{6,2}$	46,534 (40)		46,53 (6)	46,7 (11)	46,28 (18)	46,53 (4)
$\gamma_{2,0}$	57,15 (4)	57,11 (5)	57,104 (20)	57,15 (80)	56,88 (17)	57,10 (2)
$\gamma_{3,0}$						70,49 (10) [a, b]
$\gamma_{4,0}$	86,503 (20)	86,48 (6)	86,477 (10)	86,50 (48)	86,26 (14)	86,477 (10)
$\gamma_{5,1}$	88,04 (16)		87,988 (30)			87,99 (3)
$\gamma_{5,0}$	94,66 (5)		94,638 (50)			94,65 (5)
$\gamma_{8,4}$	115,40 (35)		115,40 (35)			115,14 (5)[a]
$\gamma_{9,5}$	117,681 (30)		117,702 (20)	117,72 (50)	117,41 (15)	117,692 (20)
$\gamma_{8,3}$	131,043 (30)		131,101 (25)	131,09 (52)	130,62 (15)	131,101 (25)
$\gamma_{10,6}$	134,23 (4)		134,285 (20)	134,27 (53)		134,285 (20)
$\gamma_{9,3}$			141,74 (10)			141,74 (10)
$\gamma_{10,5}$	143,208 (25)		143,249 (20)	143,27 (56)	142,96 (16)	143,230 (20)
$\gamma_{10,4}$	151,375 (35)		151,414 (20)	151,42 (60)	151,06 (17)	151,409 (20)
$\gamma_{9,2}$	155,22 (4)		155,239 (20)	155,28 (63)		155,239 (20)
$\gamma_{7,1}$	162,50 (6)	162,504 (12)	162,41 (8)	162,45 (68)		162,504 (12)
$\gamma_{7,0}$	169,17 (5)	169,162 (10)	169,156 (20)	169,18 (73)		169,159 (10)
$\gamma_{11,4}$	170,63 (8)		170,59 (6)			170,60 (6)
$\gamma_{10,2}$	180,80 (8)		180,81 (10)	180,87 (85)		180,76 (3) [a]
$\gamma_{11,3}$	186,8 (5)		186,86 (35)			186,80 (18) [a]
$\gamma_{12,11}$		190,552 (14)				190,552 (14)
$\gamma_{8,0}$	201,72 (5)		201,62 (5)	201,8 (11)		201,62 (5)
$\gamma_{9,0}$	212,415 (25)	212,4 (12)	212,290 (50)			212,34 (5) [a]
$\gamma_{10,0}$	238,04 (4)		237,862 (60)	238,0 (14)		237,86 (6)
$\gamma_{13,5}$		359,745 (40)				359,74 (4)
$\gamma_{12,1}$		440,943 (40)				440,94 (4)

[a] deduced from level energies

[b] observed by 1969HoXY (71,0 keV) and 1974HeYW (70,75 (10) keV)

The gamma-ray transitions with energies (keV) of 80, 105,147, 211, 242, 310, 383, 409, 418, 454, 465, 474, 497, 505, 513, 517, 532, 554, 555, 579, 583, 681, 690, 698, 704, 728, 745, 752, 767, 774, 784, 832, 847, 871, 874, 919, 935, 942, 943, 955, 961, 963, 968, 994, 1001, 1007, 1011, 1026, 1092, 1132, 1139, 1144 and 1201 have not been placed in the ^{233}Th decay scheme.

The gamma-ray transitions $\gamma_{7,1}$ (162 keV) and $\gamma_{11,5}$ (162 keV), $\gamma_{16,0}$ (670 keV) and $\gamma_{17,5}$ (670 keV) are doublets, and have been placed twice in the decay scheme; their intensities have been suitably divided (2005Si15).

The absolute gamma-ray emission probabilities have been adopted from 2008De31. In 2008De31 absolute photon intensities were measured using multiple purifications of stock solutions of ^{233}Th produced by the ^{232}Th(n,γ) reaction. The measurement consisted of liquid scintillation counting (LSC) and γ-ray spectroscopy with HPGe detectors. As the authors of 2008De31 quoted only statistical uncertainties for their intensity values, the evaluators have considered an additional contribution from possible systematic errors when estimating the overall uncertainties in the absolute photon intensities. This contribution was estimated on the basis of data scattering for LSC measurements and detection efficiency uncertainties for γ-ray spectroscopy discussed in 2008De31 and 2008De10. The estimations of detection uncertainties (~ 11 % for $\leq$ 20 keV, ~ 1 % for 29 keV, and ~ 0,7 % for energies $\geq$ 50 keV) have been adopted from 2008De31, 2008De10 and combined with the statistical uncertainties. In particular, the systematic uncertainty due to the absolute LSC measurements of the effective number of disintegrations in 2008De31 has been estimated as ~ 1 % on the basis of measured data scattering, and it has been used here.

P(γ)(6,65 keV) has been deduced from the absolute intensity of N1-conversion electrons of 9 (1) per 100 decays measured in 1976JeZU using the theoretical conversion coefficient α(N1) = 545 (11) for an M1 multipolarity.

The recommended absolute gamma-ray emission probability for $\gamma_{2,0}$(57,1 keV) (0,0498 (15) %) agrees well with 0,057 (11) % but is much more precise. The latter was deduced from the absolute intensity of L-conversion electrons measured in 1976JeZU and the theoretical ICC (see 2005Si15).

In Table 8 the relative gamma-ray emission probabilities measured in 2008De31 (scaling to 100 for the 57,1-keV γ-ray) are compared to the early experimental results reported without uncertainties. Such a comparison shows that the intensities in 2008De31 for the major transitions are ~ (10-30) % lower than results in 1969HoZY, 1972SeZI. This may be due to the use of not sufficiently purified ^{233}Th samples in the early measurements.

Table 8. Measured relative gamma-ray emission probabilities in the decay of ^{233}Th

	Energy (keV)	2008De31	1969HoZY, 1972SeZI (see 2005Si15)
$\gamma_{1,0}$	6,65 (5)	--	29,6
$\gamma_{4,2}$	29,373 (10)	4,34 (5)·10^3	4,6·10^3
$\gamma_{2,0}$	57,10 (2)	100	100
$\gamma_{3,1}$	63,92 (6)	--	1,5
$\gamma_{3,0}$	70,49 (10)	--	1,5
$\gamma_{7,5}$	74,51 (5)	80,4 (9)	96
$\gamma_{4,0}$	86,477 (10)	3,68 (4)·10^3	5,0·10^3
$\gamma_{5,1}$	87,99 (3)	340 (4)	333
$\gamma_{5,0}$	94,66 (5)	1,55 (2)·10^3	1,5·10^3
$\gamma_{9,6}$	108,5 (1)	--	1,1
$\gamma_{8,4}$	115,14 (5)	0,6 (13)	4,1
$\gamma_{9,5}$	117,692 (20)	5,8 (6)	2,8
$\gamma_{8,3}$	131,101 (25)	101 (2)	122
$\gamma_{10,6}$	134,285 (20)	3,6 (9)	4,1
$\gamma_{10,5}$	143,230 (20)	22,8 (15)	26
$\gamma_{10,4}$	151,409 (20)	13,4 (8)	17
$\gamma_{11,6}$	153,49 (18)	81,4 (9)	122
$\gamma_{9,2}$	155,239 (20)	4,6 (1)	1,7
$\gamma_{7,1}$	162,504 (12)	335 (4)	278
$\gamma_{11,5}$	162,504	--	315
$\gamma_{7,0}$	169,162 (10)	502 (6)	630
$\gamma_{11,4}$	170,60 (6)	101 (2)	241
$\gamma_{17,15}$	179,05 (8)	55,6 (7)	70

	Energy (keV)	2008De31	1969HoZY, 1972SeZI (see 2005Si15)
$\gamma_{10,2}$	180,76 (3)	2,2 (6)	1,3
$\gamma_{11,3}$	186,80 (18)	41,8 (13)	63
$\gamma_{12,11}$	190,552 (14)	172 (2)	241
$\gamma_{8,1}$	194,97 (7)	214 (3)	296
$\gamma_{8,0}$	201,62 (5)	44,2 (18)	57
$\gamma_{17,14}$	210,67 (8)	35,6 (18)	65
$\gamma_{-1,4}$	211,3 (2)	40 (2)	35
$\gamma_{9,0}$	212,34 (5)	13 (1)	2,8
$\gamma_{13,10}$	216,54 (8)	26 (3)	28
$\gamma_{18,15}$	226,1 (2)	34 (2)	43
$\gamma_{10,0}$	237,86 (2)	3,8 (8)	3,9
$\gamma_{12,8}$	246,14 (6)	8,2 (14)	--
$\gamma_{11,1}$	250,65 (16)	9,4 (7)	8,7
$\gamma_{13,8}$	252,78 (9)	13,2 (7)	22
$\gamma_{11,0}$	257,30 (15)	105 (2)	126
$\gamma_{12,7}$	278,7 (4)	9,4 (11)	14
$\gamma_{13,7}$	285,24 (7)	31 (2)	39
$\gamma_{15,10}$	347,64 (6)	29 (2)	22
$\gamma_{13,5}$	359,74 (4)	174 (2)	222
$\gamma_{12,4}$	361,285 (22)	43,6 (9)	70
$\gamma_{13,4}$	367,92 (7)	7,4 (15)	8,7
$\gamma_{12,3}$	377,27 (11)	55 (2)	70
$\gamma_{19,15}$	398,8 (5)	22,2 (15)	26
$\gamma_{-1,8}$	408,8 (5)	1 (1)	7,0
$\gamma_{16,11}$	412,5 (5)	16,6 (3)	24
$\gamma_{-1,9}$	418,4 (5)	18,2 (18)	22
$\gamma_{19,14}$	430,9 (4)	35,6 (7)	42
$\gamma_{20,15}$	433,2 (4)	23,4 (8)	28
$\gamma_{12,1}$	440,94 (4)	382 (4)	426
$\gamma_{12,0}$	447,762 (20)	208 (3)	278
$\gamma_{14,5}$	459,222 (7)	1,98 (2)·10^3	2,6·10^3
$\gamma_{14,4}$	467,40 (6)	28,8 (9)	33
$\gamma_{-1,12}$	473,9 (5)	6,6 (12)	6,5
$\gamma_{15,5}$	490,80 (6)	215 (4)	315
$\gamma_{-1,13}$	497,1 (4)	25,6 (8)	39
$\gamma_{15,4}$	499,02 (4)	315 (3)	389
$\gamma_{-1,14}$	505,5 (6)	11,0 (6)	9,1
$\gamma_{-1,15}$	513,4 (4)	26,6 (10)	37
$\gamma_{-1,16}$	517,0 (4)	9,2 (1)	13
$\gamma_{17,10}$	526,69 (6)	92,6 (19)	12
$\gamma_{-1,17}$	531,8 (4)	14 (2)	7,8
$\gamma_{17,9}$	552,21 (8)	33 (1)	44
$\gamma_{-1,18}$	554,9 (5)	6,2 (6)	6,5
$\gamma_{17,8}$	562,93 (8)	109 (2)	130
$\gamma_{18,10}$	573,7 (4)	66,4 (14)	78
$\gamma_{17,7}$	595,39 (6)	236 (20)	296
$\gamma_{18,9}$	599,3 (2)	58,8 (12)	87
$\gamma_{18,8}$	610,0 (3)	113 (2)	157
$\gamma_{18,7}$	642,4 (2)	40,4 (8)	52

	Energy (keV)	2008De31	1969HoZY, 1972SeZI (see 2005Si15)
$\gamma_{16,1}$	663,3 (5)	7,4 (10)	4,4
$\gamma_{17,5}$	669,901 (16)	$1{,}00\ (3)\cdot10^{3}$	$1{,}3\cdot10^{3}$
$\gamma_{17,4}$	678,04 (10)	129 (2)	161
$\gamma_{-1,22}$	681,2 (6)	28,6 (8)	30
$\gamma_{-1,23}$	698,5 (6)	21,2 (1)	22
$\gamma_{-1,24}$	703,7 (6)	18,2 (1)	20
$\gamma_{18,6}$	707,8 (3)	18,2 (1)	22
$\gamma_{18,5}$	717,0 (2)	84,2 (17)	104
$\gamma_{18,4}$	725,1 (2)	126 (2)	161
$\gamma_{18,3}$	741,1 (2)	47,2 (9)	57
$\gamma_{-1,27}$	744,9 (5)	10,6 (4)	13
$\gamma_{-1,28}$	751,6 (6)	4,6 (6)	4,4
$\gamma_{17,1}$	757,90 (7)	64,8 (13)	78
$\gamma_{17,0}$	764,55 (6)	178 (2)	222
$\gamma_{-1,30}$	774,0 (4)	21,6 (12)	26
$\gamma_{19,8}$	783,2 (5)	11,2 (7)	11
$\gamma_{-1,31}$	784,2 (5)	4,4 (6)	9,1
$\gamma_{18,1}$	805,0 (2)	42,8 (13)	57
$\gamma_{20,9}$	806,4 (5)	24,6 (14)	24
$\gamma_{18,0}$	811,6 (2)	12,0 (5)	14
$\gamma_{19,7}$	815,9 (4)	39 (2)	52
$\gamma_{20,8}$	817,0 (6)	19 (1)	30
$\gamma_{20,7}$	849,5 (5)	7,8 (5)	8,7
$\gamma_{-1,34}$	870,7 (7)	6,2 (5)	3,9
$\gamma_{-1,35}$	874,0 (5)	24,0 (8)	11
$\gamma_{19,6}$	880,9 (5)	19,4 (8)	14
$\gamma_{19,5}$	890,1 (5)	210 (8)	259
$\gamma_{19,4}$	898,3 (5)	4,4	6,1
$\gamma_{-1,37}$	935,2 (7)	73,8 (15)	91
$\gamma_{-1,38}$	941,9 (8)	9,6 (1)	14
$\gamma_{20,3}$	948,3 (5)	12,0 (7)	14
$\gamma_{-1,40}$	955 (1)	0,4 (5)	10
$\gamma_{-1,41}$	960,8 (8)	8,2 (3)	13
$\gamma_{-1,42}$	962,8 (9)	3,0 (1)	2,6
$\gamma_{-1,43}$	968,2 (9)	16,6 (7)	20
$\gamma_{19,1}$	978,2 (5)	11,6 (7)	14
$\gamma_{19,0}$	984,8 (5)	20,4 (6)	2,6
$\gamma_{-1,44}$	994 (1)	1,2 (2)	1,7
$\gamma_{-1,45}$	1001 (1)	1,6 (4)	2,2
$\gamma_{-1,46}$	1007 (1)	2,8 (4)	5,2
$\gamma_{-1,47}$	1011 (1)	3,8 (4)	7,4

6. CONSISTENCY OF RECOMMENDED DATA

The most accurate Q value, Q(M), is taken from the atomic mass adjustment table of Audi et al. (2003Au03). Comparison of Q(eff)(deduced as the sum of average energies per disintegration ($\sum E_i \times P_i$) for all emissions accompanying 233Th β- decay) with the tabulated decay energy Q(M) allows to check a consistency of the recommended decay-scheme parameters obtained in this evaluation.

Here E_i and P_i are the evaluated energies and emission probabilities of the i-th alpha particle, beta particle, gamma ray, X-ray, etc..

Consistency (percentage deviation) is determined by {[Q(M) - Q(eff))] / Q(M)} × 100. “Percentage deviations above 5 % would be regarded as high and imply a poorly defined decay scheme; a value of less than 5 % indicates the construction of a reasonably consistent decay scheme” (quoted from the article by A.L. Nichols in Appl. Rad. Isotopes 55 (2001) 23-70).

For the above ^{233}Th decay data evaluation we have Q(M) = 1243,1 (14) keV and Q(eff) = 1247 (2) keV, i.e. consistency is better than 1 %.

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^{233}Pa - Comments on evaluation of decay data
by V. P. Chechev and K. N. Kuzmenko

This evaluation was done originally in September 2004, corrected in December 2004 and in March 2006, and then updated in April 2009 with a literature cut-off by the same date.

1 Decay Scheme

The decay scheme is based on the experimental results of Kouassi et al. (1990Ko41) and NDS evaluations of 1990Ak02 and 2005Si15. In addition to the nuclear transitions well studied (1990Ak02), Singh and Tuli (2005Si15) list a large number of weak transitions and γ rays from unpublished work of de Bettencourt (1985DeZR), defining them as tentative. Latter ones have not been considered in this evaluation. The list of the tentative gamma rays is given in section 5.2.1. These gamma rays carry ≤ 1,2 % of the total intensity of all the gamma rays placed in the decay scheme.

2 Nuclear Data

Q^- value is from 2003Au03.

The recommended half-life of ^{233}Pa is based on the experimental results given in Table 1.

Table 1. Experimental values of ^{233}Pa half-life (in days)

Reference	Author(s)	Value	Measurement method
1941Gr03	Grosse et al.	27,4 (4)	β-counting
1956Mc60	Mc Isaac and Freiling	27,0 (1)	4πγ ionization chamber (4 $T_{1/2}$) and β proportional counter (2 $T_{1/2}$)
1957Wr37	Wright et al.	26,95 (6)	Gamma ionization chamber and β proportional counter (2 $T_{1/2}$)
1986Jo07	Jones et al.	26,967 (2)	Gamma ionization chamber (11 $T_{1/2}$)
1999Popov	Popov and Timofeev	26,9 (1)	Ge(Li) γ-ray spectrometer
2000Us01	Usman and MacMahon	27,02 (3)	HPGe gamma-ray spectrometer (8 gamma lines, 5 $T_{1/2}$)

The weighted mean of the six values from Table 1 of 26,967(2) is dominated by the very accurate value from 1986Jo07. The LWEIGHT computer program uses a limitation of relative statistical weights (LRSW method), and increased the uncertainty of 1986Jo07 from 0,002 to 0,025 to give a weighted mean of 26,984(18). The evaluation technique from 2000Ch01 also uses the LRSW method and some additional criteria to give the same value of 26,984 (18).The Rajeval data evaluation technique (1992Ra08) uses different criteria to adjust the uncertainties, and has increased the uncertainties of 1986Jo07 and 2000Us01 to give the same value of 26,984 (18).

Huang et al. (2005Hu06) used the analogous procedures for their statistical analysis, and adopted the mean of the normalized residuals and Rajeval technique to give the value for the ^{233}Pa half-life of 26,971 (13) d. However, they did not take into account the measurement of Popov and Timofeev (1999).

Thus, taking into account the accuracy of most of the available measurements, the best estimate of the ^{233}Pa half-life is believed to be a recommended value of 26,98 (2) days.

2.1 b- Transitions

The energies of β^- transitions have been obtained from the Q^- value and the ^{233}U level energies given in Table 2 from 2005Si15.

Table 2. ^{233}U levels populated in ^{233}Pa β^--decay

Level	Energy (keV)	Spin and Parity	Half-life	Probability of β^- transitions (%)
0	0,0	$5/2^+$	1,592 (2) × 10^5 a	6,3 (23)
1	40,350 (4)	$7/2^+$	0,11 (8) ns	0,3 (19)
2	92,16 (4)	$9/2^+$		
3	298,810 (4)	$5/2^-$		0,12 (5)
4	301,94 (9)	$5/2^-$		0,010 (2)
5	311,904 (4)	$3/2^+$	0,120 (15) ns	26,6 (32)
6	320,83 (4)	$7/2^-$		0,020 (3)
7	340,477 (4)	$5/2^+$	52 (10) ps	25,9 (32)
8	380,43 (8)	$7/2^+$		0,020 (3)
9	398,496 (4)	$1/2^+$	55 (20) ps	15,4 (8)
10	415,758 (4)	$3/2^+$	≤ 30 ps	25,4 (16)
11	456,114 (6)	$5/2^+$		0,0011 (2)

The recommended probabilities of β^--transitions have been deduced from the P(γ+ce) balance at each level of ^{233}U.

The accurate sum of intensities of β^--transitions to the ground and first excited states $[P(\beta_{0,0})+P(\beta_{0,1})]\times 100$ has been deduced as (100 % – $\Sigma P_{i,j}$ (γ+ce)(j=0,1,2)), where the latter value includes only the intensities of the gamma-ray transitions feeding the ground state and the 40,3- and 92,2-keV levels. The 92,2-keV level ($9/2^+$) cannot be fed directly in the β^- decay of ^{233}Pa ground state ($3/2^-$). This forbiddenness allows the accurate combine β^- intensity of the $\beta_{0,0}$ and $\beta_{0,1}$ transitions to be evaluated as 100% – 93,4 (22) % = 6,6 (22) % to be compared with a value of 8,8 (14) % as measured by Browne et al. (1989Br24) and deduced from the decay scheme in 1990Ko41 (6,9 (15) %) and in 2005Hu06 (7,4 (6) %), respectively.

Measured and recommended β^--transition energies and probabilities are given in Tables 3 and 4, respectively.

Table 3. Measured and recommended energies of β^- transitions (keV)

	1954Br37	1955On05	1960Un01	1963Bj03	Recommended
$\beta_{0,10}$	140 (14)	145 (10)	155 (7)	154 (5)	154,3 (20)
$\beta_{0,9}$			175 (8)		171,5 (20)
$\beta_{0,5}$	256 (4)	257 (5)	250 (5)	254 (5)	258,2 (20)
$\beta_{0,0}$	568 (5)	568 (5)		578 (10)	570,1 (20)

Table 4. Measured and evaluated probabilities (%) of β^- transitions

	1954Br37	1955On05	1963Bj03	Evaluated
$\beta_{0,10}$	50	37	32	25,4 (16)
$\beta_{0,5}$	45	58	56	26,6 (32)
$\beta_{0,0}$	5	5	12	6,3 (23)

2.2 Gamma-Ray Transitions and Internal Conversion Coefficients

The recommended energies of gamma-ray transitions are virtually the same as the gamma-ray energies because nuclear recoil is negligible.

The gamma-ray transition probabilities have been obtained from the gamma-ray emission probabilities and the total internal conversion coefficients (ICCs). Multipolarities of gamma-ray transitions have been taken from 2005Si15. The ICCs have been interpolated using the BrIcc package with the so called "*Frozen Orbital*" approximation (2008Ki07). The relative uncertainties of α_K, α_L, α_M, α_T for pure multipolarities have been taken as 2 %.

E2 admixtures for M1+E2 gamma-ray transitions in ^{233}Pa decay were determined in a whole number of measurements (see Table 5).

For the ICC evaluation the E2 admixture of 0,0166 from 1962Sc03 has been used for the gamma ray of 17,2 keV ($\gamma_{10,9}$). The best set of E2/M1 mixing ratios obtained by Krane (1986Kr10) from the angular correlation measurements has been used to determine the ICCs for the gamma rays of 28,6-keV ($\gamma_{7,5}$), 75,3-keV ($\gamma_{10,7}$), 86,6-keV ($\gamma_{9,5}$), and 103,9-keV($\gamma_{10,5}$), respectively. This set agrees mainly with the conversion electron data from 1961Al19, 1962Sc03, 1963Bi03, 1966Ze02, 1973Va33, 1985DeZR, 1988Wo01, and 1990Pe16 (Table 5). Use of the BrIcc package for correction of the above conversion electron data does not change this conclusion.

The evaluators have adopted the value of 0,54 (4) from 1962Sc03 for the 40,3-keV gamma ray ($\gamma_{1,0}$) E2 admixture that coincides with the values obtained by Zender (1966Ze02) and Krane (1986Kr10). This ratio produces a better P(γ+ce) balance for the 40,3-keV level ("1"). If the smaller value of 0,3 reported by Albridge et al. (1961 Al19) and Bisgard et al. (1963 Bi03) was used, the intensity of the β^- transition to the level "1" would have been negative (2006Ch39).

The ICC values measured by Browne et al. (1989Br24) have been adopted for the most intense, predominantly M1, 300,1- ($\gamma_{7,1}$), 311,9- ($\gamma_{5,0}$), and 340,5-keV ($\gamma_{7,0}$) transitions affected by nuclear penetration effects.

The E2/M1 mixing ratio $\delta \approx 0{,}62$ has been taken from 2005Si15 for the gamma ray of 51,8-keV ($\gamma_{2,1}$).

Table 5. Experimental and recommended E2 γ-ray admixtures

Eγ (keV)	1961 Al19	1962 Sc03	1963 Bi03	1966 Ze02	1986 Kr10	1973 Va33	1985 DeZR	1988 Wo01	1990 Pe16	Recommended admixture & δ
28,6	0,030 (5)	0,0102 (8)	0,02 (1)	0,024 (2)	0,0244 (15)	0,02	0,019 (2)	0,03 (1)	0,022 (3)	0,0244 (15) δ 0,158 (10)
40,3	0,30 (10)	0,54 (4)	0,31 (2)	0,54 (5)	0,54 (8)	0,43	0,46 (5)			0,54 (4) δ 1,08 (12)
75,3	0,01 (1)	< 0,0005	0	< 0,005	0,022 (16)	0	0,008 (4)	0		0,022 (16) δ 0,15 (8)
86,6	0,020 (5)	< 0,002	0,01 (1)	< 0,006	0,0031 (3)	0,01	0,0049 (7)	0,046 (27)		0,0031 (3) δ 0,056 (5)
103,9	0,04 (1)	< 0,03	0,01 (1)	0,020 (15)	0,010 (14)	0,01	0,022 (2)	0,073 (9)		0,010 (14) δ 0,1 (1)
300,1	0,12 (10)	0,03	0	0	0,006 (2)	0	0,025 (3)	0		0,006 (2) δ 0,08 (3)
311,9	< 0,02	< 0,03	0	< 0,016	0,010 (1)	0	0,063 (6)	0		0,010 (1) δ 0,10 (1)
415,8	0,82 (7)	0,96 (4)	0,78 (11)	0,76 (8)		0,84				0,83 (7) δ 2,2 (9)

[a] Weighted average of 1961Al19, 1962Sc03, 1963Bi03, and 1966Ze02.

3 Atomic Data

The atomic data are from Schönfeld (1996Sc06).

4 Electron Emissions

The energies of the conversion electrons have been obtained from the gamma transition energies and the electron binding energies.

The emission probabilities of the conversion electrons have been deduced using evaluated P_γ and ICC values.

The absolute emission probabilities of K Auger electrons have been deduced using the P(ce_K) values and the adopted ω_K given in section 3.

The absolute emission probabilities of L Auger electrons have been deduced using the P(ce_K) and P(ce_L) values and the adopted $\bar{\omega}_L$, n_{KL} given in section 3.

β^- average energies have been calculated using the LOGFT computer program.

5 Photon emissions

5.1 X-ray emissions

The absolute emission probabilities of U KX-rays have been deduced using the adopted value of ω_K (U) and the total evaluated absolute emission probability of K conversion electrons in the ^{233}Pa→^{233}U decay. In Table 6 the deduced values are compared to measured results. The total absolute U KX -ray emission probability of 30,7 (9) % agrees with the experimental values of 29,3 (28) % from 2008De10 and 30,0 (4) % from 2004Sh07.

The absolute emission probabilities of U LX-rays have been calculated with the EMISSION computer program using the adopted values of $\bar{\omega}_L$ (U), ω_K (U), n_{KL} (U) and the evaluated absolute emission probabilities of L_1, L_2, L_3-, and K- conversion electrons in ^{233}Pa β^--decay.

As authors of 2008De10 quote only statistical uncertainties for their intensity values, the evaluators have considered additionally a contribution of possible systematic errors to obtain the overall uncertainties in the absolute photon intensities. This contribution was estimated on the basis of detection efficiency uncertainties for γ-ray spectroscopy discussed in 2008De10: 1 % for U KX-ray emission probabilities and 20 % for U LX-ray emission probabilities.

Table 6. Experimental and recommended (calculated) absolute U KX- ray emission probabilities in decay of ^{233}Pa

	Energy (keV)	1979 Ge08	1984Va28	1990Ko41	2000 Smith	2000Sc04	2002Lu01	2004Sh07	2008De10	Recom-mended (calculated)
Kα_2	94,666	8,8 (5)	8,8 (4)	8,3 (4)		8,78 (10)	8,77 (9)	8,78 (10)	8,50 (14)	9,10 (26)
Kα_1	98,440	14,4 (8)	14,3 (5)	13,4 (7)	14,3 (3)	14,4 (4)	14,17 (14)	14,22 (17)	14,02 (24)	14,6 (4)
Kβ_3	110,421	} 5,2 (3)	1,78 (9)	1,60 (8)	1,89 (4)	1,90 (5)	1,708 (25)	1,708 (38)	1,694 (31)	} 5,25 (18)
Kβ_1	111,298		3,27 (15)	3,11 (15)			3,35 (5)	3,34 (8)	3,24 (6)	
Kβ_5	111,964			0,15 (1)			0,1230 (17)	0,1239 (28)	0,139 (18)	
Kβ_2	114,407 (11)	} 1,74 (8)	} 1,71 (8)	0,52 (7)	} 1,73 (8)	} 1,59 (9)	1,293 (23)	1,34 (5)	} 1,317 (21)	} 1,49 (10)
Kβ_4	115,012			0,78 (7)			0,0380 (6)	0,0388 (13)		
KO$_{2,3}$	115,377			} 0,39 (2)		0,332 (10)	} 0,391 (9)	} 0,399 (18)	} 0,406 (11)	} 0,31 (7)
KP$_{2,3}$	115,580									

Table 7. Experimental and recommended (calculated) absolute U XL- ray emission probabilities in decay of ^{233}Pa

	Energy (keV)	2000Sc04	2004Sh07	2008De10	Recommended (calculated)
Ll	11,62	1,18 (7)	0,78 (11)	1,19 (25)	1,05 (4)
Lα	13,93	15,7 (7)	12,7 (13)	21,5 (43)	16,9 (6)
Lβ	15,73-17,45			16,9 (34)	18,1 (6)
Lγ_1	20,17-20,84			3,2 (6)	2,25 (13)

5.2 Gamma-ray emissions

The energies of gamma rays have been taken from 1990Ko41 (see also 2005Si15) except for $\gamma_{10,9}$(17,26 keV) and $\gamma_{2,0}$(92,16 keV) which were deduced from the adopted ^{233}U levels. A comparison of the recommended γ-ray energies with early experimental results is given in Table 8.

In Table 9 the experimental and recommended absolute gamma ray emission probabilities (P_γ) are presented. All the values given in Table 8 given in Table 9 are absolute measurement results (per 100 disintegrations).

The original values from 1973Va33 and 1990Ko41 have been renormalized by the evaluators to $P\gamma_{2,0}$ (311,9 keV) = 38,3 (5). Values given in the last column are weighted averages (LRSW) of individual results taking into account the LRSW procedure and sometimes increasing the uncertainty to cover the most precise input value (2006Ch39).
$P\gamma_{10,9}$(17,26 keV) = 0,0041 has been deduced from the value of Pce(M1) = 0,0054 (1962Sc03) and the ICC value of α_{M1} = 132,3 (1993Ba60) calculated for this conversion line using an E2/M1 admixture of 0,016 (δ=0,13) from 1990Ak02.

$P\gamma_{2,1}$(51,8 keV) and $P\gamma_{2,0}$ (92,2 keV) have been obtained from the P(γ+ce) balance at the 92,2-keV level and the ratio $P\gamma_{2,1}/P\gamma_{2,0}$ = 0,21 (4) taken from 1990Ak02.

The contribution of 1 % estimated on the basis of detection efficiency uncertainty for γ-ray spectroscopy discussed in 2008De10 has been added to the overall uncertainties for the recommended γ-ray emission probabilities.

Table 8. Experimental and recommended gamma-ray energies in decay of ^{233}Pa, in keV

	1952Br84	1961Al19	1967Br20	1968Ma13	1971Vo02	1972De67	1973Va33	1988Wo01	1990Ko41	Recommended
$\gamma_{10,9}$						17,2 (1)				17,262 (6)
$\gamma_{7,5}$	28,67 (2)					28,6 (1)		28,375 (5)	28,559 (10)	28,559 (10)
$\gamma_{1,0}$	40,47 (10)	40,35 (1)				40,5 (1)			40,349 (5)	40,349 (5)
$\gamma_{7,3}$		41,65 (2)							41,663 (10)	41,663 (10)
$\gamma_{10,7}$	75,4 (2)	75,28 (1)				75,27 (3)		75,354 (4)	75,269 (10)	75,269 (10)
$\gamma_{9,5}$	87,0 (3)	86,59 (1)				86,58 (3)		86,814 (3)	86,595 (10)	86,595 (5)
$\gamma_{2,0}$							92,0 (5)		92,1 (5)	92,16 (4)
$\gamma_{10,5}$		103,86 (2)						103,971 (9)	103,860 (10)	103,860 (10)
$\gamma_{6,2}$									228,57 (5)	228,57 (5)
$\gamma_{7,2}$			248,3 (3)	248,69 (24)			248,0 (2)		248,38 (4)	248,38 (4)
$\gamma_{3,1}$							258,292)		258,45 (2)	258,45 (2)
$\gamma_{5,1}$		271,62 (23)			271,48 (8)				271,555 (10)	271,555 (10)
$\gamma_{6,1}$									280,61 (5)	280,61 (5)
$\gamma_{8,2}$									288,42 (10)	288,42 (10)
$\gamma_{3,0}$									298,81 (2)	298,81 (2)
$\gamma_{7,1}$		300,20 (24)						300,34 (2)	300,129 (5)	300,129 (5)
$\gamma_{4,0}$									301,99 (10)	301,99 (10)
$\gamma_{5,0}$		311,91 (13)						312,17 (12)	311,904 (5)	311,904 (5)

	1952Br84	1961Al19	1967Br20	1968Ma13	1971Vo02	1972De67	1973Va33	1988Wo01	1990Ko41	Recommended
$\gamma_{6,0}$									320,73 (10)	320,73 (10)
$\gamma_{7,0}$		340,51 (18)						340,81 (3)	340,476 (5)	340,476 (5)
$\gamma_{10,1}$		375,35 (32)			375,45 (4)				375,404 (5)	375,404 (5)
$\gamma_{8,0}$									380,28 (10)	380,28 (10)
$\gamma_{9,0}$		398,57 (40)			398,62 (8)				398,492 (5)	398,492 (5)
$\gamma_{10,0}$		415,87 (42)			415,76 (4)				415,764 (5)	415,764 (5)
$\gamma_{11,0}$									455,96 (10)	455,96 (10)

Table 9. Experimental and recommended absolute gamma-ray emission probabilities (%) in decay of ^{233}Pa, in %.

Eγ (keV)	1973Va33	1978Poenitz	1979Ge08	1984Va27	1985DeZR	1988Wo01	1990Ko41	2000Wo01	2000Sc04	2002Lu01 2000Lu01	2004Sh07	2006Ha53	2008De10	Recommended
17,2														
28,56	0,069 (8)			0,15 (1)	0,096 (35)	0,068 (9)	0,074 (8)			0,034 (10)	0,019 (2)			0,071 (8) [a]
40,35	0,039 (8)						0,024 (4)	0,0215 (16)		0,028 (4)	0,032 (4)			0,024 (2)
41,66	0,013 (4)						0,014 (3)							0,014 (3)
75,27	1,25 (8)		1,39 (8)	1,30 (4)		1,25 (9)	1,25 (9)	1,401 (25)	1,38 (4)	1,270 (8)				1,30 (3)
86,60	1,87 (23)		1,97 (12)			1,87 (25)	1,93 (11)			2,61 (23)				1,99 (10)
92,1	< 0,004						< 0,002							0,002 (1)
103,86	0,73 (8)		0,87 (3)	0,87 (3)		0,73 (9)	0,847 (60)	0,853 (8)	0,844 (17)	0,855 (6)	0,825 (25)			0,853 (6)
228,57					0,0058 (8)		0,0042 (7)							0,0042 (7)

Eγ (keV)	1973Va33	1978Poenitz	1979Ge08	1984Va27	1985DeZR	1988Wo01	1990Ko41	2000Wo01	2000Sc04	2002Lu01 2000Lu01	2004Sh07	2006Ha53	2008De10	Recommended
248,38	0,0039 (12)		0,059 (2)	0,06 (1)			0,058 (4)	0,0607 (12)	0,0618 (11)	0,057 (6)				0,0609 (11)
258,45	0,0039 (16)				0,031 (4)		0,027 (2)		0,0274 (6)					0,0274 (6)
271,56	0,30 (3)		0,33 (1)	0,32 (1)			0,334 (17)	0,3227 (29)	0,323 (4)	0,323 (5)	0,290 (56)			0,323 (3)
280,61					0,0116 (13)		0,011 (2)							0,011 (2)
288,42					0,0164 (5)		0,016 (3)							0,016 (3)
298,81	0,035						0,085 (7)			0,147 (29)				0,12 (5)
300,13	6,57 (31)		6,62 (10)	6,64 (6)		6,57 (46)	6,76 (7)	6,66 (6)	6,55 (7)	6,39 (6)			6,47 (8)	6,60 (21)
301,99					0,027 (4)		0,010 (2)							0,010 (2)
311,90		38,6 (15)	38,6 (5)	38,65 (39)				38,7 (4)	38,5 (4)	37,80 (23)	37,5 (24)	41,6 (9)	38,08 (51)	38,3 (5)
320,73					0,039 (12)		0,0051 (4)							0,0051 (4)
340,48	4,47 (46)		4,47 (6)	4,52 (5)		4,48 (51)		4,52 (4)	4,50 (5)	4,41 (3)	4,36 (44)		4,436 (56)	4,47 (3)
375,40			0,68 (1)	0,69 (1)				0,690 (6)	0,686 (7)	0,687 (6)	0,58 (8)			0,684 (7)
380,28					0,0039 (8)		0,0037 (9)							0,0037 (9)
398,49			1,39 (2)	1,43 (2)				1,407 (11)	1,406 (15)	1,39 (1)	1,33 (10)			1,408 (14)
415,76			1,74 (2)	1,74 (2)				1,771 (14)	1,765 (18)	1,740 (7)	1,59 (10)		1,724 (23)	1,747 (7)
455,96							0,0011 (2)							0,0011 (2)

[a] Weighted average of the values from 1988Wo01 and 1990Ko41 (see discussion in 2006Ch39).

5.2.1 Tentative gamma-ray

This section is given only for information on measurements done in the thesis of 1985DeZR. These results require confirmation and do not consider for evaluation (as well as by Singh and Tuli in Nucl. Data Sheets (2005Si05)).

Energy (keV)	Pγ (%)	Level energy (keV)
18,7 (2)	0,023 (8)	320,83
18,7 (2)	0,023 (8)	330,67
19,7 (2)	0,046 (15)	340,478
22,0 (3)		320,83
23,9 (2)	0,0031 (12)	344,56 ?
24,7 (2)	0,0031 (12)	571,36 ?
28,7 (1)		330,67
31,9 (2)	0,0023 (8)	330,67
35,3 (2)	0,0015 (4)	432,81 ?
35,8 (2)	0,0019 (8)	380,48
38,5 (2)	0,0032 (12)	340,478
38,5 (2)	0,0031 (12)	392,25 ?
39,9 (3)		380,48
40,4 (1)		432,81 ?
40,4 (1)		494,75 ?
40,7 (3)		456,113
40,7 (3)		496,65 ?
41,7 (1)	< 0,019	432,81 ?
42,7 (2)	0,0019 (8)	344,56 ?
45,8 (2)	≈ 0,0004	344,56 ?
46,7 (2)	≈ 0,0008	391,09 ?
47,7 (2)	≈ 0,0008	392,25 ?
48,8 (2)	≈ 0,0008	393,33 ?
48,8 (2)	≈ 0,0008	475,69 ?
49,7 (2)	≈ 0,0008	380,48
51,8 (2)	0,0012 (4)	353,71 ?
51,8 (2)	0,0012 (4)	392,25 ?
52,5 (2)	≈ 0,0008	393,33 ?
52,5 (2)	≈ 0,0008	432,81 ?
53,2 (2)	0,0012 (4)	397,71 ?
55,0 (2)	≈ 0,0008	353,71 ?
58,0 (2)	0,0012 (4)	398,495
59,2 (2)	≈ 0,0008	563,00 ?
59,6 (2)	0,0008 (8)	380,48
60,6 (2)	≈ 0,008	391,09 ?
60,6 (2)	≈ 0,008	414,37 ?
60,6 (2)	≈ 0,008	441,20 ?
61,6	≈ 0,0008	392,25 ?
61,6	≈ 0,0008	494,75 ?
63,2 (2)	≈ 0,0004	155,35 ?
63,2 (2)	≈ 0,0004	454,29 ?
63,6 (2)	≈ 0,0008	496,65 ?
65,5 (2)	0,0027 (8)	410,13 ?
66,4 (2)	0,0019 (8)	570,27 ?
67,5 (2)	0,0019 (8)	571,36 ?
68,5 (2)	0,0027 (8)	380,48
69,6 (2)	0,0046 (12)	410,13 ?
70,3 (2)	0,0027 (8)	391,09 ?
71,3 (2)	0,0039 (12)	392,25 ?
71,3 (2)	0,0039 (12)	565,90 ?
74,0 (2)	0,0035 (8)	414,37 ?
74,4 (2)		229,79 ?
75,3 (1)		456,113
75,3 (1)		473,04 ?
77,0 (2)	0,0019 (8)	388,68 ?
77,0 (2)	0,0019 (8)	397,71 ?
77,9 (2)	≈ 0,0012	475,69 ?
78,4 (2)	0,0077 (19)	380,48
79,1 (3)	≈ 0,0008	432,81 ?
80,8 (2)	0,0015 (4)	473,04 ?
81,8 (2)	0,0015 (4)	380,48
81,8 (2)	0,0015 (4)	393,33 ?
81,8 (2)	0,0015 (4)	473,04 ?
82,5 (2)	0,0015 (4)	427,08 ?
84,8 (2)	< 0,0131	475,69 ?
85,2	< 0,0131	315,06 ?
85,2	< 0,0131	415,758
86,6 (1)		388,68 ?
86,6 (1)		427,08 ?
87,5 (3)		441,20 ?
89,0 (3)	< 0,0147	391,09 ?
89,3 (3)	< 0,0147	410,13 ?
90,0 (2)	0,0012 (4)	388,68 ?
91,0 (2)	0,0012 (4)	546,83
91,5 (2)	0,0012 (4)	393,33 ?
92,2 (2)	0,0035 (12)	391,09 ?
92,5 (2)		432,81 ?
92,7 (2)	0,0012 (8)	473,04 ?
93,0 (2)	< 0,0015	565,90 ?
93,5 (2)	< 0,0015	414,37 ?
94,5 (3)		393,33 ?
94,5 (3)		570,27 ?
95,3 (3)		475,69 ?
95,3 (3)		571,36 ?
96,7 (2)	0,0040 (12)	441,20 ?
97,0 (2)	0,0050 (12)	494,75 ?
98,0 (2)		410,13 ?
100,6 (2)	0,0031 (12)	454,29 ?
102,1 (2)	0,0019 (4)	432,81 ?
102,5 (2)	0,0023 (8)	414,37 ?
102,5 (2)	0,0023 (8)	494,75 ?
103,8 (1)		494,75 ?
104,5 (3)		496,65 ?

Energy (keV)	Pγ (%)	Level energy (keV)
105,7 (3)	≈ 0,0008	496,65 ?
106,3 (2)	0,0008	427,08 ?
106,3 (2)	0,0008	503,90 ?
108,1 (2)	0,0012 (4)	410,13 ?
110,0 (3)		565,90 ?
111,5 (3)		410,12 ?
112,1 (3)		432,81 ?
112,4 (3)		414/37 ?
113,0 (3)	0,0035 (12)	503,90 ?
114,9 (3)		155,35 ?
115,3 (3)		427,08 ?
115,3 (3)		456,113
116,5 (3)	0,0058 (8)	496,65 ?
116,9 (1)	0,0058 (8)	415,758
119,6 (2)	≈ 0,0008	473,04 ?
122,0 (2)	0,0015 (4)	475,69 ?
125,1 (3)	0,0015 (4)	427,08 ?
125,1 (3)	0,0015 (4)	456,113
128,3 (2)	0,0012 (4)	427,08 ?
130,0 (2)	0,0012 (4)	571,36 ?
131,0 (2)	0,0015 (4)	475,69 ?
131,0 (2)	0,0015 (4)	546,83
132,9 (2)	0,0012 (4)	565,90 ?
135,2 (3)	0,0023 (8)	456,113
135,2 (3)	0,0023 (8)	475,69 ?
135,8 (2)	0,0015 (4)	563,00 ?
136,5 (2)	0,0019 (8)	546,83
139,3 (2)	0,0023 (8)	441,20 ?
139,3 (2)	0,0023 (8)	454,29 ?
142,7 (2)	0,0023 (8)	496,65 ?
143,1 (2)	0,0015 (4)	570,27 ?
144,4 (2)	0,0035 (8)	456,113
144,4 (2)	0,0035 (8)	571,36 ?
148,5 (2)	0,0027 (8)	546,83
150,5 (2)	0,0023 (8)	503,90 ?
153,7 (2)	0,0039 (8)	546,83
154,7 (2)	0,0023 (4)	475,69 ?
154,7 (2)	0,0023 (4)	546,83
156,1 (2)	0,0023 (8)	496,65 ?
157,0 (2)	0,0027 (8)	571,36 ?
157,9 (2)	0,0023 (8)	473,04 ?
159,1 (2)	0,0039 (8)	503,90 ?
160,0 (2)	0,0031 (8)	570,27 ?
161,2 (2)	0,0027 (8)	571,36 ?
162,4 (2)	0,0023 (8)	392,25 ?
163,3 (2)	0,0023 (8)	503,90 ?
166,6 (3)	0,0012 (4)	546,83
168,0 (2)	0,0031 (8)	397,71 ?
170,6 (2)	0,0050 (8)	563,00 ?
172,8 (2)	0,0027 (8)	503,90 ?
173,7 (2)	0,0042 (12)	475,69 ?
173,7 (2)	0,0042 (12)	565,90 ?
174,7 (2)	0,0042 (12)	565,90 ?
175,2 (2)	0,0012 (4)	330,67
178,0 (2)	0,0027 (8)	570,27 ?
178,0 (2)	0,0027 (8)	571,36 ?
180,1 (2)	0,0027 (8)	571,36 ?
182,7 (2)	0,0027 (8)	571,36 ?
183,3 (3)	0,0012 (4)	503,90 ?
184,8 (2)	0,0031 (8)	496,65 ?
185,7 (3)	0,0035 (8)	565,90 ?
198,5 (2)	0,0031 (8)	353,71 ?
202,1 (2)	0,0031 (8)	503,90 ?
202,1 (2)	0,0031 (8)	546,83
205,3 (2)	0,0031 (8)	503,90 ?
206,4 (2)	0,0027 (8)	546,83
209,2 (2)	0,0023 (8)	563,00 ?
215,8 (2)	0,0027 (8)	546,83
217,8 (2)	0,0031 (8)	571,36 ?
224,4 (2)	0,0023 (8)	454,29 ?
225,2 (2)	0,0046 (12)	380,48
225,2 (2)	0,0046 (12)	565,90 ?
226,1 (2)	0,0027 (8)	546,83
226,1 (2)	0,0027 (8)	570,27 ?
226,8 (2)	0,0031 (8)	571,36 ?
232,1 (2)	0,0027 (8)	563,00 ?
235,0 (2)	0,0012 (4)	546,83
236,0 (2)	0,0023 (8)	391,09 ?
238,5 (2)	0,0054 (12)	330,67
239,8 (2)	0,0031 (8)	570,27 ?
242,3 (2)	0,0027 (8)	397,71 ?
242,3 (2)	0,0027 (8)	563,00 ?
243,4 (2)	0,0023 (8)	473,04 ?
244,6 (2)	0,0027 (8)	546,83
248,1 (1)		546,83
249,6 (2)	0,0031 (8)	570,27 ?
250,4 (2)	0,0031 (8)	571,36 ?
252,3 (2)	0,0039 (8)	344,56 ?
261,4 (2)	0,0039 (12)	302,00
261,4 (2)	0,0039 (12)	353,71 ?
264,4 (2)	0,0035 (8)	563,00 ?
268,1 (2)	0,0031 (8)	570,27 ?
269,3 (2)	0,0031 (8)	571,36 ?
271,4 (1)		570,27 ?
272,8 (3)	0,0039 (8)	571,36 ?
290,1 (1)	0,0035 (8)	330,67
298,7 (2)		391,09 ?
298,7 (2)		454,29 ?
300,0 (1)		392,25 ?
304,0 (2)	0,0046 (12)	344,56 ?
305,4 (2)	0,0050 (12)	397,71 ?
313,5 (2)	0,0139 (23)	353,71 ?
317,6 (3)	0,0023 (8)	473,04 ?
330,5 (3)	0,0023 (4)	330,67

Energy (keV)	Pγ (%)	Level energy (keV)
335,9 (3)	0,0027 (8)	565,90 ?
339,5 (5)		380,48
339,5 (5)		494,75 ?
340,5 (1)		432,81 ?
341,4 (5)		496,65 ?
344,5 (3)	0,0015 (4)	344,56 ?
351,8 (3)	0,0046 (8)	392,25 ?
363,9 (3)	0,0035 (8)	456,113
374,0 (3)	0,0073 (19)	414,37 ?
386,8 (3)	0,0031 (8)	427,08 ?
393,3 (3)	0,0050 (12)	393,33 ?
400,5 (3)	0,0031 (8)	441,20 ?
402,9 (2)	0,0023 (8)	494,75 ?
404,5 (3)	0,0035 (8)	496,65 ?
410,0 (3)	0,0069 (12)	410,13 ?
414,3 (3)	0,0054 (19)	414,37 ?

Energy (keV)	Pγ (%)	Level energy (keV)
415,764 (5)		456,113
427,0 (3)	0,0019 (8)	427,08 ?
432,8 (3)	≈ 0,0008	432,81 ?
435,1 (3)	0,0012 (4)	475,69 ?
441,1 (3)	0,0019 (8)	441,20 ?
454,2 (3)	0,0012 (8)	494,75 ?
454,2 (3)	0,0012 (8)	546,83
463,6 (3)	≈ 0,0008	503,90 ?
471,1 (3)	0,0012 (4)	563,00 ?
473,8 (3)	0,0019 (8)	565,90 ?
475,6 (3)	0,0019 (8)	475,69 ?
478,0 (3)	0,0012 (4)	570,27 ?
496,9 (3)	0,0012 (8)	496,65 ?
503,7 (3)	0,0012 (4)	503,90 ?
506,3 (3)	0,0012 (8)	546,83

6. Consistency

The most accurate Q value,Q(M), is taken from the atomic mass adjustment table of Audi et al. (2003Au03). Comparison of Q(eff) (deduced as the sum of average energies per disintegration ($\sum E_i \times P_i$) for all emissions accompanying ^{233}Pa β^- decay) with the tabulated decay energy Q(M) allows to check a consistency of the recommended decay-scheme parameters obtained in this evaluation.

Here E_i and P_i are the evaluated energies and emission probabilities of the i-th alpha particle, beta particle, gamma-ray, X-ray, etc. Consistency (percentage deviation) is determined by {[Q(M)–Q(eff))]/Q(M)}×100. "Percentage deviations above 5 % would be regarded as high and imply a poorly defined decay scheme; a value of less than 5 % indicates the construction of a reasonably consistent decay scheme" (quoted from the article by A.L. Nichols in Appl. Rad. Isotopes 55 (2001) 23-70).

For the above ^{233}Pa decay data evaluation we have Q(M) = 570,1 (20) keV and Q(eff) = 572 (20) keV, i.e. consistency is 0,35 %.

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^{234}Th – Comments on Evaluation of Decay Data

by A. Luca

This evaluation was completed in May 2009. The literature available by December 31st, 2008 was included.

1. Evaluation Procedures

The Limitation of Relative Statistical Weight (LWM) method was applied for averaging numbers throughout this evaluation; this method was implemented by using the computer code LWEIGHT, ver. 4 (designed for Excel, MS Office). The uncertainty assigned to an average value in this evaluation is never lower than the lowest uncertainty of any of the experimental input values.

2. Decay Scheme

^{234}Th decays 100 % by beta minus particle emissions, mainly to ^{234}Pa^{m} - the 1.159 min. half-life metastable state of ^{234}Pa (the first experimentally established case of nuclear isomerism, by O. Hahn, in 1921). The decay scheme was studied by many authors, since early '60s (1961Ge13, 1962Br05, 1963Bj02, 1964Ab04, 1965Fo12 and 1973Go40). The first recommended values for the main ^{234}Th nuclear decay data were published in the evaluation of Coursol et al., in 1990 (1990Co08); other important evaluation can be found in 1998Ad08. In the present evaluation, the spin, parity, energy and half-life values of the ^{234}Pa excited levels, and the multipolarities of the γ-ray transitions, have been adopted from the most recent A=234 ENSDF mass-chain evaluation, published by E. Browne and J.K. Tuli (2007Br04). The very important low energy and intensity isomeric transition (maximum energy of less than 10 keV) from ^{234}Pa^{m} to the first excited level of ^{234}Pa (explaining the 73.92 keV gamma-ray transition to the ^{234}Pa ground state), was not observed yet, probably because the conversion lines are obscured by intense Auger M and Coster-Kronig electrons (according to Godart and Gizon, 1973); as a consequence, the energies of all the ^{234}Pa excited levels decaying to ^{234}Pa^{m} are known to be upheld 10 keV at most with a systematic uncertainty (usually considered as "x" keV, in 2007Br04 and other evaluations; in the present evaluation, this quantity is not written in the decay scheme, but it should be added to the energy of the excited levels, respectively subtracted from the reported beta transitions energies). A more detailed decay scheme of ^{234}Th can be found in 2007Br04. The decay of ^{234}Pa^{m} (by alpha-particle emission and isomeric transition) is not studied in this evaluation.

3. Nuclear Data

The adopted beta decay energy value $Q(\beta^-)=272\,(10)$ keV, is based on the energy measurements of Godart and Gizon (1973Go40): 198.5 (15) keV for the maximum energy of the beta minus particle emissions and 73.92 (2) keV for the isomeric transition; an uncertainty of 10 keV was assigned to the result, according to the above-mentioned considerations. The adopted value of $Q(\beta^-)$ is in agreement with the value from 2003Audi03: 273.1 (32) keV (based on some older energy measurements of the beta minus particle emissions). The value adopted by this evaluation is also in good agreement with the effective $Q(\beta^-)$ value of 273 keV (with an uncertainty of 11 keV), calculated from the decay scheme data, by using the SAISINUC software.

3.1. Half-life

In the literature, only a few measured ^{234}Th half-life ($T_{1/2}$) values are reported; these measurements are very old (the most recent is from 1948), so new half-life measurements are needed to improve the quality of the evaluation. The half-life values and their uncertainties are presented in Table 1; the value recommended by Curie et al. (1931), with an estimated uncertainty added by the evaluator, was also included. The set of data is consistent and the recommended value, 24.10 days, with an uncertainty of 0.03 day, is the weighted average (LWM, χ^2_ν=3.78) of the four input values. The references are expressed as NSR (Nuclear Science References) type keynumbers:

Table 1 : ^{234}Th Half-life values

$T_{1/2}$ (days)	Uncertainty of $T_{1/2}$ (days)	Reference
23.8	0.7	1920Ki01
24.5	0.5	1931Cu01
24.1	0.2	1939Sa11
24.101	0.025	1948Kn23

3.2. Beta transitions and emissions

In the literature, the most complete reference reporting measurements of energy and emission intensities for ^{234}Th beta minus transitions is 1973Go40.

For this evaluation, the beta transitions energies were calculated from Q(β-) and the energies of the decay scheme levels; the high energy uncertainty (10 keV) is explained by the possible low energy and intensity isomeric transition (as described above, in section 2, Decay Scheme). The intensities of the beta branches were deduced from γ-ray transition intensity balance at each level, with the exception of the main branch; its intensity was deduced from the normalization condition of the beta emissions (the sum of the all the beta transitions intensities must be 100 %). The existence of the weakest beta decay branch (95.8 keV) is questionable (2007Br04). The energy and intensity values of the beta transitions, as well as their Log ft values are shown in Table 2.

Table 2: ^{234}Th β^- Energies and Emission Probabilities

$E_{\beta-}$ (keV)	Uncertainty $E_{\beta-}$ (keV)	Transition intensity (%)	Transition intensity (%), from 1973Go40	Log ft
85	10	1.6 (6)	1.3 (7)	7.0
95	10	0.016 (5)	-	9.1
105	10	6.5 (7)	5.4 (10)	6.7
106	10	14.1 (12)	20.7 (10)	6.3
198	10	77.8 (15)	72.5 (20)	6.4

3.3. γ- transitions: γ rays and internal conversion electrons

Many measurements of the γ-ray energies and emission intensities following the ^{234}Th decay were published by different authors: 1973Go40, 1973Sa33, 1973Ta25, 1978Ch06, 1982Mo30, 1990Sc09, 1993Su37, 2004Ab03 and 2006Al28. The interest for high quality data of photon emission probabilities is justified especially in the field of environmental radioactivity monitoring. Table 3 presents measured values of the 63.30 (2) keV γ-ray emission probability following the decay of ^{234}Th. The set of data is consistent and the recommended value, 3.75 (8) %, is the weighted average (LWM, χ^2_ν=3.32) of the five input values. The references are expressed as NSR type keynumbers.

Table 3 : Absolute Emission Intensity Results (in %) for the 63.30-keV γ ray.

Gamma-ray emission probability	Uncertainty of the gamma-ray emission probability	Reference
3.3	0.3	1973Go40
4.05	0.20	1982Mo30
3.6	0.2	1990Sc09
3.99	0.20	1993Su37
3.73	0.07	2004Ab03
3.75	**0.08**	**Adopted**

Using this evaluated value and the relative photon intensity values from the measurements of Chu and Scharff-Goldhaber (1978), the corresponding absolute gamma-ray emission probabilities and their uncertainties were computed for all the γ rays and are given below in Table 4. The relative photon intensities measured by Chu and Scharff-Goldhaber were preferred to those of Godart and Gizon (1973), mainly because in this case the U KX-rays contributions were resolved from the gamma-ray peaks situated in the (90-115) keV energy range of the spectra; no other references reporting relative photon intensities measurements were found in the literature.

The intensity balance for level 3 (103.42 keV) was used to compute the emission probability for the 73.85 keV photons, but the obtained value was negative (-0.011 %); as the placement of this transition in the level scheme is uncertain (2007Br04), this low probability photon emission was not considered in this evaluation. Other possible gamma-ray transitions neither confirmed nor placed in the level scheme (proposed / observed only by some authors) are: 57.75 keV, 87.02 keV, 92.00 keV, 103.71 keV, 108.00 keV, 132.9 keV and 184.8 keV.

The internal conversion coefficients were computed with the program BrIcc, version 2.2/2008, using the “Frozen Orbitals” approximation. A difficult case is the computation of the ICC for the 112.81 keV gamma-ray transition, because this energy is too close to the K-shell binding energy for protactinium (112.6 keV) and the software can not be used directly for this purpose. Following Browne and Tuli (2007), a limit on α(K) (≤ 0.29) has been obtained from extrapolation of α(K)’s for energies higher than 113.6 keV; however, this procedure introduced a large uncertainty of the total ICC value (see Table 4).

Table 4: ^{234}Th γ-ray Energies and Absolute Emission Probabilities

E_γ (keV)	Uncertainty E_γ (keV)	Absolute Emission Probability (%)	Uncertainty of absolute emission probability (%)	Total ICC (α_T)
20.01	0.02	0.005 1	0.002 1	240 (70)
29.50	0.02	0.001 23	0.000 14	4390 (70)
62.88	0.02	0.016 4	0.002 8	25 (5)
63.30	0.02	3.75	0.08	0.405 (6)
73.92	0.02	0.013 3	0.001 4	10.6 (4)
83.31	0.05	0.061	0.005	0.196 (3)
92.38	0.01	2.18	0.19	5.27 (8)
92.80	0.02	2.15	0.19	0.1472 (21)
103.35	0.10	0.003 2	0.001 0	3.81 (6)
112.81	0.05	0.215	0.022	0.23 (14)

4. Atomic data

The K-shell fluorescence yield (ω_K), the mean L-shell fluorescence yield (ϖ_L) and the mean number of vacancies in the L-shell produced by one vacancy in the K-shell (η_{KL}) were determined using the computer program EMISSION v3.10, 28-Jan-2003: 0.970 (4), 0.488 (18) and 0.795 (5) respectively.

4.1. Auger electrons and X-rays

The relative probability values of the K Auger electron emissions (KLL, KLX, KXY) normalized to the KLL value, were computed using the same EMISSION computer program. The total K Auger electron emission probability (absolute) and the emission probability of the L Auger electrons were also calculated. The energy ranges for K and L Auger electrons were filled-in by the SAISINUC program, version 2008 April.
The relative probability (normalized to $K_{\alpha 1}$ X-rays emission) and the absolute emission probability values of the different groups of K and L X-rays were determined using the same EMISSION program. The energy range values of the K and L X-rays are from the tables linked to SAISINUC. Neither measurements of X-ray energies nor of emission probabilities were found in the literature, in order to compare them with the results of this evaluation.

5. Main production mode

The main production mode of ^{234}Th is by alpha-particle decay of the ^{238}U nuclei (^{234}Th is the daughter of ^{238}U), present in important quantities in many natural ores.

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^{234}Pa-Comments on evaluation of decay data

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This evaluation was completed in 2009. Literature available by January 2009 was included.

1 Decay Scheme

^{234}Pa disintegrates 100 % by β^- emissions to levels in ^{234}U. ^{234}Pa ground state has $J^{\pi} = 4^+$ (2007Br04).

The β^- decay scheme of ^{234}Pa is based on the measurement results of 1986Ar05. 28 observed γ-rays were not placed in the current decay scheme. These gamma rays carry about 3.2 % of the total intensity of all the gamma rays placed in the decay scheme.

The Q(β^-) value of 2195 (4) keV adopted from 2003Au03 is not in good agreement with the effective Q(β^-) value of 2336 (70) keV, calculated by the evaluators from average radiation energies using the RADLST computer program. The total intensity ΣI(β^-) deduced by the evaluators from intensity balance at each level is about 110 %.

These results suggest that the γ-ray intensity balance for some levels may be incomplete and the decay scheme has some inconsistency. Further measurements are strongly needed to determine the γ transitions and the decay scheme with greater precision.

2 Nuclear Data

The Q(β-) value is from the mass adjustment in 2003Au03.

Level energies, have been obtained from a least-squares fit to γ-ray energies (GTOL computer code). Spin and parities are from 2007Br04.

The measured and recommended ^{234}Pa half-life values are listed in Table 1.

Table 1: Measured half-life values of ^{234}Pa and recommended value

$T_{1/2}$ (h)	References	Comments
6.7	1931Cu01	Not used
6.658 (12)	1954Zi02	
6.75 (3)	1962Bj01	
6.704 (46)		Unweighted mean
6.671 (11)		Weighted mean
6.704 (46)		LWEIGHT weighted mean,χ^2= 4.7
6.70 (5)		**Recommended value**

The weighted average for this data set of the 2 discrepant experimental values is dominated by the accurate value of 1954Zi02. The LWEIGHT computer program, which uses a Limitation of Relative Statistical Weights (LRSW method), has increased the 1954Zi02 uncertainty from 0.012 to 0.030 and used a weighted mean and an external uncertainty for recommended average.

Thus, the adopted value of the ^{234}Pa half-life is 6.70 (5) hours.

2.1 β^- transitions

The maximum energies of the β^- transitions in the decay of ^{234}Pa have been deduced from the Q(β-) value (2003Au03) and the ^{234}U level energies (Table 2), obtained from a least-squares fit to recommended γ-ray energies (GTOL computer code).

Table 2: ^{234}U levels populated in ^{234}Pa β^- decay

Level energy (keV)	Spin & parity	Half-life	β^- transition probabilities (%)
0.0	0+	2.455 (6) × 10^5 a	
43.481 (15)	2+	0.252 (7) ns	
143.375 (21)	4+		< 5
296.075 (24)	6+		
497.05 (4)	8+		
786.295 (15)	1-		
809.92 (8)	0+	< 0.1 ns	
849.265 (23)	3-		< 0.8
851.73 (5)	2+	> 1.74 ps	
926.744 (21)	2+	1.38 (17) ps	
947.59 (5)	4+		< 0.8
962.55 (3)	5-		< 0.4
968.45 (3)	3+		< 2.5
989.444 (20)	2-	0.76 (4) ns	< 3.1
1023.795 (24)	3-		< 5
1023.92 (3)	4+		1.5 (13)
1069.297 (22)	4-		< 8
1085.07 (10)	2+		
1090.89 (4)	5+		0.69 (20)
1096.12 (9)	6+		
1125.29 (5)	7-		
1126.65 (3)	2+		
1127.535 (25)	5-		1.9 (10)
1165.41 (4)	3+		
1172.03 (3)	6+		
1194.761 (23)	6-		< 1.5
1214.70 (5)	4+		0.30 (12)
1237.24 (3)	1-		
1261.77 (3)	7+		
1274.32 (9)	(5+)		
1277.45 (3)	7-		
1312.20 (9)	3-		0.109 (18)
1341.33 (8)	(6+)		
1421.252 (24)	6-	33.5 (20) μs	
1447.89 (10)	5-		0.11 (3)
1456.54 (7)	(2-)		
1486.17 (12)	(3-)		0.117 (25)
1496.14 (3)	3+		< 2.7
1502.38 (8)	3,4+		0.25 (4)
1533.37 (5)	(4-)		0.21 (4)
1537.25 (3)	4+		< 0.9
1543.71 (5)	4+		0.10 (9)
1548.10 (8)	(5)		0.078 (20)
1552.554 (24)	5+	2.20 (25) ns	19.6 (18)
1581.67 (10)	(5-)		0.05 (3)
1588.84 (3)	5+		< 0.7
1619.46 (9)	(6+)		0.035 (20)
1649.99 (12)	(6-)		0.18 (4)

Level energy (keV)	Spin & parity	Half-life	β^- transition probabilities (%)
1653.35 (7)	(3+)		0.95 (13)
1693.42 (3)	5-		6.9 (8)
1722.89 (4)	3-		8.4 (9)
1723.424 (24)	4+		36 (5)
1737.42 (7)	3+		1.16 (14)
1738.18 (6)	(3+)		0.78 (19)
1761.86 (6)	(4-)		2.8 (4)
1770.79 (9)	(3+)		0.129 (17)
1782.58 (3)	5+		8 (3)
1784.19 (13)	4+		0.061 (11)
1793.05 (6)	4+		0.41 (8)
1811.62 (6)	4+		1.43 (15)
1843.88 (17)	3,4,5-		0.17 (3)
1863.08 (15)	(5+)		0.029 (7)
1881.75 (7)	4+		0.25 (3)
1916.28 (9)	3,4+		0.21 (3)
1927.51 (7)	4+		0.22 (4)
1940.52 (9)	4+		0.35 (5)
1958.75 (4)	3-		0.44 (19)
1968.84 (10)	4+,5		0.044 (12)
1981.22 (7)	4+		0.59 (8)
2000.45 (13)	(4+)		0.122 (16)
2019.82 (13)	4+		0.112 (16)
2033.54 (5)	3+,4+		0.90 (15)
2037.06 (17)	4+,5		0.055 (8)
2066.24 (10)			0.140 (24)
2068.82 (11)	3,4,5+		0.40 (7)
2101.42 (9)	5+		0.064 (11)
2115.71 (11)	4+		0.21 (3)
2144.04 (9)	3+,4+		0.42 (5)

Table 3: Measured and evaluated β^- energies (keV) and probabilities (%) in the ^{234}Pa decay

1956On07		1959De30		1968Bj06		**Evaluated**	
$E_{\beta-}$	$P_{\beta-}$	$E_{\beta-}$	$P_{\beta-}$	$E_{\beta-}$	$P_{\beta-}$	$E_{\beta-}$	**$P_{\beta-}$**
155	28	141 (10)	35.5			158 (4)	**0.055 (8)**
		274 (10)	21.4	280 (70)	12	279 (4)	**0.21 (3)**
320 (20)	32					313 (4)	**0.25 (3)**
		363 (10)	10.3			383 (4)	**1.43 (15)**
		477 (10)	16.0			472 (4)	**36 (5)**
530 (20)	27			550 (100)	63	545 (4)	**0.18 (4)**
		576 (10)	13.2			576 (4)	**0.035 (20)**
				790 (100)	19	747 (4)	**0.11 (3)**
		1042 (20)	3.6			1067 (4)	**1.9 (10)**
1130 (50)	13					1126 (4)	< 8
				1190 (100)	5	1171 (4)	< 5
				1510 (200)	≤ 1	**1346 (4)**	< 0.8

The adopted β^- transition probabilities and the associated uncertainties were deduced from the γ transition probability balance at each ^{234}U level.

The values of *logft* and average β^- energies have been calculated with the LOGFT computer program.

2.2 γ Transitions

The γ-ray transition probabilities were deduced using the γ-ray emission intensities and the relevant internal conversion coefficients.

Multipolarities and mixing ratios of γ-ray transitions are from 1967Wa26, 1968Bj06 and 2007Br04.

The internal conversion coefficient (ICC) (and its associated uncertainty) for γ-ray transitions have been interpolated from theoretical values based on the "Frozen Orbital" approximation (2002Ba85) using the BrIcc computer program (2008Ki07).

3. Atomic data

Atomic fluorescence yields (ω_K,ϖ_L, ϖ_M, η_{KL} and η_{LM}) are from Schönfeld (1996Sc06).

The X-ray and Auger electron emission probabilities have been deduced from γ-ray and conversion electron data by using the RADLST computer code.

The deduced total KX-ray emission probability is 35.7 (12) %. Measured KX-ray emission probability is 50.9 % (from I(KX-ray)/I_γ(131keV γ-ray) = 2.8 in 1967Wa26). The 30 % deviation suggests a problem with the decay scheme.

4. Electron Emissions.

The conversion electron emission probabilities have been deduced from γ-ray transition data using theoretical internal conversion coefficients.

5. Photon Emissions

5.1 γ-ray energies

Measured results for the energies of γ-rays from ^{234}Pa are listed in Table 4. The recommended values are taken from the precise measurements of 2000Ni13, 1986Ar05 and 1972Sa06, except as noted in the table.

Table 4: Measured and recommended γ-ray energy values from ^{234}Pa β^-decay

1968Bj06	1968Go20	1972Sa06	1975Ar24	1986Ar05	2000Ni13	Recommended
34.30 (4)						34.30 (4)
						41.82 (11)[a]
43.40 (5)				43.49 (2)		43.49 (2)
45.19 (5)				45.45 (5)		45.45 (5)
				54.96 (10)		54.96 (10)
				55.45 (5)		55.45 (5)
58.20 (6)				58.2 (1)		58.20 (6)
				59.19 (5)		59.19 (5)
63.40 (7)			63.0 (5)	62.70 (1)		62.70 (1)
67.10 (7)				67.25 (10)		67.25 (10)
69.90 (7)				69.46 (5)		69.46 (5)
				75.0 (3)[a]		75.0 (3)[a]
79.69 (8)			80.5 (5)	79.84 (2)		79.84 (2)
				97.17 (10)		97.17 (10)
99.67 (10)				99.86 (2)		99.86 (2)
				100.89 (2)		100.89 (2)
103.41 (11)				103.77 (2)		103.77 (2)

1968Bj06	1968Go20	1972Sa06	1975Ar24	1986Ar05	2000Ni13	Recommended
				106.68 (5)		106.68 (5)
125.20 (13)			125.3 (2)	125.46 (1)		125.46 (1)
131.00 (13)			131.28 (10)	131.30 (1)		131.30 (1)
134.37 (14)				134.61 (2)		134.61 (2)
			137.7 (5)	137.23 (5)		137.23 (5)
139.97 (14)			140.3 (2)	140.15 (2)		140.15 (2)
				140.91 (3)		140.91 (3)
144.35 (15)			143.6 (5)	143.78 (2)		143.78 (2)
~ 150.2				149.88 (3)		149.88 (3)
152.46 (16)			153.0 (2)	152.71 (2)		152.71 (2)
159.10 (16)			159.2 (3)	159.48 (2)		159.48 (2)
				164.94 (5)		164.94 (5)
			166.3 (10)	165.61 (5)		165.61 (5)
170.77 (18)			170.6 (3)	170.85 (2)		170.85 (2)
			174.6 (8)	174.55 (3)		174.55 (3)
				179.80 (8)		179.80 (8)
185.95 (19)			186.2 (5)	186.15 (2)		186.15 (2)
193.4 (2)			193.5 (5)	193.73 (3)		193.73 (3)
196.4 (2)			196.5 (10)	196.80 (5)		196.80 (5)
199.7 (2)				199.95 (5)		199.95 (5)
200.6 (2)			200.9 (3)	200.97 (3)		200.97 (3)
202.9 (2)			202.9 (3)	203.12 (3)		203.12 (3)
219.60 (22)			220.8 (5)	220.00 (8)		220.00 (8)
				221.15 (10)		221.15 (10)
				221.83 (10)		221.83 (10)
226.15 (23)			226.87 (10)	226.50 (3)		226.50 (3)
227.00 (23)				227.25 (3)		227.25 (3)
				232.21 (3)		232.21 (3)
						233.6 (2)[b]
				235.11 (3)		235.11 (3)
						235.9 (3)[b]
				240.2 (1)		240.2 (1)
245.00 (25)			245.2 (3)	245.37 (2)		245.37 (2)
						247.79 (7)[b]
248.80 (25)			249.1 (3)	249.22 (1)		249.22 (1)
				257.2 (1)		257.2 (1)
			267.1 (8)	267.12 (5)		267.12 (5)
271.85 (27)			272.1 (3)	272.28 (5)		272.28 (5)
				275.04 (10)		275.04 (10)
			277.9 (8)	278.3 (1)		278.3 (1)
293.5 (3)			293.7 (2)	293.79 (5)		293.79 (5)
				295.91 (8)		295.91 (8)
				298.7 (2)		298.7 (2)
			309.6 (8)	308.6 (2)		308.6 (2)
				310.2 (1)		310.2 (1)
						310.52 (10)[b]
312.5 (3)				313.5 (1)		313.5 (1)
316.8 (3)			316.3 (8)	316.7 (1)		316.7 (1)
			320.7 (8)	320.4 (1)		320.4 (1)
328.3 (3)			330.3 (5)	330.40 (5)		330.40 (5)

1968Bj06	1968Go20	1972Sa06	1975Ar24	1986Ar05	2000Ni13	Recommended
330.6 (3)				331.4 (1)		331.4 (1)
				340.2 (1)		340.2 (1)
				343.8 (2)		343.8 (2)
351.6 (4)			351.8 (3)	351.9 (1)		351.9 (1)
				357.9 (1)		357.9 (1)
				360.6 (3)		360.6 (3)
				365.0 (3)		365.0 (3)
369.3 (4)			369.6 (3)	369.50 (5)		369.50 (5)
371.8 (4)			372.2 (3)	372.0 (1)		372.0 (1)
				379.1 (1)		379.1 (1)
				385.4 (1)		385.4 (1)
						387.94 (6)[b]
				394.1 (1)		394.1 (1)
				397.7 (3)		397.7 (3)
				401.8 (2)		401.8 (2)
			409.8 (5)	409.8 (1)		409.8 (1)
				416.1 (1)		416.1 (1)
				425.3 (2)		425.3 (2)
427.0 (4)			426.8 (5)	426.95 (5)		426.95 (5)
						427.4 (4)[b]
			432.6 (5)	433.1 (1)		433.1 (1)
			446.9 (5)	446.6 (1)		446.6 (1)
						450.93 (4)[b]
				452.4 (3)		452.4 (3)
458.6 (5)			458.6 (3)	458.68 (5)		458.68 (5)
			461.8 (10)	461.5 (1)		461.5 (1)
				464.2 (1)		464.2 (1)
468.0 (5)			467.5 (10)	468.0 (1)		468.0 (1)
			472.1 (10)	472.3 (1)		472.3 (1)
474.0 (5)			473.5 (10)	474.2 (2)		474.2 (2)
			478.7 (10)	478.6 (1)		478.6 (1)
			480.5 (8)	481.0 (1)		481.0 (1)
			498.9 (10)	498.0 (1)		498.0 (1)
				502.0 (1)		502.0 (1)
506.0 (5)			506.8 (5)	506.75 (5)		506.75 (5)
513.6 (5)			513.7 (5)	513.4 (1)		513.4 (1)
			520.2 (5)	519.6 (1)		519.6 (1)
521.0 (5)			521.0 (5)	521.4 (1)		521.4 (1)
527.6 (5)			528.0 (5)	527.9 (1)		527.9 (1)
				529.1 (3)		529.1 (3)
			533.2 (10)	534.1 (1)		534.1 (1)
			537.1 (10)	537.2 (1)		537.2 (1)
				543.8 (1)		543.8 (1)
				553.7 (1)		553.7 (1)
			557 (1)	558.0 (2)		558.0 (2)
				559.2 (2)		559.2 (2)
				562.8 (3)		562.8 (3)
565.1 (6)			566.3 (10)	565.2 (1)		565.2 (1)
568.7 (6)				568.9 (2)		568.9 (2)
569.5 (6)			569.26 (10)	569.5 (1)		569.5 (1)

1968Bj06	1968Go20	1972Sa06	1975Ar24	1986Ar05	2000Ni13	Recommended
574.0 (6)				575.5 (1)		575.5 (1)
				584.1 (1)		584.1 (1)
			586.1 (8)	586.3 (1)		586.3 (1)
				590.3 (10)		590.3 (10)
				595.4 (2)		595.4 (2)
			596.5 (5)	596.9 (1)		596.9 (1)
			602.7 (5)	602.6 (1)		602.6 (1)
				604.6 (3)		604.6 (3)
612.0 (6)			611.4 (10)	612.0 (1)		612.0 (1)
			616.2 (5)	617.0 (2)		617.0 (2)
				619.0 (2)		619.0 (2)
623.8 (6)			623.6 (5)	624.2 (1)		624.2 (1)
629.1 (6)			627.5 (5)	628.1 (1)		628.1 (1)
			630.6 (10)	629.4 (1)		629.4 (1)
				632.6 (2)		632.6 (2)
			634.5 (10)	634.3 (2)		634.3 (2)
			643.2 (10)	643.2 (2)		643.2 (2)[×]
646.0 (7)			646.2 (10)	646.5 (1)		646.5 (1)
653.7 (7)			653.2 (8)	653.7 (1)		653.7 (1)
			655.0 (8)	655.2 (2)		655.2 (2)
657.0 (7)			658.0 (5)	657.4 (1)		657.4 (1)
			660.6 (10)	659.8 (1)		659.8 (1)[×]
			664.6 (10)	663.9 (1)		663.9 (1)
667.0 (7)			666.7 (6)	666.5 (1)		666.5 (1)
			669.8 (5)	669.7 (1)		669.7 (1)
				675.1 (1)		675.1 (1)
			683.3 (8)	683.9 (2)		683.9 (2)
687.0 (7)			685.5 (10)	685.1 (2)		685.1 (2)
692.8 (7)			692.5 (5)	692.6 (1)		692.6 (1)
699.0 (7)			699.1 (3)	699.03 (5)		699.03 (5)
706.8 (7)			706.0 (2)	705.9 (1)		705.9 (1)
						708.3 (2)[b]
			711.2 (8)	711.5 (1)		711.5 (1)[×]
				713.7 (1)		713.7 (1)
				716.5 (2)		716.5 (2)
				727.8 (2)		727.8 (2)
				730.9 (2)		730.9 (2)
732.9 (7)			733.0 (2)	733.39 (5)		733.39 (5)
737.5 (7)			738.4 (5)	738.0 (1)		738.0 (1)
~ 743.4	742.8 (6)	742.814 (22)	742.67 (20)	742.81 (3)	742.813 (5)	742.813 (5)
			746.5 (15)	745.9 (1)		745.9 (1)
				748.1 (3)		748.1 (3)
756.6 (8)			754.8 (6)	755.0 (1)		755.0 (1)
				758.9 (1)		758.9 (1)
			760 (1)	761.0 (2)		761.0 (2)
				764.8 (2)		764.8 (2)
767.0 (8)	765.0 (7)	766.358 (20)	865.7 (8)	766.4 (2)		766.4 (2)
			768.7 (10)	769.1 (1)		769.1 (1)
				772.4 (2)		772.4 (2)
			777.9 (10)	778.6 (2)		778.6 (2)[×]

1968Bj06	1968Go20	1972Sa06	1975Ar24	1986Ar05	2000Ni13	Recommended
~ 780.9			780.5 (6)	780.4 (2)		780.4 (2)
			783.1 (10)	783.4 (1)		783.4 (1)
~ 787.0	786.3 (5)	786.272 (22)	786.2 (6)	786.27 (3)		786.27 (3)
			793.6 (10)	792.8 (3)		792.8 (3)
				794.9 (2)		794.9 (2)
797.2 (8)			796.2 (5)	796.1 (1)		796.1 (1)
						799.7 (2)[b]
				802.3 (2)		802.3 (2)
804.2 (8)			804.5 (10)	804.1 (1)		804.1 (1)
806.8 (8)			805.5 (5)	805.8 (5)		805.8 (5)
808.0 (8)				808.4 (3)		808.4 (3)
810.0 (8)				810.0 (7)		810.0 (7)
			812.5 (15)	811.5 (1)		811.5 (1)
				814.2 (1)		814.2 (1)
~ 820.2			819.4 (5)	819.2 (1)		819.2 (1)
824.0 (8)			824.7 (5)	824.2 (2)		824.2 (2)[×]
826.3 (8)				825.1 (2)		825.1 (2)
				829.3 (2)		829.3 (2)
832.4 (24)			831.1 (5)	831.5 (1)		831.5 (1)
			841.9 (10)	839.5 (1)		839.5 (1)
~ 845.4			844.1 (10)	844.1 (1)		844.1 (1)
				846.1 (2)		846.1 (2)[×]
				848.9 (2)		848.9 (2)
				851.8 (1)		851.8 (1)
				857.7 (2)		857.7 (2)
				863.2 (2)		863.2 (2)
				869.7 (1)		869.7 (1)
872.0 (26)			872.9 (10)	874.0 (3)		874.0 (3)
876.4 (26)			876.7 (7)	876.0 (1)		876.0 (1)
880.2 (27)	880.0 (7)	880.514 (36)	880.6 (5)	880.5 (1)		880.5 (1)
883.0 (27)	883.0 (6)	883.237 (33)	883.5 (5)	883.24 (4)		883.24 (4)
				890.1 (4)		890.1 (4)
899.3 (27)			898.6 (5)	898.67 (5)		898.67 (5)
905.2 (28)			904.2 (10)	904.2 (1)		904.2 (1)
				916.5 (2)		916.5 (2)
				918.4 (1)		918.4 (1)
				920.5 (2)		920.5 (2)[×]
926 (3)			924.6 (10)	925.0 (1)		925.0 (1)
						926.0 (2)[a]
927.1 (28)			926.7 (5)	926.7 (1)		926.7 (1)
				935.8 (2)		935.8 (2)
				942.0 (3)		942.0 (3)
946.3 (28)	945.8 (3)	946.002 (28)	945.78 (10)	946.00 (3)		946.00 (3)
949.6 (28)				947.7 (2)		947.7 (2)
				952.7 (1)		952.7 (1)
			959 (1)	960.0 (1)		960.0 (1)
966.4 (29)			965.9 (10)	965.8 (1)		965.8 (1)
				975.1 (1)		975.1 (1)
			978.8 (10)	978.2 (3)		978.2 (3)
980.8 (29)			980.5 (5)	980.3 (1)		980.3 (1)

1968Bj06	1968Go20	1972Sa06	1975Ar24	1986Ar05	2000Ni13	Recommended
				981.6 (3)		981.6 (3)
984.5 (29)			983.4 (10)	984.2 (1)		984.2 (1)
				989.5 (1)		989.5 (1)
				992.0 (2)		992.0 (2)$^{\times}$
				994.6 (3)		994.6 (3)
				997.7 (3)		997.7 (3)
				1009.9 (3)		1009.9 (3)
				1019.5 (4)		1019.5 (4)
				1021.8 (2)		1021.8 (2)
1023.1 (30)			1022.7 (8)	1023.6 (2)		1023.6 (2)$^{\times}$
				1025.3 (2)		1025.3 (2)$^{\times}$
1028.6 (30)			1028.1 (8)	1028.7 (1)		1028.7 (1)
				1032.8 (2)		1032.8 (2)
				1035.9 (2)		1035.9 (2)$^{\times}$
				1037.9 (2)		1037.9 (2)
				1041.1 (2)		1041.1 (2)
1044.9 (31)				1044.4 (2)		1044.4 (2)
				1051.4 (2)		1051.4 (2)
				1057.8 (3)		1057.8 (3)
				1065.1 (1)		1065.1 (1)
1073 (3)			1074.4 (10)	1073.6 (2)		1073.6 (2)
1084 (3)			1082.5 (6)	1083.2 (1)		1083.2 (1)
				1085.3 (3)		1085.3 (3)
			1108.5 (6)	1106.9 (2)		1106.9 (2)
				1110.6 (1)		1110.6 (1)
1121.9 (33)			1122.3 (6)	1121.7 (1)		1121.7 (1)
				1125.2 (1)		1125.2 (1)
1126.8 (33)			1126.0 (6)	1126.8 (1)		1126.8 (1)
				1151.4 (3)		1151.4 (3)
			1153.1 (6)	1153.5 (3)		1153.5 (3)
			1171.3 (8)	1171.3 (1)		1171.3 (1)
				1173.1 (1)		1173.1 (1)
				1182.1 (2)		1182.1 (2)
		1193.767 (30)		1194.0 (2)		1194.0 (2)
1217 (4)			1217.5 (8)	1217.3 (1)		1217.3 (1)
				1220.4 (2)		1220.4 (2)$^{\times}$
1239 (4)				1237.3 (3)		1237.3 (3)
			1240.9 (8)	1241.2 (1)		1241.2 (1)
				1247.8 (2)		1247.8 (2)
				1252.6 (2)		1252.6 (2)
				1256.5 (1)		1256.5 (1)
			1277.1 (8)	1277.7 (2)		1277.7 (2)
1292 (4)			1292.8 (8)	1292.8 (1)		1292.8 (1)
				1296.4 (2)		1296.4 (2)$^{\times}$
				1301.2 (2)		1301.2 (2)$^{\times}$
				1327.0 (2)		1327.0 (2)$^{\times}$
				1342.9 (2)		1342.9 (2)
			1353.0 (6)	1352.9 (1)		1352.9 (1)
1354 (4)				1354.6 (2)		1354.6 (2)
			1358.4 (10)	1359.0 (1)		1359.0 (1)

1968Bj06	1968Go20	1972Sa06	1975Ar24	1986Ar05	2000Ni13	Recommended
				1389.6 (2)		1389.6 (2)
1394 (4)			1394.1 (5)	1393.9 (1)		1393.9 (1)
			1399.7 (10)	1397.5 (2)		1397.5 (2)
				1400.3 (1)		1400.3 (1)
				1409.1 (2)		1409.1 (2)
				1414.4 (2)		1414.4 (2)
			1427 (1)	1426.9 (1)		1426.9 (1)
				1442.8 (2)		1442.8 (2)
1446 (4)			1446.1 (8)	1445.4 (1)		1445.4 (1)
1453 (4)			1452.6 (15)	1452.7 (1)		1452.7 (1)
				1458.9 (1)		1458.9 (1)
				1475.8 (2)		1475.8 (2)
				1485.4 (2)		1485.4 (2)
				1488.0 (2)		1488.0 (2)
1493 (4)			1493.7 (10)	1493.6 (1)		1493.6 (1)
				1496.0 (2)		1496.0 (2)
				1500.0 (2)		1500.0 (2)
				1507.3 (2)		1507.3 (2)$^{\times}$
				1510.1 (2)		1510.1 (2)
1516 (5)				1515.6 (2)		1515.6 (2)
				1520.7 (2)		1520.7 (2)$^{\times}$
				1538.8 (2)		1538.8 (2)$^{\times}$
~1552			1549.2 (10)	1550.1 (1)		1550.1 (1)
				1567.0 (2)		1567.0 (2)
			1580.1 (10)	1579.9 (1)		1579.9 (1)
			1585.4 (10)	1585.9 (1)		1585.9 (1)
1595 (5)			1593.8 (8)	1594.0 (1)		1594.0 (1)
				1618.3 (2)		1618.3 (2)
			1628 (1)	1627.3 (1)		1627.3 (1)
			1638.2 (10)	1638.1 (1)		1638.1 (1)
1640 (5)				1640.5 (3)		1640.5 (3)
				1644.9 (2)		1644.9 (2)
1653 (5)				1650.2 (2)		1650.2 (2)
				1655.7 (1)		1655.7 (1)$^{\times}$
				1664.8 (3)		1664.8 (3)$^{\times}$
			1668.5 (8)	1668.4 (1)		1668.4 (1)
1671 (5)				1672.8 (1)		1672.8 (1)
				1679.5 (1)		1679.5 (1)
1688 (5)			1686.3 (10)	1685.7 (1)		1685.7 (1)
			1694.0 (8)	1693.8 (2)		1693.8 (2)
1695 (5)				1695.0 (3)		1695.0 (3)
				1700.5 (2)		1700.5 (2)
				1719.7 (2)		1719.7 (2)
				1723.2 (2)		1723.2 (2)
				1727.8 (2)		1727.8 (2)
1736 (5)			1737.9 (10)	1737.7 (2)		1737.7 (2)
				1741.1 (2)		1741.1 (2)
				1743.2 (2)		1743.2 (2)$^{\times}$
				1750.0 (1)		1750.0 (1)
1756 (5)				1757.5 (1)		1757.5 (1)$^{\times}$

1968Bj06	1968Go20	1972Sa06	1975Ar24	1986Ar05	2000Ni13	Recommended
			1768.4 (15)	1768.0 (3)		1768.0 (3)
				1770.8 (2)		1770.8 (2)
1775 (5)			1772.2 (15)	1773.0 (2)		1773.0 (2)
				1783.7 (2)		1783.7 (2)
			1796.9 (10)	1797.1 (1)		1797.1 (1)
1802 (5)				1805.8 (3)		1805.8 (3)
				1815.3 (3)		1815.3 (3)
				1819.8 (3)		1819.8 (3)
				1825.1 (3)		1825.1 (3)
1828 (5)				1830.8 (3)		1830.8 (3)[×]
			1838.20 (8)	1838.0 (2)		1838.0 (2)
1849 (6)			1850 (1)	1849.8 (2)		1849.8 (2)[×]
			1872.8 (10)	1872.8 (2)		1872.8 (2)
				1884.1 (3)		1884.1 (3)
			1891.1 (10)	1890.1 (2)		1890.1 (2)
				1893.4 (3)		1893.4 (3)
			1897.5 (10)	1896.7 (2)		1896.7 (2)
1905 (6)				1915.5 (3)		1915.5 (3)
			1926.5 (6)	1925.4 (2)		1925.4 (2)
				1927.9 (4)		1927.9 (4)[×]
				1935.2 (4)		1935.2 (4)[×]
1940 (6)			1937.8 (10)	1937.7 (3)		1937.7 (3)
				1958.0 (4)		1958.0 (4)
				1971.2 (4)		1971.2 (4)
				1977.4 (4)		1977.4 (4)
				1989.6 (4)		1989.6 (4)
				2072.2 (4)		2072.2 (4)

a: Expected but as yet unobserved, energy from level scheme.

b: Expected but as yet unobserved, energy from adopted gammas.

×: Not placed in level scheme.

5.2 Relative values of the γ-ray intensities

Measured results for the relative γ-ray intensities from ^{234}Pa are listed in table 5. The recommended values are from the measurements of 1986Ar05, except as noted in the footnotes of the table.

The values from 1975Ar24 were superseded by the same group in 1986Ar05. The uncertainties of 1968Bj06 are large (~ 20-30 %), and not listed in table. Some γ-ray intensities from 1990Sc09 are also not listed in table because these intensities contain the contributions from ^{234m}Pa decay.

Table 5: Measured and recommended relative γ-ray intensities in decay of ^{234}Pa

E_γ/keV	I_γ							
	1967Wa09	1968Bj06[!]	1975Ar24	1986Ar05	1990Sc09[!]	2006Al28[!]	LWEIGHT	Recommended
34.30								0.0036[f]
41.82[a]								0.27 (7)[d]
43.49		0.123		0.12 (3)				0.12 (3)
45.45		0.009		0.026 (8)				0.026 (8)
54.96[b]				~ 0.009				~ 0.009
54.96[b]								~ 0.009
55.45				0.026 (8)				0.026 (8)
58.20		0.0026		< 0.009				0.0026 (8)

E_γ/keV	I_γ							
	1967Wa09	1968Bj06[!]	1975Ar24	1986Ar05	1990Sc09[!]	2006Al28[!]	LWEIGHT	Recommended
59.19				0.031 (10)				0.031 (10)
62.70	3.2	2.45	3.6	1.5 (4)				1.5 (4)
67.25				0.035 (10)				0.035 (10)
69.46				0.017 (7)				0.017 (7)
75.0[a]								0.030 (6)[d]
79.84		0.11		0.06 (2)				0.06 (2)
97.17				0.23 (8)				0.23 (8)
99.86		4.64		3.1 (5)				3.1 (5)
100.89				0.12 (2)				0.12 (2)
103.77		0.114		0.23 (3)				0.23 (3)
106.68				0.035 (10)				0.035 (10)
125.46	1.2	0.79	0.61	0.76 (9)				0.76 (9)
131.30	18	17.5	17.5	17.5	17.5	17.5		17.5
134.61		0.13		0.11 (2)				0.11 (2)
137.23				0.026 (8)				0.026 (8)
140.15	0.9			0.49 (5)				0.49 (5)
140.91				0.30 (3)				0.30 (3)
143.78	0.2		0.32	0.31 (3)				0.31 (3)
149.88				0.07 (2)				0.07 (2)
152.71	6	5.25	5.78	5.8 (4)	5.08 (19)		5.2 (2)	5.8 (4)
159.48	0.6	0.44	0.61	0.63 (7)				0.63 (7)
164.94				0.05 (2)				0.05 (2)
165.61				0.07 (2)				0.07 (2)
170.85	0.4	0.44	0.55	0.49 (5)				0.49 (5)
174.55			0.21	0.16 (2)				0.16 (2)
179.80				0.043 (15)				0.043 (15)
186.15	1.8	1.5	2.02	1.71 (10)				1.71 (10)
193.73	0.5	0.6	0.51	0.48 (6)				0.48 (6)
196.80		< 0.44	0.06	0.07 (2)				0.07 (2)
199.95				0.07 (2)				0.07 (2)
200.97		0.9	0.96	0.87 (9)				0.87 (9)
203.12	2.1		1.14	1.19 (10)				1.19 (10)
220.00	0.4		0.1	0.14 (2)				0.14 (2)
221.15				0.05 (2)				0.05 (2)
221.83				0.07 (2)				0.07 (2)
226.50	10	5.6	10.1	4.1 (3)	10.25 (15)			4.7 (3)[#]
227.25		5.25		5.6 (3)				5.6 (3)
232.21				0.17 (2)				0.17 (2)
233.6[a]								~ 0.018[d]
235.11				0.11 (2)				0.11 (2)
235.9[a]								0.0044 (25)[e]
240.2				0.05 (2)				0.05 (2)
245.37	0.8	0.9	0.66	0.73 (8)				0.73 (8)
247.79[a]								3.6 (3)E-4[e]
249.22	2.5	2.19	2.45	2.4 (3)	2.14 (10)		2.2 (1)	2.4 (3)
257.2				0.05 (2)				0.05 (2)
267.12			0.15	0.17 (2)				0.17 (2)
272.28	1	0.9	0.88	1.05 (10)	1.1 (1)		1.08 (7)	1.05 (10)

E_γ/keV	I_γ							
	1967Wa09	1968Bj06[!]	1975Ar24	1986Ar05	1990Sc09[!]	2006Al28[!]	LWEIGHT	Recommended
275.04				0.09 (2)				0.09 (2)
278.3			0.06	0.04 (1)				0.04 (1)
293.79	3.7		3.4	2.9 (2)	3.0 (1)		2.98 (9)	2.9 (2)
295.91				0.14 (2)				0.14 (2)
298.7				0.013 (5)				0.013 (5)
308.6				0.020 (5)				0.020 (5)
310.2				0.07 (1)				0.07 (1)
310.52[a]								1.30 (14)E-4[e]
313.5				0.10 (1)				0.10 (1)
316.7			0.11	0.10 (1)				0.10 (1)
320.4				0.050 (6)				0.050 (6)
330.4[b]	1.1		0.75	0.75 (5)				0.75 (5)
330.4[b]								
331.4				0.07 (1)				0.07 (1)
340.2				0.039 (8)				0.039 (8)
343.8				0.033 (7)				0.033 (7)
351.9	0.5	0.6	0.53	0.40 (3)				0.40 (3)
357.9				0.035 (10)				0.035 (10)
360.6				0.017 (6)				0.017 (6)
365.0[b]				0.017 (6)				0.017 (6)
365.0[b]								
369.50	3.5	2.63	2.49	2.40 (15)	2.69 (10)		2.60 (8)	2.40 (15)
372.0	1	0.96	1.23	1.18 (8)	1.41 (10)		1.27 (6)	1.18 (8)
379.1				0.04 (1)				0.04 (1)
385.4				0.04 (1)				0.04 (1)
387.94[a]								6.9 (4)E-4[e]
394.1				0.09 (1)				0.09 (1)
397.7				0.026 (6)				0.026 (6)
401.8[×]				0.035 (10)				0.035 (10)
409.8	0.4		0.48	0.33 (3)				0.33 (3)
416.1	0.1			0.035 (10)				0.035 (10)
425.3[×]				0.035 (10)				0.035 (10)
426.95	0.8		0.47	0.44 (3)				0.44 (3)
427.4[a]								3.0 (8)E-5[e]
433.1			0.05	0.09 (1)				0.09 (1)
446.6[b]			0.11	0.11 (1)				0.11 (1)
446.6[b]								
450.93[a]								3.8 (18)E-3[e]
452.4				0.026 (8)				0.026 (8)
458.68	1.3		1.26	1.10 (6)	1.22 (10)		1.13 (5)	1.10 (6)
461.5[b]				0.033 (10)				0.033 (10)
461.5[b]								
464.2				0.03 (1)				0.03 (1)
468.0				0.21 (2)				0.21 (2)
472.3			0.21	0.35 (2)				0.35 (2)
474.2				0.035 (10)				0.035 (10)
478.6[b]			0.26	0.12 (1)				0.12 (1)
478.6[b]								
481.0	0.4		0.42	0.30 (2)				0.30 (2)

E_γ/keV	I_γ							
	1967Wa09	1968Bj06[!]	1975Ar24	1986Ar05	1990Sc09[!]	2006Al28[!]	LWEIGHT	Recommended
498.0[b]			0.09	0.06 (1)				0.06 (1)
498.0[b]								
502.0				0.026 (8)				0.026 (8)
506.75	1.5		1.4	1.25 (8)	2.14 (12)		1.7 (5)	1.25 (8)
513.4[c]	1.3		1.3	1.10 (7)				~ 0.73
513.4[c]								~ 0.37
519.6				0.38 (3)				0.38 (3)
521.4	1.1	0.9	0.81	0.72 (5)				0.72 (5)
527.9		0.6	0.61	0.38 (3)				0.38 (3)
529.1[b]	0.3			0.09 (3)				0.09 (3)
529.1[b]								
534.1				0.08 (1)				0.08 (1)
537.2			0.14	0.08 (1)				0.08 (1)
543.8				0.13 (2)				0.13 (2)
553.7				0.043 (15)				0.043 (15)
558.0[b]				0.09 (2)				0.09 (2)
558.0[b]								
559.2				0.07 (2)				0.07 (2)
562.8				0.035 (10)				0.035 (10)
565.2[b]		0.9		1.00 (6)				1.00 (6)
565.2[b]								
568.9		2.63		3.5 (4)				3.5 (4)
569.5	14.5	8.75	12.1	8.0 (8)	12.42 (16)	12.9 (38)		8.9 (8)[~]
575.5				0.026 (8)				0.026 (8)
584.1				0.17 (2)				0.17 (2)
586.3			0.09	0.07 (1)				0.07 (1)
590.3				0.035 (10)				0.035 (10)
595.4				0.09 (2)				0.09 (2)
596.9[b]			0.31	0.19 (2)				0.19 (2)
596.9[b]								
602.6	0.4		0.76	0.52 (3)				0.52 (3)
604.6				0.05 (2)				0.05 (2)
612.0		0.6	0.61	0.37 (3)				0.37 (3)
617.0[b]				0.05 (2)				0.05 (2)
617.0[b]								
619.0				0.035 (10)				0.035 (10)
624.2		0.35	0.54	0.34 (3)				0.34 (3)
628.1				0.23 (4)				0.23 (4)
629.4		0.35		0.34 (5)				0.34 (5)
632.6				0.035 (10)				0.035 (10)
634.3[b]				0.13 (2)				0.13 (2)
634.3[b]								
643.2[×]				0.026 (8)				0.026 (8)
646.5		0.9	0.19	0.11 (1)				0.11 (1)
653.7[b]		0.44	0.58	0.45 (6)				0.45 (6)
653.7[b]								
655.2	0.7			0.13 (2)				0.13 (2)
657.4	0.7	0.9		0.38 (3)				0.38 (3)
659.8[×]				0.26 (2)				0.26 (2)

E_γ/keV	I_γ							
	1967Wa09	1968Bj06[!]	1975Ar24	1986Ar05	1990Sc09[!]	2006Al28[!]	LWEIGHT	Recommended
663.9			0.9	0.52 (7)				0.52 (7)
666.5	2.2		1.49	1.13 (7)	0.92 (9)		1.05 (6)	1.13 (7)
669.7[c]	2.0		1.14	0.96 (5)	1.04 (10)		0.98 (5)	0.96 (5)
669.7[c]								< 0.0005
675.1				0.097 (10)				0.097 (10)
683.9				0.15 (3)				0.15 (3)
685.1[b]			0.24	0.14 (3)				0.14 (3)
685.1[b]								
692.6	1.3	1.5	1.4	1.20 (7)				1.20 (7)
699.03[b]	4.1	3.5	4.16	3.5 (2)	3.61 (10)		3.59 (9)	3.5 (2)
699.03[b]								
705.9	2.9	3.1	2.14	2.2 (1)				2.2 (1)
708.3[a]								0.022 (8)[e]
711.5[×]			0.18	0.15 (2)				0.15 (2)
713.7[b]				0.14 (2)				0.14 (2)
713.7[b]								
716.5				0.030 (8)				0.030 (8)
727.8				0.11 (1)				0.11 (1)
730.9				0.61 (8)				0.61 (8)
733.39	9.2	7	7.5	6.7 (4)	7.04 (11)		7.02 (11)	6.7 (4)
738.0		1.75	1.14	1.12 (7)	1.29 (11)		1.17 (6)	1.12 (7)
742.813	2.5		2.0	2.0 (1)				2.0 (1)
745.9			0.11	0.31 (3)				0.31 (3)
748.1				0.10 (2)				0.10 (2)
755.0[b]	0.6		1.4	1.18 (6)	1.29 (11)		1.21 (5)	1.18 (6)
755.0[b]								
758.9				0.24 (2)				0.24 (2)
761.0				0.07 (2)				0.07 (2)
764.8				0.19 (4)				0.19 (4)
766.4	0.4	0.26		0.25 (4)				0.25 (4)
769.1				0.18 (1)				0.18 (1)
772.4				0.07 (2)				0.07 (2)
778.6[×]				0.044 (8)				0.044 (8)
780.4	0.7		0.88	0.87 (4)				0.87 (4)
783.4			0.44	0.29 (3)				0.29 (3)
786.272	1		1.4	1.16 (6)				1.16 (6)
792.8				0.043 (10)				0.043 (10)
794.9				0.65 (8)				0.65 (8)
796.1	3.8		2.9	2.5 (2)	3.31 (15)		2.9 (4)	2.5 (2)
799.7[a]								
802.3				0.030 (8)				0.030 (8)
804.1			0.35	0.6 (2)				0.6 (2)
805.8	3	2.9	2.71	2.45 (15)				2.45 (15)
808.4				0.035 (10)				0.035 (10)
810.0								0.19 (6)[f]
811.5				0.12 (1)				0.12 (1)
814.2				0.30 (2)				0.30 (2)
819.2	2.8		2.01	1.83 (10)	2.26 (9)		2.05 (22)	1.83 (10)
824.2[×]			3.23	1.2 (1)				1.2 (1)

E_γ/keV	I_γ							
	1967Wa09	1968Bj06$^{!}$	1975Ar24	1986Ar05	1990Sc09$^{!}$	2006Al28$^{!}$	LWEIGHT	Recommended
825.1	4.3			1.83 (10)	4.16 (11)			1.83 (10)
829.3				0.35 (10)				0.35 (10)
831.5	5.3		4.46	4.0 (2)	4.77 (9)	3.8 (23)	4.38 (28)	4.0 (2)
839.5				0.030 (7)				0.030 (7)
844.1	0.4		0.44	0.41 (3)				0.41 (3)
846.1$^{\times}$				0.05 (1)				0.05 (1)
848.9				0.026 (7)				0.026 (7)
851.8				0.07 (2)				0.07 (2)
857.7				0.035 (7)				0.035 (7)
863.2				0.07 (2)				0.07 (2)
869.7				0.19 (2)				0.19 (2)
874.0				0.035 (7)				0.035 (7)
876.0	7		3.19	2.45 (2)	2.57 (8)		2.46 (2)	2.45 (2)
880.52^{c}	18		11.64	10.1 (6)	12.97 (12)		11.6 (15)	4.1 (4)
880.52^{c}								6.0 (5)
883.24	4		10.85	9.3 (6)				9.3 (6)
890.1				0.026 (7)				0.026 (7)
898.67	4.3	3.6	3.15	3.15 (20)	3.61 (8)		3.55 (8)	3.15 (20)
904.2	0.5		0.41	0.33 (2)				0.33 (2)
916.5				0.023 (6)				0.023 (6)
918.4				0.096 (10)				0.096 (10)
920.5$^{\times}$				0.028 (7)				0.028 (7)
925.0		8.8		7.6 (5)	8.69 (11)		8.64 (11)	7.6 (5)
926.0^{a}								1.7 (12)^{g}
926.7	22	8.75	14.7	8.7 (5)				7.0 (9)^{g}
935.8				0.064 (7)				0.064 (7)
942.0				0.044 (7)				0.044 (7)
946.00	19	13.1	16.1	13.0 (8)				13.0 (8)
947.7				1.57 (15)	1.90 (9)		1.81 (8)	1.57 (15)
952.7				0.08 (1)				0.08 (1)
960.0	0..2		0.09	0.07 (1)				0.07 (1)
965.8	0.4	0.7	0.09	0.46 (3)				0.46 (3)
975.1				0.026 (7)				0.026 (7)
978.2				0.087 (20)				0.087 (20)
980.3^{c}	3.8		~ 2.6	1.92 (10)	2.75 (9)			~ 2.6^{h}
980.3^{c}			~ 1.7					~ 1.7^{h}
981.6				0.7 (2)				0.7 (2)
984.2	1.5		1.49	1.57 (15)	1.84 (8)		1.78 (7)	1.57 (15)
989.5				0.10 (1)				0.10 (1)
992.0$^{\times}$				0.08 (2)				0.08 (2)
994.6				0.06 (2)				0.06 (2)
997.7				0.044 (10)				0.044 (10)
1009.9^{b}				0.064 (10)				0.064 (10)
1009.9^{b}								
1019.5				0.026 (7)				0.026 (7)
1021.8	0.4			0.14 (3)				0.14 (3)
1023.6$^{\times}$				0.06 (2)				0.06 (2)
1025.3$^{\times}$				0.05 (2)				0.05 (2)
1028.7	0.8	0.8	0.44	0.55 (3)				0.55 (3)

E_γ/keV	I_γ							
	1967Wa09	1968Bj06$^{!}$	1975Ar24	1986Ar05	1990Sc09$^{!}$	2006Al28$^{!}$	LWEIGHT	Recommended
1032.8				0.017 (4)				0.017 (4)
1035.9$^{\times}$				0.025 (9)				0.025 (9)
1037.9				0.017 (6)				0.017 (6)
1041.1				0.031 (10)				0.031 (10)
1044.4		0.44		~ 0.030				~ 0.030
1051.4				0.06 (1)				0.06 (1)
1057.8				~ 0.017				~ 0.017
1065.1				0.026 (7)				0.026 (7)
1073.6		0.21	0.17	0.10 (1)				0.10 (1)
1083.2	0.6	0.7		0.49 (3)				0.49 (3)
1085.3				0.026 (7)				0.026 (7)
1106.9				0.08 (1)				0.08 (1)
1110.6				0.06 (1)				0.06 (1)
1121.7	0.4		0.44	0.24 (3)				0.24 (3)
1125.2	0.8			0.35 (7)				0.35 (7)
1126.8				0.29 (3)				0.29 (3)
1151.4^{b}				0.031 (9)				0.031 (9)
1151.4^{b}								
1153.5				0.044 (7)				0.044 (7)
1171.3				0.087 (10)				0.087 (10)
1173.1				0.044 (7)				0.044 (7)
1182.1				~ 0.009				~ 0.009
1193.77				0.020 (5)				0.020 (5)
1217.3		0.9	0.32	0.21 (2)				0.21 (2)
1220.4$^{\times}$				0.06 (1)				0.06 (1)
1237.3				< 0.009				< 0.009
1241.2				0.22 (2)				0.22 (2)
1247.8				0.021 (5)				0.021 (5)
1252.6				0.017 (7)				0.017 (7)
1256.5				0.057 (6)				0.057 (6)
1277.7			0.24	0.043 (7)				0.043 (7)
1292.8	0.6	0.7	0.45	0.45 (3)	0.55 (6)		0.47 (3)	0.45 (3)
1296.4$^{\times}$				0.028 (6)				0.028 (6)
1301.2$^{\times}$				0.017 (4)				0.017 (4)
1327.0$^{\times}$				0.017 (4)				0.017 (4)
1342.9				0.012 (4)				0.012 (4)
1352.9	1.7	1.84	1.10	1.12 (5)	1.17 (5)		1.15 (4)	1.12 (5)
1354.6				0.13 (3)				0.13 (3)
1359.0			0.11	0.15 (2)				0.15 (2)
1389.6				0.07 (2)				0.07 (2)
1393.9	2.8	2.2	2.1	2.0 (1)	2.39 (6)		2.2 (2)	2.0 (1)
1397.5				0.08 (2)				0.08 (2)
1400.3				0.17 (2)				0.17 (2)
1409.1				0.043 (8)				0.043 (8)
1414.4				< 0.0026				< 0.0026
1426.9			0.17	0.16 (2)				0.16 (2)
1442.8				0.030 (6)				0.030 (6)
1445.4	0.3			0.31 (3)				0.31 (3)
1452.7	0.9	1	0.7	0.78 (5)	0.74 (6)		0.76 (4)	0.78 (5)

E_γ/keV	I_γ							
	1967Wa09	1968Bj06!	1975Ar24	1986Ar05	1990Sc09!	2006Al28!	LWEIGHT	Recommended
1458.9				0.09 (2)				0.09 (2)
1475.8				0.008 (3)				0.008 (3)
1485.4				0.029 (6)				0.029 (6)
1488.0				0.013 (5)				0.013 (5)
1493.6		0.26	0.17	0.10 (1)				0.10 (1)
1496.0				0.035 (8)				0.035 (8)
1500.0				0.011 (3)				0.011 (3)
1507.3×				0.019 (4)				0.019 (4)
1510.1				< 0.009				< 0.009
1515.6		0.35		0.07 (1)				0.07 (1)
1520.7×				~ 0.009				~ 0.009
1538.8×				0.013 (3)				0.013 (3)
1550.1			0.09	0.07 (1)				0.07 (1)
1567.0				0.011 (2)				0.011 (2)
1579.9			0.15	0.07 (2)				0.07 (2)
1585.9	0.3		0.26	0.14 (1)				0.14 (1)
1594.0	0.8	0.6	0.46	0.30 (2)				0.30 (2)
1618.3				0.009 (3)				0.009 (3)
1627.3			0.09	0.073 (8)				0.073 (8)
1638.1	0.3		0.19	0.20 (1)				0.20 (1)
1640.5		0.6		0.010 (3)				0.010 (3)
1644.9				0.010 (3)				0.010 (3)
1650.2				< 0.005				< 0.005
1655.7×				0.025 (3)				0.025 (3)
1664.8×				0.017 (6)				0.017 (6)
1668.41	1		0.33	0.74 (5)	0.74 (5)			0.74 (5)
1672.8				0.033 (10)				0.033 (10)
1679.5				0.074 (16)				0.074 (16)
1685.7				0.30 (2)				0.30 (2)
1693.8			0.80	0.67 (7)				0.67 (7)
1695.0	1.1	1.4		0.26 (6)				0.26 (6)
1700.5				0.10 (1)				0.10 (1)
1719.7				0.017 (5)				0.017 (5)
1723.2				0.015 (3)				0.015 (3)
1727.8				0.019 (4)				0.019 (4)
1737.7		0.19	0.07	0.072 (8)				0.072 (8)
1741.1				0.047 (6)				0.047 (6)
1743.2×				0.032 (7)				0.032 (7)
1750.0				0.062 (7)				0.062 (7)
1757.5×				0.023 (5)				0.023 (5)
1768.0	0.2		0.05	0.019 (4)				0.019 (4)
1770.8				0.065 (15)				0.065 (15)
1773.0				0.065 (15)				0.065 (15)
1783.7				0.024 (6)				0.024 (6)
1797.1	0.3		0.19	0.23 (2)				0.23 (2)
1805.8				0.005 (2)				0.005 (2)
1815.3				0.009 (3)				0.009 (3)
1819.8				0.004 (1)				0.004 (1)
1825.1				0.009 (3)				0.009 (3)

E_γ/keV	I_γ							
	1967Wa09	1968Bj06$^{!}$	1975Ar24	1986Ar05	1990Sc09$^{!}$	2006Al28$^{!}$	LWEIGHT	Recommended
$1830.8^{\times}$				0.004 (1)				0.004 (1)
1838.0^{b}			0.08	0.040 (9)				0.040 (9)
1838.0^{b}								
$1849.8^{\times}$		0.044		0.027 (6)				0.027 (6)
1872.8				0.034 (8)				0.034 (8)
1884.1				0.015 (4)				0.015 (4)
1890.1	0.4			0.14 (1)				0.14 (1)
1893.4				~ 0.006				~ 0.006
1896.7				0.10 (2)				0.10 (2)
1915.5				0.019 (4)				0.019 (4)
1925.4	0.6		0.28	0.29 (4)	0.31 (3)		0.30 (2)	0.29 (4)
$1927.9^{\times}$				0.052 (10)				0.052 (10)
$1935.2^{\times}$				~ 0.009				~ 0.009
1937.7			0.04	0.04 (1)				0.04 (1)
1958.0				0.0096 (25				0.0096 (25)
1971.2				~ 0.0026				~ 0.0026
1977.4				0.016 (4)				0.016 (4)
1989.6				0.007 (3)				0.007 (3)
2072.2				0.004 (2)				0.004 (2)

!: Normalized to I(γ131.3) = 17.5.

#: From I(γ227.25) = 5.6 (3) in 1986Ar05 and I(γ226.5+γ227.25) = 10.25 (15) in 1990Sc09.

~: From I(γ568.9) = 3.5 (4) in 1986Ar05 and I(γ569.5+568.9) = 12.42 (16) in 1990Sc09.

a: Expected but as unobserved yet.

b: Multiply placed, intensity not divided.

c: Multiply placed, intensity suitably divided.

d: I(γ+ce), from γ-ray transition intensity balance.

e: From adopted γ branching.

f: From I(γ+ce), from ce measurements(1968Bj06).

g: From Iγ(926+926.7) = 8.7 (5) and Iγ(926.7)/ Iγ(883.2) = 0.75 (8) in ^{238}Pu α decay.

h: From γγ coincidence measurements(1968Bj06).

×: Not placed in level scheme.

5.3 Absolute values of the γ-ray emission probabilities

There is no measured absolute γ-ray emission probability in the ^{234}Pa β^- decay. The normalization factor N for translation of the relative intensities to the absolute emission probabilities has been obtained from the relation of ΣI(γ+ce)(g.s.) + ΣI(γ+ce)(43.5keV level) = 100 %, excluding the 43.5-keV transition and supposing no β^- feeding to the above-mentioned two states. N = 1.04 (9).

The recommended absolute γ-ray emission probabilities (photons per 100 disintegrations) are the relative values recommended in table 5 multiplied by 1.04 (9).

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^{234m}Pa - Comments on evaluation of the decay data

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This evaluation was completed in 2009. Literature available by January 2009 was included.

1 Decay Scheme

^{234m}Pa disintegrates 99.85 (1) % by β^- emissions to levels in ^{234}U and also 0.15 (1) % through IT decay to ^{234}Pa. ^{234m}Pa isomer state has $J^\pi = (0)^-$ (2007Br04).

Measured and recommended branching ratios for ^{234m}Pa IT decay are listed in Table 1.

Table 1: Measured and recommended branching ratio for ^{234m}Pa IT decay.

IT (%)	References	Comments
0.150 (25)	1938Fe02	
0.12	1945Br05	Not used
0.63	1954Zi02	Not used
0.18 (2)	1960Fo15	
0.13 (3)	1963Bj02	Deduced by comparing $I_{ce's}$, $I_{\gamma's}$, and β- disintegration rates from ^{234g}Pa following ^{234m}Pa decay
0.15 (5)	1973Go40	
0.19 (6)		
0.19 (5)	1978Ch06	Deduced from measured I_γ(73.9 keV)
0.157 (14)	1990Sc09	Deduced from measured P_γ(131 keV)
0.126 (16)	2006Al28	Deduced from measured P_γ(131 keV)
0.151 (8)		LWEIGHT
0.15 (1)		Adopted

Statistical processing was performed with the LWEIGHT computer program.

Our recommended IT decay branching ratio is I_{IT} = 0.15 (1) % which taken from LWEIGHT result. Thus, $I_{\beta-}$= 99.85 (1) %.

The ^{234m}Pa β^- decay scheme was built based mainly on measurement results from 1963Bj02, 1967Wa09 and 1975Ar23. 16 γ-rays were not placed in the current decay scheme. The total photon intensity of these γ transitions is about 0.018 %.

The adopted Q(β^-) value of 2269(4) + x keV has been obtained from Q(β^-) = 2195 (4) keV for ^{234}Pa β^- decay (2003Au03), the energy of γ-ray transition 73.92 keV and the estimate of isomeric transition energy x < 10 keV deduced from the limit on experimental detection (1973Go40) in ^{234}Th β^- decay. The adopted Q(β^-) is in certain agreement with the effective Q(β^-) value of 2259.7 (24) keV, calculated by the evaluators from average radiation energies using the RADLST computer program. This agreement supports the completeness and correctness of the decay scheme.

2 Nuclear Data

The Q(β^-) value is from the mass adjustment in 2003Au03 and the energies of γ-ray transitions in ^{234m}Pa IT decay (see above).

Level energies, have been obtained from a least-squares fit to γ-ray energies (GTOL computer code). Spin and parities are from 2007Br04.

The measured and recommended ^{234m}Pa half-life values are listed in Table 2.

Table 2: Measured half-life values of ^{234m}Pa and recommended value

$T_{1/2}$ (min)	References	Comments
1.175 (3)	1951Ba83	
1.25 (10)	1956On07	
1.14 (1)	1963Bj02	
1.183 (37)	1969SaZR	
1.175	1969DeZX	Not used
1.159 (16)	2004Wo02	Evaluated value
1.187 (23)		Unweighted mean
1.159 (11)		LWEIGHT weighted mean,χ^2=2.54
1.159 (11)		Recommended value

The weighted average of 1.15946 for this data set of the 4 values is dominated by the accurate value of 1951Ba83. The LWEIGHT computer program, which uses a Limitation of Relative Statistical Weights (LRSW method), has increased the 1951Ba83 uncertainty from 0.003 to 0.0096 and used a weighted mean and an external uncertainty for recommended average.

Thus, the adopted value of the ^{234m}Pa half-life is 1.159 (11) minute.

2.1 β^- transitions

The maximum energies of the β^- transitions in the decay of ^{234m}Pa have been deduced from the Q(β-) value (2003Au03), and the level energies which given in Tables 3 and 4.

Table 3: ^{234}Pa levels populated in ^{234m}Pa IT decay

Level energy (keV)	Spin & parity	Half-life
0.0	4+	6.70 (5) h
73.92 (2)	(3+)	
73.92+x	(0-)	1.159 (11) min

Table 4: ^{234}U levels populated in ^{234m}Pa β^- decay

Level energy (keV)	Spin & parity	Half-life	β^- transition probabilities (%)
0.0	0+	2.455 (6)×10^5 a	97.599 (24)
43.428 (14)	2+	0.252 (7) ns	
143.279 (24)	4+		
786.243 (14)	1-		0.049 (3)
809.786 (23)	0+	< 0.1 ns	0.945 (12)
849.18 (7)	3-		
851.56 (4)	2+	> 1.74 ps	
926.659 (20)	2+	1.38 (17) ps	
989.359 (19)	2-	0.76 (4) ns	
1044.469 (15)	0+		1.006 (13)
1085.04 (4)	2+		

Level energy (keV)	Spin & parity	Half-life	β^- transition probabilities (%)
1126.32 (4)	2+		
1174.2 (4)	(1,2+)		0.004 6 (3)
1237.23 (3)	1-		0.012 1 (11)
1435.05 (5)	1-		0.009 2 (11)
1457.40 (8)	(2-)		
1500.8 (3)	(1)		0.013 1 (6)
1553.62 (6)	(1)		0.032 0 (6)
1570.53 (4)	1+		0.002 31 (19)
1591.64 (7)	(1)		0.024 9 (5)
1601.68 (4)	1+		0.001 27 (23)
1666.77 (5)	(1-)		0.006 1 (3)
1693.7? (6)	(1-)		0.002 4 (3)
1781.19 (8)	(0+,1)		0.035 7 (18)
1796.4 (6)	(1)		0.002 1 (3)
1808.97 (7)	(1-)		0.014 6 (7)
1863.11 (7)	(1)		0.003 11 (19)
1874.86 (8)	(1)		0.025 8 (3)
1911.04 (5)	(1-)		0.045 2 (8)
1936.68 (7)	(1)		0.010 8 (3)
1970.0 (5)	(1-)		0.003 89 (22)

The adopted β^- transition probabilities and the associated uncertainties were deduced from the γ transition probability balance at each level of the decay scheme.

The values of *logft* and average β^- energies have been calculated with the program LOGFT.

2.2 γ Transitions

The γ-ray transition probabilities were deduced using the γ-ray emission intensities and the relevant internal conversion coefficients.

Multipolarities and mixing ratios of γ-ray transitions are from 1963Bj02 and 2007Br04.

The internal conversion coefficient (ICC) (and its associated uncertainty) for γ-ray transitions have been interpolated from theoretical values based on the “Frozen Orbital” approximation (2002Ba85) using the BrIcc computer program (2008Ki07).

3. Atomic data

Atomic fluorescence yields (ω_K,ϖ_L, ϖ_M, η_{KL} and η_{LM}) are from Schönfeld (1996Sc06).

The X-ray and Auger electron emission probabilities have been deduced from γ-ray and conversion electron data by using the computer code RADLST.

The deduced total KX-ray emission probability of 0.67 ± 0.01 %, is in agreement with the measured value of 0.72 (1963Bj02), thus confirming the completeness of the decay scheme.

4. Electron Emissions.

The conversion electron emission probabilities have been deduced from γ-ray transition data using theoretical internal conversion coefficients.

5. Photon Emissions

5.1 γ-ray energies

Measured results for the energies of γ-rays from ^{234m}Pa decay are listed in Table 5. The recommended values were obtained mainly from measurements of 2004Br43, 2000Ni13, 1975Ar23, 1972Sa06 and 1967Wa09 using the LWEIGHT computer program, except as noted in the table.

Table 5: Measured and recommended γ-ray energy values from ^{234m}Pa decay

1963Bj02	1967Wa09	1972Sa06	1975Ar23	2000Ni13	2004Br43	LWEIGHT	Recommended
							< 10[#]
							41.82[a]
43.5							43.49 (2)[b]
							62.70 (1)[a]
							73.92 (2)[#]
							99.86 (2)[ab]
							135.32 (8)[a]
							137.23 (5)[a]
			140.1 (10)				140.1 (10)
							166.5 (1)[a]
	185.2 (5)		184.7 (5)			185.0 (4)	185.0 (4)
			193.4 (8)				193.4 (8)
							197.91 (15)[a]
			199.9 (10)				199.9 (10)
			203.3 (8)				203.3 (8)
			209.9 (4)				209.9 (4)
							233.6 (2)[a]
							235.9 (3)[ab]
236 (1)							236 (1)
			243.5 (8)				243.5 (8)[×]
			247.7 (8)				247.7 (8)
255 (5)	258.0 (5)		258.26 (3)	258.227 (3)		258.227 (3)	258.227 (3)
			275.5 (8)				275.5 (8)
			299.0 (10)				299.0 (10)
			311.0 (10)				311.0 (10)
							316.7 (1)[a]
			338.1 (8)				338.1 (8)
							340.2 (1)[a]
			357.5 (10)				357.5 (10)
			362.8 (10)				362.8 (10)
			387.6 (8)				387.6 (8)
							427.4 (2)[a]
							445.91 (10)[a]
	451.4 (6)		450.97 (10)			450.98 (10)	450.98 (10)
			453.58 (10)				453.58 (10)
			456.7 (10)				456.7 (10)
			468.43 (10)				468.43 (10)
			475.74 (10)				475.74 (10)

1963Bj02	1967Wa09	1972Sa06	1975Ar23	2000Ni13	2004Br43	LWEIGHT	Recommended
							485.44 (7)[a]
			507.5 (10)				507.5 (10)
			509.2 (8)				509.2 (8)
							516.60 (6)[a]
							526.02 (10)[a]
			543.98 (10)				543.98 (10)
							557.24 (6)[a]
			557.3 (10)				557.3 (10)[×]
			572.0 (10)				572.0 (10)
							581.19 (10)[a]
			624.6 (10)				624.6 (10)
			647.7 (8)				647.7 (8)[×]
			649.0 (10)				649.0 (10)
			655.3 (10)				655.3 (10)
			670.8 (10)				670.8 (10)
			673.9 (10)				673.9 (10)
			683.4 (10)				683.4 (10)
			691.0 (3)				691.0 (3)
			695.5 (10)				695.5 (10)
			699.02 (10)				699.02 (10)
			702.0 (1)				702.0 (1)
			705.94 (12)				705.94 (12)
			708.2 (10)				708.2 (10)
							719.01 (7)[a]
			732.5 (10)				732.5 (10)
			740.10 (8)				740.10 (8)
746 (5)	742.7 (6)	742.814 (22)	742.77 (8)	742.813 (5)		742.813 (5)	742.813 (5)
							750.12 (6)[a]
			760.3 (10)				760.3 (10)[×]
							760.53 (15)[a]
765	766.5 (6)	766.358 (20)	766.42 (10)			766.361 (20)	766.361 (20)
			781.75 (10)				781.75 (10)
							783.4 (1)[a]
	786.3 (8)	786.272 (22)	786.28 (10)			786.272 (22)	786.272 (22)
790 (5)							791.94 (5)[b]
806			805.75 (10)				805.75 (10)
			808.2 (1)				808.2 (1)
811							810.0 (7)[b]
			818.2 (5)				818.2 (5)
	825.5 (2)		825.6 (5)			825.5 (2)	825.5 (2)
			844.1 (8)				844.1 (8)
	852.1 (12)		851.58 (10)			851.6 (1)	851.6 (1)
			866.8 (10)				866.8 (10)
		880.514 (36)	880.9 (5)			880.52 (4)	880.52 (4)
		883.237 (33)	883.22 (10)			883.24 (3)	883.24 (3)

1963Bj02	1967Wa09	1972Sa06	1975Ar23	2000Ni13	2004Br43	LWEIGHT	Recommended
			887.29 (10)				887.29 (10)$^{\times}$
			921.72 (10)				921.72 (10)
			926.61 (10)				926.61 (10)
			936.3 (10)				936.3 (10)
			941.96 (10)				941.96 (10)
		946.002 (28)	945.94 (2)			945.961 (16)	945.961 (16)
			960.0 (10)				960.0 (10)
			996.1 (20)				996.1 (20)
1001	1001.3 (5)	1001.025 (22)	1000.99 (10)		1001.03 (3)	1001.026 (18)	1001.026 (18)
1045			1041.70 (10)				1041.70 (10)
			1059.4 (8)				1059.4 (8)
			1061.86 (10)				1061.86 (10)
			1081.9 (10)				1081.9 (10)
			1084.25 (10)				1084.25 (10)
			1120.6 (8)				1120.6 (8)
	1125.2 (8)		1124.93 (10)			1124.93 (10)	1124.93 (10)
1160			1174.2 (10)				1174.2 (10)
	1194.2 (6)	1193.767 (30)	1193.73 (12)			1193.77 (3)	1193.77 (3)
			1220.37 (10)				1220.37 (10)$^{\times}$
	1238.0 (7)		1237.26 (10)			1237.28 (10)	1237.28 (10)
			1353.0 (15)				1353.0 (15)$^{\times}$
	1392 (2)		1392.7 (10)			1392.6 (9)	1392.6 (9)
	1414.7 (10)		1413.88 (10)			1413.89 (10)	1413.89 (10)
1440	1435.5 (8)		1434.14 (10)			1434.16 (10)	1434.16 (10)
			1458.5 (15)				1458.5 (15)
			1501 (2)				1501 (2)
	1510.9 (7)		1510.21 (10)			1510.22 (10)	1510.22 (10)
	1528.2 (12)		1527.27 (10)			1527.28 (10)	1527.28 (10)
			1550.0 (10)				1550.0 (10)
	1554.7 (8)		1553.75 (10)			1553.77 (10)	1553.77 (10)
			1558.4 (10)				1558.4 (10)
	1570.6 (12)		1570.67 (10)			1570.67 (10)	1570.67 (10)
	1593.4 (7)		1593.8 (10)			1593.5 (6)	1593.5 (6)
			1601.8 (15)				1601.8 (15)
			1667.6 (10)				1667.6 (10)
			1694.1 (10)				1694.1 (10)
			1720.5 (15)				1720.5 (15)$^{\times}$
			1732.2 (15)				1732.2 (15)$^{\times}$
	1738.5 (7)		1737.75 (10)			1737.77 (10)	1737.77 (10)
1750	1759 (2)		1759.81 (10)			1759.81 (10)	1759.81 (10)
	1765.5 (6)		1765.44 (10)			1765.44 (10)	1765.44 (10)
	1796.5 (20)		1796.2 (10)			1796.3 (9)	1796.3 (9)
	1809.4 (7)		1809.04 (10)			1809.05 (10)	1809.05 (10)
			1819.69 (10)				1819.69 (10)
	1831.9 (10)		1831.36 (10)			1831.37 (10)	1831.37 (10)

1963Bj02	1967Wa09	1972Sa06	1975Ar23	2000Ni13	2004Br43	LWEIGHT	Recommended
			1863.09 (10)				1863.09 (10)
	1868.6 (8)		1867.69 (10)			1867.7 (1)	1867.7 (1)
	1876.3 (8)		1874.88 (10)			1874.9 (1)	1874.9 (1)
	1893.5 (8)		1893.51 (11)			1893.51 (11)	1893.51 (11)
	1911.5 (7)		1911.19 (11)			1911.20 (11)	1911.20 (11)
			1926.5 (10)				1926.5 (10)
	1937.5 (7)		1937.04 (13)			1937.01 (13)	1937.01 (13)
	1970.4 (10)		1970.0 (15)			1970.3 (8)	1970.3 (8)
					2022.24 (12)		2022.24 (12)$^{\times}$
					2041.23 (13)		2041.23 (13)$^{\times}$
					2065.80 (13)		2065.80 (13)$^{\times}$
					2093.19 (38)		2093.19 (38)$^{\times}$
					2102.14 (15)		2102.14 (15)$^{\times}$
					2136.69 (14)		2136.69 (14)$^{\times}$

#: IT decay, energy from 1973Go40.

a: Expected but as yet unobserved, energy from adopted gammas.

b: Energy from ^{238}Pu α decay.

×: Not placed in level scheme.

5.2 Relative values of the γ-ray intensities

Measurements of the relative γ-ray intensities from ^{234m}Pa are listed in table 6. The recommended values have been obtained with the LWEIGHT computer program using measurement results from 2006Al28, 2004Br43, 2000Ni13, 1992Si17, 1990Sc09, 1986Mo09, 1975Ar23 1971GuZQ and 1967Wa09.

As the measured results of 1990Sc09 and 1971GuZQ contained the contributions from ^{234g}Pa β^- decay, these contributions had to be estimated and removed from the values cited in 2007Br04. Also the measurement results of 1963Bj02 have been rejected and not listed in table as the associated uncertainties are not given.

Table 6: Measured and recommended relative γ-ray intensities from ^{234m}Pa decay

E_γ/keV	I_γ										
	1967Wa09	1971GuZQ	1975Ar23	1986Mo09	1990Sc09	1992Si17	2000Ni13	2004Br43!	2006Al28!	LWEIGHT	Recommended
< 10											17.7 (12)$^{\#}$
41.82^{a}											1.61 (8)^{b}
43.49											166.8 (4)^{b}
62.70^{a}											0.15 (4)^{d}
73.92											1.53 (12)$^{\#}$
99.86^{a}											0.96 (7)^{b}
135.32^{a}											0.000 50 (6)^{d}
137.23^{a}											0.0057 (21)^{d}
140.1			< 0.15								< 0.15
166.5^{a}											0.000 028 (6)^{d}
185.0	0.2 (1)		0.203 (17)							0.203 (17)	0.203 (17)
193.4			0.085 (17)								0.085 (17)
197.91^{a}											0.003 2 (7)^{d}

E_γ/keV	I_γ										
	1967Wa09	1971GuZQ	1975Ar23	1986Mo09	1990Sc09	1992Si17	2000Ni13	2004Br43!	2006Al28!	LWEIGHT	Recommended
199.9			0.068 (14)								0.068 (14)
203.3			0.122 (24)		0.145 (12)[c]					0.14 (1)	0.14 (1)
209.9			0.156 (17)								0.156 (17)
233.6[a]			0.059 (12)								≈ 0.1[e]
235.9[a]											0.010 (4)[d]
236											8.7 (9)[f]
243.5[×]			0.059 (10)								0.059 (10)
247.7			0.114 (26)								0.114 (26)
258.227	6.7 (17)	8.82 (24)	9.66 (39)		8.70 (4)	8.6 (6)	9.08 (24)		8.46 (33)	8.72 (4)	8.72 (4)
275.5			0.037 (7)								0.037 (7)
299.0			0.076 (15)								0.076 (15)
311.0			0.061 (12)								0.061 (12)
316.7[a]											0.022 (5)[d]
338.1			0.134 (27)								0.134 (27)
340.2[a]											0.008 5 (25)[d]
357.5			0.095 (20)								0.095 (20)
362.8			0.081 (17)								0.081 (17)
387.6[&]			0.170 (17)								0.115 (17)
387.6[&]											0.056 (4)[d]
427.4[a]											0.002 4 (6)d
445.91[a]											0.003 6 (8)[d]
450.98	0.42 (10)	0.42 (5)	0.356 (34)		0.358 (19)	0.39 (8)				0.366 (15)	0.366 (15)
453.58		0.254 (24)	0.288 (34)		0.23 (2)	0.31 (6)				0.251 (14)	0.251 (14)
456.7			0.085 (17)								0.085 (17)
468.43		0.204 (41)[c]	0.280 (27)		0.237 (16)[c]				0.19 (10)c	0.243 (13)	0.243 (13)
475.74		0.209 (42)	0.339 (34)		0.274 (18)	0.34 (9)				0.280 (15)	0.280 (15)
485.44[a]											0.002 2 (2)[d]
507.5			0.187 (17)								0.187 (17)
509.2			0.254 (34)								0.254 (34)
516.60[a]											0.001 44 (19)[d]
526.02[a]											0.001 06 (14)[d]
543.98		0.40 (8)[c]	0.441 (51)		0.404 (19)[c]	0.46 (6)			0.32 (21)c	0.412 (17)	0.412 (17)
557.24[a]											0.000 98 (13)[d]
557.3[×]			0.085 (19)								0.085 (19)
572.0			0.103 (20)								0.103 (20)
581.19[a]											0.009 4 (11)[d]
624.6			0.170 (17)								0.013 7 (14)[d]
647.7[×]			0.187 (17)								0.187 (17)
649.0[&]			0.127 (25)								0.007 (1)
649.0[&]											0.12 (3)
655.3			0.164 (17)								0.164 (17)
670.8			0.044 (10)								0.044 (10)
673.9			0.076 (15)								0.076 (15)
683.4			0.068 (14)								0.068 (14)

E_γ/keV	I_γ										
	1967Wa09	1971GuZQ	1975Ar23	1986Mo09	1990Sc09	1992Si17	2000Ni13	2004Br43!	2006Al28!	LWEIGHT	Recommended
691.0		1.09 (6)	0.932 (85)		1.073 (23)	0.92 (10)				1.06 (2)	1.06 (2)
695.5			0.187 (17)			0.28 (6)				0.194 (16)	0.194 (16)
699.02		0.70 (7)	0.095 (19)		0.68 (3)					0.68 (3)	0.68 (3)
702.0		0.85 (8)	0.915 (85)		0.846 (20)	0.93 (10)			0.67 (34)	0.852 (17)	0.852 (17)
705.94		0.72 (7)^{c}	0.481 (51)		0.656 (16)^{c}	0.47 (12)				0.61 (6)	0.61 (6)
708.2			< 0.085								< 0.085
719.01^{a}											0.003 02 (24)^{d}
732.5			0.154 (17)								0.154 (17)
740.10		1.33 (12)	1.20 (12)		1.41 (3)	1.26 (12)				1.39 (3)	1.39 (3)
742.813	13.3 (17)	11.12 (24)^{c}	9.59 (39)	11.3 (7)	10.93 (8)^{c}	10.4 (5)	12.27 (23)c			11.13 (28)	11.13 (28)
750.12^{a}											0.002 02 (27)^{d}
760.3$^{\times}$			0.187 (17)								0.187 (17)
760.53^{a}											0.000 5 (1)^{d}
766.361	36.7 (67)	37.8 (4)^{c}	35.1 (14)	39.91 (84)	38.36 (25)^{c}	37.6 (11)			35.7 (16)	38.2 (2)	38.2 (2)
781.75		0.845 (85)	0.898 (85)		0.93 (2)	0.86 (12)				0.923 (19)	0.923 (19)
783.4^{a}											0.004 6 (8)^{d}
786.272	5 (1)	6.41 (12)^{c}	5.80 (22)	6.36 (46)	6.37 (6)^{c}	5.97 (33)				6.33 (5)	6.33 (5)
791.94											0.001 17 (15)^{d}
805.75		0.718 (38)^{c}	0.509 (51)		0.820 (15)^{c}	0.49 (15)				0.73 (9)	0.73 (9)
808.2		0.34 (4)^{c}	0.356 (34)		0.303 (30)^{c}	0.39 (10)				0.332 (19)	0.332 (19)
810.0											85^{g}
818.2			0.119 (34)								0.119 (34)
825.5	0.42 (25)	0.489 (25)^{c}	0.168 (34)		0.547 (14)^{c}					0.46 (9)	0.17 (4)
844.1			0.129 (27)								0.129 (27)
851.6	0.67 (25)	0.879 (48)^{c}	0.746 (68)		0.820 (17)^{c}	0.83 (9)				0.822 (16)	0.822 (16)
866.8		0.145 (24)	0.127 (26)							0.137 (18)	0.137 (18)
880.52		0.438 (9)^{c}	0.458 (51)		0.468 (4)^{c}	0.52 (16)				0.463 (4)	0.463 (4)
883.24		0.428 (13)^{c}	0.424 (34)		0.453 (4)^{c}	0.50 (16)			0.38 (10)	0.450 (4)	0.450 (4)
887.29$^{\times}$		0.761 (36)	0.882 (85)		0.846 (15)	0.90 (12)				0.836 (14)	0.836 (14)
921.72		1.51 (7)	1.41 (14)		1.51 (2)	1.40 (15)			1.34 (45)	1.506 (19)	1.506 (19)
926.61		0.215 (11)^{c}	0.148 (15)		0.213 (3)^{c}					0.202 (18)	0.148 (15)
936.3		0.091 (23)	0.22 (5)							0.12 (2)	0.12 (2)
941.96		0.282 (24)^{c}	0.356 (34)		0.289 (12)^{c}	0.33 (6)				0.295 (10)	0.295 (10)
945.961		1.33 (3)^{c}	1.19 (12)	1.27 (15)	1.242 (11)^{c}	1.25 (37)			1.18 (31)	1.252 (10)	1.252 (10)
960.0			0.102 (34)								0.102 (34)
996.1		0.90 (5)	0.492 (85)			0.51 (10)				0.7 (2)	0.7 (2)
1001.026	100	100	100	100	100	100	100	100	100		100
1041.70		0.111 (22)	0.170 (17)		0.137 (11)					0.141 (9)	0.141 (9)
1059.4			0.131 (26)								0.131 (26)
1061.86		0.290 (24)	0.237 (17)		0.274 (15)	0.25 (10)				0.264 (10)	0.264 (10)
1081.9			0.107 (22)								0.107 (22)
1084.25			0.058 (10)		0.136 (11)^{c}					0.10 (4)	0.10 (4)
1120.6			0.204 (17)								0.204 (17)
1124.93$^{\&}$	0.50 (17)	0.495 (21)^{c}	0.475 (51)		0.436 (14)^{c}	0.48 (8)				0.456 (11)	0.046 (1)

E_γ/keV	I_γ										
	1967Wa09	1971GuZQ	1975Ar23	1986Mo09	1990Sc09	1992Si17	2000Ni13	2004Br43!	2006Al28!	LWEIGHT	Recommended
1124.93$^{\&}$											0.41 (1)
1174.2			0.227 (22)								0.227 (22)
1193.77	1.33 (33)	1.615 (36)^{c}	1.525 (85)		1.606 (16)^{c}	1.58 (14)			1.67 (78)	1.605 (15)	1.605 (15)
1220.37$^{\times}$		0.106 (23)	0.119 (34)		0.107 (11)					0.108 (10)	0.108 (10)
1237.28	0.50 (17)	0.592 (24)	0.610 (68)		0.632 (12)	0.58 (13)				0.623 (11)	0.623 (11)
1353.0$^{\times}$		0.271 (27)	0.075 (15)		0.226 (10)					0.18 (6)	0.18 (6)
1392.6	0.50 (25)	0.447 (48)	0.187 (17)		0.465 (5)					0.34 (12)	0.34 (12)
1413.89	0.2 (1)	0.279 (17)	0.254 (17)		0.274 (12)					0.270 (9)	0.270 (9)
1434.16	1.17 (33)	1.09 (6)	0.99 (10)		1.156 (15)	1.12 (17)				1.149 (15)	1.149 (15)
1458.5			0.220 (51)								0.22 (5)
1501			0.153								0.153
1510.22	1.83 (33)	1.57 (4)	1.54 (10)		1.538 (19)	1.59 (15)				1.545 (17)	1.545 (17)
1527.28	0.33 (10)	0.263 (16)	0.254 (34)		0.286 (11)					0.277 (9)	0.277 (9)
1550.0		0.153 (11)^{c}	0.220 (17)		0.151 (9)^{c}					0.162 (17)	0.162 (17)
1553.77	1.0 (2)	0.990 (24)	1.068 (85)		0.966 (16)	1.07 (18)				0.976 (13)	0.976 (13)
1558.4		0.085 (12)	0.090 (19)							0.086 (10)	0.086 (10)
1570.67	0.10 (4)	0.127 (19)	0.146 (34)		0.131 (11)					0.130 (9)	0.130 (9)
1593.5	1.33 (33)	0.284 (3)^{c}	0.458 (51)		0.253 (9)^{c}	0.45 (19)				0.278 (13)	0.278 (13)
1601.8			0.056 (25)								0.056 (25)
1667.6		0.145 (12)	0.098 (21)		0.143 (9)					0.139 (7)	0.139 (7)
1694.1		0.044 (4)^{c}	0.054 (10)		0.044 (3)^{c}					0.0445 (23)	0.0445 (23)
1720.5$^{\times}$			0.039 (17)								0.039 (17)
1732.2$^{\times}$			0.220 (34)								0.220 (34)
1737.77	3.0 (4)	2.545 (24)^{c}	2.41 (10)		2.51 (3)^{c}	2.45 (25)				2.528 (18)	2.528 (18)
1759.81$^{\times}$	0.33 (17)	0.174 (7)	0.271 (34)		0.167 (7)					0.173 (5)	0.173 (5)
1765.44	1.17 (33)	0.918 (24)	1.04 (10)		1.037 (15)	1.01 (25)				0.99 (6)	0.99 (6)
1796.3	0.10 (7)	0.036 (6)^{c}	0.037 (7)							0.037 (5)	0.037 (5)
1809.05	0.4 (1)	0.447 (12)	0.508 (51)		0.441 (9)	0.46 (9)				0.444 (7)	0.444 (7)
1819.69		0.103 (7)^{c}	0.141 (31)		0.106 (8)					0.105 (5)	0.105 (5)
1831.37	2.33 (33)	2.114 (24)	1.90 (7)		2.05 (3)	2.09 (21)				2.077 (18)	2.077 (18)
1863.09		0.139 (11)	0.144 (29)		0.143 (6)					0.142 (5)	0.142 (5)
1867.7	1.33 (33)	1.105 (11)	0.90 (9)		1.097 (16)	1.15 (17)				1.101 (9)	1.101 (9)
1874.9	1.17 (33)	0.942 (24)	0.932 (85)		0.977 (15)	0.97 (14)				0.967 (13)	0.967 (13)
1893.51	0.33 (10)	0.256 (11)^{c}	0.254 (17)		0.260 (8)^{c}	0.26 (7)				0.258 (6)	0.258 (6)
1911.20	0.83 (17)	0.737 (12)	0.627 (68)		0.751 (12)	0.74 (11)				0.742 (8)	0.742 (8)
1926.5		0.057 (5)^{c}	0.053 (10)		0.049 (5)^{c}					0.053 (4)	0.053 (4)
1937.0	0.4 (1)	0.336 (7)^{c}	0.356 (34)		0.335 (8)^{c}	0.38 (9)				0.336 (5)	0.336 (5)
1970.3	0.033 (33)	0.0483 (36)	0.066 (14)							0.049 (4)	0.049 (4)
2022.24$^{\times}$								0.022 (2)			0.022 (2)
2041.23$^{\times}$								0.013 (1)			0.013 (1)
2065.80$^{\times}$								0.008 4 (12)			0.008 4 (12)
2093.19$^{\times}$								0.002 4 (7)			0.002 4 (7)
2102.14$^{\times}$								0.007 2 (10)			0.007 2 (10)
2136.69$^{\times}$								0.008 4 (5)			0.008 4 (5)

#: I(γ+ce), from IT decay.

a: Expected but as yet unobserved.

b: From γ-ray transition intensity balance.

c: Removed the contributions from ^{234g}Pa β^- decay.

d: Deduced from adopted γ branching in 2007Br04.

e: I(γ+ce), from I(γ+ce)(γ234)/ I(γ1042) ≈ 0.7 in ^{234}Np ε decay.

f: I(γ+ce), from measured I_{ce}(K) = 70.

g: I(γ+ce), from I_{ce}(810)/ I(γ1001) = 0.51 / 0.6 in 1963Bj02.

&: Multiply placed, intensity suitably divided.

×: Not placed in level scheme.

5.3 Absolute values of the γ-ray emission probabilities

Measurements of the absolute γ-ray emission probability of 1001.026 keV per 100 disintegrations of ^{234m}Pa β^--decay and three weighted average results are listed in Table 7.

It should be noted that the uncertainties quoted in 1990Sc09, 1986Mo09, and 1971GuZQ are questionable (perhaps, only statistical errors were included) when compared with the data of 1992Si17 who used a purified ^{234m}Pa source. Thus 2 % systematic uncertainty was added by the evaluators to those measurement results.

Table 7: Measured and recommended absolute emission probability of the 1001.026 keV γ-ray per 100 disintegrations of ^{234m}Pa β^- decay

P_γ (1001.026 keV) (%)	References	Comments
0.59 (10)	1963Bj02	scintillation spectrometers
0.828 (18)	1971GuZQ	
0.92	1982Mo30	Not used
0.834 (21)	1986Mo09	Ge(Li)
0.839 (20)	1990Sc09	HPGe
0.818 (30)	1992Ja17	
0.788 (43)	1992Li05	
0.845 (21)	1992Si17	HPGe, 0.844 104 with another method
0.910 (25)	1993Su37	
0.924 (17)	1999An40	HPGe
0.861 (15)	2003Yu06	n-type Ge detector
0.923 (30)	2006Al28	HPGe, from extended sample
0.835 (11)	1998Ad08	Evaluation
0.835 (4)	1999Nz01	Evaluation
0.862 (13)		Average of all measurements with LWEIGHT program,χ^2 = 3.7
0.856 (12)		Average of all measurements with Normalised residuals method
0.848 (8)		Average of all measurements with Rajput and MacMahon method
0.848 (8)		**Recommended value**

The recommended value of the absolute γ-ray emission probability of the 1001.026 keV γ-ray is obtained with the method of averaging discrepant data of Rajput and MacMahon (1992Ra08) and adopted as the normalization factor N, with N = 0.008 48 (8) × 0.998 5 (1).

Thus, the recommended absolute γ-ray emission probabilities are the relative values recommended in Table 6 multiplied by 0.008 47 (8).

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^{234}U - Comments on evaluation of decay data
by V. Chisté and M.M. Bé

This evaluation was completed in 2005. Literature available by September 2005 was included.

1 Decay Scheme

^{234}U disintegrates by alpha emission to excited and ground state levels of ^{230}Th. Spin and half-lives of excited states are from the mass-chain evaluation of Y.A. Akovali (1993Ak02 to A = 230, and 1994Ak05 to A = 234).

2 Nuclear Data

The Q value is from atomic mass evaluation of Audi et al. (2003Au03).

The experimental ^{234}U half-life values (in years) are given in Table 1:

Table 1: Experimental values of ^{234}U half-life.

Reference	Original value (10^5 a)	Revised Value by Holden (1981HoZI and 1989Ho24)	Comments
Nier (1939Ni03)	2.70 (27)		**Not used**.
Chamberlain (1946Ch02)	2.29 (14)		**Not used**. Measurements of relative abundance of ^{234}U and ^{238}U.
Chamberlain (1946Ch02)	2.35 (14)		**Not used**. Measurements of α-activity of ^{234}U.
Baldinger (1949Ba41)	2.33 (10)		**Not used**.
Goldin (1949Go18)	2.67 (4)		**Not used**.
Kienberger (1949Ki26)	2.552 (8)		**Not used**. Superseded 1952Ki19
Fleming (1952Fl20)	2.475 (16)	2.475 (24)	**Not used**. Uncertainty increased for missing details.
Kienberger (1952Ki19)	2.520 (8)		**Not used**.
White (1965Wh05)	2.47 (3)		**Not used**.
Meadows (1970MeZN)	2.439 (14)	2.439 (18)	**Not used**. Uncertainty increased for missing details.
de Bievre (1972DeYN)	2.446 (7)	2.450 (9) *	Revised by author (see 1989Ho24)
Lounsbury (1972LoZL)	2.444 (6)	2.458 (13) *	Revised by author (see 1989Ho24)
Geidel'man (1980Ge13)	2.4604 (45)	2.459 (9) *	$4\pi\alpha$ - x coincidence. Revised uncertainty for missing details.
	2.4570 (45)		Liquid scintillator. Revised uncertainty for missing details.
Poenitz (1983 and 1985 Poenitz)	2.457 (5)		**Not used**.
Davideenam (1984Davideenam)	2.457 (5)		**Not used**. Evaluated value.
Recommended value		**2.455 (6)**	reduced χ^2 = 0.28

The first six and less precise values (1940's) were omitted from analysis. For remaining values, the evaluators have chosen to take into account the recommendations given by N.E. Holden (1989Ho24), thus the only three experimental values (*) with associated uncertainties used to the weighted average are 1972DeYN, 1972LoZL and 1980Ge13. For the data in 1980Ge13, the evaluators have chosen to use the average value of 2.459 (9) 10^5 a, calculated from two experimental values given in the paper to produce a single DDEP value from each laboratory. A weighted average has been calculated using LWEIGHT computer program (version 3). However, the treatment of uncertainties in 1989Ho24 ("… when detailed information on the uncertainties was available in each of these experiments, the standard deviation for the experiment was combined with one third of the systematic error to provide the uncertainty quoted in the table: $\sigma_{tot} = \sigma_{statistical} + 1/3\ \sigma_{systematic}$") seemed more realistic, so the evaluators recommend a half-life of *2.455 10^5 a* with a final uncertainty of *0.006 10^5 a*. The reduced - χ^2 value is 0.28.

The experimental ^{230}Th half-life values (in years) are given in Table 2:

Table 2: Experimental values of ^{230}Th half-life.

Reference	Value (a)	Uncertainty (a)
M. Curie (1930Cu02)	82300	2469
E.K. Hyde (1949Hy03)	80000	3000
R.W. Attree (1961At01)	75200	1600
J.W. Meadows (1980Me10)	75381	295
Recommend value	75500	500

The recommended value is the weighted average (calculated with LWEIGHT computer program) of $75.5\ 10^3\ a$ with an external uncertainty of $0.5\ 10^3\ a$. The reduced χ^2 value is 3.3.

The evaluated spontaneous fission partial half-life of ^{234}U is based on the experimental results given in Table 3.

Table 3: Experimental values of ^{234}U spontaneous fission half-life (in 10^{16} years).

Reference	Value	Uncertainty	Comments
A. Ghiorso (1952Gh27)	2	1	**Not used**.
H.R. von Gunten (1981Vo02)	1.42	0.08	
S. Wang (1987Sh27)	1.90	0.15	
Recommend value	1.5	0.2	reduced $\chi^2 = 5.12$

The evaluators have not use the value given in 1952Gh27, as recommended in 1989Ho24.
Evaluators' recommended value is the weighted average of the two remaining values: $1.5\ 10^{16}\ a$ with an external uncertainty of $0.2\ 10^{16}\ a$. The reduced χ^2 value is 5.12.
This value produces a spontaneous fission branching of 1.6 (2) 10^{-9} %.

2.1 a Transitions

The energies of the α-particle transitions given in Section 2.1 have been calculated from the Q_α (2003Au03) and level energies deduced by the evaluators from a least-squares fit to γ-ray energies.

2.2 g Transitions

The transition probabilities have been calculated using the γ-ray emission intensities and the relevant internal conversion coefficients (see **4.2 Gamma Emissions**).

For the 634-keV γ-ray (E0 transition), $P_{(\gamma+ce)} = 1.4\ (7)\ 10^{-5}$ % has been deduced from decay scheme balance.

Multipolarities of γ-ray transitions in decay of ^{230}Th are from 1993Ak02:
53-keV γ-ray : E2
120-keV γ-ray : E2
454-keV γ-ray : E1
503-keV γ-ray: [E2]
508-keV γ-ray: E1
581-keV γ-ray: E2
624-keV γ-ray: E0 + E2 + M1
634-keV γ-ray: E0
677-keV γ-ray: [E2]

The internal conversion coefficients (ICC's) have been calculated using the Icc99v3a computer program (GETICC dialog), which uses interpolated values from new tables of Band et al (2002Ba85). The evaluators have used a fractional uncertainty of 3 % for all conversion coefficients.

3 Atomic Data

Atomic values, ω_K, ϖ_L and n_{KL}, X-ray and Auger electrons relative probabilities are from Schönfeld and Jaβen (1996Sc06).

4 a Emissions

α-particle energies are from Q_α (2003Au03) and level energies (see section 2.1) .For the $\alpha_{0,0}$ and $\alpha_{0,1}$ emissions, the energies are from A. Rytz (1991Ri01).

The measured α-emission intensities are given in Table 4.

Table 4: Measured α-emission intensities, in %.

Energy (keV)	1955Go57	1960Ba44	1961Ko11	1963Bj03	1984Va41	1987Bo25	Recommended Value
4774.6 ($\alpha_{0,0}$)	72	72.5 (30)	73		71.38 (5)	71.37 (2)	71.37 (2)
4722.4 ($\alpha_{0,1}$)		27.15 (15)	27		28.42 (5)	28.42 (2)	28.42 (2)
4603.5 ($\alpha_{0,2}$)		= 0.37 (11)	0.3		0.206 (4)	0.199 (2)	0.210 (2)
4275.2 ($\alpha_{0,3}$)				4 (1) 10^{-5}			4 (1) 10^{-5}
4150.6 ($\alpha_{0,4}$)				1.2 (5) 10^{-5}			2.6 10^{-5}
4108.6 ($\alpha_{0,5}$)				0.3 10^{-5}			7.0 10^{-6}

The U-234 spectrum was recorded by 1984Va41, a second analysis of the same data was done by 1987Bo25, these latest values are the adopted results for the 4774 - and 4722-keV α-emissions intensity. The 4603-keV intensity is deduced from the decay scheme, the tree others being negligible.
The 4275-, 4150-, 4108- keV emission intensities are deduced from 1963Bj03 and decay scheme transition probability balance (§6.2).

6 Photon Emissions

6.1 X-rays

The X-ray and Auger electrons absolute intensities have been calculated from γ-ray data and ICC by using the EMISSION computer program.

In the Table 5 the recommended values of ^{230}Th X-ray emission probabilities are compared with the experimental results. Good agreement was found between the experimental results given by 1977Bemis, 1984Va41 and 1995Jo23 and the recommended values calculated from the decay scheme data set. This agreement confirms the completeness and consistency of the decay scheme.

Table 5: Experimental and recommended (calculated) values of ^{230}Th X-ray emission intensities.

Reference	1977Bemis	1984Va41	1995Jo23	Recommended value
11.118 – 19.504 (L X-ray)	9.81 (13)	10.35 (14)	10.02 (7)	10.2 (4)
Ll - 11.118			0.206 (3)	0.209 (12)
Lα - 12.808 – 12.967			3.42 (2)	3.48 (17)
Lη - 14.509				0.118 7)
Lβ - 14.972 – 16.425			5.17 (4)	5.16 (26
Lγ - 18.363 – 19.504			1.22 (1)	1.21 (6)

Reference	1977Bemis	1984Va41	1995Jo23	Recommended value
89.95 (X $K_{\alpha2}$)		2.53 (7) 10^{-3}		2.69 (25) 10^{-3}
93.35 (X $K_{\alpha1}$)		4.15 (10) 10^{-3}		4.4 (4) 10^{-3}

6.2 Gamma emissions

The energies of the γ-ray emissions given in Section 6 are from Y.A. Akovali (1993Ak02).
The experimental intensity of the 120-keV γ emission given in Table 6 is relative to the 53-keV γ-ray.

Table 6: Experimental relative γ emission intensity (P_{rel}) in %.

γ Energy (keV)	1966Ah02	1974HeYW	1984Va41	Recommended value
53.20	100	100 (5)	100	100.0 (25)
120.90	34 (4)	34.2 (18)	27.5 (5)	30.8 (24)

The recommended values are the weighted averages of the three values given with uncertainties. The normalization factor to convert the relative emission intensities to absolute emission intensities is calculated with the formula:

$$\text{Normalization factor} = \frac{(100\% - 71.371(19)\%)}{\sum\ [(1\ +\ a_T)P_{rel}]} = 0.001253\ (40),$$

where the sum is over all the γ transitions to the ground state and α_T is the relevant conversion coefficient. In this case, the contribution of 508 - (see next), 634 - and 677-keV γ transitions are considered negligible. The uncertainty was calculated through the propagation on the formula given above.

For the 454- and 508-keV absolute emission probabilities, the evaluators have following relations:
$P_\gamma(454) + P_\gamma(508) = 4\ (1)\ 10^{-5}$ (from 1963Bj03) and
$P_\gamma(508) = 0.60\ (4) \times P_\gamma(454)$ (from average value of measured ratios in ^{230}Pa and ^{230}Ac decays. See 1993Ak02).Then the evaluator obtains $P_\gamma(454) = 0.000025\ (6)$ % and $P_\gamma(508) = 0.0000150\ (39)$ %. For the others γ rays, the evaluators present the experimental absolute emission values given in 1993Ak02. The evaluated relative and absolute γ-rays emission intensities are given in Table 7.

Table 7: Evaluated relative and absolute γ-ray emission intensities.

Energy (keV)	Relative emission intensity (%)	Absolute emission intensity (%)
53.20 (2)	100.0 (25)	0.1253 (40)
120.90 (4)	30.8 (24)	0.0386 (32)
454.96 (5)		0.000025 (6)
503.5 (1)		0.00000095
508.16 (5)		0.0000150 (39)
581.7 (1)		0.000012 (5)
624.4 (1)		0.00000082
677.6 (1)		0.000001

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^{235}U - Comments on evaluation of the decay data

Huang Xiaolong, Wang Baosong

This evaluation was completed in 2008, and data available in the literature by June 2008 was included.

1 Decay Scheme

^{235}U disintegrates 100 % by α emission to levels in ^{231}Th. ^{235}U ground state has $J^{\pi} = 7/2^{-}$ (2003Br12). The spontaneous fission branching ratio is 7.0 (20) × 10^{-9} % (from $T_{1/2}$(SF) = 1.0 (3) × 10^{19} a (2000Ho27) and $T_{1/2}$ = 7.04 (1) × 10^{8} a.)

The α decay scheme of ^{235}U was built based on the measurements described in 1974Te03, 1975Va11 and 1977Ba72. A study of 2004Da24 showed the existence of weak α decay branches to some levels in ^{231}Th.

2 Nuclear Data

A Q value of 4678.3 (7) keV is given in 2003Au03 atomic mass adjustment.

Level energies have been obtained from a least-squares fit to γ-ray energies (GTOL computer code). Spin and parities are from 2003Br12.

The measured and evaluated ^{235}U half-life values are listed in Table 1. Notice that the uncertainties in all the tables are in the two least significant digits.

Table 1: Measured half-life values of ^{235}U and recommended value, in 10^{8} a.

References	Original value (10^{8} a)	Materials	Revised value by 2004Sc03	Comments
1939Ni03	7.13 (16)	Natural U	6.97 (24)	Pb/U activity ratio, Mass spectrometry
1950Kn17	7.53 (22)	Enriched U	7.11 (14)	Specific activity, Ionisation chamber
1951Sa30	7.07	Natural U	6.77 (21)	^{235}U/^{238}U activity ratio, Ionisation chamber
1952Fl20	7.13 (16)	Enriched U	7.12 (16)	Specific activity, proportional counter
1957Cl16	7.67	Natural U	7.64 (43)	activity ratio, Ionisation chamber
1957Wu39	6.84 (15)	Natural U	6.95 (16)	^{235}U/^{234}U activity ratios, Ionization chamber
1965De06	6.92 (9)	Natural U		^{235}U/^{238}U activity ratio, Solid-state detector, Updated by 1974De19
1965Wh05	7.13 (9)	Enriched U	7.12 (9)	Specific activity, Solid-state detector
1971Ja07	7.0381 (48)	Highly enriched U	7.04 (1)	Specific activity, proportional counter
1974De19	6.85 (9)	Highly enriched U	6.79 (13)	^{235}U central peak branching ratio, Solid-state detector
1993Bu10	7.04 (1)	Enriched U		Specific activity, (gas + NaI scintillator) Systematic error excluded
2003Br12	7.04 (1)			NDS weighted average with 1993Bu10, 1974De19, 1971Ja07, 1965Wh05, 1965De06 and 1957Wu39
			7.06 (9)	Unweighted mean
			7.04 (1)	Weighted mean,χ^2=1.12. Recommended value

The evaluators have chosen to follow the recommendations given by R. Schön (2004Sc03), who studied in detail various problems with the measurements of the half-life of ^{235}U and decided to recommend the half-life given by 1971Ja07, but multiplied by 2 its original uncertainty in order to include the systematic uncertainties that had not been considered in 1971Ja07. The weighted mean is the same as this precise measurement given in 1971Ja07.

The measured and evaluated ^{235}U spontaneous fission half-life values are listed in Table 2. The value in 1981Vo02 is recommended here.

Table 2: Measured spontaneous fission half-life values of ^{235}U and recommended value, in 10^{19}a.

$T_{1/2}$ (10^{19}a)	References	measurement method
0.018	1952Se67	Ionisation chamber; not used
0.035 (9)	1966Al23	Fission track detectors; not used
> 0.18	1974GrZA	Rotating bubble chamber; no corrections; not used
0.98 (28)	1981Vo02	99.76 % enriched; rotating bubble chamber; corrected for the (α, n, f) reaction
1.0 (3)	2003Br12	NDS, from evaluation of 2000Ho27
0.98 (28)	Recommended value	From 1981Vo02

2.1 γ-Ray Transitions

The γ-ray transition probabilities were deduced from the γ-ray emission probabilities and the relevant internal conversion coefficients.

Multipolarities and mixing ratios of γ-ray transitions are from 2003Br12.

Theoretical internal conversion coefficients (ICC) and their associated uncertainties for γ-ray transitions have been obtained using the BRICC computer program (2008Ki07), which uses the “Frozen Orbital” approximation (2002Ba85).

2.2 α-Particle Transitions

Measured energies of alpha particles are listed in Table 3. Our recommended values are from 1975Va11, 1991Ry01, 2004Da24, Q_α(2003Au03) and level energies.

Table 3: Measured and recommended values of α-particle energies (in keV) from ^{235}U α decay.

1960Ba44	1962Pi06	1966Ga03	1975Va11	1991Ry01	2004Da24	Calc. from level energy and Q(α)	Recommended
						3897.2 (7)	3897.2 (7)
		3977 (10)			3976 (5)	3975.3 (7)	3976 (5)
						3990.5 (9)	3990.5 (9)
						4013.2 (8)	4013.2 (8)
						4053.9 (7)	4053.9 (7)
		4069 (10)			4077	4077.5 (7)	4077.5 (7)
	4153	4140 (3)	4145 (6)		4152 (5)	4154.2 (7)	4152 (5)
4214	4210	4210 (3)	4209 (4)	4214.7 (19)	4215.8 (5)	4217.4 (7)	4214.7 (19)[b]

1960Ba44	1962Pi06	1966Ga03	1975Va11	1991Ry01	2004Da24	Calc. from level energy and Q(α)	Recommended
						4219.6 (7)	4219.6 (7)
			4219 (6)			4227.6 (7)	4227.6 (7)
		4240 (10)			4248 (5)	4252.6 (7)	4248 (5)
	4261				4266 (5)	4270 (4)	4266 (5)
		4267 (10)				4279.3 (7)	4279.3 (7)
			4280		4282 (5)[a]	4286.9 (7)	4286.9 (7)
		4289 (10)	4295			4302.1 (7)	4302.1 (7)
4320	4318	4319 (3)	4322 (4)		4322.9 (6)[a]	4325.4 (7)	4322 (4)
4326						4327.9 (7)	4327.9 (7)
					4364.3 (4)[a]	4361.9 (7)	4361.9 (7)
4368	4361	4362 (3)	4358 (4)	4366.1 (20)		4365.8 (7)	4366.1 (20)[b]
		4368 (5)				4381.1 (7)	4381.1 (7)
4394	4391	4394 (3)	4392 (3)	4397.8 (13)	4395.3 (4)	4396.8 (7)	4397.8 (13)[b]
4412	4414	4411 (5)	4411 (5)		4414.9 (5)	4416.1 (7)	4414.9 (5)
4438	4440	4424 (5)	4435 (5)		4437.9 (40)	4439.3 (7)	4437.9 (40)
4496	4497	4496 (3)	4501 (4)		4502.4 (7)	4504.2 (7)	4502.4 (7)
4550	4551	4550 (3)	4555 (3)		4556.0 (4)	4557.4 (7)	4556.0 (4)
4592	4592	4592 (3)	4597 (3)	4596.4 (13)	4597.3 (4)	4598.7 (7)	4596.4 (13)[b]

[a]: May be a multiplet.

[b]: From 1991Ry01.

Experimental and recommended α-particle emission probabilities are listed in Table 4. Our recommended alpha particle emission probabilities are LWM average values of measured α-particle intensities given in 1975Va11, 2004Da24 and 2005Ga36. Other recommended values are from results deduced from γ-ray transition intensity balance at each nuclear level.

Table 4: Measured and recommended values of α-particle emission probabilities from ^{235}U decay.

E_α(keV)	P_α (%)								
	1960Ba44	1962Pi06	1966Ga03	1975Va11	2004Da24	2005Ga36	Deduced from I_γ	LWM	Recommended†
3976					~0.007		≈0.0011		≈0.0011
4013.2							0.040 (1)		0.0396 (10)
4077.5						0.016 (12)	0.0177 (3)		0.016 (12)
4152		~ 0.3	1.0	0.9 (2) [a]	0.31 (2)	0.286 (18)	0.506 (14)	0.297 (13	0.294 (13)
4214.7	5.5	5.5	6.2	5.7 (6)	6.28 (11)	5.91 (7)	6.0 (4)	6.01 (12	5.95 (12)
4219.6							0.0175 (2)		0.01732 (12)
4227.6				~ 0.9			0.123 (6)		0.122 (6)
4248?			< 0.5		0.07 (1)		0.07 (1)		0.069 (10)?
4266					0.26 (2)	0.200 (16)	0.22 (8)	0.22 (3	0.22 (3)
4279.3			< 0.3				0.0332 (4)		0.0329 (5)

E_α(keV)	P_α (%)								
	1960Ba44	1962Pi06	1966Ga03	1975Va11	2004Da24	2005Ga36	Deduced from I_γ	LWM	Recommended[†]
4286.9		0.6			0.14 (1)[a]	0.066 (13)	0.096 (12)		0.065 (13)
4302.1			< 0.5				0.00969 (12)		0.00959 (13)
4322	3	2.9	3.5	4.7 (5)[a]	3.78 (8)[a]	3.37 (6)	3.3 (7)		3.33 (6)
4327.9	11						0.409 (13)		0.405 (13)
4361.9							0.208 (21)		0.206 (21)
4366.1	6	19	12.3	17 (2)[a]	18.8 (2)[a]	19.00 (13)	19 (5)		18.80 (13)
4381.1			6.1				0.107 (16)		0.106 (16)
4397.8	62	58	53.0 (13)	54 (3)	57.11 (41)	57.98 (22)	58 (5)	57.8 (3)	57.19 (20)
4414.9	2	~ 4	2.3	2.1 (2)	3.07 (7)	3.11 (6)	3.5 (22)	3.04 (16)	3.01 (16)
4437.9	3	~ 0.6	1.8	~ 0.7	0.27 (2)	0.219 (16)	0.206 (16)	0.239 (25)	0.236 (25)
4502.4	1	1.2	1.4	1.7 (2)	1.32 (5)	1.25 (4)	1.23 (24)	1.29 (5)	1.28 (5)
4556.0	3	3.7	1.7	4.5 (5)	3.74 (8)	3.87 (6)	3 (3)	3.83 (6)	3.79 (6)
4596.4	< 1	4.7	1.2	5.4 (5)	4.84 (9)	4.74 (7)	4 (4)	4.79 (6)	4.74 (6)

[†]: Normalized to a total of 100 %.

[a]: May be a multiplet.

3. Atomic data

Atomic fluorescence yields (ω_K,ϖ_L, ϖ_M, η_{KL} and η_{LM}) are from Schönfeld (1996Sc06).

The X-ray and Auger electron emission probabilities have been deduced from γ-ray and conversion electron data by using the computer code RADLST. The deduced K X-ray emission probabilities $P_{K\alpha 1}$ = 5.75 (14) agree with the measured value of 5.55 (14) in 1996Ru11, thus confirming the completeness of the decay scheme.

4. Electron Emissions.

The conversion electron emission probabilities have been deduced from γ-ray transition data using theoretical internal conversion coefficients.

5. Photon Emissions

5.1 γ-ray energy values

The experimental and our recommended γ-ray energies from ^{235}U α decay are listed in table 6. Our recommended values are mainly from the LWM averages based on measurements of 1971Cl03, 1974Te03, 1975Va11, 1977Ba72 and 1984He12 unless otherwise specified. Values in 1986LoZT are from the CRP evaluations done in 1986.

5.2 Absolute γ-ray emission probabilities

Measured relative and absolute γ-ray intensities from ^{235}U are listed together with evaluated values in Table 7. Among these measurements, 1966Ga03, 1971Cl03, 1971KrZH, 1974Te03, 1975Va11, 1977Ba72 and 1996Ru11 are measured relative γ-ray intensities. Other values reported in 1982Va04, 1983BaZZ, 1983Ol01, 1984He12, 1992Li05 and 2006Al28 are measured absolute γ-ray intensities. Thus we evaluated and recommended the γ-ray emission probability of the 185.7-keV reference line firstly.

There are 7 independent measurements of the absolute γ-ray emission probability of the 185.7-keV reference line. Among these absolute measurements, 1982Va04, 1983BaZZ and 1984He12 belong to CRP measurements. The measurement reported in 2006Al28 has not been recommended because of interference with gamma rays from a ^{226}Ra impurity.

The CRP evaluations done in 1986 are reported in 1986LoZT where a recommended P_γ(185.7) = 57.2 (2) is given. We re-calculated P_γ(185.7) and found that the LWM average value based on CRP measurements reported in 1982Va04, 1983BaZZ and 1984He12 is 57.3 (4), and LWM of 1982Va04, 1983BaZZ, 1983Ol01, 1984He12 is 57.1 (3). Our recommended value is taken from the LWM average of values given (Table 5) in 1982Va04, 1983BaZZ, 1983Ol01, 1984He12, 1992Li05 and 1999Ch12, that is, P_γ(185.7) = (57.1 ± 0.3) %.

Table 5: Experimental 185.7-keV absolute gamma-ray emission probabilities.

References	Experimental values (%)	Comments
R. Vaninbroukx (1982Va04)	57.5 (9)	
C. Baktash (1983BaZZ)	57.3 (6)	
D. G. Olson (1983Ol01)	56.1 (8)	
R. G. Helmer (1984He12)	57.2 (5)	
W. –J. Lin (1992Li05)	56.8 (13)	
H. Chatani (1999Ch12)	58 (2)	
Recommended value	57.1 (3)	$\chi^2 = 0.43$

Results for most γ rays given in 1966Ga03 and 1977Ba72 were not used because they did not have uncertainties, unless these were the only measurements for such γ-rays. Relative γ-ray intensities reported in 1971Cl03, 1971KrZH, 1974Te03, 1975Va11 and 1996Ru11 have been normalized using the present recommended P_γ = (57.1 ± 0.3) for the 185.7 keV reference line.

Our “best” recommended absolute γ-ray emission probabilities are mainly from LWM averages of measurements reported in 1971Cl03, 1971KrZH, 1974Te03, 1975Va11, 1982Va04, 1983BaZZ, 1983Ol01, 1984He12, 1992Li05 and 1996Ru11 unless otherwise specified.

Table 6: Measured and recommended values of γ-ray energies for ^{235}U α decay.

1966Ga03	1971Cl03	1974Te03	1975Va11	1977Ba72	1984He12	1986LoZT	LWM	Recommended
			19.59	19.55 (5)				19.55 (5)
		31.50 (20)	31.59 (14)	31.60 (5)			31.60 (5)	31.60 (5)
				34.7 (1)				34.7 (1)[×]
		41.70 (15)	41.1			41.4 (3)		41.4 (3)[a]
		41.96 (15)	42.1 (1)	41.95 (10)		41.96 (15)	42.01 (6)	42.01 (6)
		51.20 (10)	51.7 (4)	51.20 (5)			51.21 (4)	51.21 (4)
				54.1 (1)				54.1 (1)
			54.1	54.25 (5)				54.25 (5)
				64.45 (5)				64.45 (5)
			72.7 (2)			72.7 (2)		72.7 (2)
				73.72 (5)				73.72 (5)
	74.923 (23)	74.76 (20)	75.02 (5)			75.02 (5)	74.94 (3)	74.94 (3)
			95.7					95.7
		96.09 (2)	96.1	96.2				96.09 (2)
97 (4)								97 (4)
109 (4)	109.120 (8)	109.145 (10)	109.25 (5)	109.25 (5)		109.16 (2)	109.19 (7)	109.19 (7)
115 (4)	115.2 (3)		115.5 (2)	115.45 (5)			115.45 (5)	115.45 (5)
			120.0	120.35 (5)				120.35 (5)
			136.6	136.55 (5)				136.55 (5)
	140.75 (10)	140.758 (20)	140.80 (8)	140.75 (5)		140.76 (4)	140.76 (2)	140.76 (2)
				142.40 (5)				142.40 (5)
144 (2)	143.776 (10)	143.753 (8)	143.77 (2)	143.75 (5)	143.768 (3)	143.76 (2)	143.767 (3)	143.767 (3)
			147.0					147
151 (4)	150.960 (33)	150.939 (20)	150.94 (3)	150.85 (5)		150.93 (2)	150.936 (15)	150.936 (15)
	163.363 (10)	163.349 (9)	163.36 (2)	163.25 (5)	163.357 (3)	163.33 (2)	163.356 (3)	163.356 (3)
			173.0 (10)					173 (1)

1966Ga03	1971Cl03	1974Te03	1975Va11	1977Ba72	1984He12	1986LoZT	LWM	Recommended
			182.1					182.1
	182.72 (20)	182.65 (15)	182.7 (2)	182.60 (5)		182.61 (5)	182.62 (5)	182.62 (5)
184 (2)	185.718 (11)	185.712 (10)	185.72 (2)	185.65 (5)	185.722 (4)	185.715 (5)	185.720 (4)	185.720 (4)
196 (4)	194.941 (9)	194.938 (10)	194.94 (2)	194.95 (5)		194.94 (1)	194.940 (6)	194.940 (6)
	198.91 (15)	198.898 (15)	198.88 (6)	198.75 (10)		198.90 (2)	198.894 (14)	198.894 (14)
				199.6 (1)				199.6 (1)$^{\times}$
	202.133 (14)	202.105 (12)	202.12 (2)	202.05 (5)		202.11 (2)	202.12 (1)	202.12 (1)
	205.311 (12)	205.312 (10)	205.31 (2)	205.25 (5)	205.318 (4)	205.311 (10)	205.316 (4)	205.316 (4)
		215.26 (20)	215.28 (5)	215.3 (1)			215.28 (4)	215.28 (4)
	221.375 (40)	221.397 (25)	221.38 (2)	221.40 (5)		221.38 (2)	221.386 (14)	221.386 (14)
			228.78 (5)	228.7 (1)			228.76 (5)	228.76 (5)
	233.53 (4)	233.49 (3)	233.50 (3)	233.55 (10)		233.50 (3)	233.50 (2)	233.50 (2)
	240.93 (4)	240.95 (4)	240.87 (3)	240.75 (5)		240.87 (3)	240.88 (4)	240.88 (4)
	246.83 (4)	246.59 (10)	246.84 (2)	246.85 (5)		246.84 (4)	246.83 (2)	246.83 (2)
				251.5 (1)				251.5 (1)$^{\times}$
	266.44 (8)	266.40 (10)	266.50 (5)				266.47 (4)	266.47 (4)
		275.35 (15)						275.35 (15)
			275.24 (20)	275.50 (5)			275.49 (6)	275.49 (6)
				279.50 (5)				279.50 (5)$^{\times}$
			281.42 (5)					281.42 (5)
285 (5)			282.92 (5)	283.0 (1)			282.94 (5)	282.94 (5)
			289.56 (4)					289.56 (4)
			291.2					291.2
		291.58 (15)	291.65 (3)	291.65 (5)			291.65 (3)	291.65 (3)
				294.3 (1)				294.3 (1)$^{\times}$
			301.7 (1)					301.7 (1)
			310.69 (6)					310.69 (6)
			317.10 (8)					317.10 (8)

1966Ga03	1971Cl03	1974Te03	1975Va11	1977Ba72	1984He12	1986LoZT	LWM	Recommended
				325.8 (1)				325.8 (1)
			343.5 (2)					343.5 (2)
				345.4 (1)				345.4 (1)$^{\times}$
		345.84 (15)	345.93 (3)	345.90 (5)			345.92 (3)	345.92 (3)
350 (5)								350 (5)
			356.03 (5)					356.03 (5)
				368.5 (1)?				368.5 (1)?
				371.8 (1)				371.8 (1)$^{\times}$
		387.79 (15)	387.84 (3)	387.85 (10)			387.84 (3)	387.84 (3)
		390.27 (20)						390.27 (20)
			410.29 (4)					410.29 (4)
430 (5)				~433.0 (5)				433.0 (5)
			448.40 (6)					448.40 (6)
			455.1 (1)					455.1 (1)$^{\times}$
			517.9 (2)					517.9 (2)$^{\times}$
			742.5 (2)					742.5 (2)$^{\times}$
			794.7 (1)					794.7 (1)$^{\times}$

$^{\times}$: Not placed in level scheme.

^{a}: From 1986LoZT.

Table 7: Measured and recommended absolute γ-ray emission probabilities for ^{235}U.

E_γ(keV)	1966Ga03[a]	1971Cl03[a]	1971KrZH[a]	1974Te03[a]	1975Va11[a]	1977Ba72[a]	1982Va04	1983BaZZ	1983Ol01	1984He12	1986LoZT	1992Li05	1996Ru11[a]	LWM	Adopted[*]
19.55															60 (1)[#]
31.60				0.017 (6)		0.046									0.017 (6)
34.7[×]						0.037									0.037
41.4				0.029 (11)											0.029 (11)
42.01			0.053	0.04 (2)	0.0169	0.063		0.06 (1)			0.06 (1)			0.056 (9)	0.056 (9)
51.21				0.004 (2)[b]	0.034 (7)	0.017									0.034 (7)
54.1						0.03?									≈0.00115[#]
54.25						0.03?									≈0.0285[#]
64.45						0.018									0.018
72.7					0.116										0.116
73.72						0.01									0.01
74.94		0.0012 (1)[b]	0.137	0.051 (6)	0.074			0.51 (5)[b]			0.06 (1)				0.051 (6)
95.7															
96.09				0.091 (11)											0.091 (11)
97	<1														0.016 (4)[#]
109.19	5.1	1.60 (12)	1.59 (21)	1.77 (17)	1.48 (21)	1.03		1.53 (5)			1.54 (5)	2.17 (17)	1.80 (6)	1.66 (13)	1.66 (13)
115.45	<1	0.14 (1)[b]	0.12 (3)[b]		0.033 (12)	0.017									0.03 (1)
120.35						0.026									0.026
136.55						0.012									0.012
140.76		0.183 (13)	0.18 (2)	0.26 (3)	0.22 (3)	0.171		0.214 (15)			0.22 (2)			0.200 (12)	0.20 (1)
142.40						0.0051									0.0051
143.767	11.7	10.3 (8)	10.3 (6)	11.2 (11)	11.1 (12)	9.92	10.9 (2)	10.7 (2)	10.93 (15)	11.01 (8)	10.96 (8)	10.99 (61)	10.9 (2)	10.94 (6)	10.94 (6)
147															
150.936	<1	0.114 (9)	0.116 (32)	0.080 (11)	0.080 (11)	0.074		0.066 (10)			0.08 (1)			0.088 (26)	0.09 (3)
163.356		4.9 (4)	4.9 (3)	4.99 (51)	5.1 (5)	4.16	5.0 (1)	4.97 (10)	5.07 (8)	5.12 (4)	5.08 (4)	4.98 (12)	5.08 (5)	5.076 (26)	5.08 (3)
173			0.016		0.006 (5										0.006 (5)

E_{γ}(keV)	1966Ga03^{a}	1971Cl03^{a}	1971KrZH^{a}	1974Te03^{a}	1975Va11^{a}	1977Ba72^{a}	1982Va04	1983BaZZ	1983Ol01	1984He12	1986LoZT	1992Li05	1996Ru11^{a}	LWM	Adopted*
182.1															
182.62		0.43 (3)	0.42 (4)	0.42 (14)	0.44 (10)	0.312		0.339 (17)			0.34 (2)	0.803 (103)	0.43 (5)	0.39 (5)	0.39 (5)
185.720							57.5 (9)	57.3 (6)	56.1 (8)	57.2 (5)	57.2 (2)	56.8 (13)		57.1 (3)	57.1 (3)
194.940	4.7	0.69 (5)	0.69 (6)	0.61 (9)	0.62 (6)	0.67		0.626 (13)			0.63 (1)	0.618 (48)	0.61 (2)	0.626 (10)	0.63 (1)
198.894		0.032 (3)	0.032	0.046 (6)	0.033 (5)	0.097?		0.047 (6)			0.42 (6)			0.036 (2)	0.036 (2)
199.6$^{\times}$						0.097?									~0.06$^{\&}$
202.12		1.06 (8)	1.1 (5)	1.07 (11)	1.07 (11)	1.25		1.08 (2)			1.08 (2)	1.16 (7)	1.06 (4)	1.080 (17)	1.08 (2)
205.316		5.3 (4)	5.18 (32)	4.9 (4)	5.0 (5)	5.51	5.0 (2)	5.05 (5)	5.03 (9)	4.96 (5)	5.01 (5)	4.98 (14)	5.03 (5)	5.015 (26)	5.02 (3)
215.28			0.42	0.029 (6)	0.029 (3)	0.025								0.029 (3)	0.029 (3)
221.386		0.126 (9)	0.08	0.12 (3)	0.116 (11)	0.125		0.114 (6)			0.12 (1)			0.118 (5)	0.118 (5)
228.76			0.0085		0.0074	0.0011									0.0074
233.50		0.042 (3)	0.021	0.034 (11)	0.032			0.029 (5)			0.029 (5)			0.038 (4)	0.038 (4)
240.88		0.074 (6)	0.0032	0.063 (17)	0.085	0.089		0.076 (6)			0.075 (6)			0.074 (4)	0.074 (4)
246.83		0.063 (5)	0.021	0.046 (17)	0.085	0.067?		0.053 (3)			0.053 (3)			0.055 (3)	0.055 (3)
251.5$^{\times}$						0.067?									~0.012$^{\wedge}$
266.47		0.0080 (6)	0.0053	0.0063 (17)	0.0095									0.0078 (6)	0.0078 (6)
275.35				0.051 (6)											0.051 (6)
275.49			0.042		0.032	0.114									0.032
279.5$^{\times}$						0.264									0.264
281.42					0.0063										0.0063
282.94	0.001		0.0032		0.0063	0.004									0.0063
289.56					0.0074										0.0074
291.2															
291.65			0.021	0.040 (6)	0.032	0.095									0.040 (6)
294.3$^{\times}$						0.033									0.033
301.7					0.0053										0.0053
310.69			0.0017		0.0053										0.0053
317.10					0.0011										0.0011

E_γ(keV)	1966Ga03[a]	1971Cl03[a]	1971KrZH[a]	1974Te03[a]	1975Va11[a]	1977Ba72[a]	1982Va04	1983BaZZ	1983Ol01	1984He12	1986LoZT	1992Li05	1996Ru11[a]	LWM	Adopted*
325.8						0.004									0.004
343.5					0.0032										0.0032
345.4×						0.072?									~0.03+
345.92			0.0017	0.040 (6)	0.074	0.072?									0.040 (6)
350	0.006														0.006
356.03					0.0053										0.0053
371.8×						0.069?									
387.84				0.040 (6)	0.0085	0.159									0.040 (6)
390.27				0.040 (1)											0.040 (1)
410.29					0.0032										0.0032
433.0	0.001					0.004									0.004
448.40					0.0011										0.0011
455.1×					0.0085										0.0085
517.9×					0.00042										0.00042
742.5×					0.00042										0.00042
794.7×					0.00063										0.00063

×: Not placed in level scheme.

#: From intensity balance.

&: From P_γ(198.9 + 199.6) = 0.097 %.

^: From P_γ(246.8 + 251.5) = 0.067 %.

+: From P_γ(345.4 + 345.9) = 0.072 %.

*: Deduced using the LWM statistical method, unless otherwise specified.

a: The P_γ values have been deduced from the measured relative intensities and normalized to P_γ = (57.1 ±0.3) % for the 185.7 keV reference line.

b: This value, which deviates by a factor of about 10 from the results of the other measurements, was not used in the calculation of the recommended value.

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^{236}U – Comments on Evaluation of Decay Data
by A. Luca

This evaluation was completed in April 2008. The literature available by February 2008 was included.

1. Evaluation Procedures

The Limitation of Relative Statistical Weight (LWM) (1988WoZO) method was applied for averaging numbers throughout this evaluation; this method was implemented by using the computer code LWEIGHT, ver. 4 (designed for Excel, MS Office), [1] [2]. The uncertainty assigned to an average value in this evaluation is never lower than the lowest uncertainty of any of the experimental input values.

2. Decay Scheme

^{236}U decays 100 % by alpha-particle emissions, mainly to the ground state and to the 49 keV excited level of ^{232}Th. ^{236}U decays also by spontaneous nuclear fission, with a weak branch (about 9 10^{-8} %). According to Tretyakova et al. (1994Tr12), a very weak cluster decay of ^{236}U (~10^{-13} probability relative to the alpha emission), consisting of Ne and Mg emission, was observed. The spin, parity, energy and half-life of the ^{232}Th excited levels, and the multipolarities of the γ-ray transitions have been adopted from the A=232 ENSDF mass-chain evaluation of E. Browne (2006Br19).

3. Nuclear Data

The adopted alpha-decay energy value Q(α) = 4573.1 (9) keV, is from 2003Au03. This value is in agreement with the effective Q(α) value of 4570 keV (with an uncertainty of 260 keV), calculated from the decay scheme data, by using the SAISINUC software. This agreement proves the consistency and correctness of the decay scheme.

3.1. Half-life

The measured half-life ($T_{1/2}$) values, with the reviewed uncertainties (1989Ho24), are shown below in Table 1. After a new critical review (based on the most precise modern activity measurements by using the defined solid angle α-particle counting method, according to the Bureau International des Poids et Mesures (BIPM), Key Comparison Database, section "Calibration and Measurement Capabilities" (CMCs) - Ionizing Radiation, http://kcdb.bipm.org/AppendixC/), the uncertainty of the most recent half-life value (1972Fl03) was increased from about 0. 06 % to 0.25 %; accordingly, the half-life was rounded from 2.3415 10^7 to 2. 342 10^7 years. The set of data is consistent and the recommended value, 2.343 10^7 years, with the uncertainty of 0.006 10^7 years, is the weighted average (LWM, χ^2_ν=0.72) of the three input values. The references are expressed as NSR (Nuclear Science References) type keynumbers:

Table 1

$T_{1/2}$ (10^7 years)	Uncertainty of $T_{1/2}$ (10^7 years)	Reference
2.46	0.14	1951Ja09
2.391	0.057	1952Fl20
2.3415	0.0039	1972Fl03

The measured half-life ($T_{1/2}$) values for the ^{236}U spontaneous fission are presented below in Table2:

Table 2

$T_{1/2\ sf}$ (10^{16} years)	Uncertainty of $T_{1/2\ sf}$ (10^{16} years)	Reference
2.0	1.6	Jaffey and Hirsch, 1949 [3]
2.7	0.3	1971Co35
2.43	0.13	1981Vo02
2.7	0.4	1983Be66

The value mentioned in ref. [3] was unpublished, but it is cited in E.K. Hyde, 1964 [4]. This data set is consistent, and the recommended value, 2.49 10^{16} years, with the uncertainty of 0.13 10^{16} years, is the weighted average (LWM, $\chi^2_\nu = 0.36$) of the four input values from the first column.

3.2. Alpha transitions and emissions

In the literature, only one reference about measurements of energy and emission probability for ^{236}U alpha transitions was found: 1960Ko04. In another reference (1992It01), the measured energy of the main alpha-particle emission (4.49 MeV) was reported.
For this evaluation, the energies and the intensities of α_0 and α_{49} are from 1960Ko04. The energy of α_{162} is also from 1960Ko04, but its intensity is from γ-ray transition intensity balance. The energy of α_{333} is from $Q(\alpha) = 4573.1$ (9) keV and E(level) = 333.40 keV; its intensity is from γ-ray transition intensity balance (2006Br19). These values, as well as their α hindrance factors (HF) are shown in Table 3.

Table 3

E_α (keV)	Uncertainty E_α (keV)	Emission intensity (%)	α Hindrance Factor (HF)
4494	3	73.8 (40)	1.0
4445	5	26.1 (40)	1.2
4332	8	0.149 (22)	27.3
4168	-	0.000 14 (5)	1160

3.3. g- transitions: g rays and internal conversion electrons

Measurements of the two main γ-ray transition energies are presented in a paper by Schmorak *et al.*, 1972Sc01. Their uncertainties may have been somewhat underestimated for the detection system that they used. Measurements of the energies and relative intensities for the γ rays following the decay of ^{236}U were published only by Gehrke et al. (2002Ge02), as shown in Table 4.
The decay-scheme normalization condition applied for the ^{232}Th ground state, allowed the determination of the absolute emission probability for the 49.46 keV γ ray ($I_{\gamma 49}$, expressed in %):
$(\alpha^T_{49}+1) \cdot I_\gamma(49) + I_\alpha(4494) = 100$ %, where $\alpha^T_{49} = 324.4$ is the theoretical internal conversion coefficient (program BrIcc v2.0a, [5]) for the 49 -keV γ ray and $I_\alpha(4494) = 73.8$ (40) %. The resulting value for the absolute emission probability of the main γ ray following the ^{236}U alpha decay, is $I_\gamma(49) = 0.081$ (12) %. Using this value and the relative intensity values of the 112 keV and 171 keV γ-ray emissions measured by Gehrke *et al.*, the corresponding absolute emission probabilities and their uncertainties were computed and are given below in Table 4.

Table 4:

E_γ (keV)	Uncertainty E_γ (keV)	Relative Emission probability (%)	Absolute Emission probability (%)	Total ICC (α_T)
49.46	0.10	100	0.081 (12)	324
112.79	0.10	24.1 (1)	0.019 5 (31)	6.67
171.15	0.20	0.080 (24)	0.000 065 (22)	1.186

4. Atomic data

The K-shell fluorescence yield (ω_K), the mean L-shell fluorescence yield (ν_L) and the mean number of vacancies in the L-shell produced by one vacancy in the K-shell (η_{KL}) were determined using the computer program EMISSION v3.10, 28-Jan-2003 [6]: 0.969 (4), 0.476 (18) and 0.797 (5) respectively.

4.1. Auger electrons and X-rays

The relative probability values of the K Auger electron emissions (KLL, KLX, KXY) normalized to the KLL value, were computed using the same EMISSION computer program. The total K Auger electron emission probability (absolute) and the emission probability of the L Auger electrons were also calculated. The energy ranges for K and L Auger electrons were filled-in by the SAISINUC program [7]. The relative probability (normalized to $K_{\alpha 1}$ X-rays emission) and the absolute emission probability values of the different groups of K and L X-rays were determined using the same EMISSION program. The energy range values of the K and L X-rays are from the tables linked to SAISINUC. The results for absolute emission probabilities of LX rays (I(LX) = 9.4 (10) %) agrees with I(LX) = 9.4 (13) % given in the Table of Radioactive Isotopes [8]. The KX ray emission probabilities are so weak that are not given in reference [8].
Neither measurements of X-ray energies nor of emission probabilities were found in the literature.

5. Main production mode

The main production mode of ^{236}U is by irradiating ^{235}U nuclei with thermal neutrons in nuclear reactors; the ^{236}U is produced by thermal neutron captures: ^{235}U(n,γ)^{236}U. The neutron-capture cross section is 98.3 (8) barn [9].

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^{236}Np – Comments on evaluation of decay data
by V.P. Chechev and N.K. Kuzmenko

This evaluation was done originally in June 2006 and then updated in April 2009 with a literature cut-off by the same date.

1. DECAY SCHEME

From the systematics of the isomer levels it has been assumed in 1981Li30 (see also the analysis carried out in 1991Sc08) that the short-lived state of ^{236}Np (22,5 h) lies higher in energy than the long-lived state of ^{236}Np (1,55 × 10^5 a). In line with this assumption we consider the long-lived state of ^{236}Np as the ground state. Using Q values for electron capture decay of the isomer and ground state and a close energy cycle we can estimate the energy level spacing between these states as 60 (50) keV.

The decay scheme of the long-lived ^{236}Np includes three decay modes: β^- decay to ^{236}Pu, electron capture decay (EC) to ^{236}U and α decay to ^{232}Pa (see 2006Br20). A favored α-particle branch to the (6^-) level at ≈ 400 keV is expected in ^{232}Pa from α systematics (1972El21, 1980Sc26, 2006Br20). However, this decay was not observed experimentally.

The β^- -decay branching, $\Sigma P(\beta^-)$, and alpha-decay branching, $\Sigma P(\alpha)$, have been deduced by the evaluators from the partial half-lives $T_{1/2}(\beta^-)$ and $T_{1/2}(\alpha)$, respectively, measured in 1981Li30. The EC-decay branching, $\Sigma P(EC)$, has been obtained as the difference of $1 - \Sigma P(\beta^-) - \Sigma P(\alpha)$.

2. NUCLEAR DATA

Q^-, Q_{EC}, $Q(\alpha)$ values are from 2003Au03.

The total half-life of ^{236}Np is based on the evaluated partial half-lives $T_{1/2}(\alpha)$, $T_{1/2}(\beta^-)$, $T_{1/2}(EC)$ measured in 1981Li30.

The evaluated $T_{1/2}(\alpha) = 9,5\ (35) \times 10^7$ years has been obtained as an average of the two measurements of 1981Li30 (specific activity, ^{232}U gamma-ray of 894 keV was measured): 9,4 (35) × 10^7 and 9,6 (35) × 10^7 years. A standard deviation of the individual measurement has been adopted for the uncertainty of the evaluated alpha-decay half-life using a rule that the uncertainty assigned to the recommended value should be greater than or equal to the smallest uncertainty in any experimental value.

$T_{1/2}(\beta^-) = 1,29\ (3) \times 10^6$ years has been adopted here from the ^{236}Pu growth measurement of 1981Li30. The result of this measurement is independent of the decay scheme, and it is equal to the weighted average of 1,34 (15), 1,29 (3), 1,32 (9), 1,69 (30), 1,29 (3), 1,31 (8) (in 10^6 years) given in 1981Li30. The uncertainties of these measurements do not include any estimation of uncertainties from the decay scheme parameters. It agrees well with an earlier measurement in 1972En06 (1,29 (+ 0,07, - 0,05) × 10^5 a).

The evaluated $T_{1/2}(EC) = 1,77\ (10) \times 10^5$ years has been obtained as an average of the two ^{236}U/^{235}U mass ratio measurements in 1981Li30: 1,75 (10) × 10^5 and 1,79 (10) × 10^5 years. These ^{236}U growth measurement results are independent of the decay scheme. A standard deviation of the individual measurement has been adopted for the uncertainty of the evaluated partial EC-decay half-life. The specific gamma-ray activity method (^{236}U 160,3-keV gamma-ray was measured) was used in other measurements presented in 1981Li30 (in 10^5 years): 1,60 (4), 1,73 (2), 1,77 (11), 1,75 (10), 1,79 (10), 1,74 (1), 1,78 (10). The uncertainties of these measurements do not include an estimation of uncertainties from the decay scheme parameters.

Thus, the recommended value of the total ^{236}Np half-life obtained from the relation $T_{1/2} = [(T_{1/2}(\alpha))^{-1} + (T_{1/2}(\beta^-))^{-1} + (T_{1/2}(EC))^{-1}]^{-1}$ is 1,55 (8) × 10^5 years.

2.1.1. Electron Capture Transitions

The energies of the electron capture transitions have been deduced from the Q_{EC} value and the level energies given in Table 1 from 2006Br20 where they were deduced from a least squares fit to gamma-ray energies.

Table 1. ^{236}U levels populated in ^{236}Np electron capture decay

Level number	Energy (keV)	Spin and parity	Half-life	Probability of ε - transition (x 100)
0	0,0	0^+	$2{,}342 \cdot 10^7$ a	-
1	45,2440 (20)	2^+	234 (6) ps	-
2	149,477 (6)	4^+	124 (7) ps	0,0 (44)
3	309,785 (7)	6^+	58 (3) ps	87,8 (43)
4	687,59 (4)	1^-	3,78 (9) ns	-
5	744,18 (7)	3^-	< 0,1 ns	-
6	848,1 (8)	5^-		~ 0,09

The probabilities of the electron capture transitions $P(EC_{0,2})$ and $P(EC_{0,3})$ have been deduced from the correlations of:
$P(EC_{0,2}) + P(EC_{0,3}) = 100\ \% - \sum P(\beta^-) - \sum P(\alpha) = 87{,}8\ (6)\ \%$ and $P(EC_{0,3}) = P(\gamma_{3,2} + ce)$(160-keV).
The upper limit of $P(EC_{0,2}) < 4{,}4\ \%$ has been obtained from the level intensity balance: $P(EC_{0,2}) = 0{,}0\ (44)\ \%$. The estimate of $P(EC_{0,6}) \sim 0{,}1\ \%$ is given in 1996FiZX.

2.1.2. Beta Transitions

The energies of the β^-- transitions have been deduced from the Q^- value and the level energies given in Table 2 from 2006Br20 where they were deduced from a least squares fit to gamma-ray energies.

Table 2. ^{236}Pu levels populated in ^{236}Np β^--decay

Level number	Energy (keV)	Spin and parity	Half-life	Probability of β^-- transition (x100)
0	0,0	0^+	2,858 a	-
1	44,63 (10)	2^+		-
2	147,45 (10)	4^+		0,2 (14)
3	305,80 (11)	6^+		11,8 (12)

The β^- transition probability $P(\beta_{0,3}) = P(\gamma_{3,2}+ce)$(158-keV) and $P(\beta_{0,2}) = 12{,}0\ (6)\ \% - P(\beta_{0,3}) = 0{,}2\ (14)\ \%$. An upper limit of $P(\beta_{0,2}) < 1{,}6\ \%$ follows this result.

2.2. Gamma Transitions and Internal Conversion Coefficients

The evaluated energies of gamma-ray transitions are virtually the same as the photon energies because nuclear recoil is negligible.

The gamma-ray transition probabilities have been obtained from the gamma-ray emission probabilities and the total internal conversion coefficients (ICCs).

Multipolarities of gamma-ray transitions have been taken from 2006Br20. The ICCs have been interpolated using the BrIcc package with the so called "*Frozen Orbital*" approximation (2008Ki07) except for $\gamma_{4,1}$ (642,3-keV) and $\gamma_{4,0}$ (687,6-keV). The relative uncertainties of the ICCs for pure multipolarities have been taken as 2 %.

For $\gamma_{4,1}$(642,3-keV) and $\gamma_{4,0}$(687,6-keV) the ICC values of α_K and α_L are experimental results from ^{240}Pu α-decay study (1969Le05, 1977Po05). The ICC values of α_M and α_T for these transitions have been deduced using α_M/α_L and α_{NO}/α_M from 1971Dr11. More accurate ICC measurements for these E1 anomalously converted gamma-ray-transitions are required.

3. ATOMIC DATA

The atomic data are from Schönfeld and Janβen (1996Sc06).

4. ELECTRON EMISSIONS

The energies of the conversion electrons have been obtained from the gamma transition energies and the atomic electron binding energies.

The emission probabilities of the conversion electrons have been obtained using evaluated P(γ) and ICC values.

The absolute emission probabilities of K and L Auger electrons have been obtained using the EMISSION computer program.

β^- average energies have been obtained using the LOGFT computer program.

5. PHOTON EMISSIONS

5.1. X-Ray Emissions

The absolute emission probabilities of U and Pu KX- and LX-rays have been deduced using the EMISSION computer program.
For U LX-ray intensity calculations the theoretical fractional ratios $P_{EC}(L2)/P_{EC}(L1) = 0{,}115$ and $P_{EC}(L3)/P_{EC}(L1) = 0$ for the EC-transition to the level ''3'' (309 keV) of ^{236}U have been used (1972Dzhelepov). The calculated relative intensities of U KX- rays accompanying the electron capture of ^{236}Np are in a good agreement with the experimental results (Table 3).

Table 3. Intensities of U KX- rays (relatively to P($\gamma_{3,2}$-160,3 keV)) accompanying ^{236}Np electron capture

	1983Ah03 (experimental)	Adopted (deduced)
X_K		
$K\alpha_2$	0,61 (2)	0,64 (3)
$K\alpha_1$	0,99 (3)	1,02 (5)
$K\beta_1$'	0,38 (2)	0,368 (19)
$K\beta_2$'	0,131 (7)	0,126 (7)

5.2. Gamma Ray Emissions

5.2.1. Gamma Ray Energies (^{236}U)

The energies of gamma-rays in ^{236}Np electron capture have been taken from 2006Br20.

5.2.2. Gamma Ray Energies (^{236}Pu)

The energies of gamma-rays $\gamma_{1,0}$ (44,6 keV), $\gamma_{2,1}$ (102,8 keV), $\gamma_{3,2}$ (158,3 keV) accompanying β^- decay of ^{236}Np have been adopted from measurements given in 1983Ah02 (see also 2006Br20).

5.2.3. Gamma-Ray Emission Probabilities (^{236}U)

The evaluated gamma-ray emission probabilities P(γ) have been deduced using the relative gamma-ray intensities from 1983Ah02 (Table 4), the relation of $\sum P(EC_{0,i})$ = 87,8 (6) % = P($\gamma_{2,1}$ +ce)(104,23 keV) and the intensity balance at ^{236}U each level. We have assumed that the populations to the two lower levels ("0" and "1") in the ^{236}Np electron capture decay are negligible and have taken into account the intensity balance correlation for the gamma-ray transitions to these levels, that is P($\gamma_{1,0}$ +ce)(45,2 keV) = P($\gamma_{2,1}$ +ce) (104,2 keV).

The recommended gamma-ray emission probabilities for γ-rays de-exciting level ''4'' ($\gamma_{4,2}$(538,1 keV), $\gamma_{4,1}$(642,3 keV), and $\gamma_{4,0}$(687,6 keV)) have been deduced from the correlation:
P($\gamma_{5,4}$ +ce)(56,6 keV) = P($\gamma_{4,2}$ +ce)(538,1 keV) + P($\gamma_{4,1}$ +ce)(642,3 keV) + P($\gamma_{4,0}$ +ce)(687,6 keV) using the relative intensities for these γ-rays evaluated from the ^{240}Pu α-decay (Table 5) and assuming P($EC_{0,4}$) = 0.

Table 4. Gamma rays in decay of the long-lived ^{236}Np measured in 1983Ah02

	Energy (keV)	Relative intensity
$\gamma_{1,0}$ (^{236}U)	45,23 (3)	0,4 (1)
$\gamma_{2,1}$ (^{236}Pu)	102,82 (2)	2,9 (2)
$\gamma_{2,1}$ (^{236}U)	104,23 (2)	23 (1)
$\gamma_{3,2}$ (^{236}Pu)	158,35 (2)	13,5 (7)
$\gamma_{3,2}$ (^{236}U)	160,33 (2)	100

Table 5. Experimental and evaluated absolute emission probabilities of gamma-rays de-exciting the ^{236}U level with energy of 687,6 keV in decay of ^{240}Pu (per 10^8 α-decays) and the deduced relative intensities of these gamma-rays

	Energy (keV)	1969Le05	1971GuZY	1975OtZX	1975Dr05	1976GuZN	Evaluated	Evaluated relative intensities
$\gamma_{4,2}$	538,1	≈ 0,23 [a]		0,147 (12)			0,147 (12)	1,17 (10)
$\gamma_{4,1}$	642,3	14,5 [a]	14,5 (5) [b]	12,6 (4)	13 (1)	12,45 (30)	12,6 (3) [c]	100 (3)
$\gamma_{4,0}$	687,6	3,77 (11)	3,70 (15) [b]	3,30 (13)		3,55 (9)	3,56 (15) [d]	28,3 (13)

[a] Omitted from averaging as uncertainty is not quoted

[b] Omitted from averaging as the data of 1971GuZY have been revised in 1976GuZN

[c] Weighted average of 3 experimental values; the uncertainty is the smallest quoted uncertainty

[d] Weighted average of 3 experimental values; the uncertainty is external

5.2.4. Gamma-Ray Emission Probabilities (^{236}Pu)

The recommended gamma-ray emission probabilities P(γ) have been deduced using the relative gamma-ray intensities from 1983Ah02 (Table 4), the quantity $\sum P(\beta^-)$ = 12,05 (60) % = P($\gamma_{2,1}$+ce)(102,8 keV) and the intensity balance at each ^{236}Pu level. We have assumed that the populations to the two lower levels ("0" and "1") in the ^{236}Np beta minus decay are negligible and have taken into account the intensity balance of the gamma-ray transitions to these levels, that is P($\gamma_{1,0}$+ce)(44,6 keV) = P($\gamma_{2,1}$+ce)(102,8 keV).

6. CONSISTENCY OF RECOMMENDED DATA

The most accurate Q value, Q(M), is taken from the atomic mass adjustment table of Audi et al. (2003Au03). Comparison of Q(eff) (deduced as the sum of average energies per disintegration ($\sum E_i \times P_i$) for all emissions accompanying ^{236}Np β$^-$-decay or ^{236}Np electron capture) with the tabulated decay energy $Q^-(M) \times P(\beta^-)$ for β$^-$-decay or $Q_{EC}(M) \times P(EC)$ for electron capture allows to check a consistency of the recommended ^{236}Np decay-scheme parameters obtained in this evaluation.

Here E_i and P_i are the evaluated energies and emission probabilities of the i-th beta particle, gamma ray, X-ray, etc. The values of P(β$^-$), P(EC) are β$^-$ -decay and EC branching, respectively. Consistency (percentage deviation) is determined by {[Q(M) – Q(eff))]/ Q(M)} × 100. "Percentage deviations above 5 % would be regarded as high and imply a poorly defined decay scheme; a value of less than 5 % indicates the construction of a reasonably consistent decay scheme" (quoted from the article by A. L. Nichols in Appl. Rad. Isotopes 55(2001)23-70).

For the above ^{236}Np decay data evaluation we have for β$^-$-decay $Q^-(M) \times P(\beta^-)$ = 58 (7) keV and Q(eff, β$^-$) = 57 (7) keV, i.e. consistency is less than 2 % if we do not take into account the uncertainties, and the exact percentage deviation is (1.7 ± 17) % if we consider the uncertainties. Similarly, for ^{236}Np electron capture we have $Q_{EC}(M) \times P(EC)$ = 817 (44) keV and Q(eff, EC) = 817 (50) keV and the percentage deviation is 0 ± 8 %. These values indicate the right evaluation and inaccurate measurements of ^{236}Np decay-scheme parameters.

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^{236}Np^{m} – COMMENTS ON EVALUATION OF DECAY DATA

by V.P.Chechev and N.K.Kuzmenko

This evaluation was completed in June 2006. The literature available by May 2006 was included.

1. DECAY SCHEME

From the systematics of isomer levels it was assumed in 1981Li30 (see also the analysis carried out in 1991Sc08) that the short-lived state of ^{236}Np (22,5 h) lies higher in energy than the long-lived state of ^{236}Np (1,55 10^5 y). In line with this assumption we have considered the long-lived state of ^{236}Np as the ground state. Using Q values for electron capture decays of the isomer and ground states together with closed energy cycles we can estimate the energy level spacing between these states as 60(50) keV.
The decay scheme of the isomer ^{236}Np^{m} includes two decay modes: ß$^-$ decay to ^{236}Pu and electron capture decay (EC) to ^{236}U (see evaluations of 1991Sc08, 1996FiZX). The ß$^-$-decay branching, ΣP(ß$^-$), has been adopted from 1969Le05. The EC-decay branching, ΣP(EC), has been obtained as the difference of 1−ΣP(ß$^-$).

2. NUCLEAR DATA

Q$^-$ (^{236}Np^{m}) is from 1969Le05 (the end-point energy of the β$^-$ spectrum was measured). Q$_{EC}$(^{236}Np^{m}) has been calculated from the closed energy cycle of decays ending in ^{232}Th. The values of Q$^-$ (^{236}Np^{m}), Q$_\alpha$ (^{236}Pu), Q$^-$ (^{232}Pa), Q$_{EC}$(^{232}Pa) and Q$_\alpha$(^{236}U) from 2003Au03 were used in this calculation.
The half-life of ^{236}Np^{m} is from 1969Le05. This result agrees with other (less accurate) measurements (1949Ja01 – 22 h, 1984Gr33 – 22,5 h).

2.1. Electron Capture Transitions

The energies of the electron capture transitions have been deduced from the Q$_{EC}$ value and the level energies (Table 1) obtained from the evaluated gamma-ray energies.

Table 1. ^{236}U levels populated in the ^{236}Np^{m} electron capture decay

Level number	Energy, keV	Spin and parity	Half-life	Probability of EC - transition (×100)
0	0,0	0^+	$2,342\cdot10^7$ yr	43,1(32)
1	45,242(3)	2^+	234 ps	8,3(30)
2	149,476(15)	4^+	124 ps	-
4	687,60(5)	1^-	3,8 ns	1,64(9)

The individual EC- transition probabilities P(EC$_{1,i}$) have been deduced from the intensity balance for each level and the total EC-decay probability ΣP(e$_{1,i}$).

2.2. Beta Transitions

The ß$^-$- transition energies have been deduced from the Q$^-$ value and the level energies (Table 2) obtained from the evaluated gamma-ray energies.

Table 2. ^{236}Pu levels populated in the ^{236}Np^{m} ß$^-$-decay

Level number	Energy, keV	Spin and parity	Half-life	Probability of ß$^-$-transition (× 100)
0	0,0	0^+	2,858 yr	36(4)
1	44,63(10)	2^+		11(4)

The ß$^{-}$- transition probabilities P($\beta_{1,0}$), P($\beta_{1,1}$) have been obtained from the ratio P($\beta_{1,0}$)/P($\beta_{1,1}$) =38(7)/12(5) measured in 1959Gi58 and the total ß$^{-}$ -decay probability ΣP($\beta_{1,i}$).

2.3. Gamma Transitions and Internal Conversion Coefficients (^{236}U)

The evaluated transition energies are virtually the same as the photon energies because nuclear recoil is negligible.

The gamma-ray transition probabilities have been obtained from the gamma-ray emission probabilities and the total internal conversion coefficients (ICC's). Multipolarities of gamma-ray transitions have been taken from 1991Sc08 and 1996FiZX. The gamma-ray transition probability P($\gamma_{1,0}$ +ce)(44,6-keV) has been deduced from the relation of P($\gamma_{1,0}$ +ce)(44,6-keV)= P($\beta_{0,1}$).

ICC's have been interpolated using the BRICC computer program, except for $\gamma_{4,1}$ (642,3-keV) and $\gamma_{4,0}$ (687,6-keV) because of nuclear penetration effects. The relative uncertainties of α_K, α_L, α_M, α_T for pure multipolarities have been taken as 2%.

α_K and α_L for $\gamma_{4,1}$(642,3-keV) and $\gamma_{4,0}$(687,6-keV) are experimental values from data in ^{240}Pu α-decay (1969Le05 and 1977Po05, see also the evaluation of 2004Be). α_M and α_T for these transitions have been evaluated using α_M/α_L and α_{NO}/α_M from 1971Dr11. More accurate ICC measurements for these transitions are required.

3. ATOMIC DATA

3.1. Fluorescence yields

The fluorescence yield data are from 1996Sc06 (Schönfeld and Janßen).

3.2. X Radiations

The LX-ray energies are from 1996FiZX. The KX-ray energies and the relative KX-ray emission probabilities are from 1999Schönfeld.

The X-ray energies are based on the wavelengths given in the compilation of 1967Be65 (Bearden).

The relative KX-ray emission probabilities have been taken from 1999Schönfeld.

3.3. Auger Electrons

The ratios P(KLX)/P(KLL), P(KXY)/P(KLL) are taken from 1996Sc06.

4. ELECTRON EMISSIONS

The energies of the conversion electrons have been deduced from the gamma transition energies and the electron binding energies.

The emission probabilities of the conversion electrons have been deduced using evaluated P$_{\gamma}$ and ICC values.

The absolute emission probabilities of K and L Auger electrons have been obtained with the EMISSION computer program.

β^{-} average energies have been obtained using the LOGFT computer program.

5. PHOTON EMISSIONS

5.1. X-Ray Emissions

The absolute emission probabilities of KX- and LX-rays have been obtained with the EMISSION computer program.

For U LX-ray calculations the ratios $P_{EC}(L2)/P_{EC}(L1)$ =0,115 and $P_{EC}(L3)/P_{EC}(L1)$ =0 from the theoretical calculations of 1972Dzhelepov were used for all levels populated in the ^{236}Np^{m} electron capture decay.

5.2. Gamma Ray Emissions

5.2.1. Gamma Ray Energies (^{236}U)

The energies of gamma rays accompanying the ^{236}Np^{m} electron capture decay have been adopted from the evaluated DDEP data in ^{240}Pu α-decay (2004Be).

5.2.2. Gamma Ray Energies (^{236}Pu)

The energy of $\gamma_{1,0}$ (44,6 keV) accompanying the $ß^-$ - decay of ^{236}Np^{m} has been adopted from measurements in 1983Ah02.

5.2.3. Gamma-Ray Emission Probabilities (^{236}U)

The gamma-ray emission probability P(γ) for $\gamma_{1,0}$ (45,2 keV) has been obtained from the ratio ΣP(e$_i$)(45,2 keV) / P($\gamma_{4,1}$)(642,3 keV) = 9(3) measured in 1969Le05.

The evaluated gamma ray emission probability P($\gamma_{4,1}$)(642,3 keV) = 0,96(20)% has been deduced using the following values:

1) ΣP(e $_{1,i}$)=53(1)%;
2) measured ratio P(XKa) / P($\gamma_{3,1}$)(642,3 keV)=27,6(10) from 1969Le05;
3) theoretical value of the ratio P(XKa)/P(XKß)=0,298(5);
4) relative (partial) intensities of gamma rays de -exciting level ''4'' [$\gamma_{4,2}$ (538,1 keV), $\gamma_{4,1}$ (642,3 keV), $\gamma_{4,0}$ (687,5 keV)], which have been deduced from the absolute gamma -ray emission probabilities evaluated in the ^{240}Pu α-decay (Table 5), and a$_K$ for these gamma-rays;
5) the measured ratio ΣP$_K$ (i) P(EC$_{1,i}$)/ ΣP($ß^-_{1,i}$)=0,75(15) from 1956Gr11, which can be represented as P$_K^{(average)}$ = ΣP$_K$ (i) P(EC$_{1,i}$)/ Σ P(EC$_{1,i}$)=0,67(13).

The most accurate evaluation of P$_K^{(average)}$ (and also the new evaluation of P($\gamma_{4,1}$) (642,3 keV) and other values) may be obtained by using the theoretical P$_K$(i), the values of P(EC $_{1,i}$) deduced from P($\gamma_{4,1}$)(642,3 keV) = 0,96(20)%, and the fact that a contribution of the third term (with P(EC $_{1,4}$)) to P$_K^{(average)}$ comprises ˜ 2,5%. This value has been taken as a fractional uncertainty for the P$_K^{(average)}$ = 0,75(2).Using the latter and the relations 1) - 4) we have deduced a more accurate evaluation of P($\gamma_{4,1}$)(642,3 keV) = 1,08(6)%, and correspondingly a more accurate evaluation for other decay data.

The gamma-ray emission probability P($\gamma_{2,1}$) (104,2 keV) has been calculated from P($\gamma_{2,1}$ +ce) (104,2 keV) = P($\gamma_{4,2}$ +ce)(538,1 keV) assuming that the electron capture feeding of level "2" is negligible.

Table 5. Experimental and evaluated absolute emission probabilities of gamma rays de -exciting the ^{236}U level with energy of 687,6 keV in the decay of ^{240}Pu (per 10^8 a-decays) and the deduced relative intensities of these gamma rays

	Energy, keV	1969Le05	1971GuZY	1975OtZX	1975Dr05	1976GuZN	Evaluated	Evaluated relative intensities
$\gamma_{4,2}$	538,1	≈0,23[a]		0,147(12)			0,147(12)	1,17(10)
$\gamma_{4,1}$	642,3	14,5[a]	14,5(5)[b]	12,6(4)	13(1)	12,45(30)	12,6(3)[c]	100 (3)
$\gamma_{4,0}$	687,6	3,77(11)	3,70(15)[b]	3,30(13)		3,55(9)	3,56(15)[d]	28,3(13)

[a] Omitted from averaging as uncertainty is not quoted

[b] Omitted from averaging as the data of 1971GuZY have been revised in 1976GuZN

[c] Weighted mean of 3 experimental values; the uncertainty is the smallest quoted uncertainty

[d] Weighted mean of 3 experimental values; the uncertainty is external

5.2.4. Gamma-Ray Emission Probability (^{236}Pu)

The gamma-ray emission probability P(γ) for $\gamma_{1,0}$ (44,6 keV) has been obtained from P($\beta_{1,1}$) and the adopted α_T for this gamma-ray transition.

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^{237}U - Comments on evaluation of decay data by V.P. Chechev and N.K. Kuzmenko

This evaluation was done originally in September 2005 and then revised in April 2009 with a literature cut-off by the same date.

1 Decay Scheme

The decay scheme is based on 2006Ba41.

2 Nuclear Data

Q^- value is from 2003Au03.

The recommended half-life of ^{237}U is based on the experimental results given in Table 1.

Table 1. Experimental values of the ^{237}U half-life (in days)

Reference	Author(s)	Value
1949Me43	Melander and Slatis	6,63 (5)
1953Wa05	Huizenga and Flynn	6,75 (1)
1958Ca16	Cabell et al.	6,752 (2)

The weighted mean of the 3 values from the Table 1 of 6,752 (2) is dominated by the very accurate value of 1958Ca16. The EV1NEW computer program, which uses the limitation of relative statistical weights by 0,5 (LRSW method), increased the 1958Ca16 uncertainty from 0,002 to 0,0098 and gave 6,749 (16).

Therefore, the recommended value of ^{237}U half-life is 6,749 (16) days.

2.1 Beta Transitions

The energies of β^- transitions have been obtained from the Q^- value and the level energies given in Table 2 from 2006Ba41.

Table 2. ^{237}Np levels populated in ^{237}U β^- decay

Level	Energy, keV	Spin and Parity	Half-life	Probability of β^- transitions (×100)
0	0,0	$5/2^+$	2,144 (7)×10^6 a	-
1	33,196 29 (22)	$7/2^+$	54 (24) ps	-
2	59,540 92 (10)	$5/2^-$	67 (2) ns	6,7 (42)
3	75,899 (5)	$9/2^+$	≈ 28 ps	-
4	102,959 (3)	$7/2^-$	80 (40) ps	-
5	267,556 (12)	$3/2^-$	5,2 (2) ns	40,9 (31)
6	281,356 (18)	$1/2^-$	-	48,2 (25)
7	332,376 (16)	$1/2^+$	≤ 1,0 ns	2,9 (9)
8	368,602 (20)	$5/2^+$	-	-
9	370,928 (23)	$3/2^+$	-	1,3 (9)

The probabilities of β^- transitions have been deduced from the P(γ+ ce) balance at each level of ^{237}Np.

The 459,1 keV $\beta^-_{0,2}$ transition probability of 7 (4) % has been obtained using the relation of 100-Σ $P_i(\beta^-)$. The value deduced from the P(γ+ ce) balance is 7 (6) %.

Some experimental estimations of the β^- transition energies and probabilities are given in 1949Me43, 1953Wa05 and 1957Ra04. More precise measurements would prove beneficial.

2.2 Gamma-ray Transitions and Internal Conversion Coefficients

The recommended energies of the gamma-ray transitions are mainly the same as the gamma-ray energies because nuclear recoil is negligible for ^{237}Np.

The gamma-ray transition probabilities have been obtained from the gamma-ray emission probabilities and the total internal conversion coefficients (ICCs). Multipolarities of gamma-ray transitions have been taken from 2006Ba41. The ICCs have been interpolated using the BrIcc package with the so called "*Frozen Orbital*" approximation (2008Ki07). The relative uncertainties of the ICC for pure multipolarities have been taken as 2 %.

The ICC for the intense E1 anomalously converted gamma-ray-transitions $\gamma_{2,1}$ (26,3- keV) and $\gamma_{2,0}$ (59,5- keV) have been obtained from a joint analysis of the gamma-ray and L-, M- conversion electron probabilities measured in ^{241}Am α decay and ^{237}U β^- decay (1996Jo28, 2006Ba41). The experimental conversion electron data are given in 1959Sa10, 1964Wo03, 1966Ko06, 1966Le13, 1966Ya05, and 1998Ko61. For discussion of E1 anomalously converted gamma transitions see 1960As02, 1966Ya05, 1967Pa23, 1970Gr36, and 1996Jo28.

The E2/M1 mixing ratio of 16,6 (25) % for $\gamma_{4,2}$(43,4-keV) has been obtained by averaging the four measurement results from 1964Wo03 (17,6 (19) %), 1966Ko06 (13 (2) %), 1966Ya05 (11 (4) %), and 1998Ko61 (21,2 (22) %).

The E2/M1 mixing ratio of 15 (8) % for $\gamma_{9,7}$ (38,5-keV) has been deduced using the ratio P_{ce} (L_2; $\gamma_{9,7}$) / P_{ce} (M_3; $\gamma_{9,7}$) = 10 (5) from 1966Ya05 and the theoretical values from the BrIcc package. $P_{\gamma+ce}$ ($\gamma_{9,8}$ 2,3-keV) has been deduced assuming that there is no β^- feeding to the 368,59-keV level.

$P_{\gamma+ce}$ ($\gamma_{3,1}$ 42,7-keV) and $P_{\gamma+ce}$ ($\gamma_{3,0}$ 75,8-keV) have been deduced from $P\gamma_{3,0}/P\gamma_{3,1}$ = 3/28 (see 2006Ba41) assuming that there is no β^- feeding to the 75,92-keV level.

The gamma-ray transitions with energies 114,09 keV and 340,45 keV have not been placed in the level scheme.

3 Atomic Data

The atomic data are from Schönfeld and Janβen (1996Sc06).

4 Electron Emissions

The energies of the conversion electrons have been obtained from the gamma-ray transition energies and the electron binding energies.

The absolute emission probabilities of the conversion electrons have been calculated using recommended P_γ and ICC values.
The total absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program.

β^- average energies have been calculated using the LOGFT computer program.

5. Photon Emissions

5.1 X-ray Emissions

The absolute emission probabilities of U KX and LX-rays have been calculated using the EMISSION computer program.

In Table 3 the calculated values are compared to the experimental data. The uncertainty in the detector efficiency (2 %) was added to the uncertainties listed in 1976GuZN.

Table 3. Experimental and recommended Np KX - ray emission probabilities in decay of ^{237}U

	Energy (keV)	1966Ya05	1976GuZN	Recommended (calculated)
$K\alpha_2$	97,069	16,2 (17)	15,8 (7)	14,8 (4)
$K\alpha_1$	101,059	22,6 (24)	25,2 (9)	23,5 (6)
$K'\beta_1$	113,944	9,8 (10)	9,22 (32)	8,57 (27)
$K'\beta_2$	117,463	3,1 (4)	2,3 (5)	2,95 (10)

5.2 Gamma-rays emissions

The energies of gamma rays $\gamma_{2,1}$ (26,3-keV) and $\gamma_{2,0}$ (59,5-keV) are from 2000He14. $E\gamma_{1,0}$ (33,2 keV) has been calculated as the difference $E\gamma_{2,0}$ - $E\gamma_{2,1}$. The energies of gamma rays $\gamma_{4,3}$, $\gamma_{3,1}$, $\gamma_{4,2}$ have been taken from 1998Ko61. The rest gamma-ray energies have been adopted from 2006Ba41 based on experimental data of 1996Ya05, and 1976GuZN. Other measurements: 1957Ra04, 1963Ak04, 1968Da24, 1971Cl03. The uncertainty in the detector efficiency (2 %) was added to the uncertainties listed in 1976GuZN.

In Table 4 the experimental and evaluated absolute gamma ray emission probabilities (Pγ) are presented.

Table 4. Experimental and evaluated absolute gamma-ray emission probabilities (%) in decay of ^{237}U.

Eγ, keV	1966Ya05	1971Cl03	1976GuZN	1982BuZF	1984BaYS	1985He02	1985Wi04	Evaluated
51,01	0,21 (10)		0,340 (14)		0,44 (6)			0,340 (14)
59,54	32,9 (40)	32,8 (25)	34,5 (8)		33,8 (9)			34,1 (9)
64,83	1,15 (16)	1,19 (9)	1,30 (3)		1,31 (5)		1,282 (17)	1,286 (17)
164,61	1,80 (9)	1,82 (14)	1,84 (5)		1,85 (5)	1,865 (23)	1,853 (23)	1,855 (23)
208,00			21,7 (5)	21,5 (14)		21,2 (3)	21,2 (3)	21,28 (30)
221,80	0,0199 (18)	0,0182 (14)	0,0212 (8)		0,0199 (25)			0,0204 (8)
234,40	0,0190 (18)	0,0273 (20)	0,0205 (8)		0,0224 (40)			0,0205 (8)
267,54	0,698 (30)	0,755 (20)	0,740 (18)		0,723 (25)	0,714 (22)	0,711 (10)	0,721 (10)
332,36	1,18 (8)	1,19 (9)	1,21 (3)		1,18 (4)		1,200 (16)	1,199 (16)
335,38	0,094 (9)	0,109 (9)	0,097 (3)		0,092 (5)		0,0951 (22)	0,0958 (22)
368,59	0,045 (4)	0,044 (3)	0,043 (2)		0,042 (3)		0,0392 (17)	0,0416 (17)
370,94	0,109 (9)	0,125 (10)	0,110 (4)		0,109 (6)		0,1073 (17)	0,109 (2)

The measurement results for gamma ray emission probabilities given in 1976GuZN, 1982BuZF, 1985He02, 1985Wi04 are absolute. The measurements results given in 1966Ya05, 1971Cl03, 1984BaYS are relative. The latter ones have been renormalized by evaluators at Pγ(208 keV) = 21,3 (3) %.

$P\gamma_{6,5}$ has been deduced from Pce(M1) = 29,9 (3) %, as measured by 1966Ya05, and ICC α_{M1} = 281 (9).

$P\gamma_{4,1}$ has been deduced from $P\gamma_{4,1}$/ $P\gamma_{4,2}$ = 2,9 (4) / 73 (8), as measured in ^{241}Am α-decay (see 2006Ba41).

$P\gamma_{4,0}$ has been deduced from $P\gamma_{4,0}$/ $P\gamma_{4,2}$ = 19,5 (1) / 73 (8), as measured in ^{241}Am α-decay (see 2006Ba41).

$P\gamma_{8,2}$ has been deduced from $P\gamma_{8,2}$/ $P\gamma_{8,1}$ = 10,14 / 49,6 as measured in ^{241}Am α-decay (see 2006Ba41).

$P\gamma_{8,3}$ has been deduced from $P\gamma_{8,3}$/ $P\gamma_{5,2}$ = 0,000 12 (3), as measured by 1966Ya05.

$P\gamma_{9,7}$ has been deduced by evaluators from the ratio P_{ce} (L_2; $\gamma_{9,7}$) / P_{ce} (K; $\gamma_{5,2}$) = 0,0056 (20) from 1966Ya05 and total ICC's.

Pγ (340,4-keV) has been adopted from 1976GuZN.

6. Consistency of Recommended Data

The most accurate Q value, Q(M), is taken from the atomic mass adjustment table of Audi et al. (2003Au03). Comparison of Q(eff) (deduced as the sum of average energies per disintegration ($\sum E_i \times P_i$) for all emissions accompanying ^{237}U β^- decay) with the tabulated decay energy Q(M) allows to check a consistency of the recommended decay-scheme parameters obtained in this evaluation.

Here E_i and P_i are the evaluated energies and emission probabilities of the i-th alpha particle, beta particle, gamma ray, X-ray, etc. Consistency (percentage deviation) is determined by {[Q(M) - Q(eff))] / Q(M)} × 100. "Percentage deviations above 5 % would be regarded as high and imply a poorly defined decay scheme; a value of less than 5 % indicates the construction of a reasonably consistent decay scheme" (quoted from the article by A.L. Nichols in Appl. Rad. Isotopes 55 (2001) 23-70).

For the above ^{237}U decay data evaluation we have Q(M) = 518,6 (6) keV and Q(eff) = 519 (23) keV, i.e. consistency is not worse than 4,4 %.

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^{237}Np – Comments on evaluation of decay data
by V. P. Chechev and N.K. Kuzmenko

This evaluation was done originally in October 2007 and then updated in April 2009 with a literature cut-off by the same date. The Saisinuc software (2002Be) and associated supporting programs were used in assembling the data following the established protocol within DDEP.

1. DECAY SCHEME

Decay scheme is based on 2005Si15. It cannot be considered complete since the α-feedings measured directly in ^{237}Np α-decay and those deduced from the level gamma-ray intensity balances are not always in good agreement as shown in Table 1 (see also 2005Si15).

Table 1. Comparison of the prominent α-feedings ($P_\alpha \times 100$) measured directly in ^{237}Np α-decay with those deduced from the level gamma-ray intensity balances

Level	Level energy (keV)	$P_\alpha \times 100$ Adopted from measurements	$P_\alpha \times 100$ Deduced from γ-ray intensity balance
0	0	}2.92 (4)	1 (3)
1	6.654 (25)		
2	57.101 (14)	2.430 (17)	8 (4)
3	70.510 (25)	2.02 (2)	1.4 (3)
4	86.469 (9)	}80.1 (5)	}79.1 (24)
6	103.636 (20)		
7	109.04 (5)		
13	212.342 (18)	3.46 (3)	2.8 (9)
14	237.895 (13)	6.43 (3)	5.1 (7)

2. NUCLEAR DATA

Q(α) value is from 2003Au03.

The recommended half-life of ^{237}Np is based on the experimental results given in Table 2.

Table 2. Experimental values of ^{237}Np half-life (in 10^6 years)

Reference	Author(s)	Value	Comments and method
1949Ma01	Magnusson and LaChapelle	2.20 (11)	First isolation of the element 93 and a determination of ^{237}Np half-life
1960Br12	Brauer et al.	2.14 (1)	Specific activity
1992Lo03	Lowles et al.	2.144 (7)	Specific activity, many sources, known geometry gas flow proportional counters for α-particle counting

The weighted mean of the 3 values is 2.143 with the internal uncertainty of 0.0057 and external uncertainty of 0.0025 and $\chi^2/\nu = 0.19$. The unweighted mean is 2.161 (19). *

The recommended value of ^{237}Np half-life of 2.144 (7) × 10^6 years has been adopted from the most accurate measurement of 1992Lo03.

The recommended ^{237}Np spontaneous fission half-life $T_{1/2}$(SF) ≥ 1×10^{18} years is from 1961Dr04. The theoretical values of $T_{1/2}$(SF) are about 10^{18} yr (1988Io05) and 10^{14} yr (1992Gr16).

2.1 Alpha Transitions

The energies of the alpha transitions have been deduced from the Q value and the level energies given in Table 3 from 2005Si15 where they were deduced from a least squares fit to gamma-ray energies. The energies of the gamma rays adopted from 2005Si15 are given below, in Table 7.

Table 3. ^{233}Pa levels populated in ^{237}Np α-decay

Level	Level energy (keV)	Spin and parity	Half-life	Energy of α-particles (keV)	Probability of alpha transition (%)
0	0	$3/2^-$	26.98 (2) d	4872.7 (14)	2.41 (3)
1	6.654 (25)	$1/2^-$		4866.4 (14)	0.51 (3)
2	57.101 (14)	$7/2^-$		4816.8 (10)	2.430 (17)
3	70.510 (25)	$5/2^-$		4803.5 (10)	2.02 (2)
4	86.469 (9)	$5/2^+$	35.8 (4) ns	4788.0 (9)	47.64 (6)
5	94.645 (16)	$3/2^+$			
6	103.636 (20)	$7/2^+$		4771.4 (8)	23.0 (3)
7	109.04 (5)	$9/2^+$		4766.5 (8)	9.5 (3)
8	133.2 (10)	$(11/2^+)$		4741.3 (20)	0.019
9	163.34 (10)	$(11/2^-)$		4712.3 (20)	1.174 (13)
10	169.152 (20)	$1/2^+$		4708.3 (20)	
11	179.1 (4)	$(9/2^-)$		4698.2 (8)	0.535 (10)
12	201.594 (19)	$3/2^+$		4676.4	0.38 (2)
13	212.342 (18)	$5/2^+$		4665.0 (9)	3.46 (3)
14	237.895 (13)	$5/2^+$		4640.0 (10)	6.43 (3)
15	257.1 (4)	$5/2^-$		4619.7 (21)	0.032 (8)
16	279.71 (3)	$(7/2^+)$		4599.1 (18)	0.37 (1)
17	300.48 (3)	$7/2^+$		4578.6 (14)	0.39 (2)
18	303.59 (7)	$(9/2^+)$		4573 (3)	0.048 (23)
19	306.05 (10)	$(7/2^+)$			
20	365.93 (8)	$9/2^+$		4515.1 (19)	0.038 (4)

The recommended α-transition probabilities have been obtained by averaging the experimental results (see Table 4). The probabilities of the $\alpha_{0,8}$ - and $\alpha_{0,12}$ - transitions have been deduced from the decay scheme. The α-decay hindrance factors have been calculated using the ALPHAD computer program from the ENSDF evaluation package with r_0 = 1.517 (4) fm (see 2005Si15).

New α-transition with energy of 4550.5 (22) keV and intensity of 0.011 (3) % unplaced in ^{237}Np decay scheme was seen by 2002Wo03 (also 2000Si02).

Table 4. Experimental and recommended probabilities of α-transitions (×100) from ^{237}Np α-decay

Level	Level energy (keV)	Energy of α-particles (keV)	1961Ba44	1969Br12	1990Bo44	2002Wo03	Recommended $P_{\alpha}\times100$
0	0	4872.7 (14)	0.925	2.6 (2)	2.43 (3)	2.39 (4)	2.41 (3)
1	6.654 (25)	4866.4 (14)	0.24		0.49 (3)	0.53 (4)	0.51 (3)
2	57.101 (14)	4816.8 (10)		2.5 (4)	2.47 (2)	2.430 (17)	2.430 (17)
3	70.510 (25)	4803.5 (10)	2.014 (17)		2.06 (5)		2.014 (17)
4	86.469 (9)	4788.0 (9)		47 (9)	47.75 (20)	47.64 (6)	47.64 (6)
5	94.645 (16)						
6	103.636 (20)	4771.4 (8)		25 (6)	22.7 (4)	23.2 (3)	23.0 (3)
7	109.04 (5)	4766.5 (8)		8 (3)	9.7 (3)	9.3 (3)	9.5 (3)
8	133.2 (10)	4741.3 (20)					0.019
9	163.34 (10)	4712.3 (20)				< 1.17	< 1.17
10	169.152 (20)	4708.3 (20)				< 1.17	< 1.17
11	179.1 (4)	4698.2 (8)		0.48 (20)	0.54 (4)	0.535 (10)	0.535 (10)
12	201.594 (19)	4676.4					0.38 (2)
13	212.342 (18)	4665.0 (9)		3.32 (10)	3.43 (4)	3.478 (24)	3.46 (3)
14	237.895 (13)	4640.0 (10)		6.18 (12)	6.45 (4)	6.43 (3)	6.43 (3)
15	257.1 (4)	4619.7 (21)				0.032 (8)	0.032 (8)
16	279.71 (3)	4599.1 (18)		0.34 (4)	0.39 (2)	0.371 (9)	0.373 (9)
17	300.48 (3)	4578.6 (14)		0.40 (4)	0.41 (2)	0.369 (23)	0.393 (23)
18	303.59 (7)	4573 (3)	0.048 (23)				0.048 (23)
19	306.05 (10)						
		4550.5 (22)				0.011 (3)	0.011 (3)
20	365.93 (8)	4515.1 (19)		0.04 (2)	0.041 (4)	0.035 (4)	0.038 (4)

2.2. Gamma Transitions and Internal Conversion Coefficients

The energies of the gamma-ray transitions are virtually the same as the gamma-ray energies because nuclear recoil is negligible.

The gamma-ray transition probabilities have been deduced from their gamma-ray emission probabilities and total internal conversion coefficients (ICCs) deduced with a computer program supplied with the Saisinuc software (2002Be). The ICCs have been interpolated using the BrIcc package with the so called "*Frozen Orbital*" approximation (2008Ki07, see also 2002Ba85). The multipolarities and admixture coefficients δ have been taken from 2005Si15. The uncertainties in the ICCs for pure multipolarities have been taken as 2 %.

ICCs for the anomalously converted E1 gamma-ray transition $\gamma_{4,0}$ (86.477 keV) have been adopted from 1988Wo01 (see also 1960As02 and 1969Br12).

The conversion electron data of 1988Wo01 indicate that the gamma-transition $\gamma_{4,2}$ (29.374 keV) may be an anomalous E1. However the evaluators have been adopted the theoretical ICCs since the detector efficiency was not completely reliable for such energy as pointed out in 1988Wo01.

3. Atomic Data

The atomic data (fluorescence yields, X-ray energies and relative probabilities, and Auger electrons energies and relative probabilities) are from Schönfeld and Janβen (1996Sc06).

4. Alpha Emissions

The alpha particle energies have been taken from 2002Wo03 (see also 2000Si02). They are somewhat different (in limits of uncertainties) from those obtained from alpha transition energies taking into account nuclear recoil for ^{233}Pa.

Details of alpha transition probability evaluation are given in Section 2.1.

5. Photon Emissions

5.1. X-Ray Emissions

The absolute X-ray emission probabilities (per 100 disintegrations) have been evaluated using the experimental data, see Tables 5, 6.

Table 5. Experimental and recommended absolute Pa KX- ray emission probabilities (×100)

	1984Va27	2000Sc04	2002Lu01	2004Sh07	2008De10	Recommended
$K\alpha_2$	1.90 (10)	1.82 (5)	1.80 (20)	1.80 (3)	1.813 (20)	1.813 (20)
$K\alpha_1$	3.00 (15)	2.98 (7)	2.89 (2)	2.89 (4)	2.932 (30)	2.906 (20)
$K'\beta_1$	1.03 (5)	0.86 (2)	1.06 (2)	1.02 (4)	1.154 (14)	1.06 (10)
$K'\beta_2$	0.35 (2)		0.373 (10)	0.38 (2)	0.380 (9)	0.380 (9)

Table 6. Experimental and recommended absolute Pa LX- ray emission probabilities (×100)

	2000Sc04	2004Sh07	2008De10	Recommended
Ll	1.55 (8)	1.31 (20)	1.33 (27)	1.32 (8)
Lα	26 (3)	23.3 (24)	23.1 (47)	24.0 (24)
Lβ	29.5 (20)[a]	24.3 (31)[b]	28 (6)	28.0 (20)
Lη	0.64 (6)	0.50 (4)		0.54 (4)
Lγ	5.8 (4)[c]	5.4 (8)[d]	7.8 (16)	5.8 (4)

[a] Obtained by the evaluators from the sum absolute intensity (Pa Lβ + U Lβ) of 47.5 (19) % using the intensities of Pa Lβ-components measured in 2000Sc04 and the U Lβ-intensity of 18.0 (6) % from ^{233}Pa decay data evaluation (2006Ch39) revised in April 2009.

[b] Obtained by the evaluators from the sum absolute intensity (Pa Lβ + U Lβ) of 42.3 (30) % using the intensities of Pa Lβ-components measured in 2000Sc04 and the U Lβ-intensity of 18.0 (6) % from ^{233}Pa decay data evaluation (2006Ch39) revised in April 2009.

[c] Obtained by the evaluators from the sum absolute intensity (Pa Lγ + U Lγ) of 10.0 (4) % using the intensities of Pa Lγ-components measured in 2000Sc04 and the U Lβ-intensity of 4.18 (13) % from ^{233}Pa decay data evaluation (2006Ch39) revised in April 2009.

[d] Obtained by the evaluators from the sum absolute intensity (Pa Lγ + U Lγ) of 9.6 (8) % using the intensities of Pa Lγ-components measured in 2000Sc04 and the U Lβ-intensity of 4.18 (13) % from ^{233}Pa decay data evaluation (2006Ch39) revised in April 2009.

5.2. Gamma-Ray Emissions

Energies

The gamma-ray energies have been adopted from 2005Si15. The gamma ray energy for $\gamma_{7,6}$ (5.18 keV) has been adopted from 1990Lo04. The energies for $\gamma_{1,0}$ (6.65 keV), $\gamma_{5,4}$ (8.22 keV) and $\gamma_{7,4}$ (17.4 keV) are from ^{233}Th decay. For $\gamma_{13,12}$ (10.7 keV) and $\gamma_{8,7}$ (21.4 keV) the energies are from 1979Go12. The gamma-ray energies of $\gamma_{6,5}$ (9.0 keV) and $\gamma_{7,4}$ (22.6 keV) have been deduced from ^{233}Pa level scheme (details of information of these and other gamma-ray transitions see in 2005Si15). Table 7 contains the experimental and adopted energies of the remaining gamma rays.

Table 7. Experimental and adopted energies (in keV) of gamma rays from ^{237}Np decay

1969Br12	1969HoXY	1971Cl03	1974HeYW	1976Sk01	1979Go12	1988Wo01 (Ge-detector)	1988Wo01 (LEPS-detector)	Adopted
29.29 (10)	29.30 (5)	29.38 (2)	29.375 (20)	29.373 (10)	29.374 (20)	29.5 (17)	29.18 (21)	29.374 (20)
46.46 (10)	46.6 (1)	-	46.60 (10)	46.53 (4)	46.53 (6)	46.7 (11)	46.28 (18)	46.53 (6)
57.15 (10)	57.1 (1)	57.11 (2)	57.112 (20)	57.15 (4)	57.104 (20)	57.15 (80)	56.88 (17)	57.104 (20)
	62.9	-	62.5 (5)					62.59 (10)
			63.92 (8)					63.90 (10)
	71.0		70.75 (10)					70.49 (10)
86.49 (10)	86.40 (5)	86.49 (2)	86.486 (10)	86.503 (20)	86.477 (10)	86.50 (48)	86.26 (14)	86.477 (10)
		-		88.04 (16)				87.99 (3)
			94.66 (10)	94.66 (5)				94.64 (5)
106.22 (10)	106.30 (8)	106.30 (20)	106.15 (25)	106.12 (5)		106.17 (48)		106.15 (25)
				108.6				108.7
				115.45 (20)	115.40 (35)			115.40 (35)
117.65 (7)	117.5 (1)	117.72 (2)	117.718 (20)	117.681 (30)	117.702 (20)	117.72 (50)	117.41 (15)	117.702 (20)
131.11 (7)	131.2 (1)	131.11 (2)	131.11 (2)	131.11 (7)	131.101 (25)	131.09 (52)	130.62 (15)	131.101 (25)
134.23 (7)	134.4 (1)	134.28 (2)	134.28 (3)	134.23 (4)	134.285 (20)	134.27 (53)		134.285 (20)
				140.60 (10)	-			139.9 (1)
143.26 (7)	143.35 (5)	143.25 (1)	143.254 (10)	143.208 (25)	143.249 (20)	143.27 (56)	142.96 (16)	143.249 (20)
151.31 (7)	151.5 (1)	151.41 (1)	151.410 (15)	151.37 (4)	151.414 (20)	151.42 (60)	151.06 (17)	151.414 (20)
				153.52				153.37 (10)
155.20 (7)	155.4 (1)	155.25 (2)	155.25 (2)	155.22 (4)	155.239 (20)	155.28 (63)		155.239 (20)
162.38 (7)	162.7 (1)	162.52 (3)	162.52 (3)	162.50 (6)	162.41 (8)	162.45 (68)		162.41 (8)
169.09 (7)	169.4 (1)	169.16 (3)	169.16 (3)	169.17 (5)	169.156 (20)	169.18 (73)		169.156 (20)
170.56 (10)	171.2 (3)	170.64 (5)	170.64 (5)	170.63 (8)	170.59 (6)			170.59 (6)
175.93 (10)	176.1 (1)	176.06 (5)	176.06 (5)	176.09 (7)	176.12 (6)	176.17 (80)		176.12 (6)
180.66 (10)	180.8 (1)	180.78 (5)	180.78 (5)	180.80 (8)	180.81 (10)	180.87 (85)		180.81 (10)
186.86 (30)				186.8 (5)	186.86 (35)			186.86 (35)
191.34 (10)		191.42 (3)	191.42 (3)	191.45 (6)	191.46 (5)	191.46 (97)		191.46 (5)
193.05 (10)		193.22 (3)	193.22 (3)	193.26 (4)	193.26 (5)	193.24 (98)		193.26 (5)
				194.67 (20)				194.67 (20)
194.91 (7)	195.00 (5)	194.97 (2)	194.97 (2)	195.096 (20)	194.95 (3)	195.1 (10)		194.95 (3)
196.81 (10)	-	196.80 (10)	196.80 (10)	196.84 (6)	196.86 (5)	196.9 (10)		196.86 (5)
			199.9 (1)	200.17 (10)	199.95 (6)			199.95 (6)
201.68 (8)	201.75 (10)	201.67 (20)	201.670 (25)	201.72 (5)	201.62 (5)	201.8 (11)		201.62 (5)
			202.9 (2)	202.69 (25)				202.9 (2)
209.07 (8)	209.1 (2)	209.18 (3)	209.18 (3)	209.25 (5)	209.19 (5)	209.2 (12)		209.19 (5)
212.28 (7)	212.4 (1)	212.33 (2)	212.33 (2)	212.42 (5)	212.29 (5)	212.4 (12)		212.29 (5)
213.92 (10)	-	213.96 (4)	213.96 (4)	214.09 (5)	214.01 (5)	214.1 (12)		214.01 (5)
				222.52 (25)				222.6 (2)
229.84 (10)	229.9 (1)	229.90 (10)	229.90 (10)	230.01 (10)	229.94 (5)			229.94 (5)
237.91 (7)	238.2 (1)	237.91 (2)	237.908 (10)	238.04 (4)	237.862 (60)	238.0 (14)		237.86 (2)
248.6 (4)	248.8 (1)	248.8 (5)	248.8 (5)	248.9 (1)	248.95 (10)			248.95 (10)
257.14 (40)	257.3 (2)	257.15 (50)	257.15 (50)	257.20 (20)	257.09 (20)			257.09 (20)
262.48 (40)	262.6 (2)	262.42 (50)	262.42 (50)	262.44 (15)	262.44 (20)			262.44 (20)

Emission Probabilities

The value $P\gamma_{14,12}$ (36.32 keV) of 0.000 05 (1) has been adopted from 1990Lo04. The values $P\gamma_{-1,1}$ (21.5 keV)) of 0.003 56 (13) and $P\gamma_{-1,2}$ (27.7 keV) of 0.008 4 (7) have been adopted from 2004Sh07. The values $P\gamma_{17,14}$ (62.59 keV) of 0.000 06 (2), $P\gamma_{3,1}$ (63.9 keV) of 0.000 108 (4) and $P\gamma_{10,5}$ (74.54 keV) of 0.000 12 (3) have been adopted from 1981Ba68. The value $P\gamma_{9,2}$ (106.15 keV) of 0.000 49 (1) has been adopted from 2002Lu01. For absolute gamma-ray emission probabilities see 1981Ba68, 1984Va27, 2000Sc04, 2000Wo01, 2002Wo03, 2004Sh07. The remaining relative emission probabilities are listed in Table 9. These have been renormalized by the evaluators to Pγ (86.48 keV) = 12.26 (12) % obtained as a weighted average of 1984Banham , 1984Va27, 2000Sc04, 2000Wo01, 2002Wo03, 2002Lu01, 2004Sh07, 2008De10.

There are significant unexplained (as stated in 2002Wo03) discrepancies in the intensities of several gamma rays with the following energies: 29.4, 46.5, 88.0, 117.7, 169.2, 193.3, 195.0, 257.1 and 279.6 keV.

The value of $P\gamma_{4,0}$ (86.48 keV) used for normalization of the decay scheme is itself discrepant since this gamma ray and the gamma ray with the energy 86.6 keV from the decay of its daughter ^{233}Pa become apparent as a complex peak, and the separated intensities in various studies are not always in good agreement. Table 8 contains the experimental and evaluated values of the absolute emission probability of gamma ray $\gamma_{4,0}$ (86.48 keV). The results of 2000Sc04, 2002Lu01 and 2004Sh07 given in Table 8 have been corrected taking into account the intensity of gamma ray with the energy 86.6 keV from the decay of ^{233}Pa: Pγ (^{233}Pa, 86.6 keV) = 1.99 (11) %, see 2006Ch39.

Table 8. Experimental and recommended values of the 86.48 keV γ ray emission probability

1984Banham	1984Va27	2000Wo01 2002Wo03	2000Sc04	2002Lu01	2004Sh07	2008De10	Recommended
12.20 (12)	12.44 (33)	12.86 (21)	12.1 (3)	12.02 (12)#	11.6 (5)	12.38 (13)	12.26 (12)

Although the $P\gamma_{4,0}$ (86.48 keV) =11.40 (24) % is given in 2002Lu01, the evaluators used more accurate value of 14.01 (6) % measured in 2002Lu01 for Pγ (86.48+86.6 from ^{233}Pa decay) to deduce $P\gamma_{4,0}$ (86.48 keV)=12.02 (12) %.

The recommended values of the gamma ray emission probabilities given in Table 9 have been obtained by averaging experimental data using the LWEIGHT computer program. The uncertainty assigned in this evaluation to the recommended value is always greater than or equal to the smallest uncertainty in any of the experimental values used in the statistical processing.

The systematic uncertainties (1 %) of U KX-ray emission probability from 2008De10 have been added to statistic uncertainties measured in 2008De10.

The systematic uncertainties (20 %) of U LX-ray emission probability from 2008De10 have been added to statistic uncertainties measured in 2008De10.

Table 9 (part 1). Experimental and recommended emission probabilities of gamma rays in ^{237}Np decay

Eγ	1969Br12	1976Sk01	1979Go12	1981Ba68 1984Banham	1984Va27	1988Wo01 (Ge-detector)	1988Wo01 (LEPS-detector)
29.37	13.7 (20)	16.2 (9)	10.1 (10)	15.4 (2)	15.03 (40)	-	19.2 (9)
46.53	0.137 (20)	0.12 (2)	0.10 (1)	0.104 (6)	0.10 (1)	0.12 (1)	0.14 (2)
57.10	0.412 (38)	0.433 (25)	0.37 (4)	0.373 (11)	0.39 (1)	0.34 (1)	0.43 (3)
62.6		0.012		0.006 (2)			
63.9				0.0108 (4)			
86.48	12.6	12.3	12.3	12.20 (12)	12.44 (33)	12.3	12.3
87.99	0.157 (20)	0.14 (4)	0.12 (1)	0.138 (3)	0.14 (1)	-	-
94.64		0.62 (4)	0.54 (5)				
106.15		0.044 (9)	0.05 (5)				
108.7							
115.40		0.26 (8)					
117.70	0.167 (20)	0.180 (12)	0.148 (15)	0.175 (2)	0.168 (5)	0.16 (7)	0.15 (2)
131.1	0.087 (9)	0.10 (1)	0.079 (8)	0.086 (1)	-	0.091 (5)	0.09 (2)
134.28	0.069 (8)	0.081 (16)	0.062 (6)	0.071 (1)	-	0.080 (5)	
143.25	0.412 (40)	0.462 (28)	0.40 (4)	0.430 (4)	0.434 (10)	0.43 (1)	0.42 (3)
151.41	0.244 (30)	0.249 (16)	0.223 (23)	0.236 (2)	0.232 (6)	0.248 (7)	0.20 (3)
153.4		0.007 (2)					

155.24	0.095 (9)	0.097 (7)	0.085 (9)	0.0917 (10)	-	0.086 (6)	-
162.4		0.041 (7)	0.027 (4)			0.032 (4)	-
169.16	0.074 (8)	0.082 (9)	0.072 (7)	0.0711 (7)	-	0.057 (4)	-
170.59		0.016 (2)	0.024 (5)				
176.12		0.017 (3)				0.02 (4)	-
180.8		0.022 (5)	0.021 (4)			0.015 (2)	-
186.86		0.003 (3)					
191.46		0.017 (3)	0.026 (5)			0.014 (5)	-
193.26		0.043 (4)	0.05 (5)			0.049 (3)	-
194.67		0.05 (2)					
194.95	0.206 (20)	0.169 (21)	0.16 (2)	0.184 (2)	0.188 (5)	0.191 (6)	-
196.86		0.023 (3)	0.019 (4)			0.021 (2)	-
201.6		0.044 (5)	0.044 (5)			0.041 (4)	-
209.2		0.019 (2)	0.016 (3)			0.010 (2)	-
212.3	0.157 (20)	0.166 (11)	0.157 (16)	0.150 (2)	0.155 (5)	0.156 (4)	
214.0		0.047 (4)	0.06 (4)			0.034 (1)	
222.6		0.002 (2)					
229.94		0.011 (3)	0.018 (4)				
237.86	0.067 (6)	0.075 (9)	0.062 (7)	0.0586 (12)	-	0.059 (3)	-
248.95		0.005 (2)	0.05 (1)				
257.09		0.007 (3)	0.019 (6)				
262.44		0.008 (2)	0.007 (1)				
279.65		0.002 (2)	0.011 (4)				
288.3							

Table 9 (part 2). Experimental and recommended emission probabilities of gamma rays in ^{237}Np decay

Eγ	1990Lo04	2000Sc04	2000Wo01	2002Lu01	2004Sh07	2008De10	Recommended
29.37	13.7 (1)	14.1 (15)	13.2 (4)	13.51 (16)	13.15 (36)	15.08 (16)	14.3 (6)
46.53	0.112 (1)	0.104 (4)	0.1067 (19)	0.163 (5)	0.100 (13)	0.114 (3)	0.109 (4)
57.10	0.360 (2)	0.354 (8)	0.360 (5)	0.366 (3)	0.356 (16)	0.458 (6)	0.381 (21)
62.6							0.006 (2)
63.9	0.0090 (9)						0.0107 (4)
86.48	12.3	14.1 (3) $^{\&}$	12.86 (21)	14.01 (6) &	13.6 (5)$^{\&}$	12.38 (13)$^{\&}$	12.26 (12)
87.99	0.143 (1)			0.167 (4)	0.134 (13)	0.144 (5)	0.143 (3)
94.64				0.615 (23)	0.575 (19)	0.730 (10)	0.66 (7)
106.15	0.048 (1)				0.0509 (26)	0.0573 (28)	0.0509 (29)
108.7		0.0864 (19)		0.070 (3)	0.0723 (36)		0.071 (3)
115.40	0.47 (11)*	0.332 (10)*					0.0026 (8)#
117.70	0.168 (1)	0.169 (4)	0.188 (3)	0.184 (12)	0.169 (17)	0.1660 (29)	0.171 (4)
131.1	0.079 (1)	0.0857 (22)		0.088 (3)	0.075 (5)		0.084 (5)
134.28	0.064 (1)	0.0670 (28)		0.075 (3)	0.073 (6)		0.069 (5)
143.25	0.387 (2)	0.443 (8)	0.439 (5)	0.428 (3)	0.394 (24)	0.423 (6)	0.42 (4)
151.41		0.232 (24)	0.228 (3)	0.244 (3)	0.223 (14)	0.234 (4)	0.234 (2)
153.4							0.007 (2)
155.24	0.080 (1)	0.0889 (18)		0.091 (6)	0.087 (6)		0.088 (8)
162.4		0.0327 (12)					0.033 (1)
169.16		0.0633 (19)		0.092 (11)			0.0672 (3)
170.59							0.020 (4)
176.12		0.012 (4)					0.015 (3)
180.8		0.0158 (10)					0.016 (1)
186.86							0.003 (3)
191.46		0.0192 (12)		0.015 (4)	0.023 (5)		0.019 (1)
193.26		0.0437 (10)		0.030 (5)	0.041 (8)		0.044 (1)
194.67	0.033 (1)			0.033 (8)	0.03 (1)		0.033 (1)

194.95	0.156 (2)	0.177 (5)	0.161 (4)	0.164 (7)	0.161 (34)		0.174 (20)
196.86		0.0208 (12)		0.024 (5)	0.020 (4)		0.0208 (1)
201.6		0.0393 (9)					
209.2		0.0142 (9)		0.019 (2)	< 0.02		0.0150 (15)
212.3		0.151 (3)	0.148 (3)	0.150 (4)			0.17 (1)
214.0	0.132 (2)	0.0362 (8)		0.039 (2)			0.037 (2)
222.6							0.002 (2)
229.94							0.014 (3)
237.86		0.0569 (6)		0.056 (3)	0.067 (4)		0.0573 (6)
248.95		0.0050 (14)		0.006 (3)			0.005 (1)
257.09							0.02 (1)
262.44		0.00471 (18)					0.0048 (2)
279.65		0.0109 (4)					0.0108 (4)
288.3		0.0164 (5)					0.0162 (5)

* Sum intensity of $\gamma_{12,14}$ and KX(Pa)

Adopted from 2005Si15

$^{\&}$ Measured Pγ86.48+86.6 keV from ^{233}Pa decay)

6. Electron Emissions

The energies of the conversion electrons have been obtained from the gamma transition energies and the electron binding energies. The emission probabilities of conversion electrons have been deduced from the evaluated P(γ) and ICC values.

The number of K- and L- Auger electrons per 100 disintegrations has been deduced using the evaluated XK- and XL- emission probabilities.

7. Consistency of recommended data

The most accurate Q value, Q(M), is taken from the atomic mass adjustment table of Audi et al. (2003Au03). Comparison of Q(eff) (deduced as the sum of average energies per disintegration ($\sum E_i \times P_i$) for all emissions accompanying ^{237}Np α- decay) with the tabulated decay energy Q(M) allows to check a consistency of the recommended decay-scheme parameters obtained in this evaluation.

Here E_i and P_i are the evaluated energies and emission probabilities of the i-th alpha particle, beta particle, gamma ray, X-ray, etc. Consistency (percentage deviation) is determined by {[Q(M)– Q(eff))]/ Q(M)} ×100. "Percentage deviations above 5 % would be regarded as high and imply a poorly defined decay scheme; a value of less than 5 % indicates the construction of a reasonably consistent decay scheme" (quoted from the article by A.L. Nichols in Appl. Rad. Isotopes 55 (2001) 23-70).

For the above ^{237}Np decay data evaluation we have Q(M) = 4958.3 (12) keV and Q(eff) = 4966 (21) keV, i.e. consistency is not superior, but better than 1 %.

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^{238}U - Comments on evaluation of decay data
by V. Chisté and M.M. Bé

This evaluation was completed in January 2006, and the literature available at this date has been included here.

1 Decay Scheme

^{238}U disintegrates by alpha emission to two excited levels and to the ground state of ^{234}Th. Spin and half-lives of excited states are from the mass-chain evaluation of Y.A. Akovali (1983El11 and 1994Ak05 for A = 234) and F.E. Chukreev (2002Ch52 for A = 238).

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).

Experimental ^{238}U half-life values (in years x 10^9) are given in Table 1:

Table 1: Experimental values of ^{238}U half-life.

Reference	Original value (10^9 a)	Revised Value by Schön (2004Sc03)	Comments
Kovarik (1932Ko01)	4.52		**Not used**. Natural U.
Schiedt (1935Schiedt)	4.42 (3)	4.46 (3) **(a)** 4.41 (5) **(b)**	**Not used**. Natural U. Corrected for ^{235}U. **(a)** ^{234}U and ^{238}U assumed to be in equilibrium. **(b)** ^{234}U and ^{238}U assumed to be not in equilibrium.
Curtis (1941Curtis)	4.514 (9)		**Not used**. Natural U. Lacking details.
Kienberger (1949Ki26)	4.490 (10)	4.495 (18)	**Not used**. Enriched U.
Kovarik (1955Ko13)	4.507 (9)	4.51 (2) **(a)** 4.46 (5) **(b)**	**Not used**. Natural U. **(a)** ^{234}U and ^{238}U assumed to be in equilibrium. **(b)** ^{234}U and ^{238}U assumed to be not in equilibrium.
Lechman (1957Le21)	4.56 (3)		**Not used**. Enriched U.
Steyn (1959St45)	4.460 (10)	4.457 (4) **(a)** 4.41 (4) **(b)**	**Not used**. Natural U. **(a)** ^{234}U and ^{238}U assumed to be in equilibrium. **(b)** ^{234}U and ^{238}U assumed to be not in equilibrium.
Jaffey (1971Ja07)	4.4683 (24)	4.468 (5)	Highly enriched U.
Recommended value		**4.468 (5)**	

The evaluators have chosen to follow the recommendations given by R. Schön (2004Sc03), who studied in detail various problems with the measurements of the half-life of ^{238}U. So, the recommended value is the half -life obtained by Jaffey (1971Ja07), but its original uncertainty was multiplied by 2 (as suggested by Schön (2004Sc03)) in order to take into account the systematic uncertainties which were not considered by 1971Ja07.

Experimental ^{234}Th half-life values (in days) are given in Table 2:

Table 2: Experimental values of ^{234}Th half-life.

Reference	Value (d)	Uncertainty (d)
M. Curie (1931Cu01)	24.5	
B.W. Sargent (1939Sa11)	24.1	0.2
G.B. Knight (1948Kn23)	24.101	0.025
Recommended value is (from 1994Ak05)	24.10	0.03

The recommended value is *24.10 d* with an uncertainty of *0.03 d*, from Y. A. Akovali (1994Ak05).

The evaluated spontaneous fission partial half-life of ^{238}U is based on the experimental results given in Table 3.

Table 3: Experimental values of spontaneous fission decay rate of ^{238}U (λ^{238}, in 10^{-17} years^{-1}).

Reference	Value	Uncertainty	Comments by Holden (2000Ho27)
W.J. Withehouse (1950Whitehouse)	8.38	0.52	Ionization chamber.
E. Sègres (1952Se67)	8.60	0.29	Ionization chamber.
R.L. Fleischer (1964Fl07)	6.85	0.20	**Not used.** Mica-uranium sandwich.
A. Spadavecchia (1967Sp12)	8.42	0.10	Rotating bubble chamber.
J.H. Roberts (1968Ro15)	7.03	0.11	**Not used.** Mica-uranium sandwich.
H.R. von Gunten (1969Vo24)	8.66	0.22	Fission products of ^{238}U.
D. Galliker (1970Ga27)	8.46	0.06	Rotating bubble chamber.
D. Storzer (1970Storzer)	8.49	0.76	Fission tracks in dated uranium glass.
J.D. Kleeman (1971Kl14)	6.8	0.6	**Not used.** Lexam-uranium sandwich.
W.M. Thury (1971Th17)	8.66	0.43	Third order coincidence.
M.P.T. Leme (1971Le11)	7.30	0.16	**Not used.** Mica-uranium sandwich.
H.A. Khan (1973Kh10)	6.82	0.55	**Not used.** Mica-uranium sandwich.
K.N. Ivanov (1974Iv01)	7.12	0.32	**Not used.** Mica-uranium sandwich.
V. Emma (1975Em03)	7.2	0.2	**Not used.** Mica-uranium sandwich.
G.A. Wagner (1975Wa37)	8.7	0.6	Fission tracks in dated uranium glass.
K. Thiel (1976Th12)	8.57	0.42	Fission tracks in dated uranium glass.
M. Kase (1978Ka40)	8.22	0.20	Ionization chamber.
A.G. Popeko (1980Po09)	7.9	0.4	Multiple neutron coincidence.
E.R.V. Spaggiari (1980Sp10)	9.26	0.17	**Not used.** Mica-uranium sandwich.
Z.N.R. Baptista (1981Ba70)	6.6	0.2	**Not used.** Mica-uranium sandwich.
J.C. Hadler (1981Hadler)	8.6	0.4	**Not used.** Mica-uranium sandwich.
H.G. de Carvalho (1982De22)	11.8	0.7	**Not used.** Fission tracks in ordinary glass.
S.N. Belenky (1983Be66)	8.35	0.40	Multiple neutron coincidence.
B. Vartanian (1984Va34)	8.23	0.43	**Not used.** Fissions tracks (plastic, uranium foils).
M.P. Ivanov (1985Iv01)	8.29	0.27	Double ionization chamber.
S.S. Liu(1991Liu)	7.03	0.21	**Not used.** Solid-state track detectors.
Recommended value of λ^{238} (in 10^{-17} years^{-1})	8.451	0.060	reduced $\chi^2 = 0.30$
Recommended half-life value (in 10^{15} years)	8.202	0.060	

The evaluators, following the recommendations of N.E. Holden (2000Ho27), have not used in their calculations the measurements with fission tracks in mica-uranium, lexan-uranium sandwiches or ordinary glass, because they significantly disagree with the rest (for more details see 2000Ho27). Thus the experimental values with associated uncertainties used in the weighted average calculation are those from 1950Whitehouse, 1952Se67, 1967Sp12, 1969Vo24, 1970Ga27, 1970Storzer, 1971Th17, 1975Wa37, 1976Th12, 1978Ka40, 1980Po09, 1983Be66 and 1985Iv01. A weighted average has been calculated using LWEIGHT computer program (version 3). Based on the Chauvenet's criterion, Popeko's value (1980Po09) has been shown to be an outlier.

The recommended value of λ^{238} is the weighted average (calculated with LWEIGHT computer program) of *8.451* $10^{-17}a^{-1}$ with an internal uncertainty of *0.046* $10^{-17}a^{-1}$. However, evaluators have adopted an uncertainty of *0.060* $10^{-17}a^{-1}$, minimum input value.

Using this value of λ^{238} and the formula:

$$t_{1/2} = \frac{\ln(2)}{l^{238}},$$

the evaluators have deduced a partial spontaneous fission half-life of *8.202(60)* $10^{15}a$ for ^{238}U and a spontaneous fission branching of 5.45 (4) 10^{-05} %.

2.1 a Transitions and Emissions.

The energies of the α-particle transitions given in Section 2.1 have been calculated from Q_α (2003Au03) and level energies.

The energies of $\alpha_{0,0}$, $\alpha_{0,1}$ and $\alpha_{0,2}$ emissions given in Section 4 are from A. Rytz (1991Ri01).

Measured α-emission intensities are given in Table 4.

Table 4: Measured α-emission intensities, in %.

Energy (keV)	1959Ko58	2000Ga05	Recommended Value
4198 ($\alpha_{0,0}$)	77 (4)	77.54 (50)	77.54 (50)
4151 ($\alpha_{0,1}$)	23 (4)	22.33 (50)	22.33 (50)
4038 ($\alpha_{0,2}$)	0.23 (7)	0.13 (3)	0.13 (3)

The results of these two intensity measurements (1959Ko58 and 2000Ga05) are consistent with each other. Evaluators have adopted the most recent and precise results of Garcia-Toraño (2000Ga05).

2.2 g Transitions

The γ-ray probabilities of the 49- and 113-keV transitions have been deduced from decay-scheme balance by using the recommended experimental alpha emission intensity values (2000Ga05). (see **2.1** a **Transitions and Emissions**).

Multipolarities of γ-ray transitions in the decay of ^{234}Th are from 1994Ak05:
49-keV γ-ray : E2
113-keV γ-ray: [E2]

The internal conversion coefficients (ICC's) have been calculated using the Icc99v3a computer program (GETICC dialog), which uses the new tables of Band et al (2002Ba85) (results of calculation for "hole" and "no hole" are the same). The evaluators have used a fractional uncertainty of 3 % for all conversion coefficients.

3 Atomic Data

Values of atomic values quantities ω_K, ϖ_L and n_{KL}, are from Schönfeld and Janβen (1996Sc06).

3.1 X rays and Auger electrons

The relative probabilities of X-ray and Auger electrons have been calculated from γ-ray data using the EMISSION computer program.

4 a Emissions

See **2.1** a **Transitions and Emissions.**

5 Electron emissions

The Auger electrons emission probabilities have been calculated from γ-ray data using the EMISSION computer program.

6 Photon Emissions

6.1 K x-rays

X-ray emission probabilities have been calculated from γ-ray data using the EMISSION computer program.

6.2 g-ray emissions

The energies of the γ-ray emissions given in Section 6 are from Y.A. Akovali (1994Ak05).

The absolute γ-ray emission intensities have been deduced from the absolute γ-ray transition probabilities and the internal conversion coefficients (ICC's). (see **2.2** g **Transitions.**).

Table 5 shows the recommended absolute γ-ray (photon) emission intensities of the 49- and 113-keV emissions as well as the experimental results obtained from direct measurements of emission intensities.

The agreement is not good, maybe due to experimental difficulties (many peaks of different contaminant isotopes in this energy region) when measuring these weak γ-ray intensities.

Table 5: Experimental absolute γ emission intensity in %.

γ Energy (keV)	1984Ro21	1990Ko40	1996Ru11	Recommended value
49.55	0.064 (8)	0.059 (2)		0.0698 (26)
113.5	0.0102 (15)		0.07 (1)	0.0174 (47)

A fair agreement has been found between the results given by J-C. Roy (1984Ro21) and the evaluators' recommended value for the 49-keV γ-ray.

For the 113-keV γ-ray, there is no good agreement either between results of direct experimental measurements or between those latter and the recommended value. In this energy region the experimental difficulties are associated with presence of many small peaks from different isotopes in the γ-ray spectrum.

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^{238}Np - Comments on evaluation of decay data
by V. P. Chechev and N.K. Kuzmenko

This evaluation was completed in November 2006 with a literature cut off by the same date.

1. Decay Scheme

The decay scheme is based on the evaluation of Chukreev *et al.* (2002Ch52) and can be basically considered completed.

2. Nuclear Data

Q^- value is from 2003Au03.

The evaluated half-life of ^{238}Np is based on the experimental results given in Table 1.

Table 1. Experimental values of the ^{238}Np half-life (in days)

Reference	Author(s)	Value
1950Fr53	Freedman *et al.*	2,10 (1)
1958Al92	Albridge *et al.*	2,16 (15)
1966Qa01	Qaim	2,117 (2)
1990Ch35	Chang *et al.*	2,0980 (3)*
2006Re09	Rengan *et al.*	2,1024 (5)*

* Only statistical uncertainty

The evaluators increased the relativeuncertainties of 1990Ch35 and 2006Re09 to 0,05% to take into account possible systematic uncertainties. The LWEIGHT computer program has omitted the outlier of 1958Al92 and used a weighted average of 2,1024 with the expanded uncertainty of 0,0044 to give a recommended value.

The adopted value of the ^{238}Np half-life is 2,102 (5) days.

2.1. Beta Transitions

The energies of β^- transitions have been calculated from the Q^- value and the level energies given in Table 2 from 2006Re09. The probabilities of β^--transitions have been deduced from the P(γ+ce) balance for each level of ^{238}Pu.

The β transition probability to the 44 -keV level has been deduced from the 44 -keV level intensity balance using P($\gamma_{1,0}$ +ce)(44,07-keV) obtained from the intensity balance for the ground state (see 2.2)

Table 2. ^{238}Pu levels populated in the ^{238}Np β^--decay

Level number	Level Energy, keV	Spin and parity	Half-life	Probability of β^--transition (%)
0	0,0	0^+	87,74 (3) a	-
1	44,08 (2)	2^+	177 (5) ps	41,0 (25)
2	145,95 (2)	4^+		-
3	303,38 (6)	6^+		-
4	605,14 (4)	1^-		0,103 (3)
5	661,40 (6)	3^-		0,036 (3)
6	763,24 (11)	5^-		-
7	941,46 (8)	0^+		-
8	962,78 (2)	1^-		1,25 (1)
9	968,2 (4)	(2^-)		0,082 (6)
10	983,09 (7)	2^+		0,27 (3)
11	985,45 (5)	2^-		0,49 (1)
12	1028,54 (2)	2^+		44,75 (19)
13	1069,94 (2)	3^+		11,50 (7)
14	1082,56 (6)	$(4)^-$		-
15	1202,46 (8)	$(3)^-$		0,51 (6)

Table 3. Measured and evaluated β^- energies (keV) and probabilities (%) in the ^{238}Np decay

1955Ra28		1956Ba95	1962Bo03		**Evaluated**	
Eb$^-$	**Pb$^-$**	**Pb$^-$**	**Eb$^-$**	**Pb$^-$**	**Eb$^-$**	**Pb$^-$**
			200	8	221,6 (4)	11,50 (7)
			250 (10)	31		
258	53	55			263,0 (4)	44,75 (19)
			280 (10)	20		
			1133	2,8		
1272	47	45	1236 (5)	38	1247,4 (4)	41,0 (25)

2.2. Gamma Transitions and Internal Conversion Coefficients

The evaluated energies of gamma-ray transitions are essentially the same as the gamma-ray energies because nuclear recoil is negligible.

The P(γ+ce) values have been calculated from the gamma -ray emission probabilities and the total internal conversion coefficients (ICC's).

For E0- gamma transition 941,5-keV ($\gamma_{7,0}$) the value P(ce) = 0,0106 (9) is based on measurements P(ceK) of 1981Le15 and ICC ratios from the BrIcc package.

The experimental values of ICC's (from 1981Le15) have been adopted for the following gamma-ray transitions: 120,11-keV ($\gamma_{15,14}$), 220,9-keV ($\gamma_{-1,6}$), 923,9-keV ($\gamma_{13,2}$), (E0+E2) gamma-ray transition 939-keV ($\gamma_{10,1}$) (see also 1960Al29), 983,0-keV ($\gamma_{10,0}$) and 984,5-keV ($\gamma_{12,1}$). ICC's have been interpolated from the BrIcc package. The relative uncertainties of α_K, α_L, α_M, α_T for pure multipolarities have been taken as 2 %. The multipolarities and E2/M1, M2/E1 mixing ratios have been taken from 2002Ch52. These are based on conversion electron measurements of 1952Du12, 1956Ba95, 1956Sm18, 1960As10, and 1965Ak02.

P($\gamma_{1,0}$ +ce)(44,08-keV) has been deduced from the intensity balance for the ground state assuming that there is no beta-feeding to the ''0''-level. The second forbidden beta-transition is expected to the ground state with lg *ft* > 15 which implies < 0,01 % (2006Re09).

3. Atomic Data

3.1. Fluorescence yields

Fluorescence yield data are from 1996Sc06 (Schönfeld and Janßen).

3.1.1. X rays

The Pu KX-ray relative emission probabilities have been taken from 1999ScZX

3.1.2. Auger Electrons

The energies of Auger electrons have been calculated from atomic electron binding energies.
The P(KLX)/P(KLL), P(KXY)/P(KLL) ratios have been taken from 1996Sc06.

5. Electron Emissions

The energies of the conversion electrons have been calculated from the gamma transition energies and the electron binding energies.

The emission probabilities of the conversion electrons have been calculated using evaluated P_γ and ICC values.

The absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program.

β^- average energies have been calculated using the LOGFT computer program.

6. Photon emissions

6.1. X-Ray Emissions

The absolute emission probabilities of Pu KX- and LX-rays have been calculated using the EMISSION computer program.

Table 4. Measured and evaluated probabilities of Pu KX in the decay of ^{238}Np.

	1972Wi22	1981Le15	Evaluated
Kα_2	0,18(1)		0,210 (8)
Kα_1	0,272(12)		0,332 (12)
Kβ'_1		0,11	0,122 (5)
Kβ'_2		0,050	0,042 (2)

6.2. Gamma Emissions

The gamma ray energies have been evaluated from experimental data (Table 3)

Table 5. The measured and recommended gamma ray energies in the ^{238}Np β^--decay (keV).

1970Lederer	1972Wi22	1981Le15	2006Re09	Recommended
44	44,08 (3)		44,06 (2)	44,07 (2)
101,93 (4)	101,88 (2)		101,88 (3)	101,88 (2)
			103,74 (2)	103,74 (2)
			116,27 (8)	116,27 (8)
			117,27 (8)	117,27 (8)
119,9 (1)	120,14 (5)		120,09 (5)	120,11 (5)
			120,5	120,5
			120,70 (8)	120,70 (8)
			121,70 (8)	121,70 (8)
132,49 (11)	132,6 (6)		132, 8 (5)	132,5 (1)
157,4 (3)		157,42 (5)	157,42	157,42 (5)
173,78 (11)	174,06 (8)		174,08 (5)	174,08 (5)
220,87 (11)			220,87	220,87 (11)
301,19 (12)	301,81 (19)		301,37 (7)	301,37 (7)
319,29 (11)			319,96 (20)	319,29 (11)
321,75 (20)			321,75	321,75 (20)
323,98 (9)	324,08 (17)		324,07 (15)	324,02 (9)
357,60 (9)	357,64 (7)		357,68 (9)	357,64 (7)
378,05 (13)			378,0 (10)	378,05 (13)
380,28 (13)	380,33 (22)		380,33 (10)	380,31 (10)
421,15 (11)	421,12 (16)		421,05 (10)	421,10 (10)
459,8 (2)		459,80 (22)	459,8 (2)	459,8 (2)
515,58 (12)	515,47 (17)	515,25 (19)	515,53 (7)	515,51 (7)
561,09 (10)	561,15 (7)	561,02 (10)	561,17 (5)	561,14 (5)
605,24 (13)	605,14 (9)	605,04 (10)	605,18 (5)	605,16 (5)
617,45 (12)	617,39 (11)	617,22 (12)	617,41 (5)	617,39 (5)
837,18 (15)	837,0 (4)	837,01 (15)	836,88 (7)	836,96 (7)
882,65 (7)	882,63 (3)		882,63 (3)	882,63 (3)
897,28 (20)		897,33 (10)	897,55 (30)	897,34 (10)
918,70 (7)	918,69 (4)	918,7 (2)	918,70 (4)	918,70 (4)
923,99 (6)	923,98 (2)		923,99 (2)	923,99 (2)
936,57 (9)	936,61 (6)		936,60 (5)	936,60 (5)
939,00 (10)	938,6 (5)	938,91 (10)	938,85 (30)	938,94 (10)
941,39 (6)	941,38 (5)		941,41 (4)	941,40 (4)
941,5 (3)				941,5 (3)
962,80 (7)	962,77 (3)	962,8 (2)	962,76 (2)	962,76 (2)
984,46 (7)	984,45 (2)	984,5 (1)	984,45	984,45 (2)
1025,87 (6)	1025,87 (2)		1025,87 (2)	1025,87 (2)
1028,54 (6)	1028,54 (2)	1028,5 (2)	1028,53 (2)	1028,54 (2)

The absolute emission probabilities for gamma -rays have been deduced from the evaluated relative intensities (see Table 6) using the weighted mean P($\gamma_{12,1}$)(984,5-keV) = 0,2518 (13) of the two absolute measurement results: 0,2517 (13) from 2006Re09 and 0,2519 (21) from 1990Ch15.

It should be noted that in 1981Le15 the differing absolute value of P($\gamma_{12,1}$)(984,5-keV) = 0,278 (8) was deduced from an intensity balance for the ground state of ^{238}Pu.

Using the value of 0,397 (6) from 2006Re09 for the relative gamma ray intensity of $\gamma_{1,0}$ (44,07-keV) and the evaluated relative intensities for the remaining gamma -rays from Table 4, we obtain from the ground state intensity balance the value of P($\gamma_{12,1}$)(984,5-keV) = 0,257 (6) which supports our above more exact value and disagree with 1981Le15.

The absolute gamma ray intensity for $\gamma_{1,0}$ (44,07-keV) has been deduced from the evaluated P($\gamma_{1,0}$ + c.e.)(44.07 keV) and the adopted total ICC.

The absolute gamma ray intensities for $\gamma_{5,1}$ (617,36-keV) and $\gamma_{6,2}$ (617,36-keV) have been deduced using the ratio P($\gamma_{5,1}$)(617,36-keV) /P($\gamma_{6,2}$)(617,36-keV) = 65/9 adopted from 1981Le15.

The relative gamma ray intensity (P'(γ)) and energy for $\gamma_{9,4}$ (924-keV) have been adopted from 1970Be57.

The recommended P'(γ) for $\gamma_{1,0}$ (44,07-keV) has been obtained as a ratio of the evaluated P($\gamma_{1,0}$)(44,07-keV) to P($\gamma_{12,1}$)(984,5-keV) and it has also been compared to measured values.

Table 6. Measured and evaluated relative gamma-ray intensities.

Energy (keV)	1972Wi22	1981Le15*	1990Ch35	2006Re09	Recommended
44,07	≈0,2	0,32 (4) [a]	0,35 (4)	0,397 (6)	0,406 (9)
99,53				0,771 (8)	0,771 (8)
101,9	0,88 (2)	0,97 (4)	1,01 (3)	1,01 (1)	1,00 (3)
103,7				1,24 (1)	1,24 (1)
116,3				0,158	0,158
117,3				0,295	0,295
120,1	0,41 (2)	0,37 (3)		0,453 (9)	0,40 (2)
120,5				0,079	0,079
120,7					
121,7				0,040 (4)	0,040 (4)
132,5	0,013 (7)	0,0101 (7)		0,0056 (3)	0,0056 (3)
157,4		≈0,004			≈0,004
174,0	0,11 (1)	0,094 (4)	0,091 (3)	0,088 (6)	0,091 (3)
220,9		0,0122 (14)		0,007 (6)	0,012 (2)
301,4	0,05 (1)	0,043 (4)	0,040 (4)	0,054 (11)	0,042 (4)
319,3		0,032 (4)		0,038 (12)	0,033 (4)
321,8		0,0047 (22)		0,008 (8)	0,005 (2)
324,0	0,070 (11)	0,058 (4)	0,057 (3)	0,061 (10)	0,058 (3)
336,4					0,0009 (5)
357,6	0,22 (2)	0,191 (11)	0,200 (5)	0,20 (1)	0,200 (5)
378,0		0,012 (2)		0,008 (8)	0,012 (2)
380,3	0,05 (1)	0,043 (2)		0,064 (12)	0,044 (2)
421,1	0,096 (15)	0,083 (4)	0,087 (4)	0,079 (12)	0,085 (4)
459,8		≈0,011		0,009 (6)	0,009 (6)
515,5	0,14 (2)	0,155 (7)	0,148 (5)	0,14 (1)	0,150 (5)
561,1	0,43 (2)	0,41 (2)	0,416 (7)	0,461 (16)	0,423 (7)
605,2	0,31 (3)	0,284 (14)	0,318 (9)	0,29 (2)	0,306 (9)
617,39 (5) } 617,4	0,29 (3)	0,266 (14)	0,270 (9)	0,262 (12)	0,268 (9)
837,0	0,076 (22)	0,101 (7)		0,079 (3)	0,082 (3)
882,6	3,19 (16)	3,13 (11)	3,23 (3)	3,17 (2)	3,19 (2)
885,0				0,16 (2)	0,16 (2)
897,3		0,029 (4)	0,029 (4)	0,032 (8)	0,029 (4)
918,7	2,16 (11)	2,12 (7)	2,11 (2)	2,09 (2)	2,10 (2)
923,99	10,4 (5)	10,3 (3)	10,4 (1)	10,32 (6)	10,34 (6)
924					0,26
936,6	1,39 (7)	1,44 (4)	1,46 (2)	1,41 (11)	1,45 (2)
938,9	0,13 (6)	0,10 (3)	0,13 (1)	0,13 (1)	0,13 (1)
941,4	1,91 (10)	1,98 (7)	2,04 (2)	1,97 (2)	2,00 (2)
941,5					
962,8	2,56 (13)	2,52 (7)	2,56 (3)	2,56 (3)	2,56 (3)
968,5	0,06 (2)	-	-	0,004	0,06 (2)
983,0					0,27 (8)
984,4	100	100	100	100	100
1025,9	34,5 (17)	34,9 (22)	34,59 (50)	34,82 (18)	34,79 (18)
1028,5	72,5 (36)	73,0 (29)	72,61 (70)	72,42 (37)	72,47 (37)

* Absolute gamma-ray emission probabilities cited in 1981Le15 (normalized to 27,8 for the 984,5-keV gamma- ray) have been converted to the relative gamma-ray intensities.

[a] Measured value. In 1981Le15 it is noted that the value deduced from an intensity balance is 0,36 (2).

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^{238}Pu – Comments on evaluation of decay data
by V. P. Chechev

This evaluation was done originally in March 2003, corrected in June 2004, and then updated in June 2009 with a literature cut-off by the same date.

1. DECAY SCHEME

The decay scheme is based on 2007Br04. Some expected weak gamma-ray transitions were not observed directly in ^{238}Pu α-decay but have been adopted from decay of ^{234}Pa and ^{234}Np.

2. NUCLEAR DATA

Q(α) value is from 2003Au03.

The recommended half-life of ^{238}Pu is based on the experimental results given in Table 1.

Table 1. Experimental values of ^{238}Pu half-life (in years)

Reference	Author(s)	Original value [a]	Re-estimated value [a]	Measurement method	Used for final averaging
1950Jaffey	Jaffey and Lerner	89.59 (37)	89.3 (9) [b]	Direct decay (4 samples)	No
1951Jaffey-1	Jaffey and Magnusson	77	-	Growth of ^{238}Pu from ^{238}Np	No
1951Jaffey-2	Jaffey	89 (9)	-	Direct decay	No
1951Seaborg	Seaborg et al.	92 (2)		Growth of ^{238}Pu from ^{242}Cm	No
1954Jo10	Jones et al.	89			No
1957Ho71	Hoffman et al.	86.41 (30)	86.4 (5) [b]	Growth of ^{238}Pu from ^{242}Cm	No
1965Eichelber	Eichelberger et al.	87.60 (6)	-	Calorimetry	No
1967Jordan	Jordan	87.22 (52)	-	Calorimetry	No
1969Benson	Benson	87.75 (5)	-	Calorimetry	No
1974StYG	Strohm and Jordan	87.77(3)	-	Calorimetry	Yes
1976Po08	Polyukhov et al.	86.98 (20)	87.0 (7) [c]	Specific activity	Yes
1977Di04	Diamond et al.	87.71 (3)	-	Growth of ^{238}Pu from ^{242}Cm	Yes
1981Ag06	Aggarwal et al.	87.98 (51)	-	Relative activity ^{238}Pu/^{239}Pu	Yes
1981 Sevastyanov	Sevastyanov and Yarina	86.51 (30)	86.5 (9) [d]	Direct decay (1 sample)	No

[a] Uncertainty at the level of 1σ.
[b] Re-estimated in 1977Di06.
[c] Re-estimated by the evaluator using analysis of 1977Di06.
[d] Re-estimated by the evaluator.

By omitting two values reported without uncertainties, the weighted average of the remaining 12 values is 87.73 with an internal uncertainty of 0.019 and χ^2/ν = 2.0. The average value of 87.73 (3) could be adopted for half-life of ^{238}Pu. However several calorimetric results obtained in the same laboratory (MLM) may be correlated. In fact, the value 87.77 (3) (1974StYG) comes from the latest calorimetric measurement at this laboratory. Also, the early inaccurate experimental results published in 1950 – 1957 may be omitted, as they were obtained with samples of low isotopic purity. Besides, there are grounds for omitting the result of 1981Sevastyanov (V. D. Sevastyanov and V. P. Jarina, Voprosi Atomnoi Nauki i Tekhniki, seriya Jadernie Konstanti. 5(44)(1981)21), as it was obtained only from one sample using an inaccurate method of direct decay.

Therefore, the four best experimental results obtained by different methods were used for the final statistical analysis. These are 87.77 (3) – 1974StYG; 87.0 (7) – 1976Po08; 87.71 (3) –1977Di04 and 87.98 (51) – 1981Ag06. The weighted average of these data sets is 87.74 with an internal uncertainty of

0.021 and $\chi^2/\nu = 1.1$. The recommended value of ^{238}Pu half-life is 87.74 (3) years where the uncertainty is the smallest experimental uncertainty.

The evaluated spontaneous fission half-life of ^{238}Pu has been based on the experimental results given in Table 2. The weighted average of 5 selected values (with reported uncertainties) is 4.74 with an internal uncertainty 0.081 and $\chi^2/\nu = 0.72$.

The recommended value of ^{238}Pu spontaneous fission is 4.74 (12)·10^{10} years where the uncertainty is the smallest experimental uncertainty.

Table 2. Experimental values of ^{238}Pu spontaneous fission half-life (in 10^{10} years)

Reference	Author(s)	Original value [a]	Re-estimated value [a]	Measurement method	Used for final averaging
1949Jaffey	Jaffey and Hirsch	4.9 (4)	4.7 (6) [b]	Ioniz. chamber	Yes
1952Se67	Segre	2.6	3.9 [b]	Ioniz. chamber	No
1961Dr04	Druin et al.	5.0 (6)	5.1 (6) [b]	Photoemulsion	Yes
1972Ha11	Hastings and Strohm	4.77 (14)	-	Si(Au)	Yes
1975GaZX	Gay and Sher	4.63 (12)	-	Fission fragm. coincid. in mica	Yes
1988SeZY	Selitsky et al.	5.01 (21)	-	2π ioniz. chamber	Yes

[a] Uncertainty at the level of 1σ.

[b] Adjusted in 1972Ha11 to ^{238}Pu half-life of 87.77 yr. See also 2000Ho27.

2.1. Alpha Transitions

The energies of the alpha transitions have been obtained from the Q value and the level energies given in Table 3 from 2007Br04.

Table 3. ^{234}U levels populated in ^{238}Pu α decay

Level number	Energy, keV	Spin and parity	Half-life	Probability of α-transition (x100)
0	0,0	0+	2.455 (6) 10^5 yr	71.04 (6)
1	43.4981 (10)	2+	0.252 (7) ns	28.85 (6)
2	143.352 (4)	4+		0.104 (3)
3	296.072 (4)	6+		0.00292 (4)
4	497.04 (3)	8+		6.80 (23)·10^{-6}
5	786.288 (16)	1-		8.21 (16)·10^{-6}
6	809.907 (18)	0+	< 0.1 ns	1.0·10^{-4}
7	849.266 (18)	3-		7.5 (22)·10^{-8}
8	851.74 (3)	2+	> 1.74 ps	8.1·10^{-6}
9	926.720 (15)	2+	1.38 (17) ps	1.30 (5)·10^{-6}
10	947.64 (6)	4+		2.3·10^{-7}
11	989.430 (13)	2-	0.76 (4) ns	1.50 (15)·10^{-7}
12	1023.77 (3)	4+		~ 2.0·10^{-7}
13	1044.536 (23)	0+		1.17(7)·10^{-6}
14	1085.26 (4)	2+		~ 1.2·10^{-6}

The probabilities of the most intense transitions $\alpha_{0,0}$ and $\alpha_{0,1}$ have been obtained by averaging experimental data (Table 4). The probabilities of all the remaining α-transitions have been deduced from the P(γ+ce) balances at relevant levels in ^{234}U.

Table 4. Experimental and recommended values of α-transition probabilities (×100) in the decay of ^{238}Pu

	Energy keV	1954 As07	1957 Ko33	1970 Ba72	1971 So15	1984 Ah06	1984 Bo41	1984 Burns	1987 Bo25	1998 Ya17	Recommended
$\alpha_{0,0}$	5499	72 [a]	71.1 (12)	72.2 [a]	70.7 (2)	70.9 (1)	70.91 (10)	71.11 (4)	71.3 (6)	71.14 (10)	71.04 (6) [b]
$\alpha_{0,1}$	5456	28 [a]	28.7 (12)	27.8 [a]	29.3 (2)	29.0 (1)	28.98 (10)	28.78 (4)	28.6 (4)	28.74 (10)	28.85 (6) [b]
$\alpha_{0,2}$	5358		0.13 (1)	0.068 [a]	0.1 [a]	0.106 (3)	0.105 (5)	0.1002 (17)		0.114 (10)	0.104 (3) [c]
$\alpha_{0,3}$	5208		0.005 (1)	0.0018 [a]		0.036 (5)	0.0030 (1)				0.00292 (4) [d,e]
$\alpha_{0,4}$	5010			$\sim 4\cdot10^{-6}$							$6.80\ (23)\cdot10^{-6}$ [e]
$\alpha_{0,5}$	4726			$2.2\cdot10^{-5}$							$8.21\ (16)\ 10^{-6}$ [e]
$\alpha_{0,6}$	4703			$5\cdot10^{-5}$							$1.0\cdot10^{-4}$ [e,f]
$\alpha_{0,7}$	4664										$7.5\ (22)\cdot10^{-8}$ [e]
$\alpha_{0,8}$	4662			$< 2\cdot10^{-5}$							$8.1\cdot10^{-6}$ [e]
$\alpha_{0,9}$	4588			$(1.2\cdot10^{-5})$							$1.30\ (5)\cdot10^{-6}$ [e]

[a] Omitted from averaging because no uncertainty was reported.

[b] Weighted average of 7 experimental values; uncertainty is external.

[c] Weighted average of 5 experimental values (with quoted uncertainties) is 0.104 (3); the value deduced from P(γ+ce) balance is 0.1030 (24); the recommended value is 0.104 (3).

[d] Agrees well with the experimental value from 1984Bo41

[e] Evaluated from P(γ+ce) balance.

[f] Value of $1.2\ (4)\cdot10^{-4}$ was obtained by α–γ and α-ce coincidences in 1963Bj03.

2.2. Gamma Transitions and Internal Conversion Coefficients

The recommended energies of gamma-ray transitions are virtually the same as the gamma-ray energies because nuclear recoil is negligible for ^{234}U.

Gamma-ray transition probabilities [P(γ+ce)] have been deduced from the gamma-ray emission probabilities and total internal conversion coefficients (ICCs). The ICCs have been interpolated using the BrIcc package with the so called "*Frozen Orbital*" approximation (2008Ki07). The uncertainties in the ICCs for pure multipolarities have been taken as 2 %.

The emission probabilities of E0- and (E0+E2)- transitions have been obtained by using experimental conversion electron intensities from ^{234}Pa and ^{234}Np decays (see 2007Br04) and data from ^{238}Pu α-decay of 1963Bj03, 1964Le17, 1964Le22.

3. ATOMIC DATA

3.1. Fluorescence yields

Fluorescence yield data are from 1996Sc06 (Schönfeld and Janβen).

3.2. X Radiations

The U KX-ray energies have been taken from 1999Schönfeld where the calculated values based on X-ray wavelengths from 1967Be65 (Bearden). In Table 5 the recommended values of U KX-ray energies are compared with experimental values.

The relative K X-ray emission probabilities have been taken from 1999Schönfeld.

Table 5. Experimental and recommended (calculated) values of U KX-ray energies (keV)

	1976GuZN	1982Ba56	1983Ah02	Recommended
Kα_2	94.655 (5)	94.656 (2)	94.67 (2)	94.666
Kα_1	98.442 (5)	98.435 (2)	98.45 (2)	98.440
Kβ_3	110.42 [a]	110.416 (3)	110.42 (3)	110.421
Kβ_1	111.30 [a]	111.300 (2)	111.31 (2)	111.298
Kβ_5	-	111.868 (5)- Kβ_5'' 112.043 (5)- Kβ_5'	112.01 (5)	111.964
K$\beta_{2,4}$	114.54 [a]	-	114.50 (3)	114.46
KO$_{2,3}$	115.40 [a]	-	115.40 (5)	115.377

The energies of U LX-rays taken from the SAISINUC software supporting programs agree with the measurements of 1994Le37 where the fine structure of LX-radiation was measured in decays of ^{239}Pu and ^{240}Pu.

3.3. Auger Electrons

The energies of Auger electrons are from the SAISINUC software supporting programs.

The ratios P(KLX)/P(KLL), P(KXY)/P(KLL) are from 1996Sc06.

4. ALPHA EMISSIONS

The energy of alpha particles corresponding to the alpha transition to the ground state of ^{234}U, E($\alpha_{0,0}$), has been adopted from the absolute measurement of 1971Gr17 with a correction of – 0.18 keV recommended by A. Rytz in 1991Ry01 because of changes in calibrations energies.

The energies of all other alpha particles have been calculated from Q(α), E($\alpha_{0,0}$) and the level energies taking into account the recoil energies.

In Table 6 the deduced (recommended) values of α-particle energies are compared with the experimental results obtained by using magnetic and semiconductor spectrometry.

Table 6. Experimental and recommended values of α-particle energies (keV) in decay of ^{238}Pu.

	Measured [a]						Recommended
	1954As07	1957Ko33	1962Le11	1968Ba25	1970Ba72	1971Gr17	
$\alpha_{0,0}$	5499	5497.7 (10)	5499.2 (8)	5499.2 (10)	5499.2 (8) [c]	5499.03 (20) [b]	5499.03 (20) [b]
$\alpha_{0,1}$	5456	5454.7 (10)	5456.3 (8)	5456.1 (10)	5456.1	5456.3 (4)	5456.3 (2)
$\alpha_{0,2}$	5358	5358.6 (10)	5362 (1)		5357.7		5358.1 (2)
$\alpha_{0,3}$		5215 (5)			5205.6		5208.0 (2)
$\alpha_{0,4}$					≈5015		5010.4 (2)
$\alpha_{0,5}$					4724		4726.0 (2)
$\alpha_{0,6}$					4704		4702.8 (2)
$\alpha_{0,7}$					-		4664.1 (2)
$\alpha_{0,8}$					4661		4661.7 (2)
$\alpha_{0,9}$					≈4590		4587.9 (2)

[a] Original values have been adjusted for changes in calibration energies as suggested in 1991Ry01.

[b] Absolute measurement; this value is recommended in 1991Ry01 and used in 2003Au03 for obtaining Q(α).

[c] Value is from 1962Le11; adopted in 1970Ba72 as calibration energy.

5. ELECTRON EMISSIONS

The energies of conversion electrons have been obtained from the gamma-ray transition energies and atomic-electron binding energies.

The emission probabilities of conversion electrons have been deduced from the evaluated P(γ) and ICC values. Below the experimental L1:L2:L3 conversion electron sub-shell intensities from 1969Am02 are compared with theoretical values for the most intense E2 transition of $\gamma_{1,0}$ (43.498 keV).

Theoretical	Measured
3.85 (11) : 113 (3) : 100	3.99 (22) : 114.7 (20) : 100

The total absolute emission probabilities of K Auger electrons have been deduced using the evaluated total P(XK) and the adopted fluorescence yield ω_K.

The total absolute emission probability of L Auger electrons have been deduced using the total evaluated P(XL) and the adopted fluorescence yield ϖ_L.

6. PHOTON EMISSIONS

6.1. X-Ray Emissions

6.1.1. M X-Rays

The total absolute emission probability of MX–rays is based on the measurement (1990Po14) of the relative emission probability P(MX)/P(LX) = 0.194 (24).

6.1.2. L X-Rays

The calculation of the total absolute emission probability of LX-rays [P(XL)], using the EMISSION computer program (2000Schönfeld), gives P(XL) = 10.55 (25) %. The available experimental results for P(XL) are discrepant: 13 % - 1954As07; 10.6 (3) % - 1964Ha14; 12.83 (14) % - 1968By01; 9.2 (1) % - 1968Salgueiro; 11.2 (4) % - 1968Swinth; 11.4 (3) % - 1971Swinth; 14.18 (11) % - 1976Va23; 11.38 (10) % - 1977Bemis; 11.55 (18) % - 1984Bo41; 10.62 (32) % - 1984DrZX and 1984BaYT; 10.63 (8) % - 1995Jo23.

The result of the most accurate and latest measurement (1995Jo23) agrees well with the calculated values and with the value from 1984DrZX where the fine structure of LX-radiation was measured. The value from 1995Jo23 has been adopted as the recommended absolute emission probability of U LX–rays from decay of ^{238}Pu: P(XL) = 10.63 (8) %.

For the evaluation of emission probabilities of the LX-ray components Ll, Lα, Lβη, Lγ the measured values given in Table 7 were renormalized by the evaluator to the adopted value P(XL) = 10.63 (8) % and then averaged. In Table 8 the evaluated emission probabilities are compared with values calculated in 1995Jo23 from alpha-branching ratios, theoretical ICC and theoretical atomic branching ratios.

Table 7. Experimental absolute emission probabilities of U LX-rays from α decay of ^{238}Pu

	1976Va23	1977Bemis	1984Bo41	1995Jo23
Ll	-	0.26 (1)	0.260 (7)	0.231 (3)
Lα	5.05 (6)	4.15 (7)	4.06 (6)	3.81 (3)
Lβη	7.41 (9)	5.61 (7)	5.85 (9)	5.31 (4)
Lγ	1.48 (2)	1.36 (2)	1.38 (2)	1.29 (1)

Table 8. Renormalized experimental, evaluated, and calculated absolute emission probabilities of U LX-rays from α decay of ^{238}Pu

	1976Va23 (measured)	1977Bemis (measured)	1984Bo41 (measured)	1995Jo23 (measured)	Adopted (averaged)	Calculated (1995Jo23)	Calculated (EMISSION code)
Ll	-	0.24 (1)	0.239 (7)	0.231 (3)	0.235 (4) [b]	0.234	0.232 (8)
Lα	3.77 (5)	3.88 (7)	3.74 (6)	3.81 (3)	3.80 (3) [c]	3.78	3.73 (12)
Lβη	5.53 (7) [a]	5.24 (7)	5.38 (8)	5.31 (4)	5.31 (4) [c]	5.42	5.23 (16)
Lγ	1.10 (2) [a]	1.27 (2)	1.27 (2)	1.29 (1)	1.28 (1) [c]	1.26	1.23 (4)

[a] Omitted from averaging based on statistical considerations.
[b] Weighted average; uncertainty is internal.
[c] Weighted average; uncertainty is the smallest experimental one.

6.1.3. KX-Rays

The absolute X-ray emission probability of U Kα_2 with energy 98.44 keV (P(Kα_2)) has been adopted from 1976GuZN. The absolute emission probabilities of all other X-rays have been deduced from their relative emission probabilities using the adopted P(Kα_2) = $1.69\ (4)\cdot 10^{-4}$ %. (The uncertainty of this value includes an additional 2 % detector efficiency uncertainty).

The total absolute KX-ray emission probability P(XK) = $3.56\ (11)\cdot 10^{-4}$ %, obtained using P(Kα_2) and the ratio of P(XK) / P(Kα_2), exceeds the value calculated from ω_K and the total emission probability of K–conversion electrons $P^{(ce)}$(XK) = $2.6\cdot 10^{-4}$ %. This disagreement may be due to an inaccurate estimation of K-conversion electron intensities from E0 and (E0 + E2) transitions in decay of ^{238}Pu.

6.2. Gamma-Ray Emissions

6.2.1. Gamma-Ray Energies

The energies of prominent gamma-rays $\gamma_{1,0}$(43.5 keV), $\gamma_{2,1}$(99.9 keV) and $\gamma_{3,2}$(152.7 keV) have been taken from 1984He19, with a correction of 5.8 ppm in the gamma-ray energy scale as provided by 2000He14. The energies of gamma-rays $\gamma_{13,5}$(258.2 keV) and $\gamma_{5,1}$(742.8 keV) are from 2000Ni13. The remaining gamma-ray energies have been taken from 2007Br04 based on the measurements of 1969LeZX and also 1954As07, 1955Ch02, 1956Ne17, 1971Cl03, 1971GuZY, 1971Ma68, 1976GuZN, 1984Ov01. Several of gamma-rays were not observed in ^{238}Pu α-decay and their energies have been taken from the decay of ^{234}Pa and ^{234}Np (2007Br04). The experimental and recommended gamma-ray energies are given in Table 9.

Table 9. Experimental and recommended gamma-ray energies (keV) from ^{238}Pu α decay [a]

	1969LeZX	1971GuZY	1972Sc01	1976GuZN	1984He19	Recommended
$\gamma_{1,0}$		43.492 (10)	43.491 (9)	43.477 (5)	43.498 (1)	43.498 (1)
$\gamma_{2,1}$	99.84 (4)	99.871 (10)	99.85 (1)	99.864 (5)	99.853 (3)	99.852 (3)
$\gamma_{3,2}$	152.71 (5)	152.77 (3)	152.719 (19)	152.68 (2)	152.720 (2)	152.719 (2)
$\gamma_{4,3}$	200.9 (2)	200.98	201.017 (30)	200.98		200.97 (3)
$\gamma_{14,7}$	235.9 (3)					235.9 (3)
$\gamma_{13,5}$	258.3 (2)	258.23				258.227 (3)
$\gamma_{14,5}$	299.2 (2)					299.1 (2)
$\gamma_{7,2}$	706.1 (3)	705.6		705.6		705.9 (1)
$\gamma_{8,2}$	708.4 (2)	708.4		708.4		708.3 (2)
$\gamma_{5,1}$	742.77 (10)	742.82		742.82		742.813 (5)
$\gamma_{6,1}$	766.39 (10)	766.41 (2)		766.41		766.38 (2)
$\gamma_{5,0}$	786.30 (10)	786.30		786.30		786.27 (3)
$\gamma_{7,1}$	805.8 (3)	805.42		805.4		805.80 (5)
$\gamma_{8,1}$	808.25 (15)	808.23		808.2		808.20 (10)
$\gamma_{8,0}$	851.70 (10)	851.73		851.7		851.70 (10)
$\gamma_{12,2}$	880.5 (3)					880.5 (1)

	1969LeZX	1971GuZY	1972Sc01	1976GuZN	1984He19	Recommended
$\gamma_{9,1}$	883.23 (10)	883.21				883.24 (4)
$\gamma_{10,1}$	904.37 (15)	904.34				904.37 (15)
$\gamma_{9,0}$	926.72 (15)	926.73				926.72 (10)
$\gamma_{14,2}$	941.9 (2)	942.02				941.94 (10)
$\gamma_{11,1}$	946.0 (3)	946.12				946.00 (3)
$\gamma_{13,1}$	1001.03 (15)	1001.10				1001.03 (3)
$\gamma_{14,1}$	1041.8 (3)	1041.90				1041.7 (2)
$\gamma_{14,0}$	1085.4 (3)	1085.40				1085.4 (2)

[a] Other much more inaccurate measurement results can be found in 1954As07, 1955Ch02, 1956Ne17, 1971Cl03 and 1971Ma68. They agree with those given in Table 9.

6.2.2. Gamma-Ray Emission Probabilities

The experimental and recommended absolute gamma-ray emission probabilities P(γ) for prominent γ-rays (with energies < 200 keV) are given in Table 10. The recommended P(γ) values have been obtained by averaging several experimental results. They agree well with the values deduced from intensity balances at relevant ^{234}U levels using P(α) and total ICCs.

Table 10. Experimental and recommended absolute emission probabilities (per 10^4 α-decays) for prominent gamma-rays from the decay of ^{238}Pu

	E_γ (keV)	1976GuZN	1976Um01	1979 Vaninbroukx	1984Bo41	1984He19	1984Ov01	1994Ba91	Recommended (averaged) [a]	Deduced [b]
$\gamma_{1,0}$	43.5	3.93 (8)	4.11 (8)	3.93 (12)	3.96 (10)	3.82 (8)			3.97 (8)	4.06 (8)
$\gamma_{2,1}$	99.8	0.724 (14)			0.730 (11)	0.743 (8)	0.631 (38) [c]		0.735 (8)	0.741 (25)
$\gamma_{3,2}$	152.7	0.0956 (20)			0.0928 (14)	0.0936 (10)	0.086 (4) [c]	0.0923(7)	0.0930 (7)	0.095 (4)

[a] Weighted averages; uncertainties are the smallest experimental values.
[b] Deduced from P(α) values and total ICCs.
[c] Omitted based on statistical considerations.

The relative emission probabilities of $\gamma_{14,7}$(235.9 keV), $\gamma_{13,8}$(258.2 keV) and $\gamma_{14,5}$(299.1 keV) have been adopted from 1969LeZX. The absolute emission probability of $\gamma_{10,2}$ (804.4 keV) has been deduced using the ratio of P(γ 804.4 keV) / P(γ 904.4 keV) = 1.8 (7) measured in ^{234}Pa β^--decay (2007Br04). P(γ) values for other gamma-rays, which were also not observed in the ^{238}Pu α-decay, have been deduced from decay of ^{234}Pa and ^{234}Np (2007Br04) using experimental relative gamma-ray emission probabilities.

The absolute emission probabilities of all other weak gamma-rays (with energies more than 200 keV) have been deduced from their evaluated relative emission probabilities given in Table 11.

The value P(γ766) = 2.19 (5)·10^{-7} measured in 1976GuZN (the uncertainty includes an additional 2 % detector efficiency uncertainty) was used as a normalization factor. This value agrees well with the value of 2.19 (9)·10^{-7}, deduced from the measured in 1979Ce04 P(γ786) = 3.16 (9)·10^{-8} and the relative intensity P(γ786) / P(γ766) = 0.144 (4), as well as with the value of 2.21 (15)·10^{-7} measured in 1984Ov01. The latter value has been obtained by the evaluator from authors' Pγ renormalized to P(γ 152.7-keV) = 9.30 (7)·10^{-6}.

Table 11. Experimental and recommended relative emission probabilities of gamma-rays with energy more than 200 keV from decay of ^{238}Pu

		1969LeZX	1971GuZY	1971Ma68	1976GuZN	1979Ce04	1984Ov01	Recommended
$\gamma_{4,3}$	201.0	15 (3)	17.8 (3)		18.6 (4)	17.0 (5)		17.9 (4)
$\gamma_{14,7}$	235.9	0.04 (2)						0.04 (2)
$\gamma_{13,5}$	258.2	0.35 (5)	0.28 (6)					0.32 (5)
$\gamma_{14,5}$	299.1	0.20 (5)						0.20 (5)
$\gamma_{7,2}$	705.9	0.42 (6) [a]	0.225 (23)		0.23 (10)		0.25 (10)	0.23 (5)
$\gamma_{8,2}$	708.3	1.15 (9) [a]	2.24 (23)	2.5 (6)	2.29 (23)	2.5 (6)	1.7 (3)	2.22 (14)
$\gamma_{5,1}$	742.8	23.2 (4)	23.1 (2)	25.7 (15)	23.6 (5)	23.8 (4)	22.6 (12)	23.3 (2)
$\gamma_{6,1}$	766.4	100	100	100	100	100	100	100
$\gamma_{5,0}$	786.3	14.5 (3)	14.7 (2)	14.9 (10)	15.0 (3)	14.4 (4)	13.7 (5)	14.6 (2)
$\gamma_{7,1}$	805.8	0.56 (6)	0.56 (6)		0.59 (3)		0.7 (2)	0.58 (3)
$\gamma_{8,1}$	808.2	3.40 (8)	3.57 (10)	3.2 (5)	3.65 (13)	3.52 (18)	4.0 (4)	3.50 (8)
$\gamma_{8,0}$	851.7	5.79 (20)	5.79 (11)	6.6 (6)	5.89 (17)		4.9 (5)	5.81 (11)
$\gamma_{12,2}$	880.5	0.7 (2)					0.65 (16)	0.68 (16)
$\gamma_{9,1}$	883.2	3.43 (15)	2.72 (27)	3.3 (5)		3.54 (25)	3.2 (6)	3.30 (17)
$\gamma_{10,1}$	904.4	0.30 (4)	0.26 (8)				0.25 (10)	0.28 (5)
$\gamma_{9,0}$	926.7	2.53 (10)	2.56 (10)	2.7 (6)		2.58 (13)	2.4 (3)	2.55 (10)
$\gamma_{14,2}$	941.9	2.06 (9)	2.19 (9)	2.2 (6)		2.23 (27)	1.9 (4)	2.13 (9)
$\gamma_{11,1}$	946.0	0.40 (6)	0.43 (9)					0.42 (6)
$\gamma_{13,1}$	1001.0	4.39 (14)	5.42 (33) [a]	4.0 (7)		4.61 (18)	4.1 (5)	4.46 (14)
$\gamma_{14,1}$	1041.7	0.84 (7)	0.95 (10)	0.7 (3)			1.3 (3)	0.90 (7)
$\gamma_{14,0}$	1085.4	0.34 (4)	0.95 (10) [a]	1.1 (4) [a]			0.5 (2)	0.35 (4)

[a] Omitted on the basis of statistical considerations.

7. Consistency of recommended data

The most accurate Q value, Q(M), is taken from the atomic mass adjustment table of Audi et al. (2003Au03). Comparison of Q(eff)(deduced as the sum of average energies per disintegration ($\sum E_i \times P_i$) for all emissions accompanying ^{238}Pu α- decay) with the tabulated decay energy Q(M) allows to check a consistency of the recommended decay-scheme parameters obtained in this evaluation.

Here E_i and P_i are the evaluated energies and emission probabilities of the i-th alpha particle, beta particle, gamma-ray, X-ray, etc. Consistency (percentage deviation) is determined by $\{[Q(M)– Q(eff))]/Q(M)\} \times 100$. "Percentage deviations above 5 % would be regarded as high and imply a poorly defined decay scheme; a value of less than 5 % indicates the construction of a reasonably consistent decay scheme" (quoted from the article by A.L. Nichols in Appl. Rad. Isotopes 55 (2001) 23-70).

For the above ^{238}Pu decay data evaluation we have Q(M) = 5593.20 (19) keV and Q(eff) = 5593(5) keV. Thereafter, the percentage deviation is (0.00 ± 0.09) %, i.e. consistency is superior.

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^{239}U – COMMENTS ON EVALUATION OF DECAY DATA

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This evaluation was completed in October 2008 and updated in March 2009 with a literature cut - off by the same date.

1. DECAY SCHEME

Decay scheme is based on 2003Br12. Most (99 %) of ^{239}U beta decay feeds the well-studied ^{239}Np levels below 118 keV. However more than 30 excited states of ^{239}Np have been associated with weak ^{239}U beta transitions and in this part the decay scheme cannot be considered as completed.

Several unplaced gamma rays were observed in 2006Wo03. These gamma rays carry ≤ 2 % of the total intensity of all the gamma rays placed in the decay scheme.

Wong and Griffin (2006Wo03), based on the energies of many of these gamma rays, suggested different versions of their placement including alternative with respect to 2003Br12. These suggestions require an additional careful analysis. Therefore the evaluators have been accepted only small change in the decay scheme from 2003Br12 associated with moving the 1197 -keV level off and adding the new 849,45-keV level.

The 1197-keV level stated in 2003Br12 has been deleted from the level scheme since the 535 -, 1122- and 1197 - keV gamma transitions previously reported were not observed in 2006Wo03 and attributed to possible impurities. The new (declared in 2006Wo03) 849,45-keV level de-exciting via 502-, 608-, 728-, 775- and 849- keV gamma rays has been placed to the decay scheme.

It should be noted that a number of ^{239}Np levels reported only from nuclear reactions may be populated (according to the data of 2006Wo03) in ^{239}U β^--decay.

Several gamma rays previously reported were not observed with high reliability in 2006Wo03. They were ascribed to fission product impurities in their study.

2. NUCLEAR DATA

Q^- value is from 2003Au03.

The recommended half-life of ^{239}U is based on the experimental results given in Table 1.

Table 1. Experimental values of ^{239}U half-life (in minutes)

Reference	Author(s)	Original value	Re-estimated	Measurement method
1943Mi10	Mitchell et al.	23,54 (5)		β-counting
1947Fe05	Feather and Krishnan	23,5 (7)		β- and gamma-ray counting
1969Hu21	Hunt et al.	23,40 (5)		β-counting
1989Ab05	Abzouzi et al.	23,44 (2) [a]	23,44 (11)	Gamma-ray counting
2008Griffin	Griffin	23,37 [b]	23,37 (10)	Liquid scintillation counting

[a] Uncertainty may include only statistical errors. The evaluators have taken into account the contribution of possible systematic errors (uncertainty of the Type B) associated with the gamma-ray counting method (see Comments on evaluation of ^{233}Th half-life).

[b] Author did not report the uncertainty. Possible statistical and systematic errors associated with the used LSC method were discussed in 2008De10 under the measurements of ^{233}Th half-life (22 min). The evaluators have estimated an overall relative uncertainty of ~ 0,4 % (see Comments on evaluation of ^{233}Th half-life).

The unweighted mean of the 6 values from Table 1 is 23,45 (3), the weighted mean is 23,46, the internal uncertainty is 0,032, the external uncertainty is 0,035. The LWEIGHT computer program recommended the weighted mean and its internal uncertainty. The smallest experimental uncertainty is 0,05. Therefore, the recommended value of ^{239}U half-life is 23,46 (5) minutes.

2.1. Beta Transitions

The energies of β^- transitions have been obtained from the Q^- value and the ^{239}Np level energies given in Table 2 from 2003Br12.

Table 2. ^{239}Np levels populated in ^{239}U β^--decay

Level	Energy (keV)	Spin and Parity	Half-life	
0	0,0	5/2+	2,356 (3) d	14,4 (22)
1	31,1310 (12)	7/2+		9,4 (15)
2	71,210 (2)	9/2+		
3	74,664 (1)	5/2-	1,39 (3) ns	72,8 (19)
4	117,727 (20)	7/2-	= 40 ps	2,2 (4)
5	122,5 (10)	(11/2+)		
6	173,10 (4)	9/2-		
7	241,36 (5)	(11/2-)		
8	260,799 (17)	(3/2-)		
9	438,83 (5)	(11/2+)		
10	448,178 (16)	(3/2-)		
11	452,736 (2)	(5/2+,7/2-)		
12	474,36 (6)			0,0033 (4)
13	517,998 (20)	(7/2-)		0,063 (2)
14	530,29 (6)			0,0029 (4)
15	563,89 (4)			0,0247 (7)
16	579,40 (4)	(9/2-)		
17	662,282 (17)	(5/2-)		0,261 (6)
18	695,229 (23)	(7/2-)		0,0118 (11)
19	781,93 (4)			
20	784,94 (5)			
21	819,26 (3)	(7/2)		0,228 (3)
22	844,10 (3)	(5/2,7/2)		0,215 (3)
23	849,44 (9)			0,0264 (4)
24	863,46 (6)	(3/2,5/2,7/2)		0,0005 (2)
25	959,18 (3)			0,0284 (7)
26	964,234 (20)	(7/2-)		0,211 (3)
27	966,55 (5)	(7/2,9/2-)		0,0008 (2)
28	992,158 (22)	(7/2-)		0,0262 (9)
29	1013,64 (8)			0,0074 (4)
30	1040,37 (4)	(5/2-,7/2)		0,0077 (4)
31	1049,24 (4)	(9/2-)		0,0059 (4)
32	1096,99 (3)			0,0060 (5)

The emission probabilities of β^--transitions have been deduced from the P(γ+ce) balance at each level of ^{239}Np. β^--transitions with P(β) < 0,5 % are tentative because of unplaced γ-ray transitions (see 2006Wo03).

2.2. Gamma-ray Transitions and Internal Conversion Coefficients

The recommended energies of the gamma-ray transitions are virtually the same as the gamma-ray energies because nuclear recoil is negligible for ^{239}Np.

The gamma-ray transition probabilities have been obtained from the gamma -ray emission probabilities and the total internal conversion coefficients (ICC). Multipolarities of gamma-ray transitions have been taken from 2003Br12. The ICC have been interpolated using the BrIcc package with the so called "*Frozen Orbital*" approximation (2008Ki07). The relative uncertainties of the ICC for pure multipolarities have been taken as 2 %.

P($\gamma_{2,0}$ + ce)(71,2-keV) and P($\gamma_{7,2}$ + ce)(170,2-keV) have been obtained from the level P(γ+ce) balance assuming that there is no beta-feeding to the 2- and 7- levels, respectively.

The M1/E2 mixing ratios for $\gamma_{1,0}$ - 31,1 keV (0,028), $\gamma_{4,3}$ - 43,1 keV (0,126) and $\gamma_{6,4}$ -55,2 keV (0,26) have been taken from ^{243}Am α decay (2003Br12).

The remaining gamma transition multipolarities and M1/E2 mixing ratios have been adopted from ^{239}U β^--decay (see 2003Br12) based on measurements of 1957Ho07, 1964Bl11, 1969En02.

3. ATOMIC DATA

The atomic data (fluorescence yields, X-ray energies and relative probabilities, and Auger electrons energies and relative probabilities) have been deduced by using the SAISINUC software (2002Be).

4. ELECTRON EMISSIONS

The energies of the conversion electrons have been calculated from the gamma -ray transition energies and the electron binding energies.

The absolute emission probabilities of the conversion electrons have been obtained using the recommended P_γ and ICC values.

The absolute emission probability of K Auger electrons has been deduced from the recommended ΣKX = 0,305 (10) %. The absolute emission probability of L Auger electrons has been obtained using the recommended P_γ and ICC values with the EMISSION computer program.

β^- average energies have been calculated using the LOGFT computer program.

5. PHOTON EMISSIONS

5.1. X-Ray Emissions

The recommended absolute emission probabilities of KX- rays have been obtained using the total number of K vacancies of 0,314 (10) % deduced in 2008Griffin from their KX-ray measurements.

The recommended absolute emission probabilities of LX -rays have been obtained using the recommended P_γ , ICC values and the total number of K vacancies with the EMISSION computer program. The calculated total absolute intensity of LX-rays of 16,1 (5) % can be compared with the value of 17 (4) % measured in 2008Griffin (here the author's value of 18,1 % has been corrected to the evaluated $P\gamma_{2,0}$ (74,7 keV) = 51,6 (13) % used instead of 53,9 (5) % measured in 2008Griffin). The uncertainty of the measured LX -ray intensity was not given in 2008Griffin. It has been accepted by the evaluators using the relative uncertainty of the detection efficiency for energies at and below 20 keV ~ 20 % estimated in 2008De10.

5.2. Gamma-Ray Emissions

The gamma ray energies < 120 keV have been obtained from the adopted level energies.

The gamma ray energies > 120 keV have been adopted from 2006Wo03. They agree mainly with the values from 2003Br12 based on experimental data of 1964Bl11, 1969Cl12, 1971Ar47, 1975Pa04, 1979Bo30, 1982Ah04 and data from nuclear reactions. The exceptions comprise the gamma -ray transitions feeding the ^{239}Np ground state and the gamma rays with energies from 2006Wo03 different from 2003Br12. In such cases the recommended gamma ray energies have been obtained from the adopted level energies.

Several unplaced gamma rays observed in decay of ^{239}U, a-decay of ^{243}Am, and the particle transfer reactions were discussed in 2006Wo03 in detail. The transfer reactions and a-spectroscopy give direct information on level energies, but with uncertainties ~ 3 keV. Gamma ray spectroscopy, unsupported by coincidence correlations, gives relatively precise energies, but often placements are ambiguous. Therefore, all such gamma rays have been qualified by the evaluators as unplaced in the decay scheme.

The absolute emission probabilities for most intense gamma rays have been evaluated from experimental data (Table 4). The results of 1984Holloway are superseded by the same group in 1996Sa23 and have not been included in the procedure of averaging.

Table 4. Experimental and evaluated absolute emission probabilities (%) for most intense gamma-rays in decay of ^{239}U.

Eγ (keV)	1964 Bl11	1965 Yurova	1968 Ma06	1969 Cl12	1984 Holloway	1996 Sa23	2008 Griffin	**Evaluated**
31,1					0,065 (7)	0,064 (7)	0,075 (4)	**0,072 (4)**
43,5	4,1 (2)			4,45 (60)	4,18 (13)	4,07 (11)	4,93 (15)	**4,35 (28)**
74,7		47 (4)	62 (9)	50 (5)	48,2 (10)	49,2 (12)	53,9 (5)	**51,6 (13)**
86,7				0,060 (6)	0,052 (6)	0,053 (6)	0,054 (5)	**0,055 (5)**
117,7				0,145 (15	0,13 (4)	0,14 (3)	0,099 (9)	**0,113 (9)**

$P\gamma_{2,0}$ (71,2 keV) and $P\gamma_{7,2}$(170,2 keV) have been obtained from the P(γ+ce) and α_T .The value of $P\gamma_{4,3}$ (43,1 keV) has been deduced using the ratio $P\gamma_{4,3}$ / $P\gamma_{4,0}$ = 0,115 (12) from 1969En02.

The remaining absolute gamma ray emission probabilities for gamma rays with energy more than 120 keV have been deduced from relative gamma ray emission probabilities P_γ^{rel} (2006Wo03). Thereto the evaluators have used the coefficient k = P_γ^{rel} (74,7 keV) / 0,539 (5) given in 2008Griffin. It was corrected to the evaluated P_γ (74,7 keV) = 0,516 (13) taking also into account the detection efficiency uncertainty (0,7 %): k = 218,1 (48). The obtained P_γ agree with the values from 2003Br12 based on experimental data of 1964Bl11, 1965Yurova, 1968Ma06, 1969Cl12, 1971Ar47 and 1984Holloway.

6. CONSISTENCY OF RECOMMENDED DATA

The most accurate Q value, Q(M), is taken from the atomic mass adjustment table of Audi et al. (2003Au03). Comparison of Q(eff)(deduced as the sum of average energies per disintegration ($\sum E_i \times P_i$) for all emissions accompanying ^{233}Th β- decay) with the tabulated decay energy Q(M) allows to check a consistency of the recommended decay-scheme parameters obtained in this evaluation.

Here E_i and P_i are the evaluated energies and emission probabilities of the i-th alpha particle, beta particle, gamma ray, X-ray, etc. Consistency (percentage deviation) is determined by $\{[Q(M) – Q(eff)]/Q(M)\} \times 100$. “Percentage deviations above 5 % would be regarded as high and imply a poorly defined decay scheme; a value of less than 5 % indicates the construction of a reasonably consistent decay scheme” (quoted from the article by A.L. Nichols in Appl. Rad. Isotopes 55 (2001) 23-70).

For the above ^{239}U decay data evaluation we have Q(M) = 1261,5 (16) keV and Q(eff) = 1263 (36) keV, i.e. consistency is better than 2 %.

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^{239}Np – Comments on evaluation of decay data
by V.P. Chechev and N.K. Kuzmenko

This evaluation was completed in June 2006. The literature available by May 2006 was included.

1. Decay Scheme

Decay scheme has been taken from 2003Br12.

2. Nuclear Data

Q^- value is from 2003Au03.

The evaluated half-life of ^{239}Np is based on the experimental results given in Table 1.

Table 1. Experimental values of the ^{239}Np half-life (in days)

Reference	Author(s)	Value
1956Wi25	Wish	2,346 (4)
1959Co63	Connor and Fairweather	2,34 (2)
1959Co93	Cohen *et al.*	2,366 (3)
1966Qa01	Qaim	2,354 (8)
1969Bi12	Bigham *et al.*	2,346 (4)
1990Ab06	Abzouzi *et al.*	2,3565 (4)

The weighted average of 2,3564 for this discrepant data set of the 6 values is dominated by the very accurate value of 1990Ab06. The LWEIGHT computer program, which uses a limitation of relative statistical weights (LRSW method), has increased the 1990Ab06 uncertainty from 0,0004 to 0,0020 and used a weighted average and an external uncertainty having led to 2,356 (3) as a recommended value.

Thus, the adopted value of the ^{239}Np half-life is **2,356 (3) days**.

2.1. Beta Transitions

The energies of β^- transitions have been calculated from the Q^- value and the level energies given in Table 2 from 2003Br12 where they have been deduced from a least squares fit to gamma-ray energies (see also 1996FiZX).

Table 2. ^{239}Pu levels populated in the ^{239}Np β^--decay

Level	Energy (keV)	Spin and parity	Half-life	Probability of β^--transition (%)
0	0	1/2+	24100 (11) a	-
1	7,861 (2)	3/2+	36 (3) ps	6,5 (10)
2	57,276 (2)	5/2+	101 (5) ps	0,4 (72)
3	75,706 (3)	7/2+	83 (8) ps	-
4	163,76 (2)	9/2+	73 (4) ps	-
5	285,460 (2)	5/2+	1,12 (5) ns	43,0 (22)
6	330,125 (4)	7/2+		9,4 (14)
7	387,41 (2)	9/2+		-
8	391,586 (3)	7/2-	193 (4) ns	38,8 (9)
9	469,8 (4)	(1/2-)		0,0027

Level	Energy (keV)	Spin and parity	Half-life	Probability of β^--transition (%)
10	492,2 (3)	3/2-		0,02
11	505,2	(5/2-)		0,0074
12	511,81 (6)	7/2+		1,56 (16)
13	556,2	(7/2-)		0,0026

The probabilities of β^--transitions have been deduced from the P(γ+ce) balance for each level of ^{239}Np. Measured and evaluated β^--transition probabilities are given in Table 3.

Table 3. Measured and evaluated probabilities (%) of β^- -transitions

	1952Fr25	1956Ba95	1959SCo63	Adopted
$\beta_{0,8}$	52	45	28	38,8 (9)
$\beta_{0,6}$	10	27	13,5	9,4 (14)
$\beta_{0,5}$	31	21	48	43,0 (22)
$\beta_{0,2}$	1,7	}	4	0,4 (72)
$\beta_{0,1}$	4,8	}7	6,5	6,5 (10)

2.2. Gamma-ray Transitions and Internal Conversion Coefficients

The evaluated energies of gamma -ray transitions are virtually the same as the photon energies because nuclear recoil is negligible.

The gamma-ray transition probabilities, P(γ+ce), have been calculated from the gamma -ray emission probabilities and the total internal conversion coefficients (ICC's). Multipolarities of gamma -ray transitions have been taken from 2003Br12 (see also 1996FiZX). ICC's have been interpolated from the BrIcc package. The relative uncertainties of α_K, α_L, $\alpha_{M,}$ α_T for pure multipolarities have been taken as 2 %. The transition $\gamma_{8,5}$ is anomalously converted, ICC's for this transition have been taken from the measurements of 1959Ew90.

P($\gamma_{1,0}$ +ce)(7,86-keV) has been deduced from the intensity balance for the ground state assuming that there is no beta -feeding to the ''0'' -level. P($\gamma_{3,2}$ +ce) (18,43 -keV) has been deduced from the intensity balance for the level ''3'' (75,70-keV) assuming that there is no beta-feeding to the ''3''-level.

The mixing ratios (d) for gamma -ray transitions have been taken from 2003Br12 based on measurements of 1959Ew90, 1972Kr07, 1990Si12 and 1991Sh06.

3. Atomic Data

3.1. Fluorescence yields

The fluorescence yield data are from 1996Sc06 (Schönfeld and Janßen).

3.2. X Radiations

The LX-ray energies are from 1996FiZX. The KX-ray energies and the relative KX-ray emission probabilities are from 1999Schönfeld .

The ratios P(KLX)/P(KLL), P(KXY)/P(KLL) are from 1996Sc06.

4. Electron Emissions

The energies of the conversion electrons have been calculated from the gamma transition energies and the electron binding energies.

The emission probabilities of the conversion electrons have been calculated using evaluated P_γ and ICC values.

The absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program.

β^- average energies have been calculated using the LOGFT computer program.

5. Photon Emissions

5.1. X-Ray Emissions

The absolute emission probabilities of Pu KX- and LX-rays have been calculated using the EMISSION code.

Measured and calculated absolute emission probabilities of Pu KX-rays are given in Tables 4.

Table 4. Measured and calculated absolute emission probabilities (%) of Pu KX-rays.

	1972Ah02	1982Ah04	Calculated
$K\alpha_2$ (Pu)	14,4 (6)	12,8 (4)	13,5 (4)
$K\alpha_1$ (Pu)	22,2 (6)	20,4 (6)	21,4 (6)
$K\beta'_1$ (Pu)	-	7,3 (3)	7,84 (25)
$K\beta'_2$ (Pu)	2,8 (1)	2,6 (1)	2,72 (10)

5.2. Gamma-Ray Emissions

The gamma ray energies, Eγ, for $\gamma_{1,0}$ (7,86-keV) , $\gamma_{2,1}$ (49,4-keV) and $\gamma_{4,2}$ (106,5-keV) were calculated from the level energies. The gamma ray energies with $E\gamma > 334,3$ keV have been taken from 1974HeYW. The other gamma energies were adopted from 2003Br12 based on experimental data of 1959Ew90, 1965Ma17, 1972Po04, 1979Bo30 and 1982Ah04.

P($\gamma_{1,0}$)(7,86-keV) has been deduced from P($\gamma_{1,0}$ +ce) (7,86-keV) and the adopted α_T.

P($\gamma_{3,2}$)(18,43-keV) has been deduced from P($\gamma_{3,1}$) (67,84-keV) and the ratio of P($\gamma_{3,2}$ +ce) (18,43-keV)/P($\gamma_{3,1}$) (67,88-keV) < 0,2 from 1996FiZX.

P($\gamma_{2,0}$)(57,273-keV) = 0,12 (3) % has been deduced from P($\gamma_{2,1}$) (49,41-keV) and P($\gamma_{2,1}$) (49,41-keV)/ P($\gamma_{2,0}$)(57,27-keV) = 0,85 (12) from 1996FiZX.

P($\gamma_{7,6}$)(57,29-keV) ~ 0,012 % has been deduced from P($\gamma_{7,6}$)(57,3-keV) + P($\gamma_{2,0}$)(57,273 -keV) = 0,135 (7) % and P($\gamma_{2,0}$)(57,273-keV).

P($\gamma_{8,6}$)(61,88-keV) and P($\gamma_{3,1}$)(67,84-keV) have been taken from 1974HeYW.

P($\gamma_{7,5}$)(101,96-keV) has been taken from ^{239}Am e decay (see 2003Br02).

P($\gamma_{8,4}$)(227,83-keV) has been taken from the decay scheme (see 2003Br02).

P($\gamma_{6,1}$)(322,3-keV) has been deduced from the Pγ branching in ^{239}Am e decay and ^{243}Cm a decay (see 2003Br02).

P($\gamma_{4,3}$)(88,06-keV), P($\gamma_{4,2}$)(106,50-keV) and P($\gamma_{6,4}$)(166,39-keV) have been calculated from the conversion data of 1959Ew90 and the adopted α_T.

P($\gamma_{7,3}$)(311,70-keV) = 0,002 (2) % has been deduced from P($\gamma_{7,3}$)(311,70-keV)/P($\gamma_{7,6}$)(57,29-keV) = 0,34 (14) from 1996FiZX.

The absolute emission probabilities of the other gamma-rays have been evaluated from experimental data (Table 5).

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2003Br12	E.Browne, Nucl,Data Sheets 98, 665 (2003) (Gamma ray and level energies, gamma ray multipolarities, decay scheme)

Table 5. Experimental and evaluated absolute emission probabilities (%) for gamma-rays in the decay of ^{239}Np.

E $_{\gamma}$(keV)	1972Ah02	1974Yu04	1974HeYW	1977St35 1991Po17	1979Mo25	1982Ah04	1984Va41	1986Ch17	1986Wo05	1992Ha02	Adopted
44,66						0,13 (1)					0,13 (1)
49,41			0,18 (3)			0,11 (1)					0,145 (35)
57,273						0,135 (7)					0,12 (3)
57,3											~0,012
61,46						1,29 (6)	1,29 (2)		1,40 (7)	1,27 (3)	1,29 (2)
106,12	27,8 (9)			26,6 (10)		26,4 (8)	27,50 (40)	26,08 (38)	25,23 (28)	25,6 (2)	25,9 (3)
181,69	0,075 (8)					0,083 (4)	0,07 (1)		0,085 (5)	0,088 (2)	0,086 (2)
209,75	3,42 (10)			3,36 (14)		3,30 (10)	3,46 (5)	3,28 (5)	3,43 (7)	3,47 (3)	3,42 (3)
226,38				0,24 (3)		0,290 (16)	0,28 (2)		0,230 (14)	0,25 (1)	0,255 (14)
228,18	11,4 (3)			11,78 (44)		11,2 (3)	11,21 (18)	11,05 (14)	10,91 (16)	11,54 (5)	11,32 (22
254,41	0,11 (1)					0,110 (6)	0,12 (1)		0,1078 (27)	0,113 (4)	0,110 (3)
272,84	0,08 (1)					0,077 (4)	0,08 (1)		0,0762 (24)		0,077 (3)
277,60	14,5 (5)	14,1 (4)		15,0 (4)	14,30 (24)	14,5 (4)	14,38 (21)	14,21 (13)	14,53 (17)	14,46 (10)	14,4 (1)
285,46	0,76 (2)			0,93 (6)		0,790 (25)	0,77 (2)	0,765 (9)	0,797 (10)	0,80 (1)	0,78 (1)
315,88	1,52 (5)			1,63 (7)		1,60 (5)	1,60 (3)	1,55 (2)	1,604 (20)	1,60 (1)	1,59 (1)
334,31	1,95 (7)			2,1 (1)		2,06 (6)	2,08 (3)	1,99 (2)	2,050 (25)	2,05 (2)	2,04 (2)
392,4			0,0016								0,0016
429,5			0,0039								0,0039
434,7			0,013								0,013
447,6			0,00026								0,00026
454,2			0,00082								0,00082
461,9			0,0016								0,0016
469,8			0,0011								0,0011
484,3			0,001								0,001
492,3			0,006								0,006
497,8			0,0032								0,0032
498,7			0,001								0,001
504,2			0,00078								0,00078

^{239}Pu – Comments on evaluation of decay data
by V. P. Chechev

This evaluation was originally done in October 2005 and then revised in January 2007. The literature available by January 2007 has been included.

1. Decay Scheme

The decay scheme is based on the evaluation of Browne (2003Br12). It can be considered as basically completed though there are weak gamma rays observed in experiment and unplaced in the decay scheme. Besides several weak gamma transitions expected from the decay scheme have not been observed in ^{239}Pu alpha decay yet. They have been taken from data on nuclear reactions, in particular, from ^{234}U(n,γ)-reaction (1979Al03), and also from ^{235}Pa β^- decay (1986Mi10).

Many alpha transitions to ^{235}U excited levels with energy more than 600 keV were not observed either. They are expected from data on level spins and gamma rays de-excited these levels (see 2003Br12).

2. Nuclear Data

Q(α) value is from 2003Au03.

The evaluated half-life of ^{239}Pu is based on the experimental results given in Table 1. Re-estimated values and uncertainties were used for averaging where necessary.

Table 1. Experimental values of the ^{239}Pu half-life (in years)

Reference	Author(s)	Value	Measurement method
1970OeZZ	Oetting	24 048 (25) [a, b]	Calorimetry
1975Al15	Alexandrov *et al.*	24 060 (19) [b]	Specific activity
1975GlZQ	Glover *et al.*	24 115 (80)	Specific activity
1977Ja08	Jaffe *et al.*	24 124 (14)	Specific activity
1977Ja08	Jaffe *et al.*	24 139 (13)	Mass spectrometry
1978Se12	Seabaugh *et al.*	24 101 (10) [b]	Calorimetry
1978Gunn	Gunn	24 102 (10) [b]	Calorimetry
1978Lu10	Lucas *et al.*	24 112 (33) [c]	Specific activity
1978Ma45	Marsch *et al.*	24 164 (17) [b]	Mass spectrometry
1978Pr07	Prindle *et al.*	24 019 (15) [d]	Specific activity
1978Pr07	Prindle *et al.*	24 089 (19) [d]	Mass spectrometry
1981Brown	Brown	24 088 (25) [b]	Specific activity

[a] Value corrected in 1977Ja08 is given.

[b] Uncertainty quoted by authors for the 95 % confidence level has been reduced by a factor 2.

[c] Uncertainty combined from a standard deviation of 16 yr and a systematic error of 50 yr by Holden (1989Ho24) is given.

[d] Uncertainty corrected by Holden (1989Ho24) is given.

The weighted mean of the 12 values is 24 100 with the internal uncertainty of 4,5 and external uncertainty of 11 and χ^2/ν = 5,9. The unweighted mean is 24 097 (12). The LWEIGHT computer program has chosen the weighted mean and the external uncertainty of 11.

Thus, the recommended value of the ^{239}Pu half-life is 24 100 (11) years. It agrees well with the value of 24 101 (12) years deduced from constant matching in a least-squares fit of thermal data for fissile nuclei (1984Di08) and can be compared to the recommended values from the Russian handbook

(1988ChZL) of 24 100 (20) years and from the critical review by Glover and Nichols (1990GlZZ) of 24 113 (11) years.

The adopted ^{239}Pu spontaneous fission half-life of 8 (2) × 10^{15} years is the value recommended in 2000Ho27. It is based on the experimental results given in Table 2.

Table 2. Experimental values of the spontaneous fission ^{239}Pu half-life (in 10^{15} years)

Reference	Author(s)	Value	Measurement method
1952Se67	Segre	5,5 (16)	Ionization chamber
1985Dr09	Druzhinin *et al.*	7,8 (16)	$\lambda_{SF} / \lambda_{\alpha} = 3{,}1\ (6) \cdot 10^{-12}$

2.1 Alpha Transitions

The energies of the alpha transitions have been deduced from the Q value and the level energies given in Table 3 from 2003Br12. The latter ones were deduced from a least squares fit to γ ray energies from ^{239}Pu α decay. The energies of the gamma rays adopted from 2003Br12 are given below, in Table 9.

Table 3. ^{235}U levels populated in the ^{239}Pu α-decay

Level number	Energy, keV	Spin and parity	Half-life	Probability of α-transition (%)
0	0	7/2–	$7{,}04(1) \cdot 10^{8}$ y	~0,03 [b]
1	0,0765 (4)	1/2+	≈26 min	70,79 (10)
2	13,0400 (21)	3/2+	0,50(3) ns	17,14 (4)
3	46,207 (10)	9/2–		< 0,02
4	51,7007 (11)	5/2+	191(5) ps	11,87 (3)
5	81,741 (4)	7/2+		0,052 (8)
6	103,035 (10)	11/2–		0,0375 (12)
7	129,2961 (10)	5/2+		0,013 (4)
8	150,467 (15)	9/2+		0,0182 (27)
9	170,708 (14)	13/2–		
10	171,388 (5)	7/2+		0,0034 (10)
11	197,119 (14)	11/2+		0,007 (1)
12	225,423 (8)	9/2+		0,0050 (7)
13	249,130 (12)	15/2–		0,0030 (16)
14	291,144 (19)	11/2+		0,0007 (3)
15	294,669 (15)	13/2+		0,0018 (5)
16	332,845 (4)	5/2+		0,00354 (7)
17	338,52 (6)	17/2–		$\approx 2{,}2 \cdot 10^{-5}$
18	357,30 (6) **?**	(15/2+)		$1{,}7\ (4) \cdot 10^{-5}$
19	367,069 (8)	7/2+		0,000944 (17)
20	393,225 (6)	3/2+		0,00125 (3)
21	414,779 (11)	9/2+		0,00075 (11)
22	426,755 (3)	5/2+		0,00570 (5)
23	445,716 (20)	7/2+		$4{,}00\ (11) \cdot 10^{-5}$
24	474,297 (13)	7/2+		0,00056 (5)
25	509,92 (17)	(9/2+)		$3{,}3\ (7) \cdot 10^{-6}$
26	533,228 (10)	9/2+		0,00086 (3)
27	608,08 (5)	11/2+		$1{,}2\ (4) \cdot 10^{-5}$
28	633,17 (6)	(5/2)–		$2{,}84\ (7) \cdot 10^{-6}$
29	637,81 (5)	3/2–		$3{,}22\ (21) \cdot 10^{-6}$
30	658,97 (4)	1/2–		$2{,}64\ (6) \cdot 10^{-5}$
31	664,541 (23)	(5/2)–		$6{,}31\ (11) \cdot 10^{-6}$
32	670,99 (4)	(7/2)–		$< 3{,}4 \cdot 10^{-8}$
33	701,02 (3)	(7/2)–		$7{,}07\ (13) \cdot 10^{-6}$
34	703,757 (19)	3/2–		$1{,}14\ (3) \cdot 10^{-5}$
35	720,25 (3)	(9/2)–		$2{,}13\ (9) \cdot 10^{-6}$
36	750,07 (16)	(9/2–)		$3{,}4\ (4) \cdot 10^{-7}$
37	761,04 (5)	(1/2)–		$1{,}03\ (17) \cdot 10^{-7}$

Level number	Energy, keV	Spin and parity	Half-life	Probability of α-transition (%)
38	769,27 (6)	1/2+		$2,7\ (3)\cdot10^{-5}$
39	769,5 (3)	3/2–		$1,03\ (12)\cdot10^{-5}$
40	777,59 (19)	(11/2)–		$2,47\ (19)\cdot10^{-7}$
41	779,51 (3)	3/2+		$1,01\ (11)\cdot10^{-6}$
42	805,72 (6)	3/2–		$8,4\ (14)\ )\cdot10^{-8}$
43	821,25 (4)	5/2+		$3,0\ (3)\cdot10^{-7}$
44	843,859 (10)	(1/2)+		$2,28\ (12)\cdot10^{-7}$
45	845,3 (10) **?**	(7/2+)		$\sim4,2\cdot10^{-8}$
46	865,20 (2) [a]	3/2+		$9,8\ (13)\cdot10^{-8}$
47	891,89 (15)	5/2+		$1,99\ (12)\cdot10^{-7}$
48	968,451 (20)	3/2+		$6,1\ (15)\cdot10^{-8}$
49	970,52 (22) **?**	(5/2,7/2)		$4,1\ (4)\cdot10^{-8}$
50	986,65 (17)	(13/2-)		$7,7\ (7)\cdot10^{-8}$
51	992,72 (22)	(5/2+)		$2,0\ (3)\cdot10^{-7}$
52	1057,58 (13)	(7/2)		$9,3\ (9)\cdot10^{-8}$
53	1116,20 (20) **?**	(5/2–)		$2,1\ (5)\cdot10^{-8}$

[a] Obtained as a sum of E(level '10') and E($\gamma_{46,10}$)

[b] Value based on systematics (see 2003Br12 and comments therein)

The probabilities of the most intense transitions $\alpha_{0,1,}$ $\alpha_{0,2}$ and $\alpha_{0,4}$ have been obtained by averaging experimental results from measurements with semi-conductor detectors of 1987Bo25, 1992Bl13, 1993Ga28, 1994Ra27, 1996Sa24, 1996Vi07 and 2002Da21 (see Table 4). They agree with each other and disagree with early measurements with magnetic spectrometers of 1961Dz05, 1963Ba09, 1976BaZZ (Table 4) and 1952As28, 1957As83, 1957No15. The values evaluated from the above experimental results have been recommended as more precise than those that are deduced from γ-ray transition intensity balances.

The probabilities of the transitions $\alpha_{0,k}$ (k =5÷8, 10, 13, 15, 16, 19÷22, 24, 26) evaluated from all the available experimental data reported with uncertainties are compared in Table 4 with the values deduced from intensity balances. The latter ones were recommended as more precise. The experimental P(α)-values have been recommended in those cases ($\alpha_{0,11,}$ $\alpha_{0,12,}$ $\alpha_{0,14}$) where the intensity balances were used for obtaining P(γ+ce)-values (see several γ-ray transitions with deduced ICC and (E2/M1)-admixture ratios in section 2.2).

The probabilities of the remaining α-transitions including unobserved but expected from the decay scheme have been evaluated from the P(γ+ce) balances for corresponding levels of ^{235}U.

The values of hindrance factors were calculated using ALPHAD code and r_0 (^{235}U) = 1,5122, average of r_0 (^{234}U) = 1,5075 and r_0 (^{236}U) = 1,5168 from 1998Ak04.

Table 4. Experimental and recommended probabilities (%) of most intense α-transitions observed in ^{239}Pu decay *

	α-part. energy	1961 Dz05	1963Ba09 1976BaZZ	1965 Ho04	1966 Ah02	1987 Bo25	1992 Bl13	1993 Ga28**	1994 Ra27	1996 Sa24	1996 Vi07	2002 Da21**	Evaluated from data of the measurements	Deduced from P(γ+ce) balance	Recommended
$\alpha_{0,1}$	5156	72	73,3 (8)			71,2 (7)	70,73 (46)	70,77 (14)	71,6 (2)	70,91 (11)	71 (5)	70,71 (10)	70,79 (10) ^{a}	70,8 (4)	70,79 (10)
$\alpha_{0,2}$	5144	17	15,1 (8)			16,7 (5)	17,56 (28)	17,11 (14)	16,6 (2)	17,12 (9)	18 (4)	17,16 (4)	17,14 (4) ^{b}	17,1 (3)	17,14 (4)
$\alpha_{0,4}$	5106	11	11,5 (8)	11,5		12,1 (2)	11,80 (19)	11,94 (7)	11,8 (1)	11,84 (5)	11,1 (15)	11,88 (3)	11,87 (3)^{c}	11,9 (3)	11,87 (3)
$\alpha_{0,5}$	5076	0,038	0,036 (3)	0,043			0,03 (1)	0,078 (8)		0,054 (6)		0,057 (2)	0,050 (7) ^{d}	0,052 (8)	0,052 (8)
$\alpha_{0,6}$	5055	0,030	0,025 (5)	≥0,0033				0,047 (13)		0,036 (4)		0,044 (2)	0,038 (4) ^{e}	0,0375 (12)	0,0375 (12)
$\alpha_{0,7}$	5029		0,005 (1)	0,0038	0,005			0,009 (3)		0,016 (2)		0,023 (1)	0,014 (9) ^{f}	0,013 (4)	0,013 (4)
$\alpha_{0,8}$	5009	0,018	0,013 (5)	0,011				0,017 (2)		0,021 (6)		0,034 (2)	0,017 (2) ^{g}	0,0182 (27)	0,0182 (27)
$\alpha_{0,10}$	4988	0,008	0,007 (2)	0,0041	0,006			0,013 (2)				0,018 (1)	0,010 (2) ^{h}	0,0034 (10)	0,0034 (10)
$\alpha_{0,11}$	4963	0,008	0,006 (3)	0,0044				0,007 (1)				0,0157 (12)	0,007 (1) ^{h}		0,007 (1)
$\alpha_{0,12}$	4935	0,008	0,0040 (10)	0,0029	0,003			0,0060 (10)				0,0135 (11)	0,0050 (7) ^{h}		0,0050 (7)
$\alpha_{0,13}$	4912	~0,003	0,0005 (3)					0,0024 (9)				0,0097 (9)	0,0007 (3) ^{h}	0,0030 (16)	0,0030 (16)
$\alpha_{0,14}$	4870		0,0007 (3)									0,0089 (9)	0,0007 (3) ^{i}		0,0007 (3)
$\alpha_{0,15}$	4867	0,004	0,002 (2)	0,0007	0,0008			0,0019 (7)				0,011 (1)	0,0019 (7) ^{h}	0,0018 (5)	0,0018 (5)
$\alpha_{0,16}$	4829		0,0015	0,0021	0,0021			0,0024 (7)					0,0024 (7)	0,00354 (7)	0,00354 (7)
$\alpha_{0,19}$	4796		0,0007 (2)	0,0008	0,0007			0,0012 (6)					0,0075 (19) ^{j}	0,000944 (17)	0,000944 (17)
$\alpha_{0,20}$	4770		0,0008 (3)	≥0,001	0,0006			0,0015 (6)					0,00094 (27) ^{j}	0,00125 (3)	0,00125 (3)
$\alpha_{0,21}$	4749		≈0,0006		0,0004							0,0059 (8)	≈0,0005 ^{k}	0,00075 (11)	0,00075 (11
$\alpha_{0,22}$	4737	0,007	0,0045 (10)	0,003	0,005			0,0051 (8)				0,0109 (10)	0,0045 (10) ^{h}	0,00570 (5)	0,00570 (5)
$\alpha_{0,24}$	4690				0,0005 (2)								0,0005 (2)	0,00056 (5)	0,00056 (5)
$\alpha_{0,26}$	4632				0,0007 (2)								0,0007 (2)	0,00086 (3)	0,00086 (3)

* Other measurements: 1957No15, 1963Bj03, 1981AhZV, 1984Ah06, 1990An33. The 1957No15 results are from measurements with magnetic spectrometer. In 1963Bj03 the $\alpha_{0,30}$ and $\alpha_{0,38}$ probabilities (%) were measured: 0,00008(3) and 0,000025(8), respectively. These values have been adopted as recommended $\alpha_{0,30}$ and $\alpha_{0,38}$ probabilities. The value of α_{30} probability (%) calculated from γ-ray transition intensity balance of 0,000 026 4 (6) disagrees with 1963Bj03 and the calculated value of α_{38} probability (%) of 0,000 027 (4) agrees well with 1963Bj03. In 1984Ah06 the ($\alpha_{0,1}$+$\alpha_{0,2}$)- probability (%) was measured as 88,0 (6) in agreement with all the available measurements. In 1990An33 the $\alpha_{0,1}$, $\alpha_{0,2}$, $\alpha_{0,4}$ -probabilities (%) were measured: 73 (1), 15 (1), 12 (1), respectively.

** 2002Da21 analyzed α spectrum of 1993Ga28. The values of 1993Ga28 are combined results from measurements at CIEMAT (Spain) and IRMM (Belgium).

[a] The LWEIGHT computer program has identified one after another 1996Vi07, 1994Ra27 and 1987Bo25 values as outliers and recommended a weighted average (70,79) of the 4 remaining values and an internal uncertainty of 0,064. The smallest experimental uncertainty of 0,10 is adopted for the evaluated value.

[b] The LWEIGHT computer program has identified 1996Vi07 as outlier and (after omitting this value) recommended a weighted average (17,14) of the 6 remaining values and an internal uncertainty of 0,034. The smallest experimental uncertainty of 0,04 is adopted for the evaluated value.

[c] The LWEIGHT computer program has identified one after another 1996Vi07 and 1987Bo25 values as outliers and (after omitting these values) recommended a weighted average (11,87) of the 5 remaining values and an internal uncertainty of 0,023. The smallest experimental uncertainty of 0,03 is adopted for the evaluated value.

[d] The LWEIGHT computer program has increased the uncertainty of 2002Da21 to 0,00247 and recommended a weighted average (0,050) of the 5 discrepant experimental values (1976BaZZ, 1992Bl13, 1993Ga28, 1996Sa24, 2002Da21) with the expanded uncertainty of 0,007.

[e] The LWEIGHT computer program has increased the uncertainty of 2002Da21 to 0,00304 and recommended a weighted average (0,038) of the 4 experimental values (1976BaZZ, 1993Ga28, 1996Sa24, 2002Da21) with an external uncertainty (0,004).

[f] The LWEIGHT computer program has recommended a weighted average (0,014) of the 4 highly discrepant experimental values (1976BaZZ, 1993Ga28, 1996Sa24 and 2002Da21) and expanded the uncertainty to 0,009.

[g] A weighted average of the 3 experimental values (1976BaZZ, 1993Ga28, 1996Sa24). The value of 0,034 (2) from 2002Da21 has been omitted as outlier. This big value leads to the appreciable intensity disbalance for the level “8” (150,5 keV).

[h] A weighted average of the 2 experimental values (1976BaZZ, 1993Ga28). The value from 2002Da21 has been omitted as this big value leads to the considerable intensity imbalance. Reported experimental data are discrepant.

[i] Value from 1976BaZZ. The value from 2002Da21 has been omitted as this big value leads to the considerable intensity imbalance.

[j] A weighted average of the values from 1976BaZZ and 1993Ga28.

[k] An unweighted average of the values from 1976BaZZ and 1966Ah02. The value from 2002Da21 has been omitted as this big value leads to the considerable intensity imbalance

2.2. Gamma Transitions and Internal Conversion Coefficients

The gamma-ray transition probabilities and total internal conversion coefficients (ICC's) for (M1+E2)-transitions $\gamma_{2,1}$ (12,98 keV), $\gamma_{3,0}$ (46,21 keV), $\gamma_{4,2}$ (38,66 keV), $\gamma_{12,10}$ (54,04 keV), $\gamma_{11,8}$ (46,68 keV) and $\gamma_{14,12}$ (65,71 keV) were deduced from intensity balances for the corresponding levels ("2", "3", "4", "10", "11" and "14", respectively). The total internal conversion coefficients (ICC's) and (E2/M1)-admixture ratios for these transitions were obtained using the α-transition probabilities and γ-ray emission probabilities evaluated from experimental data. For the gamma -ray transition $\gamma_{3,0}$ (46,21 keV) the values of P(γ+ce), total ICC and (E2/M1) -admixture ratio have been deduced supposing a negligible intensity of the questionable α-transition to the level "3" (1/2+→9/2−).

For gamma-ray transition $\gamma_{5,4}$ (30,04 keV) the value P(γ+ce) = 0,033 (11) % is obtained from the intensity balance for the level "5" by use of the value P($\alpha_{0,5}$) = 0,050 (7) % evaluated directly from α-spectrometric experimental data. This corresponds to the adopted M1 multipolarity for $\gamma_{5,4}$ -transition: P($\gamma_{5,4}$+ce) = 0,0346 (14) % has been deduced using the theoretical α_T (M1) = 58,6 (12).

The multipolarity of the gamma -ray transition $\gamma_{10,7}$ (41,93 keV) has also been adopted as M1 because even small E2 admixture leads to larger total ICC disturbing P(γ+ce) - balance for the level "7"(129,3 keV).

The transition probabilities for the remaining gamma-rays have been deduced from their gamma-ray emission probabilities and total ICC's interpolated from theoretical values of 2002Ba85 using the BrIcc package (Table 11). The multipolarities and admixture coefficients δ(E2/M1) have been taken from 2003Br12 (see comments therein and in footnotes to Table 11). The uncertainties of α_K, α_L, α_M, α_T for pure multipolarities have been taken as 2 %.

The total ICC for E0+M1 transitions are experimental values from (n, γ) reaction data of 1979Al03 (see 2003Br12 and comments therein).

3. Atomic Data

3.1. Fluorescence yields

The fluorescence yield data are from 1996Sc06 (Schönfeld and Janßen).

3.2. X Radiations

The energies of U LX-rays were deduced from 1994Le28 and 1994Le37 where the fine structure of LX radiation was measured in the decay of ^{239}Pu. Other measurements of U LX -rays can be found in 1983Ah02, 1984Bo41, 1992Ba08 and 1995Jo23.

The U KX-ray energies were taken from 1999ScZX where the calculated values based on X-ray wavelengths from 1967Be65 (Bearden). In Table 5 the adopted values of U KX -ray energies are compared with experimental values.

Table 5. Experimental and adopted (calculated) values of U KX-ray energies (keV)

	1976GuZN	1982Ba56	1983Ah02	Adopted
$K\alpha_2$	94,655 (5)	94,656 (2)	94,67 (2)	94,666
$K\alpha_1$	98,442 (5)	98,435 (2)	98,45 (2)	98,440
$K\beta_3$	110,42	110,416 (3)	110,42 (3)	110,421
$K\beta_1$	111,30	111,300 (2)	111,31 (2)	111,298
$K\beta_5$	-	111,868 (5)- $K\beta_5''$ 111,868 (5)- $K\beta_5'$	112,01 (5)	111,964
$K\beta_{2,4}$	114,54	-	114,50 (3)	114,46
$KO_{2,3}$	115,40	-	115,40 (5)	115,377

3.3. Auger Electrons

The ratios P(KLX)/P(KLL), P(KXY)/P(KLL) are taken from 1996Sc06.

4. Alpha emissions

The energy of the alpha particles corresponding to the alpha transition to the first excited state of ^{235}U, E($\alpha_{0,1}$), has been adopted from the absolute measurement of 1980RyZX taking into account the correction of −0,11 keV recommended by A. Rytz in 1991Ry01.

The energies of all other α-emission energies have been deduced from the alpha transition energies taking into account the recoil energies.

In Table 6 the deduced (evaluated) values of α-emission energies are compared with the experimental results obtained with alpha spectrometers.

Table 6. Experimental and evaluated α-emission energies in ^{239}Pu decay (keV)

	Measured [a]					Recommended in 1991Ry01	Evaluated
	1962Le11	1963Ba09	1966Ho09	1968Ba25	1981AhZV		
$\alpha_{0,1}$	5156,7 (6)	5156,6 (8)	5157	5156,6 (8)		5156,59 (14)[b]	5156,59 (14)
$\alpha_{0,2}$	5144,0 (7)	5144	5144	5144,3 (8)		5144,3 (8)	5143,82 (21)
$\alpha_{0,4}$	5106,0 (7)	5106	5105	5105,8 (8)		5105,8 (8)	5105,81 (21)
$\alpha_{0,5}$		5077	5075		5076 (5)		5076,28 (21)
$\alpha_{0,6}$		5055	5055		5054 (5)		5055,34 (21)
$\alpha_{0,7}$		5030	5029		5028 (3)		5029,51 (21)
$\alpha_{0,8}$		5009	5007		5006 (5)		5008,70 (21)
$\alpha_{0,10}$		4987	4988		4987 (3)		4988,13 (21)
$\alpha_{0,11}$		4962	4960		4960 (5)		4962,83 (21)
$\alpha_{0,12}$		4936	4932		4934 (3)		4935,00 (21)
$\alpha_{0,13}$		4913			4912 (5)		4911,69 (21)
$\alpha_{0,14}$		4872			4871 (5)		4870,38 (21)
$\alpha_{0,15}$		4867	4864		4866 (5)		4866,91 (21)
$\alpha_{0,16}$		4829	4829		4828 (3)		4829,38 (21)
$\alpha_{0,19}$		4800	4794		4795 (4)		4795,73 (21)
$\alpha_{0,20}$			4769		4769 (5)		4770,01 (21)
$\alpha_{0,21}$					4749 (5)		4748,81 (21)
$\alpha_{0,22}$		4738	4739		4736 (3)		4737,05 (21)
$\alpha_{0,24}$		4694	4694		4691 (3)		4690,29 (21)
$\alpha_{0,26}$ [c]		4635	4639		4632 (3)		4632,35 (21)

[a] Original values have been adjusted taking into account changes in calibration energies as suggested in 1991Ry01.

[b] Absolute measurement; the value has been adopted as recommended in 1991Ry01 (see text above).

[c] Other measurements: 1963Bj03, 1975Ba65, 1992Fr04, 1999Sa19. In 1963Bj03 the $\alpha_{0,38}$ and $\alpha_{0,30}$ energies were measured: ≈ 4380 keV and 4510 (20) keV, respectively. In 1975Ba65 the measurement value of the $\alpha_{0,1}$ energy (5156,77 (41) keV) is reported. In 1992Fr04 the $\alpha_{0,1}$ energy was measured by time-of-flight method: 5155,36 (19) keV. In 1999Sa19 alpha peak fitting parameters for analysis of the complex alpha spectrum ^{239}Pu + ^{240}Pu (keV) were deduced and the following alpha energies were used: $\alpha_{0,1}$.-5156,59; $\alpha_{0,2}$.-5143,90; $\alpha_{0,4}$.-5105,80; $\alpha_{0,5}$.-5076,00.

5. Electron Emissions

The energies of the conversion electrons have been calculated from the gamma transition energies and the electron binding energies. The emission probabilities of conversion electrons have been deduced from the evaluated P(γ) and ICC values. The experimental spectrum of the conversion electrons in the decay of ^{239}Pu is given in 1965Tr03. The conversion electrons were measured also in 1979Al03.

The total absolute emission probability of K Auger electrons has been calculated using the evaluated total emission probability of U KX-rays and the adopted $\omega_K = 0,970$ (4).

The absolute total emission probability of L Auger electrons were computed using the evaluated total absolute emission probability of U LX–rays and the adopted $\varpi_L = 0,500$ (19).

6. Photon Emissions

6.1. X-Ray Emissions

6.1.1. LX-Rays

The evaluated absolute emission probabilities of U LX –rays have been obtained as weighted means of measurement values from 1992Bl07 (and 1994Mo36 by the same group), 1994Le28 and 1994Le37 (Table 7). The uncertainties of the evaluated values are not less than the smallest quoted experimental uncertainties.

Table 7. Experimental and evaluated values of absolute LX-ray emission probabilities in the decay of ^{239}Pu (per 100 disintegrations)

LX-ray	Energy, keV	1992Bl07, 1994Mo36	1994Le28	1994Le37	Evaluated
Ll	11,62	0,0996 (11)	0,1027 (21)	0,1016 (17)	0,1008 (11)
Lt	11,90	-	0,00214 (18)	-	0,00214 (18)
Lα_2	13,44	- [a]	0,143 (5)	0,150 (18)	0,146 (13)
Lα_1	13,62	- [a]	1,507 (19)	1,498 (31)	1,503 (22)
Lη	15,40	0,0566 (10)	0,0498 (10)	0,0544 (9)	0,0537 (19)
Lβ	17,06	2,301 (23)[b]	2,27 (4)[b]	2,28 (5)[b]	2,288 (23)
Lγ	20,30	0,568 (6)[b]	0,564 (10)[b]	0,579 (14)[b]	0,569 (6)
LX total		4,67 (5)	4,63 (5)	4,66 (6)	4,66 (5)

[a] .In 1992Bl07 the total Lα-ray intensity of 1,649 (20) was measured in agreement with the value of 1,649 (18) from 1994Le28 and the value of 1,648 (36) from 1994Le37.

[b] In all the three quoted works the intensities of individual L_β and Lγ components were also measured.

The evaluated P(XL) = 4,66 (5) % exceeds slightly the value of 4,5 (1) % calculated using the evaluated total absolute emission probability of L conversion electrons and the adopted value ϖ_L = 0,500 (19).

Other measurement results of P(XL) are: 5,3 (5) % (1966Ah02), 4,76 (12) % (1968Swinth), 4,60 (10) % (1971Swinth), 4,50 (14) % (1984Geidelman).

6.1.2. KX-Rays

The evaluated absolute emission probabilities of U KX –rays have been obtained as weighted means of measurement values from 1976GuZN and 1994Mo36 (Table 8). Uncertainty in detector efficiency (2 %) was added to the uncertainties listed in 1976GuZN and their values were renormalized to the adopted absolute emission probability of the γ-ray $\gamma_{7,0}$ (129,3 keV) of 6,31 (4)×10^{-3}.

Table 8. Experimental and evaluated values of absolute U KX-ray emission probabilities in the decay of ^{239}Pu (per 100 disintegrations)

KX-ray	Energy, keV	1976GuZN	1994Mo36	Evaluated
Kα_2	94,666	0,004 25 (9)	0,004 17 (4)	0,004 18 (4)
Kα_1	98,440	0,006 81 (14)	0,006 52 (9)	0,006 61 (9)
Kβ_3	110,421	0,000 801 (16)	0,000 797 (6)	0,000 798 (6)
Kβ_1	111,298	0,001 56 (3)	0,001 536 (12)	0,001 536 (20)
Kβ_5	111,964	0,000 031 (3)	0,000 054 (11)	0,000 033 (3)
K$\beta_{2,4}$	114,46	0,000 633 (18)	0,000 629 (7)	0,000 629 (7)
K_{OP}	115,37-115,58	0,000 654 (16)	0,000 708 (9)	0,000 68 (3)
KX total		0,014 74 (29)	0,014 41 (14)	0,014 47 (14)

6.2. Gamma-Ray Emissions

The recommended γ-ray energies have been adopted from 2003Br12 based on experimental data of 1979Al03 ((n, γ)-results) and 1968Cl02, 1971GuZY, 1976GuZN, 1982He02, 1992Bl07, 1994Mo36 (^{239}Pu α-decay). Other measurements: 1965Tr03, 1966Ah02, 1966Ho09 (Table 9). For several weak transitions γ-ray the energies have been deduced directly from the level energies or adopted from 1979Al03 (see footnotes to Table 9).

The absolute γ-ray emission probabilities have been deduced using the evaluated γ-ray relative probabilities and the absolute emission probability of the γ-ray $\gamma_{7,0}$ (129,3 keV) of 6,31 (4)$\times10^{-5}$ obtained as a weighted average of the 5 absolute measurement results (per 10^5 disintegrations): 6,26 (13) from 1976GuZN, 6,23 (4) from 1980Despres, 6,41 (5) from 1982He02, 6,48 (10) from 1984Iw02 and 6,31 (4) from 1994Mo36. The uncertainty (0,04) of the evaluated value is the smallest experimental uncertainty.

The relative experimental and evaluated γ-ray emission probabilities are given in Table 10. The evaluated values have been obtained by averaging experimental values listed in Table 10 or have been adopted from one of the experimental works, in most cases from 1976GuZN. The averaging -out has been done using the LWEIGHT computer program. The uncertainties are not less than the smallest experimental uncertainties.

In Table 11 the multipolarities, E2/M1 mixing ratios and ICC are shown for soft gamma rays with energy less than 120 keV and comments of deducing multipolarities (with uncertainties for E2/M1 mixing ratios where possible) are given. The δ-mixing ratios for other gamma rays (with energy more than 120 keV) are given in the footnote at the bottom of Table 11.

Table 9. Experimental and adopted energies of gamma rays in ^{239}Pu decay (keV)

	1965 Tr03	1966 Ah02	1966 Ho09	1968 Cl02	1971 GuZY	1976 GuZN	1979 Al03	1982 He02	1994 Mo36	Adopted
$\gamma_{1,0}$										0,0765 (4)
$\gamma_{2,1}$					13,0				12,975 (10)	12,975 (10)
$\gamma_{-1,1}$									14,22 (3)	14,22 (3)
$\gamma_{5,4}$					30,09	30,04 (10)		30,251 (10)	30,03 (10)	30,04 (2)
$\gamma_{4,2}$		38,7 (1)	37		38,69			38,660 (2)		38,661 (2)
$\gamma_{-1,2}$					40,57	40,41 (5)				40,41 (5)
$\gamma_{10,7}$				41,99 (10)		42,06 (3)			41,93 (5)	41,93 (5)
$\gamma_{3,0}$		46,2 (1)			46,23			46,218 (10)		46,21 (5)
$\gamma_{11,8}$						46,69 (10)			46,68 (3)	46,68 (3)
$\gamma_{7,5}$					47,56				47,60 (3)	47,60 (3)
$\gamma_{4,1}$		51,6 (1)	52		51,628	51,629 (10)	51,628 (4)	51,624 (1)		51,624 (1)
$\gamma_{12,10}$					54,05	54,040	54,026 (5)	54,039 (8)		54,039 (8)
$\gamma_{6,3}$		56,8 (2)			56,828	56,838		56,825 (3)		56,828 (3)
$\gamma_{14,12}$					65,69	65,74 (10)		65,675 (20)		65,708 (30)
$\gamma_{9,6}$					67,69	67,67		67,674 (12)		67,674 (12)
$\gamma_{5,2}$		68,3 (2)	69		68,73	68,72	68,697 (3)	68,696 (6)		68,696 (6)
$\gamma_{8,5}$										68,73 (2) ^{b}
$\gamma_{-1,3}$										74,96 (10)
$\gamma_{7,4}$		77,6 (2)		77,60 (5)		77,607	77,599 (2)	77,592 (14)		77,592 (14)
$\gamma_{13,9}$				78,48 (5)	78,38	78,42		78,44 (3)		78,43 (2)
$\gamma_{17,13}$										89,39 (6) ^{b}
$\gamma_{10,5}$				89,59		89,59		89,73 (4)	89,64 (3)	89,64 (3)
$\gamma_{12,7}$						96,13 (5)			96,14 (3)	96,14 (3)
$\gamma_{15,11}$			97,4 (6)		97,6 (3)					97,6 (3)
$\gamma_{8,4}$			98,7 (5)		98,81	98,78 (2)				98,78 (2)
$\gamma_{6,0}$		103,0	102,8 (8)		103,03	103,02 (2)		103,086 (14)		103,06 (3)
$\gamma_{11,5}$			117,6 (11)		115,35	115,38 (5)				115,38 (5)
$\gamma_{7,2}$		116,0			116,24	116,26 (2)	116,262 (3)			116,26 (2)
$\gamma_{10,4}$					119,72	119,708		119,73 (3)	119,70 (3)	119,70 (3)

	1965 Tr03	1966 Ah02	1966 Ho09	1968 Cl02	1971 GuZY	1976 GuZN	1979 Al03	1982 He02	1994 Mo36	Adopted
$\gamma_{14,10}$										119,76 (2) ^{b}
$\gamma_{12,6}$				122,35 (12)						122,35 (12)
$\gamma_{37,29}$							123,228 (5)			123,228 (5)
$\gamma_{21,14}$					123,67	123,62 (5)				123,62 (5)
$\gamma_{9,3}$			124,3 (15)		124,52	124,51 (3)				124,51 (3)
$\gamma_{10,3}$		125,0			125,17	125,21 (10)				125,21 (10)
$\gamma_{7,0}$		129,3 (2)	129,3 (3)		129,28	129,294 (10)	129,302 (2)	129,296 (1)		129,296 (1)
$\gamma_{19,12}$		141,7 (3)			141,64	141,657 (20)		141,62 (4)		141,657 (20)
$\gamma_{12,5}$					143,4		143,655 (6)			143,35 (20)
$\gamma_{15,8}$		144,2	144,1 (8)		144,19	144,211		144,201 (3)		144,201 (3)
$\gamma_{13,6}$		146,0			146,05	146,077		146,094 (6)		146,094 (6)
$\gamma_{10,2}$					158,3	158,1 (3)				158,1 (3)
$\gamma_{18,11}$				159,6 (2)		160,19 (5)				160,19 (5)
$\gamma_{16,10}$			160,3 (11)	160,07 (13)	161,45		161,449 (3)	161,482 (12)		161,450 (15)
$\gamma_{17,9}$					168,1	167,81 (5)				167,81 (5)
$\gamma_{10,0}$		171,4	171,3 (5)		171,34	171,344	171,370 (11)	171,393 (6)		171,393 (6)
$\gamma_{42,28}$							172,560 (11)			172,560 (8)
$\gamma_{12,4}$					173,6	173,70 (5)				173,70 (5)
$\gamma_{12,3}$		179,2 (2)	178,6 (8)		179,17	179,19		179,220 (12)		179,220 (12)
$\gamma_{-1,4}$					184,3	184,55 (5)				184,55 (5)
$\gamma_{14,6}$					188,27	188,23 (10)				188,23 (10)
$\gamma_{21,12}$		189,1	189,2 (16)		189,34	189,32		189,360 (10)		189,360 (10)
$\gamma_{-1,5}$				193,13 (12)		193,13 (12)	195,220 (12)			193,13 (12)
$\gamma_{19,10}$		195,6	195,7 (8)		195,65	195,66	195,70 (2)	195,679 (8)		195,679 (8)
$\gamma_{-1,6}$					197,98	196,87 (5)	196,872 (7)			196,87 (5)
$\gamma_{16,7}$		203,5	203,5 (8)	203,34 (8)	203,52	203,537	203,553 (7)	203,550 (5)		203,550 (5)
$\gamma_{21,11}$										218,0 (5)
$\gamma_{12,0}$			224,9 (15)		225,43	225,37		225,384 (15)		225,42 (4)
$\gamma_{19,7}$				238,2 (2)	237,77	237,38	237,774 (6)	237,77 (10)		237,77 (10)
$\gamma_{26,14}$			241,2 (20)		242,09	242,08 (3)				242,08 (3)
$\gamma_{21,10}$					243,33	243,38		243,38 (3)		243,38 (3)
$\gamma_{14,3}$					244,80	244,95 (5)	244,583 (8)			244,92 (5)
$\gamma_{24,12}$					248,95	248,95		248,95 (5)		248,95 (5)
$\gamma_{22,10}$		255,5	255,1 (5)	258,20 (10)	255,33	255,38		255,384 (15)		255,384 (15)
$\gamma_{20,7}$		264,0			263,93	263,93	263,916 (4)	263,97 (3)		263,95 (3)
$\gamma_{30,20}$					265,54	265,7 (3)				265,7 (3)
$\gamma_{16,4}$					281,2	281,2 (2)				281,2 (2)
$\gamma_{19,5}$					285,3	285,3 (2)				285,3 (2)
$\gamma_{22,7}$		297,6	297,8 (8)		297,43	297,49	297,42 (3)	297,46 (3)		297,46 (3)
$\gamma_{24,10}$					302,87	302,87		302,87 (5)		302,87 (5)
$\gamma_{26,12}$					307,81	307,85		307,85 (5)		307,85 (5)
$\gamma_{21,6}$		311,8	312,8 (15)		311,69	311,74		311,78 (4)		311,78 (4)
$\gamma_{23,7}$					316,35	316,41	316,444 (6)	316,41 (4)		316,41 (3)
$\gamma_{16,2}$					319,7	319,68 (10)				319,68 (10)

	1965 Tr03	1966 Ah02	1966 Ho09	1968 Cl02	1971 GuZY	1976 GuZN	1979 Al03	1982 He02	1994 Mo36	Adopted
$\gamma_{19,3}$		321,1			320,8	320,88		320,862 (20)		320,862 (20)
$\gamma_{24,8}$	324	323,9	322,8 (8)		323,76	323,81	323,853 (4)	323,841 (29)		323,84 (3)
$\gamma_{16,0}$	331,1 (5)	333,0	333,2 (5)		332,80	332,838	332,841 (2)	332,845 (5)		332,845 (5)
$\gamma_{26,11}$	336,1 (7)	336,3			336,06	336,107		336,120 (12)		336,113 (12)
$\gamma_{20,4}$	342,6 (7)	341,7	340,0 (20)		341,48	341,510 (2)	341,510 (2)	341,502 (19)		341,506 (10)
$\gamma_{24,7}$										345,001 (13) [b]
$\gamma_{22,5}$	345,6 (7)	345,1 (3)	345,2 (5)		344,96	345,014	345,003 (4)	345,013 (4)		345,013 (4)
$\gamma_{-1,7}$						350,8 (3)				350,8 (3)
$\gamma_{19,2}$					354,1	354,0 (5)				354,0 (5)
$\gamma_{26,10}$	363,5 (10)		363,4 (20)		361,9	361,89		361,90 (6)		361,89 (5)
$\gamma_{19,0}$		367,4			367,02	367,050		367,096 (26)		367,073 (25)
$\gamma_{21,3}$		368,7	369,3 (15)		368,53	368,550		368,557 (27)		368,554 (20)
$\gamma_{22,4}$	375,2 (3)	375,2 (2)	376,3 (5)		375,02	375,042	375,043 (7)	375,054 (3)		375,054 (3)
$\gamma_{20,2}$	380,7 (7)	380,4	381,3 (15)		380,16	380,166	380,173 (3)	380,191 (6)		380,191 (6)
$\gamma_{26,8}$	383,2 (7)	382,9	382,7 (15)		382,72	382,751		382,698 (16)		382,75 (5)
$\gamma_{24,5}$	392,5 (7)				392,45	392,53	392,552 (6)	392,53 (3)		392,53 (3)
$\gamma_{20,1}$	393,4 (7)	393,4 (3)	393,5 (8)		393,06	393,14	393,138 (6)	393,14 (3)		393,14 (3)
$\gamma_{23,3}$					399,44	399,51	399,530 (12)	399,54 (9)		399,53 (6)
$\gamma_{25,6}$	406,2 (5)		408,0 (15)		406,2 (5)	406,9		406,77 (25)		406,8 (2)
$\gamma_{27,11}$					410,77	411,15 (30)				411,2 (3)
$\gamma_{42,20}$										412,49 (6) [b]
$\gamma_{22,2}$	414,0 (3)	413,7	414,2 (5)		413,69	413,712	413,710 (13)	413,713 (5)		413,713 (5)
$\gamma_{24,4}$	422,8 (7)	422,6	423,4 (8)		422,57	422,586	422,596 (8)	422,598 (19)		422,598 (19)
$\gamma_{22,1}$		426,7			426,67	426,68 (8)				426,68 (3)
$\gamma_{24,3}$						428,4 (3)				428,4 (3)
$\gamma_{26,6}$					430,0	430,08 (10)				430,08 (10)
$\gamma_{23,0}$			445,8 (8)		445,78	445,72 (3)	445,740 (17)	445,81 (10)		445,72 (3)
$\gamma_{-1,8}$						446,82 (20)				446,82 (20)
$\gamma_{26,5}$	452,0 (7)	451,6	451,9 (5)		451,45	451,474		451,481 (10)		451,481 (10)
$\gamma_{27,8}$					457,57	457,61 (5)				457,61 (5)
$\gamma_{24,2}$					461,29	461,25 (5)				461,25 (5)
$\gamma_{25,3}$					463,8	463,9				463,9 (3)
$\gamma_{24,0}$					474,4	473,9				473,9 (5)
$\gamma_{26,4}$			480,7 (20)		481,55	481,54		481,78 (12)		481,66 (12)
$\gamma_{26,3}$					487,0	487,06				487,06 (10)
$\gamma_{31,10}$					493,1	493,08 (5)				493,08 (5)
$\gamma_{-1,9}$						497,0				497,0 (5)
$\gamma_{27,5}$						526,4				526,4 (4)
$\gamma_{-1,10}$					538,9	538,8 (2)				538,8 (2)
$\gamma_{33,8}$					550,6	550,5 (2)				550,5 (2)
$\gamma_{-1,11}$					557,7	557,3 (5)				557,3 (5)
$\gamma_{36,10}$						579,4 (3)				579,4 (3)
$\gamma_{31,5}$						582,89	582,75 (8)			582,89 (10)
$\gamma_{29,4}$					586,4	586,3	586,940 (14)			586,3 (3)

	1965 Tr03	1966 Ah02	1966 Ho09	1968 Cl02	1971 GuZY	1976 GuZN	1979 Al03	1982 He02	1994 Mo36	Adopted
$\gamma_{43,12}$						596,0				596,0 (5)
$\gamma_{33,6}$					598,4	597,99 (5)				597,99 (5)
$\gamma_{36,8}$						599,6 (2)				599,6 (2)
$\gamma_{40,10}$					607,3	606,9 (2)				606,9 (2)
$\gamma_{-1,12}$						608,9 (2)				608,9 (2)
$\gamma_{31,4}$					612,9	612,83 (3)	612,838 (6)			612,83 (3)
$\gamma_{35,6}$					617,4	617,10 (10)	617,212 (7)			617,10 (10)
$\gamma_{31,3}$					618,9	618,28 (6)	618,335 (6)			618,28 (6)
$\gamma_{33,5}$						619,21 (6)				619,21 (6)
$\gamma_{29,2}$							624,75 (10)			624,78 (5)
$\gamma_{32,3}$					624,8	624,78 (5)				624,78 (3)
$\gamma_{28,0}$					633,19	633,15 (6)	633,088 (6)			633,15 (6)
$\gamma_{29,1}$										637,73 (5) [b]
$\gamma_{29,0}$			636,0 (30)		637,97	637,84 (6)	637,77 (1)			637,80 (5)
$\gamma_{38,7}$					640,15	640,075		639,99 (10)		639,99 (10)
$\gamma_{30,2}$			645,5 (30)		646,02	645,969	645,894 (5)	645,98 (3)		645,94 (4)
$\gamma_{33,4}$					649,5	649,32 (6)				649,32 (6)
$\gamma_{-1,13}$						650,529 (60)				650,529 (60)
$\gamma_{34,4}$					652,19	652,074	652,052 (5)	651,79 (10)		652,05 (2)
$\gamma_{33,3}$					654,86	654,88 (8)	654,80 (2)			654,88 (8)
$\gamma_{30,1}$					658,99	658,929	658,862 (5)	658,63 (15)		658,86 (6)
$\gamma_{31,0}$					664,67	664,58 (5)	664,520 (12)			664,58 (5)
$\gamma_{36,5}$						668,2 (5)				668,2 (5)
$\gamma_{43,4}$						670,8				670,8 (5)
$\gamma_{32,0}$										670,99 (4)
$\gamma_{40,6}$					674,2	674,05 (3)				674,05 (3)
$\gamma_{40,5}$										674,4 (5)
$\gamma_{-1,14}$					686,16	685,97 (11)	685,861 (6)			685,97 (11)
$\gamma_{-1,15}$						688,1 (3)				688,1 (3)
$\gamma_{34,2}$					690,85	690,81 (8)	690,730 (22)			690,81 (8)
$\gamma_{-1,16}$						693,2 (5)				693,2 (5)
$\gamma_{46,10}$							693,81 (1)			693,81 (1) [c]
$\gamma_{41,5}$						697,8				697,8 (5)
$\gamma_{-1,17}$						699,6 (5)				699,6 (5)
$\gamma_{33,0}$					701,00	701,1 (2)				701,1 (2)
$\gamma_{34,1}$					703,79	703,68 (5)	703,680 (22)			703,68 (5)
$\gamma_{-1,18}$						712,96 (5)				712,96 (5)
$\gamma_{44,7}$						714,71	714,57 (1)			714,71 (14)
$\gamma_{39,4}$					717,76	717,72	718,23 (1)	718,0 (5)		718,0 (5)
$\gamma_{35,0}$						720,3 (5)				720,3 (5)
$\gamma_{47,10}$							720,550 (25)			720,56 (3)
$\gamma_{41,4}$					727,81	727,9	727,860 (25)			727,9 (2)
$\gamma_{46,7}$						736,5	735,910 (15)			736,5 (5)
$\gamma_{-1,19}$						742,7 (5)				742,7 (5)

	1965 Tr03	1966 Ah02	1966 Ho09	1968 Cl02	1971 GuZY	1976 GuZN	1979 Al03	1982 He02	1994 Mo36	Adopted
$\gamma_{37,2}$						747,4	747,97 (1)			747,4 (5)
$\gamma_{38,2}$					}	}756,4 (2)	756,190 (35)			756,23 (6) [b]
$\gamma_{39,2}$			756,0 (30)		}756,40	}	756,87 (6)			756,4 (4)
$\gamma_{47,7}$							762,6 (2)			762,6 (2)
$\gamma_{45,5}$						763,7	763,60 (15)			763,60 (15) [c]
$\gamma_{41,2}$			766,8 (30)			766,6	766,53 (4)			766,47 (3)
$\gamma_{51,12}$							767,29 (4)			767,29 (4)
$\gamma_{38,1}$							769,15 (8)		769,19 (4) [a]	769,15 (8)
$\gamma_{39,1}$					769,38	769,4 (5)	769,59			769,4 (5)
$\gamma_{43,4}$							769,87 (2)			769,54 (4)
$\gamma_{-1,20}$						777,1				777,1 (3)
$\gamma_{41,1}$					779,5	779,61	779,42 (2)			779,43 (3) [b]
$\gamma_{-1,21}$					787,3	786,9 (2)	786,90 (2)			786,9 (2)
$\gamma_{-1,22}$					793,0	788,5 (3)				788,5 (3)
$\gamma_{42,2}$						792,9	792,58 (5)			792,68 (6) [b]
$\gamma_{-1,23}$					796,5	796,9 (3)				796,9 (3)
$\gamma_{-1,24}$					803,3	803,2 (2)				803,2 (2)
$\gamma_{42,1}$						805,9	805,65 (1)			805,65 (6) [b]
$\gamma_{43,2}$					808,2	808,4	808,19 (4)			808,21 (4) [b]
$\gamma_{46,4}$					813,9	813,7	813,510 (17)			813,7 (2)
$\gamma_{50,9}$						816,0 (2)				816,0 (2)
$\gamma_{43,0}$					821,1					821,25 (4) [b]
$\gamma_{51,10}$						821,3 (2)				821,3 (2)
$\gamma_{-1,25}$						826,8 (3)				826,8 (3)
$\gamma_{-1,26}$					828,8	828,9 (2)	828,82 (4)			828,9 (2)
$\gamma_{52,12}$					832,1	832,5				832,2 (2)
$\gamma_{-1,27}$						837,3 (2)				837,3 (2)
$\gamma_{47,4}$					839,0	840,4	840,26 (10)			840,4 (2)
$\gamma_{44,1}$					843,8	844,0	843,78 (1)			843,780 (10)
$\gamma_{47,2}$					879,0	879,2				879,2 (3)
$\gamma_{47,1}$						891,0				891,0 (3)
$\gamma_{-1,28}$						895,4 (3)				895,4 (3)
$\gamma_{-1,29}$						898,1 (3)				898,1 (3)
$\gamma_{-1,30}$						905,5 (3)				905,5 (3)
$\gamma_{-1,31}$						911,7 (3				911,7 (3)
$\gamma_{49,4}$						918,7 (3)				918,7 (3)
$\gamma_{-1,32}$						931,9 (3)				931,9 (3)
$\gamma_{50,3}$					940,1	940,3 (3)				940,3 (3)
$\gamma_{48,2}$					956,4	955,6	955,390 (21)			955,41 (2) [b]
$\gamma_{49,2}$						957,6 (3)				957,6 (3)
$\gamma_{48,1}$							968,390 (34)			968,37 (2)
$\gamma_{51,2}$					979,5	979,7				979,7 (3)
$\gamma_{-1,33}$						982,7 (3)				982,7 (3)
$\gamma_{53,7}$					986,7	986,9	986,920 (35)			986,92 (4) [c]

	1965 Tr03	1966 Ah02	1966 Ho09	1968 Cl02	1971 GuZY	1976 GuZN	1979 Al03	1982 He02	1994 Mo36	Adopted
$\gamma_{51,1}$					992,5	992,7	992,639 (33)			992,64 (3) [c]
$\gamma_{52,4}$					1005,5	1005,7				1005,7 (3)
$\gamma_{-1,34}$						1009,4 (3)				1009,4 (3)
$\gamma_{52,0}$					1057,3					1057,3 (2)

[a] Measured in 1980Despres

[b] Obtained as a level energy difference

[c] Adopted from 1979Al03

Table 10. Experimental and evaluated relative emission probabilities of gamma rays in decay of ^{239}Pu [&]

	Energy, keV	1966 Ah02	1976 GuZN	1980 Despres	1982 He02	1984 Iw02	1992 Bl07	1994 Mo36	Evaluated
$\gamma_{1,0}$	0,077								~0,00016 [a]
$\gamma_{2,1}$	12,98						540 (14)	540 (14)	540 (14)
$\gamma_{-1,1}$	14,22							87 (6)	87 (6) *
$\gamma_{5,4}$	30,04		3,47 (13)		15,4 (4)			4,4 (13)	3,47 (13)
$\gamma_{4,2}$	38,66	152 (15)	168 (4)		157,0 (4)		165,8 (24)	165,5 (21)	166 (3)
$\gamma_{-1,2}$	40,41		2,58 (26)						2,58 (26) *
$\gamma_{10,7}$	41,93		2,64 (10)		4,07 (10)			2,31 (24)	2,59 (12)
$\gamma_{3,0}$	46,21	16 (2)	11,8 (12)		14,6 (7)			11,43 (17)	11,5 (2)
$\gamma_{11,8}$	46,68		0,93 (6)		1,2 (1)			0,74 (4)	0,80 (9)
$\gamma_{7,5}$	47,60							0,99 (4)	0,99 (4)
$\gamma_{4,1}$	51,62	410 (40)	431 (9)		422 (3)		434 (6)	431 (4)	427 (3)
$\gamma_{12,10}$	54,04		3,19 (8)		3,01 (7)			3,08 (4)	3,08 (4)
$\gamma_{6,3}$	56,83	16 (2)	18,0 (4)		17,4 (4)			18,26 (21)	18,0 (2)
$\gamma_{14,12}$	65,71		0,72 (4)		0,72 (6)			0,82 (5)	0,75 (4)
$\gamma_{9,6}$	67,67		2,57 (7)		2,70 (11)			2,40 (4)	2,50 (8)
$\gamma_{5,2}$	68,70	}14 (2)	8,15 (18)		7,9 (2)			7,69 (10)	5,7 (16) [b]
$\gamma_{8,5}$	68,73	}							2,1 (10) [b]
$\gamma_{-1,3}$	74,96								0,60 (10) [c] *
$\gamma_{7,4}$	77,59	11,2	6,23 (13)		6,8 (2)			6,02 (8)	6,08 (9)
$\gamma_{13,9}$	78,43		2,43 (6)		2,1 (2)			2,44 (4)	2,43 (4)
$\gamma_{17,13}$	89,39								~0,03 [d]
$\gamma_{10,5}$	89,64				0,47 (8)			0,43 (3)	0,43 (3)
$\gamma_{12,7}$	96,14		0,36 (7)					0,60 (3)	0,60 (3)
$\gamma_{15,11}$	97,6								1,4 (10) [e, a]
$\gamma_{8,4}$	98,78		19,5 (7)					23,2 (11)	21,4 (18)
$\gamma_{6,0}$	103,06		3,47 (9)					3,42 (9)	3,44 (9)
$\gamma_{11,5}$	115,38		7,27 (18)						7,3 (8) [f]
$\gamma_{7,2}$	116,26		9,54 (24)					8,99 (17)	9,2 (3)
$\gamma_{10,4}$	119,70		}0,479 (14)		}0,53 (2)			0,479 (29)	0,33 (4) [g]
$\gamma_{14,10}$	119,76		}		{				0,15 (2) [g, i]
$\gamma_{12,6}$	122,35		0,05 (3)					0,015 (2)	0,015 (2) [i]
$\gamma_{37,29}$	123,23								0,000025 (6) [h]
$\gamma_{21,14}$	123,62		0,315 (20)					0,376 (14)	0,376 (14)
$\gamma_{9,3}$	124,51		0,98 (4)					1,08 (3)	1,08 (3)
$\gamma_{10,3}$	125,21		1,13 (3)					0,892 (24)	0,892 (24)
$\gamma_{7,0}$	129,30	100	100	100	100	100		100	100

	Energy, keV	1966 Ah02	1976 GuZN	1980 Despres	1982 He02	1984 Iw02	1992 Bl07	1994 Mo36	Evaluated
$\gamma_{19,12}$	141,66	0,6 (1)	0,511 (15)	0,45 (7)	0,46 (8)	0,63 (18)			0,509 (15)
$\gamma_{12,5}$	143,35		0,276 (12)	0,45	}4,80 (9)	}4,75 (13)			0,276 (12)
$\gamma_{15,8}$	144,20	5 (1)	4,52 (10)	4,75 (24)	}	}			4,52 (10)
$\gamma_{13,6}$	146,09	2,1 (2)	1,90 (4)	1,80 (18)	2,00 (10)	1,91 (10)			1,91 (4)
$\gamma_{10,2}$	158,1		0,0160 (16)						0,0160 (16)
$\gamma_{18,11}$	160,19		0,099 (20)						0,099 (20) [i]
$\gamma_{16,10}$	161,45		1,92 (4)	2,00 (12)	1,96 (4)	1,91 (10)			1,94 (10)
$\gamma_{17,9}$	167,81		0,047 (12)						0,047 (12)
$\gamma_{10,0}$	171,39	1,8 (2)	1,76 (5)	1,69 (10)	1,74 (4)	1,70 (9)			1,74 (4)
$\gamma_{42,28}$	172,56								~0,00005 [h]
$\gamma_{12,4}$	173,70		0,049 (12)						0,049 (12)
$\gamma_{12,3}$	179,22	1,2 (2)	1,05 (3)	1,04 (8)	1,04 (3)	1,00 (5)			1,04 (3)
$\gamma_{-1,4}$	184,55		0,034 (10)						0,034 (10) *
$\gamma_{14,6}$	188,23		0,174 (18)						0,174 (18)
$\gamma_{21,12}$	189,36	1,5 (2)	1,33 (4)	1,33 (12)	1,30 (2)	1,28 (3)			1,30 (2)
$\gamma_{-1,5}$	193,13		0,142 (15)						0,142 (15) *
$\gamma_{19,10}$	195,68	1,9 (2)	1,70 (4)	1,64 (11)	1,68 (3)	1,68 (4)			1,68 (3)
$\gamma_{-1,6}$	196,87		0,059 (7)						0,059 (7) *
$\gamma_{16,7}$	203,55	9 (1)	8,95 (18)	8,94 (42)	8,90 (13)	8,95 (14)			8,93 (13)
$\gamma_{21,11}$	218,0								0,019 (16) [i]
$\gamma_{12,0}$	225,42		0,249 (11)	0,22 (2)	0,23 (2)	0,23 (2)			0,238 (11)
$\gamma_{19,7}$	237,77		0,230 (10)	0,23 (2)		0,32 (2)			0,230 (10)
$\gamma_{26,14}$	242,08		0,117 (8)	}	}	}			0,117 (8)
$\gamma_{21,10}$	243,38		0,404 (11)	}0,41	}0,38 (3)	}0,61 (4)			0,404 (11)
$\gamma_{14,3}$	244,92		0,081 (8)	}	}	}			0,081 (8)
$\gamma_{24,12}$	248,95		0,115 (12)	0,112 (11)	0,11 (1)	0,106 (20)			0,111 (10)
$\gamma_{22,10}$	255,38	1,6 (2)	1,29 (4)	1,27 (10)	1,27 (3)	1,23 (3)			1,26 (3)
$\gamma_{20,7}$	263,95	0,6 (1)	0,417 (15)	0,40 (4)	0,42 (4)	0,39 (3)			0,411 (15)
$\gamma_{30,20}$	265,7		0,025 (6)						0,025 (6)
$\gamma_{16,4}$	281,2		0,035 (5)	0,033 (10)		0,025 (13)			0,034 (5)
$\gamma_{19,5}$	285,3		0,030 (6)	0,03					0,030 (6)
$\gamma_{22,7}$	297,46	0,9 (1)	0,802 (23)	0,77 (8)	0,78 (2)	0,77 (2)			0,78 (2)
$\gamma_{24,10}$	302,87		0,081 (7)	0,070 (12)	0,075 (10)	0,074 (12)			0,077 (7)
$\gamma_{26,12}$	307,85		0,088 (6)	0,076 (12)	0,08 (2)	0,073 (12)			0,083 (6)
$\gamma_{21,6}$	311,78	0,5 (1)	0,412 (12)	0,39 (4)	0,40 (3)	0,36 (8)			0,408 (12)
$\gamma_{23,7}$	316,41		0,217 (8)	0,21 (4)	0,20 (4)	0,196 (14)			0,211 (8)
$\gamma_{16,2}$	319,7		0,077 (8)			}0,85 (2)			0,077 (8)
$\gamma_{19,3}$	320,86	0,8 (1)	0,856 (19)	0,86 (8)	0,86 (3)	}			0,856 (19)
$\gamma_{24,8}$	323,84	0,9 (1)	0,866 (19)	0,82 (8)	0,84 (2)	0,81 (2)			0,84 (2)
$\gamma_{16,0}$	332,85	8 (1)	8,08 (16)	7,64 (32)	7,70 (11)	7,64 (11)			7,74 (11)
$\gamma_{26,11}$	336,11	1,8 (2)	1,81 (4)	1,72 (13)	1,73 (4)	1,75 (4)			1,76 (4)
$\gamma_{20,4}$	341,51	1,2 (1)	1,058 (22)	1,05 (10)	1,00 (4)	1,02 (2)			1,03 (2)
$\gamma_{24,7}$	345,00	}	}						<0,8 [i]
$\gamma_{22,5}$	345,013	}8,7 (9)	}8,93 (18)	8,75 (30)	8,67 (13)	8,61 (11)			8,69 (11)
$\gamma_{-1,7}$	350,8		0,028 (6)						0,028 (6) *
$\gamma_{19,2}$	354,0		0,012 (5)						0,012 (5)
$\gamma_{26,10}$	361,89		0,195 (11)	0,18 (2)	0,22 (2)	0,17 (1)			0,185 (11)

	Energy, keV	1966 Ah02	1976 GuZN	1980 Despres	1982 He02	1984 Iw02	1992 Bl07	1994 Mo36	Evaluated
$\gamma_{19,0}$	367,07	1,6 (2)	1,38 (3)	1,38 (6)	1,44 (3)	1,35 (2)			1,38 (3)
$\gamma_{21,3}$	368,55	1,4 (2)	1,44 (3)	1,39 (6)	1,37 (3)	1,38 (2)			1,39 (2)
$\gamma_{22,4}$	375,05	25 (3)	25,1 (5)	24,9 (8)	24,2 (3)	24,2 (3)			24,4 (3)
$\gamma_{20,2}$	380,19	5 (1)	4,87 (10)	4,78 (26)	4,75 (7)	4,77 (6)			4,78 (6)
$\gamma_{26,8}$	382,75	4 (1)	4,13 (8)	4,08 (32)	4,02 (6)	4,04 (5)			4,05 (5)
$\gamma_{24,5}$	392,53		}8,83 (18)	}8,72 (35)	}8,55 (13)	1,91 (25)			1,91 (25)
$\gamma_{20,1}$	393,14	10 (1)	}	}	}	6,64 (26)			6,64 (26)
$\gamma_{23,3}$	399,53		0,097 (4)		0,09 (1)	0,103 (17)			0,097 (4)
$\gamma_{25,6}$	406,8		0,010 (4)		0,046 (11)				0,010 (4)
$\gamma_{27,11}$	411,2		0,11 (5)						0,11 (5)
$\gamma_{42,20}$	412,49					}23,0 (3)			~0,00029[j]
$\gamma_{22,2}$	413,71	25 (3)	23,8 (5)	23,8 (8)	23,0 (3)	}			23,2 (3)
$\gamma_{24,4}$	422,60	2,0 (3)	1,90 (4)	1,91 (14)	1,88 (4)	1,90 (3)			1,90 (3)
$\gamma_{22,1}$	426,68	0,3 (1)	0,372 (9)	0,36 (4)		0,42 (2)			0,379 (9)
$\gamma_{24,3}$	428,4		0,0160 (16)						0,0160 (16)
$\gamma_{26,6}$	430,1		0,069 (3)	0,068 (7)		0,065 (6)			0,068 (3)
$\gamma_{23,0}$	445,72		0,139 (4)	0,146 (15)		0,13 (11)			0,139 (4)
$\gamma_{-1,8}$	446,8		0,0135 (20)						0,0135 (20) *
$\gamma_{26,5}$	451,48	3,4 (5)	3,02 (7)	3,08 (19)	2,96 (4)	2,93 (4)			2,96 (4)
$\gamma_{27,8}$	457,61		0,0238 (5)	0,026 (3)		0,023 (6)			0,0239 (5)
$\gamma_{24,2}$	461,25		0,0363 (8)						0,0363 (8)
$\gamma_{25,3}$	463,9		0,0044 (5)						0,0044 (5)
$\gamma_{24,0}$	473,9		0,0009 (5)						0,0009 (5)
$\gamma_{26,4}$	481,7		0,0735 (15)	0,077 (8)		0,069 (4)			0,0731 (15)
$\gamma_{26,3}$	487,1		0,042 (3)						0,042 (3)
$\gamma_{31,10?}$	493,08		0,0139 (5)	0,014 (2)		0,013 (3)			0,0139 (5)
$\gamma_{-1,9}$	497,0		0,0007 (4)						0,0007 (4) *
$\gamma_{27,5}$	526,4		0,0009 (3)						0,0009 (3)
$\gamma_{-1,10}$	538,8		0,0049 (3)						0,0049 (3) *
$\gamma_{33,8}$	550,5		0,0067 (4)	0,0074 (8)		0,0079 (31)			0,0069 (4)
$\gamma_{-1,11}$	557,3		0,0006 (3)						0,0006 (3) *
$\gamma_{36,10}$	579,4		0,0014 (3)						0,0014 (3)
$\gamma_{31,5}$	582,9		0,0098 (4)						0,0098 (4)
$\gamma_{29,4}$	586,3		0,00244 (25)						0,00244 (25)
$\gamma_{43,12}$	596,0		0,00062 (19)						0,00062 (19)
$\gamma_{33,6}$	597,99		0,0267 (10)	0,032 (3)		0,030 (3)			0,0275 (10)
$\gamma_{36,8}$	599,6		0,0032 (4)						0,0032 (4)
$\gamma_{40,10}$	606,9		0,00192 (20)						0,00192 (20)
$\gamma_{-1,12}$	608,9		0,00185 (19)						0,00185 (19) *
$\gamma_{31,4}$	612,83		0,0151 (8)	0,025		0,016 (4)			0,0151 (8)
$\gamma_{35,6}$	617,10		0,0214 (12)	}0,08 (1)	}0,09 (1)	}0,069 (5)			0,0214 (12)
$\gamma_{31,3}$	618,28		0,0326 (12)	}	}	}			0,0326 (12)
$\gamma_{33,5}$	619,21		0,0193 (12)						0,0193 (12)
$\gamma_{29,2}$	624,78		0,0073 (3) }						0,0073 (3)[k]
$\gamma_{32,3}$	624,78		}						<0,0003[k]
$\gamma_{28,0}$	633,15		0,0404 (9)	0,043 (4)		0,036 (3)			0,0404 (9)
$\gamma_{29,1}$	637,73		}0,0409 (10)	}0,047 (5)		}0,047 (4			0,0101 (10)[k]

	Energy, keV	1966 Ah02	1976 GuZN	1980 Despres	1982 He02	1984 Iw02	1992 Bl07	1994 Mo36	Evaluated
$\gamma_{29,0}$	637,80		}	}		}			0,0304 (30) ^{k}
$\gamma_{38,7}$	639,99		0,131 (3)	0,139 (14)	0,16 (2)	0,142 (5)			0,134 (3)
$\gamma_{30,2}$	645,94		0,238 (5)	0,25 (3)	0,21 (2)	0,236 (6)			0,236 (5)
$\gamma_{33,4}$	649,32		0,0114 (8)						0,0114 (8)
$\gamma_{-1,13}$	650,53		0,0043 (7)						0,0043 (7) *
$\gamma_{34,4}$	652,05		0,105 (3)	0,105 (11)	0,125 (15)	0,102 (5)			0,105 (3)
$\gamma_{33,3}$	654,88		0,0359 (8)	0,029 (7)		0,023 (5)			0,0359 (8)
$\gamma_{30,1}$	658,86		0,155 (4)	0,159 (16)	0,125 (14)	0,150 (5)			0,152 (4)
$\gamma_{31,0}$	664,58		0,0265 (6)	0,027 (3)		0,026 (3)			0, 0265 (6)
$\gamma_{36,5}$	668,2		0,00063 (19)						0,00063 (19)
$\gamma_{43,4}$?	670,8		}0,00014 (4)						<0,00014 (4) $^{l,\ i}$
$\gamma_{32,0}$?	670,99		}						<0,00014 (4) $^{l,\ i}$
$\gamma_{40,6}$	674,05		0,0082 (3)	}0,0096 (10)		0,0080 (3)			0,0080 (3) ^{k}
$\gamma_{40,5}$	674,4			}					0,0016 (2) ^{k}
$\gamma_{-1,14}$	685,97		0,0199 (5)	0,0158 (16)		0,023 (4)			0,0199 (5) *
$\gamma_{-1,15}$	688,1		0,00177 (18)						0,00177 (18) *
$\gamma_{34,2}$	690,81		0,0089 (5)	0,0104 (10)		0,014 (3)			0,0093 (7)
$\gamma_{-1,16}$	693,2		}0,00080 (24)						0,0005 (2) ^{g} *
$\gamma_{46,10}$	693,81		}						0,0003 (1) ^{g}
$\gamma_{41,5}$	697,8		0,00117 (24)						0,00117 (24)
$\gamma_{-1,17}$	699,6		0,00126 (25)						0,00126 (25) *
$\gamma_{33,0}$	701,1		0,0082 (3)	0,0095 (10)		0,0106 (34)			0,0083 (3)
$\gamma_{34,1}$	703,68		0,063 (2)	0,067 (7)		0,070 (4)			0,065 (2)
$\gamma_{-1,18}$	712,96		0,00082 (10)						0,00082 (10) *
$\gamma_{44,7}$	714,7		0,00125 (13)						0,00125 (13)
$\gamma_{39,4}$	718,0		0,0438 (9)	0,048 (5)		0,042 (3)			0,0438 (9)
$\gamma_{35,0}$	720,3		}0,00078 (8)						0,00046 (5) ^{g}
$\gamma_{47,10}$	720,56		}						0,00032 (3) ^{g}
$\gamma_{41,4}$	727,9		0,00198 (11)						0,00198 (11)
$\gamma_{46,7}$	736,5		0,00048 (14)						0,00048 (14)
$\gamma_{-1,19}$	742,7		0,00060 (18)						0,00060 (18) *
$\gamma_{37,2}$	747,4		0,00129 (26)						0,00129 (26)
$\gamma_{38,2}$	756,23		}0,0554 (11)	}0,061 (6)		}0,054 (4)			0,044 (8) ^{g}
$\gamma_{39,2}$	756,4		}	}		}			0,011 (3) ^{g}
$\gamma_{47,7}$	762,6								~0,00016 ^{g}
$\gamma_{45,5}$	763,60		0,00052 (26)						0,00035 ^{g}
$\gamma_{41,2}$	766,47		}0,00439 (24)						0,0021 (3) ^{g}
$\gamma_{51,12}$	767,29		}						0,0022 (5) ^{g,i}
$\gamma_{38,1}$	769,15		}0,179 (4)	}0,20 (2)		}0,187 (5)			0,081 (16) ^{g}
$\gamma_{39,1}$	769,4		}	}		}			0,108 (19) ^{g}
$\gamma_{43,4}$	769,54		}	}		}			- ^{m}
$\gamma_{-1,20}$	777,1		0,00044 (11)						0,00044 (11) *
$\gamma_{41,1}$	779,43		0,00217 (14)						0,00217 (14)
$\gamma_{-1,21}$	786,9		0,00138 (14)						0,00138 (14) *
$\gamma_{-1,22}$	788,5		0,00056 (11)						0,00056 (11)
$\gamma_{42,2}$	792,68		0,00032 (6)						0,00032 (6)
$\gamma_{-1,23}$	796,9		0,00024 (5)						0,00024 (5) *

	Energy, keV	1966 Ah02	1976 GuZN	1980 Despres	1982 He02	1984 Iw02	1992 Bl07	1994 Mo36	Evaluated
$\gamma_{-1,24}$	803,2		0,00102 (7)						0,00102 (7) *
$\gamma_{42,1}$	805,65		0,00044 (7)						0,00044 (7)
$\gamma_{43,2}$	808,21		0,00193 (10)						0,00193 (10)
$\gamma_{46,4}$	813,7		0,00072 (7)						0,00072 (7)
$\gamma_{50,9}$	816,0		0,00039 (6)						0,00039 (6)
$\gamma_{43,0}$	821,25		}0,00088 (9)						0,00079 (17) [n]
$\gamma_{51,10}$	821,3		}						~0,00009 [n]
$\gamma_{-1,25}$	826,8		0,00029 (10)						0,00029 (10) *
$\gamma_{-1,26}$	828,9		0,00212 (13)						0,00212 (13) *
$\gamma_{52,12}$	832,2		0,00047 (6)						0,00047 (6)
$\gamma_{-1,27}$	837,3		0,00031 (6)						0,00031 (6) *
$\gamma_{47,4}$	840,4		0,00077 (8)						0,00077 (8)
$\gamma_{44,1}$	843,78		0,00214 (12)						0,00214 (12)
$\gamma_{47,2}$	879,2		0,00058 (6)						0,00058 (6)
$\gamma_{47,1}$	891,0		0,00119 (13)						0,00119 (13)
$\gamma_{-1,28}$	895,4		0,00012 (4)						0,00012 (4) *
$\gamma_{-1,29}$	898,1		0,00028 (6)						0,00028 (6) *
$\gamma_{-1,30}$	905,5		0,00012 (4)						0,00012 (4) *
$\gamma_{-1,31}$	911,7		0,00022 (5)						0,00022 (5) *
$\gamma_{49,4}$	918,7		0,00014 (5)						0,00014 (5)
$\gamma_{-1,32}$	931,9		0,00020 (7)						0,00020 (7) *
$\gamma_{50,3}$	940,3		0,00079 (8)						0,00079 (8)
$\gamma_{48,2}$	955,41		0,00049 (5)						0,00049 (5)
$\gamma_{49,2}$	957,6		0,00051 (5)						0,00051 (5)
$\gamma_{48,1}$	968,37								~0,00044 [h]
$\gamma_{51,2}$	979,7		0,00044 (7)						0,00044 (7)
$\gamma_{-1,33}$	982,7		0,00017 (4)						0,00017 (4) *
$\gamma_{53,7}$	986,92		0,00033 (7)						0,00033 (7)
$\gamma_{51,1}$	992,64		0,00042 (6)						0,00042 (6)
$\gamma_{52,4}$	1005,7		0,00028 (4)						0,00028 (4)
$\gamma_{-1,34}$	1009,4		0,00022 (4)						0,00022 (4) *
$\gamma_{52,0}$	1057,3								0,00071 (11) [j]

[&] Other measurements for some γ rays: 1965Tr03, 1966Ho09, 1968Cl02, 1971GuZY, 1981UmZZ, 1992Ba08, 1992Co10, 1997Bu23, 1997Ko52.

* Unplaced in level scheme.

[a] Deduced from P(γ+ce) and total ICC.

[b] Intensity suitably divided for doublet in 2003Br12 (see comments therein).

[c] From 1971GuZY. Reported also in Coulomb excitation, see comments in 2003Br12.

[d] Intensity suitably divided for doublet in 2003Br12 using systematics.

[e] Seen in conversion electron spectrum only (1965Tr03).

[f] From 1976GuZN and corrected for X-ray component in 2003Br12.

[g]. Intensity suitably divided for doublet in 2003Br12 based on (n, γ) data (1979Al03).

[h] From (n, γ) data (1979Al03). See 2003Br12.

[i] Placement of this transition in the level scheme is uncertain (2003Br12).

[j] From 2003Br12.

[k] Intensity suitably divided for doublet in 1996Firestone.

[l] Multiply placed, undivided intensity given.

[m] E0-transition.

[n] Possible doublet (see 2003Br12); multiply placed.

Table 11. Energies, multipolarities, E2/M1 mixing ratios and ICC for soft gamma rays (< 120 keV) in decay of ^{239}Pu [*]

Energy (keV)	Multipolarity	δ-mixing ratio	K	L1	L2	L3	L	M	TOT
0,0765 (4)	E3								
12,975 (10)	M1+0,19 (2) %E2[a]	0,0436 (23)[a]						451 (13)	607 (17)[a]
14,22 (3)									
30,04 (2)	(M1)[a]			104,9 (21)	12,42 (25)	0,687 (14)	118,0 (24)	28,7 (6)	157 (3)
38,661 (2)	M1+22,2 (16) %E2[a]	0,534 (24)[a]		42,3 (8)	110 (7)	96 (7)	249 (14)	67 (4)	339 (19)
40,41 (5)									
41,93 (5)	(M1)[a]			39,3 (8)	4,66 (9)	0,249 (5)	44,2 (9)	10,71 (21)	58,6 (12)
46,21 (5)	M1+1,8 (5) %E2[a]	0,134 (19)[a]		29,0 (6)	7,0 (11)	3,3 (9)	39,4 (19)	9,8 (5)	52,6 (27)[a]
46,68 (3)	M1+9 (5) %E2[a]	0,32 (9)[a]		26,6 (12)	21 (10)	16 (9)	63 (17)	17 (5)	86 (24)[a]
47,60 (3)	(M1)			27,0 (5)	3,22 (6)	0,170 (3)	30,4 (6)	7,37 (15)	40,4 (8)
51,624 (1)	E2			4,20 (8)	120,4 (24)	101,8 (20)	226 (5)	62,6 (13)	310 (6)
54,039 (8)	M1[a]			18,6 (4)	2,22 (4)	0,1154 (23)	21,0 (4)	5,08 (10)	27,8 (6)
56,828 (3)	M1+5,0 (8) %E2[b]	0,23 (2)[b]		15,4 (3)	5,7 (7)	3,3 (5)	24,3 (11)	6,14 (30)	32,6 (15)
65,708 (30)	M1+4 (6) %E2[a]	0,21 (16)[a]		10,1 (7)	2,8 (29)	1,35 (24)	14 (5)	3,,6 (13)	19 (6)[a]
67,674 (12)	M1+3,63 (11) %E2[b]	0,194 (3)[b]		9,33 (19)	2,34 (5)	1,01 (3)	12,7 (4)	3,15 (9)	16,9 (5)
68,696 (6)	E2			1,19 (24)	31,6 (6)	24,5 (5)	57,3 (11)	15,9 (3)	78,6 (16)
68,73 (2)	(M1+20 %E2)[c]	0,5[c]		7,6	7,2	4,9	20	5,2	27
74,96 (10)									

Energy (keV)	Multipolarity	δ-mixing ratio	K	L1	L2	L3	L	M	TOT
77,592 (14)	M1(+20 (32) %E2) [d]	0,5 (5) [d]		5,3 (2)	4 (5)	2,7 (40)	12 (7)	3,2 (21)	17 (10)
78,43 (2)	M1(+20 (32) %E2) [d]	0,5 (5) [d]		5,2 (17)	4 (5)	2,6 (40)	12 (7)	3,1 (20)	16 (10)
89,39 (6)	[M1]			4,28 (9)	0,519 (10)	0,0253 (5)	4,82 (10)	1,167 (23)	6,40 (13)
89,64 (3)	(M1+E2)						11 (6)	2,8 (17)	14 (8)
96,14 (3)	[E2]			0,318 (6)	6,72 (14)	4,63 (9)	11,67 (23)	3,24 (7)	16,0 (3)
97,6 (3)	M1+20 (19) %E2 [d]	0,5 (3) [d]		2,71 (6)	1,6 (11)	0,9 (8)	5,2 (14)	1,3 (4)	7,0 (19)
98,78 (2)	E2			0,289 (6)	5,94 (12)	4,05 (8)	10,28 (21)	2,85 (6)	14,1 (3)
103,06 (3)	E2			0,250 (5)	4,90 (10)	3,29 (7)	8,44 (17)	2,34 (5)	11,58 (23)
115,38 (5)	E2			0,172 (3)	2,95 (6)	1,88 (4)	5,00 (10)	1,39 (3)	6,87 (14)
116,26 (2)	M1(+24 (36) %E2) [d]	0,56 (56) [d]	8,4 (18)	1,5 (6)	0,9 (9)	0,5 (6)	2,9 (6)	0,74 (16)	12,2 (26)
119,70 (3)	(M1+E2)		5 (5)				3,1 (11)	0,8 (3)	9 (4)
119,76 (2)	[E2]		0,200 (4)	0,154 (3)	2,49 (5)	1,57 (3)	4,22 (8)	1,169 (23)	5,99 (12)

* For gamma rays with energies more than 120 keV the multipolarities are taken from 2003Br12 based on conversion electron data of 1965Tr03, experimental (n,γ) results of 1979Al03 or assigned from the decay scheme (in square brackets). The δ-mixing ratios are: 1,0 (10) for $\gamma_{26,5}$ (451,5 keV), < 1 for $\gamma_{40,10}$ (606,9 keV), < 0,5 for $\gamma_{28,0}$ (633,2 keV), 1,2 (2) for $\gamma_{46,7}$ (736,5 keV), 0,6 (2) for $\gamma_{46,7}$ (955,4 keV) and 0,6 (3) $\gamma_{46,7}$ (968,4 keV).

[a] Deduced from intensity balance.

[b] From muonic ^{235}U atom.

[c] From systematics.

[d] From conversion electron data of 1965Tr03.

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^{240}Pu – Comments on evaluation of decay data

by V. P. Chechev

This evaluation was done originally in 2004 (2004BeZQ, 2005ChZU) and then updated in June 2009 with a literature cut-off by the same date.

1. DECAY SCHEME

The decay scheme is based on 2006Br20. Some expected weak gamma-ray transitions have not been observed directly in ^{240}Pu alpha decay but were adopted from decay of ^{236}Pa and ^{236}Np and from data on nuclear reactions.

The alpha transitions to ^{236}U highly excited levels with energy of 958.960 and 967 keV were not observed. They are expected from data on level spins and gamma-rays de-excited these levels.

2. NUCLEAR DATA

Q(α) value is from 2003Au03.

The recommended half-life of ^{240}Pu is based on the experimental results given in Table 1. Re-estimated values were used for averaging where necessary.

Table 1. Experimental values of ^{240}Pu half-life (in years)

Reference	Author(s)	Original value	Re-estimated value	Measurement method
1951In03	Inghram et al.	6580 (40)	6500 (45) [b, c]	Mass-Spectrometry
1951We21	Westrum	6300 (600)		α-Particle Counting
1954Farwell	Farwell et al.	6760		α-Particle Counting
1956Bu92	Butler et al.	6600 (100)		α-Particle Counting
1959Dokuchaev	Dokuchaev	6620 (50)	6610 (55) [b]	α-Particle Counting
1968Oe02	Oetting	6524 (10)	6537 (15) [c]	Calorimetry
1978Ja11	Jaffey et al.	6569 (6)	6569 (7) [c]	α-Particle Counting
1984Be19	Beckmann et al.	6574 (6) [a]	6574 (7) [c]	Mass-Spectrometry
1984St06	Steinkruger et al.	6571 (9) [a]		α-Particle Counting
1984Lu04	Lucas and Noyce	6552.2 (20)	6552.2 (66) [c]	α-Particle Counting
1984Ru04	Rudy et al.	6552.4 (17)	6552.4 (66)	Calorimetry
2007Ah05	Ahmad et al.	6545 (19)		Ingrowth of ^{240}Pu in ^{244}Cm source, ^{240}Pu/^{244}Cm activity ratio measurement

[a] Quoted uncertainties, corresponding to 95 % confidence level, have been reduced by a factor 2.

[b] Re-estimated in 1978Ja11.

[c] Re-estimated in 1986LoZT.

With omitting the value of 1954Farwell reported without uncertainty the weighted average of the remaining 11 values is 6561 yr with the internal uncertainty 3.1 yr and external uncertainty 3.8 yr.

According to the criterion adopted by the members of the CRP (1986LoZT) a minimum uncertainty of the recommended ^{240}Pu half-life should be attributed as 7 years.

Therefore, the adopted value of the ^{240}Pu half-life is 6561 (7) years.

The recommended of ^{240}Pu spontaneous fission half-life is based on the experimental results given in Table 2.

Table 2. Experimental values of ^{240}Pu spontaneous fission half-life (in 10^{11} years)

Reference	Author(s)	Measure-ment value	Measurement method	Used for final averaging
1953Ki72	Kinderman	1.314 (26)	Low geometry α-counting	No
1954Ba14	Barclay et al.	1.225 (30)	Low geometry α-counting	No
1954Ch74	Chamberlain et al.	1.20	Low geometry α-counting	No
1959Mi90	Mikheev et al.	1.20	Low geometry α-counting	No
1962Wa13	Watt et al.	1.340 (15)	Low geometry α-counting	No
1963Ma50	Malkin et al.	1.45 (2)	Low geometry α-counting	No
1967White	White	1.27 (5)	No details available	No
1967Fi13	Fieldhouse et al.	1.176 (25)[a]	SF neutron emission rates	Yes
1979BuZC	Budtz-Jorgensen et al.	1.15 (3)	Fragment spectra, ionization chamber	Yes
1984An25	Androsenko et al.	1.15 (3)	SF neutron emission rates	Yes
1988SeZY	Selickij et al.	1.17 (3)	Fragment detection in 2π geometry	Yes
1989Dy01	Dytlewski et al.	1.12 (2)	Neutron coincidences and low geometry α-counting	Yes
1991Iv01	Ivanov et al.	1.15 (2)	λ_{SF} /λα in ^{240}Pu standards	Yes

[a] Re-estimated in 2000Ho27. Original value is 1.170 (25).

Early measurement values have been omitted from averaging according to analysis of Holden and Hoffman (2000Ho27). The weighted average of 6 selected values is 1.15 with the internal uncertainty 0.010 and external uncertainty 0.0087.

The recommended value of the ^{240}Pu spontaneous fission is 1.15 (2) 10^{11} years where the uncertainty is the smallest quoted uncertainty.

2.1 Alpha Transitions

The energies of the alpha transitions have been obtained from the Q value and the level energies given in Table 3 from 2006Br20.

Table 3. ^{236}U levels populated in ^{240}Pu α-decay

Level number	Energy, keV	Spin and parity	Half-life	Probability of α-transition (× 100)
0	0	0^+	2.343 (6)·10^7 yr	72.74 (18)
1	45.2440 (20)	2^+	234 (6) ps	27.16 (19)
2	149.477 (6)	4^+	124 (7) ps	0.0863 (18)
3	309.785 (7)	6^+	58 (3) ps	0.001082 (18)
4	522.25 (5)	8^+	24 (2) ps	4.7 (5)·10^{-5}
5	687.59 (4)	1^-	3.78 (9) ns	1.93 (4)·10^{-5}
6	744.18 (7)	3^-	< 0.1 ns	
7	919.14 (17)	0^+		≈ 6.5·10^{-7}
8	957.90 (17)	(2^+)		< 1.7·10^{-7}
9	960.3 (3)	(2^+)		< 1.3·10^{-7}
10	966.62 (9)	1^-		< 1·10^{-7}

The probabilities of the most intense transitions $\alpha_{0,0}$ and $\alpha_{0,1}$ were obtained by averaging experimental data (Table 4). The probabilities of all the remaining α-transitions have been deduced from the P(γ+ce) balances at relevant levels in ^{236}U. The $\alpha_{0,6}$-transition probability of 1.3 (7) 10^{-8} % has been taken from 2006Br20.

Table 4. Experimental and recommended values of α-transition probabilities (×100) in ^{240}Pu decay

	α-particle energy keV	1956 Ko67	1956 Go43	1952 As28 1957 As83	1969 Le05	1977 Ba69	1984 Ah06	1990 An33	1992 Bl13	1994 Ra27	1994 Sa63	1996 Vi07	2004 Si03	Recommended
$\alpha_{0,0}$	5168	75.5	75.5	76		73.51 (36)	72.8 (1)	73.0 (5)	72.55 (20)	73.1 (1)	72.5 (11)	74 (2)	72.56 (6)	72.74 (18) [a]
$\alpha_{0,1}$	5124	24.4	24.5	24		26.39 (21)	27.1 (1)	27.0 (5)	27.35 (10)	26.8 (1)	27.5 (11)	26 (2)	27.35 (7)	27.16 (19) [b]
$\alpha_{0,2}$	5021	0.091 (6)	0.085 (15)	0.1		0.096 (5)	0.090 (5)		0.10 (2)					0.0863 (18) [c]
$\alpha_{0,3}$	4864	0.0032 (1)				0.001								0.001082 (18) [c]
$\alpha_{0,4}$	4655													4.7 (5)·10^{-5} [c]
$\alpha_{0,5}$	4492				2.1(4) 10^{-5}									1.93 (4)·10^{-5} [c]

[a] LWEIGHT computer program has increased the uncertainty of 2004Si03 to 0.0649 and recommended a weighted average (72.74) with the expanded uncertainty of 0.18 so range includes the most precise value of 72.56.

[b] LWEIGHT computer program has recommended a weighted average (27.16) with the expanded uncertainty of 0.19 so range includes the most precise value of 27.35.

[c] Deduced from (γ+ce)-intensity balance at relevant levels.

2.2. Gamma Transitions and Internal Conversion Coefficients

The recommended energies of gamma-ray transitions are virtually the same as the gamma-ray energies because nuclear recoil is negligible for ^{234}U.

The gamma-ray transition probabilities were deduced from the gamma-ray emission probabilities and total internal conversion coefficients (ICCs). The ICCs have been interpolated using the BrIcc package with the so called "*Frozen Orbital*" approximation (2008Ki07). The uncertainties in the ICCs for pure multipolarities have been taken as 2 %. The multipolarities have been taken from 2006Br20.

The experimental values of ICC have been adopted for the E1 anomalously converted gamma-ray transitions $\gamma_{5,1}$ (642.4 keV) and $\gamma_{5,0}$ (687.6 keV).

3. ATOMIC DATA

3.1. Fluorescence yields

The fluorescence yield data are from 1996Sc06 (Schönfeld and Janβen).

3.2. X-Rays

The energies of U LX-rays taken from the SAISINUC software supporting programs agree with the measurements of 1994Le28 and 1994Le37 where the fine structure of LX-radiation was measured in decays of ^{239}Pu and ^{240}Pu. Other measurements of U LX-rays can be found in 1983Ah02, 1984Bo41, 1992Ba08 and 1995Jo23.

The U KX-ray energies have been taken from 1999Schönfeld where the calculated values based on X-ray wavelengths from 1967Be65 (Bearden). In Table 5 the adopted values of U KX-ray energies are compared with experimental values.

The relative KX-ray emission probabilities were taken from 1999Schönfeld.

Table 5. Experimental and recommended (calculated) values of U KX-ray energies (keV)

	1976GuZN	1982Ba56	1983Ah02	Adopted
$K\alpha_2$	94.655 (5)	94.656 (2)	94.67 (2)	94.666
$K\alpha_1$	98.442 (5)	98.435 (2)	98.45 (2)	98.440
$K\beta_3$	110.42	110.416 (3)	110.42 (3)	110.421
$K\beta_1$	111.30	111.300 (2)	111.31 (2)	111.298
$K\beta_5$	-	111.868 (5) - $K\beta_5''$ 112/043 (5) - $K\beta_5'$	112.01 (5)	111.964
$K\beta_{2,4}$	114.54	-	114.50 (3)	114.46
$KO_{2,3}$	115.40	-	115.40 (5)	115.377

3.3. Auger Electrons

The energies of Auger electrons are from the SAISINUC software supporting programs.

The ratios P(KLX)/P(KLL), P(KXY)/P(KLL) are taken from 1996Sc06.

4. ALPHA EMISSIONS

The energy of alpha particles corresponding to the alpha transition to a ground state of ^{236}U, $E(\alpha_{0,0})$, has been adopted from the absolute measurement of 1972Go33 taking into account the correction of – 0.17 keV recommended by A.Rytz in 1991Ry01.

The energies of all other alpha particles have been deduced from $Q(\alpha)$, $E(\alpha_{0,0})$ and the level energies taking into account the ^{236}U recoil energies.

In Table 6 the deduced (recommended) values of α-particle energies are compared with the experimental results.

Table 6. Experimental and recommended α-particle energies in decay of ^{240}Pu, keV

	Measured [a]						Recommended
	1956 Ko67	1956 Go43	1952As28 1957As83	1962 Le11	1972 Go33	1977 Ba69	
$\alpha_{0,0}$	5166	5165	5168 (4)	5167.7 (7)	5168.13 (15) [b]	5168.13 (15) [b]	5168.13 (15) [b]
$\alpha_{0,1}$	5122	5121	5123 (5)	5123.3 (7)	5123.26 (23)	5123.45 (25)	5123.6 (2)
$\alpha_{0,2}$	5021 (2)	5020	5019			5021.3 (5)	5021.1 (2)
$\alpha_{0,3}$	4858 (5)	4856				4863.4 (5)	4863.5 (2)

[a] Original values have been adjusted taking into account changes in calibration energies as suggested in 1991Ry01.

[b] Absolute measurement; the value was adopted as recommended in 1991Ry01 and used in 2003Au03 for obtaining $Q(\alpha)$.

It should be noted that Sibbens and Pommé (2004Si03) measured (using a 50 mm^2 high-resolution planar silicon detector) the energies of ^{240}Pu alpha particles relatively to reference peaks of ^{238}Pu and ^{239}Pu for a ^{238,239,240}Pu mixture. They obtained $E(\alpha_{0,0})$ = 5168.54 (14) keV and $E(\alpha_{0,1})$ = 5124.10 (15) keV discrepant with other published data.

5. ELECTRON EMISSIONS

The energies of the conversion electrons have been obtained from the gamma transition energies and the atomic-electron binding energies.

The emission probabilities of conversion electrons have been deduced from the evaluated P(γ) and ICC values. The experimental spectrum of the conversion electrons in decay of ^{240}Pu is given in 1958Sa21.

The absolute emission probabilities of K Auger electrons have been calculated using the EMISSION computer program (2000Schönfeld).

The total absolute emission probability of L Auger electrons has been deduced using the adopted total absolute emission probability of U LX–rays and fluorescence yield ϖ_L = 0.500 (19).

6. PHOTON EMISSIONS

6.1. X-Ray Emissions

The absolute emission probabilities of U LX–rays have been obtained as weighted averages of measurement results from 1994Le28 and 1994Le37. The uncertainties are the smallest quoted uncertainties.

The total absolute emission probability of U LX–rays P(XL) = 10.34 (15) %, adopted from measurements of 1994Le28, 1994Le37, agrees well with the value of P(XL) = 10.14 (23) %, calculated with using the EMISSION computer program (2000Schönfeld). The measurement result of 1970Swinth (11.5 (3) %) disagrees with the adopted and calculated values.

The absolute KX–ray emission probabilities have been calculated using the EMISSION computer program (2000Schönfeld).

6.2. Gamma-Ray Emissions

The energies of gamma-rays have been adopted from 2006Br20 based on the available experimental data from ^{240}Pu α-decay (Table 7) and data from decay of ^{236}Pa and ^{236}Np.

Table 7. Measured in ^{240}Pu α-decay [a] and recommended values of gamma-ray energies (keV)

	1969Le05	1971GuZY	1972Sc01	1974HeYW	1975OtZX	1976GuZN	1981He16	Recommended
$\gamma_{1,0}$		45.235 (20)	45.242 (6)			45.232 (5)	45.244 (3)	45.2440 (20)
$\gamma_{2,1}$		104.233 (10)	104.233 (5)	104.15 (2)		104.244 (5)	104.234 (6)	104.233 (5)
$\gamma_{3,2}$		160.35 (50)	160.310 (8)	160.27 (2)	160.312 (10)	160.280 (15)	160.308 (3)	160.308 (3)
$\gamma_{4,3}$			212.4 (1)		212.48 (5)			212.46 (5)
$\gamma_{5,2}$	538.05 (30)				538.09 (15)			538.10 (10)
$\gamma_{5,1}$	642.43 (10)			642.48 (15)	642.33 (10)	642.48		642.34 (5)
$\gamma_{5,0}$	687.77 (15)			688.01 (15)	687.57 (10)	687.7		687.56 (10)
$\gamma_{7,1}$	873.91 (20)				873.92 (15)			874.0 (2)

[a]. For other much more inaccurate measurements results, see in 1958Sa21, 1959Tr37 and 1972CiZS.

The experimental and recommended gamma-ray emission probabilities for γ-rays with energy less than 200 keV are given in Table 8. The recommended P(γ) values have been obtained by averaging several experimental results (except for P($\gamma_{1,0}$) that calculated from intensity balance).

Table 8. Experimental and recommended emission probabilities of gamma-rays in ^{240}Pu decay with energy less than 200 keV (per 10^4 α-decays)

	Energy (keV)	1971 GuZY	1972 Sc01	1975 OtZX	1976 GuZN	1976 Um01	1981 He16	1981 Morel	1994 Ba91	Recom-mended
$\gamma_{1,0}$	45.24	4.50 (10) [a]	4.50 [b]		4.53 (9) [d]	4.61 (14) [e]	4.35 (9)			4.62 (9) [f]
$\gamma_{2,1}$	104.23	0.700 (14) [a]	0.91 (5) [c]	0.70 [b]	0.698 (14) [d]		0.718 (7)			0.714 (7) [g]
$\gamma_{3,2}$	160.31	0.0420 (8) [a]	0.049 (12) [c]	0.0408 (10)	0.0402 (8) [d]		0.0402 (4)	0.0402 (7)	0.04065 (17)	0.04045 (22) [h]

[a] Omitted from averaging as the results of 1971GuZY were superseded in 1976GuZN.

[b] Omitted from averaging as an uncertainty is not quoted.

[c] Omitted on statistical considerations (using Chauvenet's criterion).

[d] The uncertainty quoted in 1976GuZN was re-estimated in 1986LoZT to include a 2 % detector efficiency uncertainty.

[e] The uncertainty quoted in 1976Um01 was re-estimated in 1986LoZT to include a 2 % detector efficiency uncertainty and 1 % from the sample isotopic composition.

[f] Deduced from intensity balance at level 45,24 keV using $P(\alpha_{0,1})$ = 27,16 (19) % and total ICC $\alpha_T(\gamma_{1,0})$ = 589 (12). The recommended value agrees with the measurement of 1976Um01and differs from the measurement result of 1981He16.

[g] Weighted average of 1976GuZN and 1981He16; the uncertainty is the smallest quoted uncertainty.

[h] LWEIGHT computer program identified an outlier (1972Sc01). With the five remained experimental values for processing the program increased the uncertainty of 1994Ba91 to 0.00030 and recommended a weighted average; the uncertainty is internal.

The emission probabilities of $\gamma_{4,3}$(212 keV) and $\gamma_{5,2}$(538 keV) have been adopted from absolute measurements of 1975OtZX. The emission probabilities of $\gamma_{5,1}$(642 keV) and $\gamma_{5,0}$(687 keV) have been obtained by averaging experimental data (Table 9).

Table 9. Experimental and recommended emission probabilities of gamma-rays de-exciting the ^{236}U level with energy of 687.6 keV in ^{240}Pu decay (per 10^8 α-decays)

	Energy, keV	1969Le05	1971GuZY	1975OtZX	1975Dr05	1976GuZN	Recommended
$\gamma_{5,2}$	538.1	≈ 0.23 [a]		0.147 (12)			0.147 (12)
$\gamma_{5,1}$	642.4	14.5 [a]	14.5 (5) [b]	12.6 (4)	13 (1)	12.45 (30)	12.6 (3) [c]
$\gamma_{5,0}$	687.6	3.77 (11)	3.70 (15) [b]	3.30 (13)		3.55 (9)	3.56 (9) [c]

[a] Omitted from averaging as an uncertainty is not quoted.

[b] Omitted from averaging as the results of 1971GuZY were superseded in 1976GuZN.

[c] Weighted average of 3 experimental values; the uncertainty is the smallest quoted uncertainty.

The emission probability of $\gamma_{7,1}$ (874 keV) was obtained as a weighted average of measurement results from 1969Le05 and 1975OtZX.

The weak gamma-rays with energy more than 900 keV were reported in 1969Le05 and 1976GuZN. They are expected from the decay scheme but their emission probabilities ($<10^{-7}$ per 100 decays) were determined with a great inaccuracy.

7. CONSISTENCY OF RECOMMENDED DATA

The most accurate Q value, Q(M), is taken from the atomic mass adjustment table of Audi et al. (2003Au03). Comparison of Q(eff)(deduced as the sum of average energies per disintegration ($\sum E_i \times P_i$) for all emissions accompanying ^{240}Pu α- decay) with the tabulated decay energy Q(M) allows to check a consistency of the recommended decay-scheme parameters obtained in this evaluation.

Here E_i and P_i are the evaluated energies and emission probabilities of the i-th alpha particle, beta particle, gamma-ray, X-ray, etc. Consistency (percentage deviation) is determined by {[Q(M) - Q(eff))] / Q(M)} × 100. "Percentage deviations above 5 % would be regarded as high and imply a poorly defined decay scheme; a value of less than 5 % indicates the construction of a reasonably consistent decay scheme” (quoted from the article by A. L. Nichols in Appl. Rad. Isotopes 55(2001) 23-70).

For the above ^{240}Pu decay data evaluation we have Q(M) = 5255.75 (14) keV and Q(eff) = 5255 (9) keV. Thereafter, the percentage deviation is (0.00 ± 0.17) %, i.e. consistency is superior.

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^{241}Pu – Comments on evaluation of decay data
by V.P.Chechev and N.K. Kuzmenko

This evaluation was completed in November 2005 and corrected in September 2006. The literature available by September 2006 was included.

1. Decay Scheme

The decay scheme is based on the evaluation of 2006Ba41 (see also the evaluations of 1995Ak01 and 1978El02). It can be considered as basically completed though some very weak gamma transitions were not observed in ^{241}Pu alpha decay.

It should be noted there is an ambiguity in the placement of 121,2 keV γ–transition in ^{237}U level scheme due to doublet (7/2+, 11/2+) near 204 keV. Following 2006Ba41 we show the above γ–transition in Pu-241 α-decay as going from the level 7/2+ while Fotiades *et al.* (2004Fo01) observed this transition in (n,2n)-reaction as going from the level 11/2+.

The upper limit of SF decay is from 1985Dr09.

2. Nuclear Data

Q(α) value is from 2003Au03.

The evaluated ^{241}Pu half-life is based on the experimental data given in Table 1. A detailed review of half-life measurements up to 1985 can be found in 1987Ag03. References to earlier measurements are listed in 1978El02. Discrepancies in the measurements were examined by 1986Ha06 and 1987Ba84 in terms of chemical dependency of low-energy β^- decay. In 1986Ha06 a conclusion is drawn that chemical variations (~ 0,3 %) cannot be accountable completely for half-life discrepancies (≥ 1 %).

Table 1. Experimental values of the ^{241}Pu half-life (in years)

Reference [a]	Author(s)	Measurement method	Stated value	Revised value	Comments
1953Ma19	MacKenzie *et al.*	Ingrowth of ^{241}Am by α counting	13,0 (2)	14,1 (2)	Re-estimated for the ^{241}Am half-life of 432,6 (6) a
1956Ro26	Rose and Milstead	Ingrowth of ^{241}Am by 60-keV γ counting	12,77 (28)	13,87 (30)	Re-estimated for the ^{241}Am half-life of 432,6 (6) a. OMITTED: outlier
1960Br15	Brown *et al.*	Ingrowth of ^{241}Am by α counting	13,24 (24)	14,12 (26)	Re-estimated for the ^{241}Am half-life of 432,6 (6) a
1961Sm03	Smith	Ingrowth of ^{241}Am α-emission	13,0 (3)	14,1 (3) 13,3 (3)	Re-estimated for the ^{241}Am half-life of 432,6 (6) a
1966French	French *et al.*	Change in ^{241}Pu/Pu ratio by MS	13,59 (46)		Quoted in 1987Ag03 OMITTED: outlier
1966Stepan	Stepan and Nisle	Change in ^{241}Pu reactivity with time	13,63 (36)		OMITTED: updated in 1970Ni02
1967Shields	Shields	Change in ^{241}Pu/Pu ratio in a Pu isotopic standard in 2 years by MS	14,4 (2)		Quoted in 1967Oe01. Stated uncertainty at 0,95 C.L. OMITTED: updated in 1970Sh18

1968Ca19	Cabell	Change in ^{241}Pu/^{240,242}Pu ratios in 4,5 years by MS	14,98 (33)		OMITTED: updated in 1971Ca15, outlier
1970Ni02	Nisle and Stepan	Change in ^{241}Pu reactivity with time (in 2,5 yr)	14,63 (27)		
1970Sh18	Shields	Change in ^{241}Pu/Pu ratio in a Pu isotopic standard in 4 years by MS	14,6 (4)	14,6 (2)	Stated uncertainty at 0,95 C.L. For statistical analysis it has been multiplied by 0,5
1971Ca15	Cabel and Wilkins	Change in ^{241}Pu/^{240,242}Pu ratios in 6,65 years by MS	15,16 (19)		OMITTED: outlier
1972 Whitehead	Whitehead *et al.*	Ingrowth of ^{241}Am by 60-keV γ counting	14,91 (15)	14,96 (15)	Re-estimated for the ^{241}Am half-life of 432,6 (6) a OMITTED: updated in 1977Whitehead, outlier
1973JoYT	Jordan	Calorimetric determination of power decay	14,355 (7)		Quoted in 1974StYG
1973Ze02	Zeigler and Ferris	Change in ^{241}Pu/^{240}Pu ratio by MS	14,89 (11)		OMITTED: outlier
1975WiYM	Wilkins	Change in ^{241}Pu/^{240,242}Pu ratio by MS	15,02 (10)		OMITTED: outlier
1976McZB	McKean and Crouch	Change in ^{241}Pu/^{240,242}Pu ratio by MS	14,35 (6)		
1977Crouch	Crouch and McKean	Change in ^{241}Pu/^{240,242}Pu ratio by MS	14,41 (12)		Average of measurement results from 1976-1977 series of experiments
1977 Whitehead	Whitehead	Ingrowth of ^{241}Am 60-keV γ ray	14,56 (15)		
1978 Vaninbroukx	Vaninbroukx	Ingrowth of ^{241}Am by α and 60-keV γ ray counting	14,60 (10)		
1978 Vaninbroukx	Vaninbroukx	Change in ^{241}Pu/^{240}Pu ratio by MS	14,30 (14)		
1979Garner	Garner and Machlan	Change in ^{241}Pu/^{240,242}Pu ratio by MS	14,38 (7)		
1980Ag02	Aggarwal and Jane	Ingrowth of ^{241}Am by α spectrometry	14,42 (9)		80 α-spectrometric measurements in 457 days
1980Ma45	Marsch *et al.*	Change in ^{241}Pu/^{242}Pu ratio in 3,6 yr by MS	14,38 (6)	14,38 (3)	Stated uncertainty at 0,95 C.L. For statistical analysis it has been multiplied by 0,5
1981Ag01	Aggarwal *et al.*	Ingrowth of ^{241}Am by IDAS	14,52 (8)		
1981Ag07	Aggarwal *et al.*	Ingrowth of ^{241}Am by α spectrometry and APS	14,44 (6)		Average of the measurement results from two independent series of experiments
1982Ag01	Aggarwal *et al.*	Ingrowth of ^{241}Am by IDMS	14,32 (11)	14,32 (6)	Revised uncertainty, see 1989Ho24

1982Hiyama	Hiyama *et al.*	Change in ^{241}Pu/Pu ratio by MS	14,29 (15)		Quoted in 1989Ho24
1983DeZX	De Bievre *et al.*	Change in ^{241}Pu/^{240}Pu ratio in 6 years by MS	14,33 (2)		OMITTED: superseded in 1997DeZY
1985Ag02	Aggarwal *et al.*	Changes in ^{241}Pu/^{240}Pu, ^{241}Pu/^{239}Pu, ^{241}Pu/^{242}Pu ratios in 5 years by MS	14,38 (2)		In 1985Ag02 it is noted that values from 1980Ag02, 1981Ag01, 1981Ag07, 1982Ag01 were obtained in independent sets of experiments
1986Ti04	Timofeev *et al.*	Ingrowth of ^{241}Am by IDMS	14,57 (10)	14,57 (5)	Stated uncertainty at 0,95 C.L. For statistical analysis it has been multiplied by 0,5
1989Pa21	Parker *et al.*	Change in ^{241}Pu/^{239}Pu ratio by high resolution γ-spectrometry	14,355 (40)		156 sets of normalized spectral full energy peak-area ratios from 13 plutonium samples during 10 years
1997DeZY	De Bievre and Verbruggen	Change in ^{241}Pu/^{240}Pu ratio by precision MS	14,290 (6)	14,290 (3)	Stated uncertainty at 0,95 C.L. For statistical analysis it has been multiplied by 0,5

MS=Mass Spectrometry, IDMS=Isotope Dilution Mass Spectrometry, IDAS=Isotope Dilution Alpha Spectrometry

[a] In 1978El02 two more experimental values of are quoted from the private communications of 1977RGZZ and 1978RGZZ. These values are intermediate results of experiments and not discussed later on including the review of 1987Ag03.

After omitting the five superseded values from 1966Stepan, 1967Shields, 1968Ca19, 1972Whitehead and 1983DeZX the data set for statistical processing includes the 24 values. The LWEIGHT computer program using the LRSW analysis has identified the four outliers of 1971Ca15, 1975WiYM, 1973Ze02 and 1956Ro26 and increased the uncertainty of 1997DeZY by 2,04 times. The weighted average of the remaining twenty three values is 14,327, with an internal uncertainty of 0,037, a reduced χ^2 of 5,34, and an external uncertainty of 0,010. The unweighted average is 14,371 (34). The LWEIGHT program has chosen the weighted average and expanded the final uncertainty to 0,037 so range includes the most precise value of 14,290.

The adopted value of the ^{241}Pu half-life is 14,33 (4) years, or 5234 (15) days.

Possible chemical effects do not exceed or about the stated relative uncertainty of the half-life.

2.1. Beta Transition

^{241}Pu decays by β^- emission to the ground state of ^{241}Pu (Table 2).

Table 2. ^{241}Am level populated in the ^{241}Pu β^--decay

Level	Energy, (keV)	Spin and parity	Half-life	Probability (%)
0	20,8 (2)	$5/2^-$	432,6 (6) a	99,997 56 (2)

The experimental and evaluated values of the β^- transition energy are given in Table 3.

The value $Q^- = 20{,}78\ (20)$ keV from 1999YaZX was superseded by the same group in 1999Dr13 and 2000Dr02. Audi *et al.* (2003Au03) give $Q^- = 20{,}78\ (13)$ keV taking into account the value from 1999YaZX (see also 2005Ma88).

Table 3. Experimental values of the ^{241}Pu β^- transition energy (keV)

Level	1952Fr25	1956Sh31	1999Dr13 2000Dr02	Evaluated
0	20,5 (12)	20,8 (2)	20,7 (3)	20,8 (2)

The probability of the β^--transition was deduced from the evaluated α branching (Table 4).

Table 4. Experimental and evaluated values of α branching (α/β^-), per decay, in the ^{241}Pu decay

1961Sm03	1968Ah01	1976GuZN	1977VaYR	Evaluated
$2,44\ (10)\cdot 10^{-5}$	$2,45\ (8)\cdot 10^{-5}$	$2,46\ (1)\cdot 10^{-5}$	$2,42\ (2)\cdot 10^{-5}$	$2,44\ (2)\cdot 10^{-5}$

2.2. Alpha Transitions

The energies of the alpha transitions have been deduced from Q_α value and the level energies given in Table 5. The level energies were calculated from the gamma -ray energies except for the levels “8”,”9” and “10” the energies of which were taken from 1996FiZX.

Table 5. ^{237}U levels populated in the ^{241}Pu α decay

Level number	Energy, (keV)	Spin and parity	Half-life	Experimental probability of α transition (%) 1965Ba26	Experimental probability of α transition (%) 1968Ah01	Adopted probability of α transition (%)
0	0,0	$1/2^+$	6,752 (2) d	$8,6\cdot 10^{-6}$		$8,6\ (10)\cdot 10^{-6}$
1	11,39 (2)	$3/2^+$		$2,5\cdot 10^{-5}$		$2,5\ (2)\cdot 10^{-5}$
2	56,30 (12)	$5/2^+$		$0,88\cdot 10^{-5}$	$1,00\ (12)\cdot 10^{-5}$	$1,00\ (12)\cdot 10^{-5}$
3	82,97 (13)	$7/2^+$		$2,73\cdot 10^{-5}$	$3,2\ (3)\cdot 10^{-5}$	$3,2\ (3)\cdot 10^{-5}$
4	159,96 (2)	$5/2^+$	3,1 (1) ns	$2,04\cdot 10^{-3}$	$2,03\ (4)\cdot 10^{-3}$	$2,03\ (4)\cdot 10^{-3}$
5	204,19 (14)	$7/2^+$		$3,00\cdot 10^{-4}$	$2,95\ (8)\cdot 10^{-4}$	$2,95\ (8)\cdot 10^{-4}$
6	260,95 (17)	$9/2^+$	-	$2,88\cdot 10^{-5}$		$2,9\ (3)\cdot 10^{-5}$
7	274,0 (10)	$(7/2)^-$	155 (6) ns		$0,5\ (2)\cdot 10^{-5}$	$0,5\ (2)\cdot 10^{-5}$
8	316 (5)	$(9/2)^-$	-		$\approx 1,7\cdot 10^{-6}$	$\approx 1,7\cdot 10^{-6}$
9	327 (3)	$11/2^+$	-	$\approx 7\cdot 10^{-7}$		$\approx 7\cdot 10^{-7}$
10	367 (3)	$(11/2^-)$			$\approx 7\cdot 10^{-7}$	$\approx 7\cdot 10^{-7}$

The absolute alpha transition probabilities, $P(\alpha_i)$, were calculated using the value of $2,44\ (2)\cdot 10^{-5}$ for the ^{241}Pu alpha decay branching. The uncertainties of $P(\alpha_{0,0})$ and $P(\alpha_{0,1})$ have been estimated using the relative uncertainty of the sum of $P(\alpha_{0,0})$ and $P(\alpha_{0,1})$ (equal to 1/15) from 1968Ah01.

The probabilities of α-transitions (per 100 α decays) are from the measurements of 1965Ba26 and 1968Ah01. Other measurements: 1976BaZZ. The values of hindrance factors have been calculated using ALPHAD code and $r_0 = 1,5156\ (9)$ from 1998Ak04.

2.3. Gamma-ray Transitions and Internal Conversion Coefficients

The evaluated energies of gamma-ray transitions are virtually the same as the photon energies because nuclear recoil is negligible.

The gamma-ray transition probabilities, $P_{\gamma+ce}$, were deduced from the gamma-ray emission probabilities and the total internal conversion coefficients (ICC's) interpolated from the BrIcc package. The relative uncertainties of α_K, α_L, α_M, α_T for pure gamma ray multipolarities have been taken as 2 %.

$P_{\gamma+ce}$ ($\gamma_{1,0}$ 11,39-keV), $P_{\gamma+ce}$ ($\gamma_{3,2}$ 26,6-keV), $P_{\gamma+ce}$ ($\gamma_{5,4}$ 44,18-keV), $P_{\gamma+ce}$ ($\gamma_{2,1}$ 44,86-keV) and $P_{\gamma+ce}$ ($\gamma_{6,5}$ 56,76-keV) were derived from the intensity balances using the adopted probabilities of α-transitions to the corresponding levels. The E2/M1 mixing ratios for $\gamma_{5,4}$ (44,18-keV), $\gamma_{2,1}$ (44,86-keV) and $\gamma_{6,5}$ (56,76-keV) have been deduced from the calculated total conversion coefficients. The gamma transition multipolarities and the E2/M1 mixing ratios for the remaining gamma transitions have been adopted from the analysis of the ^{237}U level scheme in 1995Ak01.

The transition $\gamma_{6,4}$ (100,94 keV) was not observed experimentally; it is obscured by U KX-rays. This transition is given in 1995Ak01.

3. Atomic Data

3.1. Fluorescence yields

The fluorescence yield data are from 1996Sc06 (Schönfeld and Janßen).

3.2. X Radiations

The relative KX-ray emission probabilities are from 1999ScZX.

3.3. Auger Electrons

The ratios P(KLX)/P(KLL), P(KXY)/P(KLL) are from 1996Sc06.

4. Electron Emissions

The energies of the conversion electrons have been calculated from the gamma transition energies and the electron binding energies.

The emission probabilities of the conversion electrons have been calculated using the evaluated P_γ and ICC values.

The total absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program.

β^- average energy was adopted from the measurement of 1968Oe01. The calculated value is discrepant: 5,23(5) keV.

5. Alpha Emissions

In Table 6 the experimental and adopted energies of α particles (in keV) are given. The original values of 1965Ba26, 1968Ba25 were increased by 0,4 keV and the values of 1968Ah01 by 0,6 keV because of changes in calibration energies, as recommended by Rytz in 1991Ry01. Other measurements: 1953As40, 1964Dz03, 1976BaZZ, 1984Gl03.

The adopted energies of α particles have been obtained from Q_α value and the level energies given in Table 5 taking into account the relevant recoil energies.

Table 6. α - particle energies in the ^{241}Pu decay (keV)

	1965Ba26 1968Ba25	1968Ah01	Adopted (calculated from Q_α)
$\alpha_{0,10}$		4693 (6)	4694 (3)
$\alpha_{0,9}$	4732		4733 (3)
$\alpha_{0,8}$		4743 (5)	4744 (5)
$\alpha_{0,7}$		4784 (5)	4785,1 (11)
$\alpha_{0,6}$	4798	4798 (3)	4798,0 (5)
$\alpha_{0,5}$	4853,3 (12)	4853 (3)	4853,8 (5)
$\alpha_{0,4}$	4896,3 (12)	4896 (3)	4897,3 (5)
$\alpha_{0,3}$	4971	4973 (3)	4973,1 (5)
$\alpha_{0,2}$	4998	5000 (4)	4999,2 (5)
$\alpha_{0,1}$	5041	5043 (3)	5043,4 (5)
$\alpha_{0,0}$	5051	5056 (5)	5054,6 (5)

6. Photon Emissions

6.1. X-Ray Emissions

The absolute emission probabilities of U KX and LX -rays have been calculated using the EMISSION code.

		Energy, (keV)	Number of photons per 100 disintegrations
X_K	$K\alpha_2$ (U)	94,666	$3,00\ (7)\cdot 10^{-4}$
	$K\alpha_1$ (U)	98,440	$4,79\ (10)\cdot 10^{-4}$
	$K\beta_3$ (U)	110,421	}
	$K\beta_1$ (U)	111,298	} $1,79\ (5)\cdot 10^{-4}$
	$K\beta_5$ (U)	111,964	}
	$K\beta_{2,4}$ (U)	114,46	}$0,59\ (2)\cdot 10^{-4}$
	$KO_{2,3}$ (U)	115,377	}
X_L	Ll (U)	11,619	$0,336\ (12)\cdot 10^{-4}$
	$L\alpha_2$ (U)	13,438	$0,556\ (19)\cdot 10^{-4}$
	$L\alpha_1$ (U)	13,615	$4,87\ (17)\cdot 10^{-4}$
	$L\eta$ (U)	15,399	$0,0444\ (13)\cdot 10^{-4}$
	$L\beta$ (U)	15,727 – 18,206	$4,77\ (8)\cdot 10^{-4}$
	$L\gamma$ (U)	19,507 – 20,714	$1,09\ (2)\cdot 10^{-4}$

6.2. Gamma-Ray Emissions

In Table 7 the experimental and adopted energies of gamma -rays are given (see also the evaluation of 1988ChZL). Other measurements: 1952Fr25, 1965Ba35, 1976Um01, 1979Ce04, 1993Dr05.

The energies of $\gamma_{1,0}$ (11,39 keV), $\gamma_{3,2}$ (26,67 keV) and $\gamma_{6,4}$ (100,94 keV) have been calculated from the level scheme: $E\gamma_{1,0}$ (11,39 keV) = $E\gamma_{4,0}$ - $E\gamma_{4,1}$; $E\gamma_{3,2}$ (26,67 keV) = $E\gamma_{4,2}$ - $E\gamma_{4,3}$; $E\gamma_{6,4}$ (100,94 keV) = $E\gamma_{5,4}$ + $E\gamma_{6,5}$.

Table 7. Experimental and evaluated gamma-ray energies in the ^{241}Pu decay (keV)

	1968Ah01	1971GuZN 1976GuZN	1972Cline	Adopted
$\gamma_{1,0}$		11,39		11,39 (2)
$\gamma_{3,2}$				26,67 (4)
$\gamma_{5,4}$		44,19 (3)	44,175 (30)	44,18 (3)
$\gamma_{2,1}$	44,7 (3)	44,86 (10)		44,86 (10)
$\gamma_{2,0}$	56,6 (2)	56,30 (12)	56,412 (30)	56,30 (12)
$\gamma_{6,5}$		56,76 (10)		56,76 (10)
$\gamma_{3,1}$		71,60 (7)	71,672 (40)	71,64 (9)
$\gamma_{4,3}$	76,9 (2)	76,96 (10)	77,014 (40)	77,01 (4)
$\gamma_{6,4}$				100,94 (11)
$\gamma_{4,2}$	103,5 (2)	103,680 (5)	103,540 (40)	103,680 (5)
$\gamma_{7,4}$	114,0 (10)		115,342 (40)	114,0 (10)
$\gamma_{5,3}$	120,7 (5)	121,2 (10)	121,220 (30)	121,22 (5)
$\gamma_{4,1}$	148,5 (2)	148,567 (10)	148,560 (20)	148,567 (10)
$\gamma_{4,0}$	160,0 (2)	160,00 (4)	159,960 (20)	159,96 (2)

In Table 8 the experimental and evaluated absolute gamma-ray emission probabilities are given. The evaluated values have been obtained using the LWEIGHT computer program. The uncertainty assigned in this evaluation to the recommended value is always greater than or equal to the smallest uncertainty in any of the experimental values used in the statistical processing.

Table 8. Experimental and evaluated absolute emission probabilities of gamma rays in the ^{241}Pu decay per 10^6 disintegrations

Eγ (keV)	1968Ah01	1976GuZN	1976Um01	1978DiZU	1985He02	1985Wi04	1994Ba91	Evaluated
44,18		0,042 (2)						0,042 (2)
44,86		0,0084 (10)						0,0084 (10)
56,30		0,025 (2)						0,025 (2)
56,76		0,010 (1)						0,010 (1)
71,64		0,029 (2)						0,029 (2)
77,0	0,18 (2)	0,220 (8)			0,211 (5)	0,203 (4)		0,207 (4)
100,94		0,00072						0,00072
103,68	1,10 (12)	1,03 (3)		1,04 (5)	1,02 (3)	1,032 (12)		1,03 (2)
114,0		0,062 (12)						0,062 (12)
121,22		0,0070 (7)						0,0070 (7)
148,6	2,20 (22)	1,86 (3)	1,91 (4)	1,85 (7)	1,863 (17)	1,855 (16)	1,863 (8)	1,863 (8)
159,9	0,078 (8)	0,0671 (15)			0,0654 (19)	0,0651 (14)	0,06321 (40)	0,0645 (9)

The absolute emission probability of $\gamma_{6,4}$ (100,94 keV) has been deduced from the ratio of P_γ ($\gamma_{6,4}$; 100,94 keV) /P_γ ($\gamma_{6,5}$; 56,76 keV) = 5,87 which has been calculated in 1995Ak01 by using the Alaga rule.

The absolute emission probabilities of the remaining gamma rays have been adopted from 1976GuZN.

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^{241}Am - Comments on evaluation of decay data
by V. P. Chechev and N. K. Kuzmenko

This evaluation was done originally in October 2002, revised in January 2004 and then updated in September 2009 with a literature cut-off by the same date.

1 Decay Scheme

The scheme of ^{241}Am decay is rather complex. It contains more than forty excited levels in ^{237}Np populated by alpha- and gamma-ray transitions (2006Ba41, 1995Ak01). The intense population takes place only for lower levels with the energy less than 230 keV (8 excited levels and ground state in ^{237}Np) and in this part the decay scheme is mainly defined. Nevertheless here there are some gamma-ray transitions scarcely studied and expected but not certainly observed such as 27-keV, 54-keV, 97-keV that leads to not so good intensity balance for some levels. Additional difficulties are due to anomalous internal conversion of the 26-keV and 59-keV gamma ray transitions because of “penetration effects” (1996Jo28, 2008Go10).

For high levels the decay scheme has not been completed yet since many observed gamma-ray transitions were not placed and some expected gamma transitions were not observed. The population of these levels does not exceed 0,1 %.

The unplaced gamma rays carry ≤ 0,6 % of the total intensity of all the gamma rays placed in the decay scheme.

2 Nuclear Data

Q value is from Audi et al. (2003Au03).

The recommended ^{241}Am half-life is based on the experimental results given in Table 1.

Table 1. Experimental values of ^{241}Am half-life (in years).

Reference	Author(s)	Original value	Measurement method
1967Oe01	Oetting and Gunn	432,7 (7)	Calorimetry
1968Br22	Brown and Propst	433 (7)	Specific Activity Determination
1968St02	Stone and Hulet	436,6 (30)	Specific Activity Determination
1972Jo07	Jove and Robert	426,3 (21)	Calorimetry
1974StYG	Strohm and Jordan	432,5 (7)	Calorimetry
1974StYZ		435,0 (7)	Specific Activity Determination
1974Po16	Polyukhov et al.	432,8 (16)	Specific Activity Determination
1975Ra35	Ramthun and Muller	432,0 (2)	Calorimetry

The values before 1967 have been omitted due to their large systematic uncertainties (those values lead to the ^{241}Am half-life of 458 years).

The eight values were used for statistical processing. The uncertainty of 1975Ra35 was increased to 0,38 a to adjust weights according to the LRSW method.

Statistical processing of the final data set with the reduced χ^2 of 3,58 gives the unweighted mean of 432,6 (11) years and the weighted mean of 432,6 with an internal uncertainty of 0,27 and an external uncertainty of 0,51.

The LWEIGHT computer program has used the weighted mean and expanded the uncertainty to 0,6 so range includes the most precise value of 432,0 (1975Ra35). Therefore, the recommended value of ^{241}Am half-life is 432,6 (6) years.

The value of 1,2 (3) 10^{14} years has been adopted for ^{241}Am spontaneous fission half-life as recommended in 2000Ho27.

2.1 α Transitions

The energies of the alpha transitions have been deduced from the Q value and ^{237}Np level energies given in Table 2 from 2006Ba41 where they were deduced from a least-squares fit to gamma ray energies.

Table 2. ^{237}Np levels populated in ^{241}Am α-decay.

Level number	Energy (keV)	Spin and parity	Half-life	Probability of α-transition (×100)
0	0,0	$5/2^{+}$	2,144 (7) 10^{6} yr	0,38 (1)
1	33,19629 (22)	$7/2^{+}$	54 (24) ps	0,23 (1)
2	59,54092 (10)	$5/2^{-}$	67 (2) ns	84,45 (10)
3	75,899 (5)	$9/2^{+}$	~ 56 ps	< 0,04
4	102,959 (3)	$7/2^{-}$	80 (40) ps	13,23 (10)
5	129,99 (3)	$11/2^{+}$		~ 0,01
6	158,497 (11)	$9/2^{-}$		1,66 (3)
7	191,53 (6)	$13/2^{+}$		
8	225,957 (16)	$11/2^{-}$		0,014 (3)
9	267,556 (17)	$3/2^{-}$	5,2 (2) ns	5 10^{-4}
10	281,356 (20)	$1/2^{-}$		
11	305,05 (3)	$13/2^{-}$		0,0022 (3)
12	316,8 (2) ?			
13	324,420 (23)	$(7/2^{-})$		0,0013
14	332,376 (16)	$1/2^{+}$	≤ 1 ns	
15	359,7 (1)	$(5/2^{-})$		6 10^{-4}
16	368,602 (20)	$5/2^{+}$		9 10^{-4}
17	370,928 (23)	$3/2^{+}$		3 10^{-4}
18	395,53 (4)	$15/2^{-}$		7 10^{-4}
19	418,2 (1) ?			
20	434,12 (5)	$(11/2^{-})$		4 10^{-4}
21	444,78 (10) ?			
22	452,545 (22)	$9/2^{+}$		~ 4 10^{-4}
23	459,693 (24)	$7/2^{+}$		~ 4 10^{-4}
24	486,21 (9)	$(9/2^{-})$		1,1 10^{-4}
25	497,01 (5)	$17/2^{-}$		
26	514,19 (4)	$(3/2^{-})$		
27	546,12 (6)	$(5/2^{-})$		1 10^{-4}
28	590,09 (4)	$(7/2^{-})$		
29	592,33 (7)	$13/2^{+}$		
30	597,99 (9)	$11/2^{+}$		
31	646,03 (17)	$(9/2^{-})$		
32	666,19 (10)	$(5/2^{+}, 7/2^{-})$		
33	721,961 (13)	$5/2^{-}$		7 10^{-4}

Level number	Energy (keV)	Spin and parity	Half-life	Probability of α-transition (×100)
34	755,685 (19)	$7/2^-$		8,6 10^{-5}
35	770,57 (5)			
36	799,82 (4)	$9/2^-$		4 (3) 10^{-5}
37	805,77 (12)	($7/2^+$, $9/2^+$)		
38	853,36 (15)	$11/2^-$		
39	861,65 (19)	($5/2^+$, 7/2)		
40	920,88 (20)			
41	946 (2)			
42	962 (3) ?			
43	1014 (3) ?			

The probabilities of the alpha transitions $\alpha_{0,0}$, $\alpha_{0,1}$, $\alpha_{0,2}$, $\alpha_{0,4}$ and $\alpha_{0,6}$ have been obtained by averaging experimental values from the spectrometric measurements carried out for the last twenty five years (Table 3). Earlier measurements for these alpha transitions see in 2006Ba41.

Table 3. Experimental and recommended probabilities (%) of the most intense alpha transitions.

	α-particle energy (keV)	1984Ah06 1993Ahmad	1987Bo25	1994Bl12	1996 Bueno	1996 Sanchez	1998Ya17	Recommended
$\alpha_{0,0}$	5544	0,36 (1)	0,34 (5)	0,36 (5)	0,5 (2)	0,36 (3)	0,394 (9)	0,38 (1)
$\alpha_{0,1}$	5511	0,23 (1)	0,22 (3)	0,22 (6)	-	0,28 (3)	0,224 (7)	0,23 (1)
$\alpha_{0,2}$	5486	84,6 (2) [a]	84,7 (9)	84,69 (28)	84,5 (8)	84,5 (3)	84,30 (7)	84,45 (10)
$\alpha_{0,4}$	5443	13,1 (1) [a]	13,0 (3)	13,08 (24)	12,5 (3)	13,2 (3)	13,40 (8)	13,23 (10)
$\alpha_{0,6}$	5388	1,65 (8)	1,6 (1)	1,66 (6)	1,6 (2)	1,65 (7)	1,67 (2)	1,66 (3)

[a] The $\alpha_{0,2}$ and $\alpha_{0,4}$ probabilities from 1984Ah06 were superseded by the same author in 1993Ahmad. The latter values are given in Table 3.

The probabilities of the alpha transitions $\alpha_{0,3}$, $\alpha_{0,5}$, $\alpha_{0,9}$, $\alpha_{0,13}$, $\alpha_{0,15}$, $\alpha_{0,33}$ have been adopted from the magnetic spectrometer measurements of 1964Ba26. The probabilities of the $\alpha_{0,8}$ and $\alpha_{0,11}$ transitions have been obtained from measurements of 1955Go57, 1964Ba26 and 1965Mi06. The probabilities of the $\alpha_{0,34}$ and $\alpha_{0,36}$ transitions have been deduced from the intensity balance of gamma transitions.

2.2 γ Transitions

The recommended energies of the gamma-ray transitions are virtually the same as the gamma-ray energies because nuclear recoil is negligible for ^{237}Np.

The gamma-ray transition probabilities have been deduced from their gamma-ray emission probabilities and the evaluated total ICC's.

ICC's for the intense E1 anomalously converted gamma-ray transitions $\gamma_{2,1}$ (26,3 keV) and $\gamma_{2,0}$ (59,5 keV) have been obtained from a joint analysis of the gamma ray and L-, M- conversion electron probabilities measured in ^{241}Am α decay and ^{237}U β^-decay (1996Jo28, 2006Ba41). Experimental conversion electron data are given in 1959Sa10, 1964Wo03, 1966Ko06, 1966Le13, 1966Ya05, and 1998Ko61. For discussion of anomalous electric dipole gamma-ray transitions see 1960As02, 1966Ya05, 1967Pa23, 1970Gr36, 1996Jo28, and 2008Go10. In 2008Go10 an assessment of ICCs for a number of such transitions was made. In particular, the total ICCs for gamma-ray transitions $\gamma_{2,1}$ (26,3 keV) and $\gamma_{2,0}$ (59,5 keV) in ^{237}Np have been assessed as 7,9 (8) and 0,99 (9), respectively.

ICC's for other gamma transitions have been interpolated using the BrIcc computer program, version v2.2a, data set BriccFO (2008Ki07). Multipolarities of the gamma-ray transitions and E2/M1 mixing ratios have been adopted from 2006Ba41 based on the measurements of 1959Sa10, 1964Wo03, 1966Ko06, 1966Ya05, 1998Ko61.

The E2 admixture of 16,6 (25) % for M1+E2 gamma-ray transition $\gamma_{4,2}$(43,4-keV) has been obtained by averaging the four measurement results from 1964Wo03 (17,6 (19) %), 1966Ko06 (13 (2) %), 1966Ya05 (11 (4) %), and 1998Ko61 (21,2 (22) %).

3 Atomic Data

The atomic data (fluorescence yields, X-ray energies and relative probabilities, and Auger electrons energies and relative probabilities) were deduced by using the Saisinuc software (2002Be). The fluorescence yield ϖ_M is from 1989Hubbell.

The XL -ray energies are taken from 2001Sc08.

The XK -ray energies are taken from 1999Schönfeld. Below these calculated (adopted) values are compared with the experimental results of 1982Ba56 and 1983Ah02:

	Calculated (1999Schönfeld)	Measured in 1982Ba56	Measured in 1983Ah02
Kα_2	97,069	97,069 (3)	97,08 (2)
Kα_1	101,059	101,057 (3)	101,07 (2)
Kβ_3	113,303	113,308 (4)	113,30 (2)
Kβ_1	114,234	114,244 (3)	114,24 (2)
Kβ_5	114,912	-	114,95 (2)
Kβ_2	117,463		117,51 (3)
Kβ_4	117,876		
KO$_{2,3}$	118,429	-	118,45 (5)

4 α Emissions

The recommended energies of alpha particles have been deduced from the energies of alpha transitions taking info account the recoil energies for ^{237}Np.

The experimental values of the alpha particle energies from spectrometric measurements are given in 1971Gr17, 1968Ba25, 1968Ka09, 1965Mi06, 1964Ba26, 1962Le11, 1957Ro20, 1955Go57 (see also 2006Ba41). Most of them have lesser accuracy in comparison with the recommended values.

5 Electron emissions

The energies of the conversion electrons have been obtained from the gamma-ray transition energies and the atomic electron binding energies.

The emission probabilities of the conversion electrons have been deduced using the evaluated P_γ and ICC values. The total absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program.

6 Photon emissions

6.1 X-ray emissions

The total absolute emission probability of Np MX - rays is the experimental result of 1971Ka48.

The recommended absolute emission probabilities of Np LX - rays have been obtained by averaging of experimental results (per 100 disintegrations) shown in Table 4.

Table 4. Experimental and recommended absolute Np LX-ray emission probabilities (%) [a].

	1971 Ge11	1971 Wa28	1974 Ca16	1976 GuZN	1980 Cohen	1988 Co07	1992 Bl07	1994 Le37	2008 Le07	**Recom-mended**	2001Sc08 (calculated)
Ll	0,81 (7)	0,87 (6)	0,86 (2)	0,806 (40)	0,87 (3)	0,83 (3)	0,837 (10)	0,864 (12)	0,837 (9)	**0,844 (9)** [b]	0,842 (27)
Lα	12,6 (9)	13,5 (12)	13,20 (25)	13,2 (7)	13,2 (3)	12,7 (4)	13,01 (10)	13,03 (13)	13,00 (12)	**13,02 (10)** [b]	13,3 (4)
Lη	} 19,1 (14)	19,1 (14)	19,25 (40)	19,2 (10)	19,78 (36)	0,368 (5)	0,377 (15)	0,369 (12)	0,404 (5)	**0,384 (20)** [c]	0,383 (16)
Lβ						18,3 (6)	18,61 (15)	18,39 (19)	18,65 (13)	**18,58 (13)** [b]	20,0 (6)
Lγ	4,75 (35)	4,75 (35)	4,85 (15)	4,94 (25)	4,96 (20)	4,8 (2)	4,815 (38)	4,74 (8)	4,84 (3)	**4,83 (3)** [b]	5,17 (14)

[a] In addition to given references the value of 19,46 (16) for Lη+Lβ was obtained in 1974Ga40.

[b] The smallest uncertainty of the experimental results.

[c] The LWEIGHT computer program has used the weighted mean of 0,3843 and expanded the uncertainty so range includes the most precise value of 2008Le07.

The experimental results of 1993Lépy (per 100 disintegrations) are quoted in 2001Sc08: Ll - 0,875 (18), Lα - 13,10 (21), Lη - 0,354 (8), Lβ - 18,5 (4), Lγ - 4,84 (8). These results were superseded in 1994Le37 and were not used by the evaluators for statistical processing.

The evaluated total absolute emission probability of LX - rays P(XL) = 37,66 (17) % can be compared with the value of 36,8 (21) % calculated using the EMISSION computer program.

The absolute emission probabilities of Np XK -rays have been calculated using the EMISSION computer program. The recommended value of the total absolute emission probability P(XK) = 0,003 82 (10) % can be compared with measurements of 1976GuZN which give P(XK) = 0,004 01 (10) %.

Below the experimental data of 1976GuZN are compared with the calculated values of absolute emission probability for KX-ray components:

	1976GuZN (measured) [a]	Recommended (calculated)
$K\alpha_2$	0,001 18 (4)	0,001 134 (30)
$K\alpha_1$	0,001 89 (6)	0,001 81 (5)
$K\beta_1'$	7,1 (3) 10^{-4}	6,58 (21) 10^{-4}
$K\beta_2'$	2,29 (15) 10^{-4}	2,26 (8) 10^{-4}

[a] The uncertainties quoted in 1976GuZN have been increased by 2 % to allow for the uncertainty of the detector calibration.

6.2 Gamma-ray emissions

6.2.1 Gamma-ray energies

The gamma ray energies have been taken mainly from 2006Ba41 (see also the evaluation of 1988ChZL). Some gamma ray energies have been deduced directly from the adopted ^{237}Np level energies.

The recommended gamma ray energy values are based on measurements of 1955Da02, 1959Sa10, 1964Wo03, 1966Ko06, 1966Ya05, 1968Je01, 1968Ka09, 1970Ne11, 1976GuZN, 1978Ge06, 1978Ge17, 1978Ov01, 1979Ar11, 1984Ov02, and 1998Ab43.

The energies of gamma rays $\gamma_{2,1}$ (26,3 keV) and $\gamma_{2,0}$ (59,5 keV) have been adopted from 2000He14. The energy of gamma ray $\gamma_{1,0}$ (33,2 keV) has been deduced as the difference of $E\gamma_{2,0}$ - $E\gamma_{2,1}$. The energies of gamma rays $\gamma_{3,1}$ (42,7 keV), $\gamma_{4,2}$ (43,4 keV), and $\gamma_{8,4}$ (123,0 keV) have been taken from 1998Ko61. The gamma ray with energy of 32,183 keV has been adopted from 1976GuZN and was not reported by others.

The energies of gamma rays $\gamma_{27,26}$ (31,9 keV), $\gamma_{17,14}$ (38,5 keV), $\gamma_{14,10}$ (51,0 keV), $\gamma_{5,3}$ (54,1 keV), $\gamma_{13,9}$ (56,9 keV), $\gamma_{7,5}$ (61,6 keV), $\gamma_{14,9}$ (64,8 keV), $\gamma_{36,33}$ (77,9 keV), $\gamma_{11,8}$ (79,0 keV), $\gamma_{15,9}$ (92,4 keV) and $\gamma_{5,1}$ (96,8 keV) have been deduced from the adopted ^{237}Np level energies. These gamma ray transitions were not observed in the ^{241}Am α-decay; they are expected from the decay scheme (see 2006Ba41).

The gamma rays $\gamma_{20,11}$ (129,1 keV), $\gamma_{23,13}$ (135,3 keV), $\gamma_{30,23}$ (138,3 keV) and unplaced in decay scheme gamma rays with energies of 128,05 keV and 136,7 keV have been adopted from 1979Ar11 and were not observed by others.

Many unplaced gamma rays are reported only in 1998Ab43.

6.2.2 Gamma-ray emission probabilities

The recommended absolute emission probabilities (Pγ) of the most intense gamma rays $\gamma_{1,0}$ (26,3 keV), $\gamma_{2,1}$(33,2 keV), $\gamma_{4,2}$ (43,4 keV) and $\gamma_{2,0}$(59,5 keV) have been deduced from the available experimental data (Table 5).

Table 5. Experimental and recommended values of the most intense gamma rays in ^{241}Am α-decay.

Reference	P$\gamma_{1,0}$ (26,3 keV) ×100	P$\gamma_{2,1}$ (33,2 keV) ×100	P$\gamma_{4,2}$ (43,4 keV) ×100	P$\gamma_{2,0}$ (59,5 keV) ×100
1952Be24	2,8 (3)			40,0 (15)
1957Ma17	2,5 (2)		0,073 (7)	35,9 (6)
1964Mc12				34,6 (7)
1965Mi06				38,0 (6)
1969Pe17				35,3 (6)
1971Ge11	2,23 (18)	0,104 (11)	0,057 (18)	
1974Ca16	2,4 (1)			
1975Le09				36,3(4)
1976GuZN	2,45 (5)			
1976Pl05				35,5 (3)
1978Ge06	2,54 (26)	0,106 (11)	0,073 (7)	
1983Ah02		0,125 (8)		
1983De11	2,41 (5)			
1983Hu04				35,82 (17) [d]
1984Ov02		0,12 (1)	0,066 (5)	
1987De22				36,36 (17)
1992Bl07	2,395 (19)	0,1233 (28)	0,0654 (29)	36,03 (25)
1992Ma16				35,6 (2)
2005Iw01	2,06 (3)			35,87 (17)
Recommended	**2,31 (8)** [a]	**0,1215 (28)** [b]	**0,0669 (29)** [c]	**35,92 (17)** [e]

[a] The LWEIGHT computer program has used the weighted mean of 2,31 and expanded the uncertainty so range includes the most precise value of 1992Bl07.

[b] The LWEIGHT computer program has used the weighted mean of 0,12148 and external uncertainty of 0,0028. The smallest value of experimental uncertainties is also 0,0028.

[c] The LWEIGHT computer program has used the weighted mean of 0,0669 and internal uncertainty of 0,0022. The smallest value of experimental uncertainties is 0,0029.

[d] Uncertainty quoted by authors (0,12) has been increased to 0,17 by the evaluators to include possible systematic errors in correction factors to 59,5-keV-peak counting rate.

[e] The LWEIGHT computer program has identified one by one the three outliers of 1952Be24, 1965Mi06 and 1964Mc12 and used the weighted mean of 35,92 (8). The smallest value of experimental uncertainties of 0,17 has been adopted as the uncertainty.

The absolute emission probabilities of gamma rays $\gamma_{3,1}$ (42,7 keV), $\gamma_{6,4}$ (55,6 keV), γ(57,8 keV), $\gamma_{8,6}$ (67,5 keV), and $\gamma_{4,1}$ (69,8 keV) have been adopted from the measurements of 1978Ge06.

The absolute emission probabilities of gamma rays $\gamma_{6,2}$ (99,0 keV), $\gamma_{4,0}$ (103,0 keV), $\gamma_{8,4}$ (123,0 keV), and $\gamma_{6,1}$ (125,3 keV) have been adopted from the measurements of 1976GuZN.

The remaining weak gamma ray emission probabilities ($P\gamma < 10^{-5}$) have been adopted from the evaluations of 2006Ba41 and 1988ChZL, based mainly on the measurements of 1976GuZN and 1978Ge17 with Ge(Li) detectors, and (for gamma rays with energy more than 200 keV) from the measurements of 1998Ab43 with 40 % HPGe detector and intense purified sources. The uncertainties quoted in 1998Ab43 have been increased by 1 % to allow for the uncertainty of the detector calibration.

Other measurements of Pγ are given in 19840v02, 1983Hu04, 1983De11, 1983Ah02, 1979Ce04, 1978Ge06, 1976Pl05, 1975Le09, 1974Ca16, 1974HeYW, 1971Ge11, 1971Cl03, 1967Gu08, 1967Br26, 1966Ko06, 1965Mc12, 1965Be38, 1957Ro20, 1957Ma17, 1956Ho38, 1955Tu13, 1955Ja01, 1955Da02, 1955Ba31, and 1952Be24.

The gamma ray emission probabilities quoted in 1976GuZN and also in 19840v02, 1978Ge06, 1974Ca16, 1971Ge11, 1967Gu08 have been normalized to Pγ (59,54 keV) = 0,3592. The gamma ray emission probabilities from 1971Cl03, 1978Ge17 have been normalized to Pγ (208,00 keV) = $7{,}86\,10^{-6}$.

7 Consistency of recommended data

The most accurate Q value, Q(M), is taken from the atomic mass adjustment table of Audi et al. (2003Au03). Comparison of Q(eff) (deduced as the sum of average energies per disintegration ($\sum E_i \times P_i$) for all emissions accompanying ^{241}Am α- decay) with the tabulated decay energy Q(M) allows to check a consistency of the recommended decay-scheme parameters obtained in this evaluation.

Here E_i and P_i are the evaluated energies and emission probabilities of the i-th alpha particle, gamma ray, X-ray, etc. Consistency (percentage deviation) is determined by $\{[Q(M) - Q(eff))] / Q(M)\} \times 100$. “Percentage deviations above 5 % would be regarded as high and imply a poorly defined decay scheme; a value of less than 5 % indicates the construction of a reasonably consistent decay scheme” (quoted from the article by A.L. Nichols in Appl. Rad. Isotopes 55 (2001) 23-70).

For the above ^{241}Am decay data evaluation we have Q(M) = 5637,82 (12) keV and Q(eff) = 5638 (8) keV, i.e. consistency is better than 0,15 %.

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^{242}Pu - Comments on evaluation of decay data
by V. P. Chechev

This evaluation was done originally in 2004 (2004BeZQ, 2005ChZU) and then updated in June 2009 with a literature cut-off by the same date.

1 Decay Scheme

The decay scheme can be basically considered completed though weak alpha transitions to some highly excited ^{238}U levels (with energy more than 307 keV, see 2002Ch52) are possible but have not been observed yet. They are expected from data on level spins and Q(α) value and cannot appreciably influence intensity balances at the four lower levels well established.

2 Nuclear Data

Q(α) value is from 2003Au03.

The recommended half-life of ^{242}Pu is based on the experimental results given in Table 1. Re-estimated values were used for averaging where necessary.

Table 1. Experimental values of ^{242}Pu half-life (in 10^5 years).

Reference	Author(s)	Original value	Re-estimated value	Measurement method
1956Bu64	Butler et al.	3.73 (5)	3.65 (5) [a]	^{242}Pu/^{238}Pu, mass- and α-spectrometry
1956Bu92	Butler et al.	3.79 (5)		Specific activity, ionization chamber
1956Me37	Metch et al.	3.88 (10)	3.85 (10) [a]	^{242}Pu/^{240}Pu, mass- and α-spectrometry
1969Be06	Bemis et al.	3.869 (16)	3.82 (3) [b]	^{242}Pu/^{239}Pu, mass- and α-spectrometry
1970Du02	Durham and Molson	3.66 (7)	3.67 (7) [a]	^{242}Pu/^{238}Pu, mass- and α-spectrometry
1976Bu23	Bulaynitsa et al.	3.702 (7) [c]		Specific activity, 4πα-X coincidences
1976Os05	Osborne and Flotov	3.763 (9)		Calorimetry
1978MeZL	Meadows	3.736 (25)	3.708 (29) [a]	^{242}Pu/^{239}Pu, mass- and α-spectrometry
1979Ag03	Aggarwal et al.	3.742 (24)		^{242}Pu/^{239}Pu, mass- and α-spectrometry
1979Ag03	Aggarwal et al.	3.766 (25)		^{242}Pu/^{238}Pu, mass- and α-spectrometry

[a] Re-estimated in 1979Ag03 using the values of 87.74 yr for ^{238}Pu half-life and 24110 yr for ^{239}Pu half-life.

[b] Re-estimated in 1976Bu23 as a result of analysis of systematic uncertainties in 1969Be06 and using better values of auxiliary half-lives (see also 1979Ag03).

[c] Quoted uncertainty, corresponding to 95 % confidence level, has been reduced by a factor 2.

The weighted average of the ten values is 3.7304 with the internal uncertainty 0.0051 and external uncertainty 0.0116 and $\chi^2/\nu = 3.16$. The uncertainty of 1976Bulaynitsa was increased to 0.007 24 to adjust weights according to the Limitation of Relative Statistical Weight method.

The LWEIGHT computer program has used the weighted average and expanded the uncertainty to 0.0284 so range includes the most precise value of 3.702 (1976Bu23).

The recommended value of ^{242}Pu half-life is 3.73 (3) 10^5 years.

The recommended spontaneous fission half-life of ^{242}Pu is based on the experimental results given in Table 2.

Table 2. Experimental values of the spontaneous fission ^{242}Pu half-life (in 10^{10}years).

Reference	Author(s)	Original value	Re-estimated value [a]	Measurement method
1956Studier	Studier and Hirsch	6.7 (7)		Quoted by Mech et al.(1956); no details available
1956Me37	Mech et al.	7.06 (19)	6.79 (19)	α/SF; low geometry α-counting and Ar-CH_3 counter for SF
1956Bu92	Butler et al.	6.64 (10)	6.65 (10)	α/SF; ionization chamber
1961Dr04	Druin et al.	6.6 (7)		Gas scintillator; relative to α half-life of ^{238}Pu
1963Ma50	Malkin et al.	7.45 (17)		Gas scintillator; specific activity
1978MeZL	Meadows	6.80 (5)	6.74 (5)	α/SF; relative to half-life of ^{239}Pu
1980Kh05	Khan et al.	7.43		Mica fission track detector
1988SeZY	Selickij et al.	6.86 (26)		Fission fragment detection in 2π geometry

[a] Re-estimated in 2000Ho27.

Omitting the value of 1980Kh05 reported without uncertainty, the weighted average of the seven remaining values is 6.79 with the internal uncertainty 0.032 and external uncertainty 0.090 and $\chi^2/\nu = 2.94$.

The adopted value of the ^{242}Pu spontaneous fission is 6.79 (10) 10^{10} years where the uncertainty is the smallest quoted experimental uncertainty.

2.1 α Transitions

The energies of the alpha transitions were obtained from the Q value and the level energies given in Table 3 from 2002Ch52.

Table 3. ^{238}U levels populated in the ^{242}Pu α-decay.

Level number	Energy, keV	Spin and parity	Half-life	Probability of α-transition (× 100)
0	0,0	0^+	$4.468 (5)\cdot10^9$ yr	76.53 (17)
1	44.915 (13)	2^+	206 (3) ps	23.44 (17)
2	148.39 (3)	4^+		0.030 4 (13)
3	307.19 (8)	6^+		0.000 84 (6)

The probabilities of the transitions of $\alpha_{0,0}$, $\alpha_{0,1}$and $\alpha_{0,2}$ have been obtained by averaging the direct alpha-emission measurement results (the most accurate of them are from 1986Va33) and the values deduced from the gamma-ray transition probability (P(γ+ce)) balances at the corresponding ^{238}U levels. The deduced values are based on the measurements of absolute gamma-ray emission probabilities (P(γ)) from 1986Va33 (see Table 6) and adopted total internal conversion coefficients (ICCs).

Such averaging is possible as in 1986Va33 the independent measurements were carried out for alpha-emission intensities (with Si(Au) detector) and gamma-ray intensities (with two Ge detectors). The correlation between these measurements can be only due to the same sources used but it is negligible taking into account a large difference between the methods and detectors. Determination of the ^{242}Pu disintegration rates for six sources required for the absolute gamma intensity measurements was made in 1986Va33 using absolute alpha particle counting under well-defined low solid angles, i.e. out of connection with the alpha - emission intensity measurements with Si(Au) detector.

The probability of the $\alpha_{0,3}$-transition has been deduced from the P(γ+ce) balance at the ^{238}U level of 307.19 keV (Table 4).

Table 4. Experimental, deduced and recommended values of α-transition probabilities (× 100) in ^{242}Pu decay.

	α-particle energy (keV)	1953Asaro	1956Hu96	1976Baranov	1986Va33	Deduced from P(γ) measured in 1986Va33	Recommended
$\alpha_{0,0}$	4902	80 (6) [a]	74 (4) [a]	79.7 (20) [b]	76.45 (17)	77.3 (6)	76.53 (17) [c]
$\alpha_{0,1}$	4858	20 (6) [a]	26 (4) [a]	20.2 (20) [b]	23.52 (17)	22.7 (6)	23.44 (17)[c]
$\alpha_{0,2}$	4756	-	-	-	0.029 0 (14)	0.031 7 (13)	0.030 4 (13)
$\alpha_{0,3}$	4600	-	-	-	-	0.000 84 (6)	0.000 84 (6)

[a] No uncertainties were quoted by the authors. The uncertainties adopted here were estimated by R. Vaninbroukx from the spectra shown in the papers (1986LoZT).

[b] The uncertainties of 2.7 for 79.7 and 1.1 for 20.2 quoted by the authors were re-estimated by R. Vaninbroukx (1986LoZT).

[c] Weighted average of the five values including direct measurement results and deduced value, uncertainty is the smallest quoted one.

[d] Weighted average of the two values including direct $\alpha_{0,2}$-transition measurement result and deduced value, uncertainty is the smallest quoted one.

2.2 γ Transitions

The recommended energies of gamma-ray transitions are virtually the same as the gamma-ray energies because nuclear recoil is negligible for ^{234}U.

The gamma-ray transition probabilities have been deduced from the gamma-ray emission probabilities and total internal conversion coefficients (ICCs). The ICCs have been interpolated using the BrIcc package with the so called "*Frozen Orbital*" approximation (2008Ki07). The uncertainties in the ICCs for pure multipolarities have been taken as 2 %. The multipolarities have been taken from 2002Ch52.

3 Atomic Data

3.1. Fluorescence yields

The fluorescence yield data are from 1996Sc06 (Schönfeld and Janβen).

3.2 X-rays and Auger electrons

The energies of U LX-rays taken from the SAISINUC software supporting programs agree with the measurements of 1994Le37 where the fine structure of LX radiation was measured in decay of ^{240}Pu.

The U KX-ray energies have been taken from 1999Schönfeld where the calculated values based on X-ray wavelengths from 1967Be65.

The relative KX-ray emission probabilities have been taken from 1999Schönfeld.

The energies of Auger electrons are from the SAISINUC software supporting programs. The ratios P(KLX)/P(KLL), P(KXY)/P(KLL) are taken from 1996Sc06.

4 Alpha Emissions

The α-emission energies have been obtained from Q value and ^{238}U level energies taking into account the ^{238}U recoil energies. In Table 5 the recommended values of α-emission energies are compared with the experimental results from alpha-spectrometric measurements and also with the evaluated data by A. Rytz (1991Ry01).

Table 5. Experimental and recommended α-emission energies in decay of ^{242}Pu (keV).

	Measured [a]				1991Ry01	Recommended
	1953Asaro	1956Hu96	1956Ko67	1968Ba25		
$\alpha_{0,0}$	4904.6 (20)	4903.7 (30)	4907.2 (30)	4900.4 (12)	4902.3 (14)	4902.3 (10)
$\alpha_{0,1}$	4860.6 (20)	4859.7 (30)	4863.2 (30)	4856.1 (12)	4858.1 (15)	4858.2 (10)
$\alpha_{0,2}$	-	-	-	-	-	4756.2 (10)
$\alpha_{0,3}$	-	-	-	-	-	4600.1 (10)

[a] Original values have been adjusted taking into account changes in calibration energies as suggested in 1991Ry01.

5 Electron Emissions

The energies of conversion electrons have been obtained from the gamma-ray transition energies and the atomic-electron binding energies. The emission probabilities of the conversion electrons have been deduced from the evaluated P(γ) and ICC values.

The absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program (2000Schönfeld).

6 Photon emissions

6.1 X-ray Emissions

The absolute emission probability of U MX–rays (αβ) in decay of ^{242}Pu has been deduced from the relative intensity P(XMαβ)/P(XLηβ) = 0.41 (4) measured in 1990Po14.

The absolute emission probabilities of U KX- and U LX-rays in decay of ^{242}Pu have been calculated using the EMISSION computer program (2000Schönfeld).

6.2 Gamma-ray Emissions

The energies of gamma-rays have been adopted from 1972Sc01.

The absolute emission probabilities of the gamma-rays $\gamma_{1,0}$ (44.915 keV) and $\gamma_{2,1}$ (103.50 keV) have been deduced from the recommended P(α) values (Table 4) and the adopted total ICCs on the basis of intensity balances at the corresponding ^{238}U levels. The absolute emission probability of the gamma-ray $\gamma_{3,2}$ (158.80 keV) has been adopted from the direct measurement of 1986Va33 (Table 6).

Table 6. Experimental and recommended absolute emission probabilities of gamma-rays (×100) in ^{242}Pu decay.

	Energy (keV)	1972Sc01	1986Va33	Recommended
$\gamma_{1,0}$	44.915	-	0.037 2 (7)	0.038 4 (8)
$\gamma_{2,1}$	103.50	0.008 1 (9) [a]	0.002 63 (9)	0.002 53 (12)
$\gamma_{3,2}$	158.80	0.005 (2) [a]	0.000 298 (20)	0.000 298 (20)

[a] Not used in the evaluation as considered in 1986LoZT.

7 Consistency of recommended data

The most accurate Q value, Q(M), is taken from the atomic mass adjustment table of Audi et al. (2003Au03). Comparison of Q(eff)(deduced as the sum of average energies per disintegration ($\sum E_i \times P_i$) for all emissions accompanying ^{242}Pu α- decay) with the tabulated decay energy Q(M) allows to check a consistency of the recommended decay-scheme parameters obtained in this evaluation.

Here E_i and P_i are the evaluated energies and emission probabilities of the i-th alpha-particle, beta particle, gamma-ray, X-ray, etc. Consistency (percentage deviation) is determined by {[Q(M) - Q(eff))] / Q(M)} × 100. “Percentage deviations above 5 % would be regarded as high and imply a poorly defined decay scheme; a value of less than 5 % indicates the construction of a reasonably consistent decay scheme” (quoted from the article by A.L. Nichols in Appl. Rad. Isotopes 55 (2001) 23-70).

For the above ^{242}Pu decay data evaluation we have Q(M) = 4984.5 (10) keV and Q(eff) = 4984 (13) keV. Thereafter, the percentage deviation is (0.01 ± 0.26) %, i.e. consistency is superior.

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^{242}Am - Comments on evaluation of decay data

by A. L. Nichols

Evaluated: March 2007/September 2008

Evaluation Procedure

Limitation of Relative Statistical Weight Method (LWM) was applied to average the decay data when appropriate.

Decay Scheme

A relatively simple decay scheme was constructed from the β^-/EC ratio and branching fraction measurements of Hoff *et al.* (1955Ho67, 1959Ho02), Baranov and Shlyagin (1955Ba31), Asaro *et al.* (1960As05), Gasteiger *et al.* (1969Ga17), Aleksandrov *et al.* (1969Al20) and Gabeskiriya (1972Ga35). There are no known well-defined gamma-ray spectroscopic studies.

Some confusion arose during the course of the 1950s as to the correct identity of the ground and metastable states of ^{242}Am. This problem was resolved in 1960 by Asaro *et al.* (1960As05) when the 16-hour half-life activity was shown to be the ground state. The possible existence of an alpha branch has been extensively considered by Barnes *et al.* (1959Ba22) and Aleksandrov *et al.* (1969Al20). While Barnes *et al.* found such a branching fraction ($BF_\alpha = 0.004\,76\ (14)$), subsequent studies have shown no evidence for this particular decay mode, and Aleksandrov *et al.* were only able to set a limit of less than 10^{-7} of the total ^{242}Am decay.

Nuclear Data

^{242}Am needs to be better characterized for improved quantification of the production and decay heat contribution of ^{242}Cm.

Half-life

The recommended half-life of 16.01 (2) hours has been adopted from three known sets of measurements (1953Ke38, 1969Al20, 1982Wi05). Five independent half-life measurements were individually reported by Aleksandrov *et al.* (1969Al20) from which a value of 16.07 (14) h was calculated (LWM). A limited data set of effectively three studies is rather unsatisfactory, and further measurements are required to determine the half-life with much greater confidence.

Half-life measurements

Reference	Half-life (hours)
1953Ke38	16.01 ± 0.02
1969Al20	16.07 ± 0.14
1982Wi05	16.1 ± 0.1
Recommended value	16.01 ± 0.02

Gamma Rays

Energies

All gamma-ray transition energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of Akovali were adopted (2002Ak06), and used to determine the energies and associated uncertainties of the gamma-ray transitions that depopulate the first excited states of ^{242}Pu and ^{242}Cm.

Emission Probabilities

There are no known dedicated measurements of the gamma-ray emission probabilities. Under these unsatisfactory circumstances, the proposed gamma-ray decay data were derived from the tabulated P_{ce}/P_{β} data of Baranov and Shlyagin (1955Ba31) and the BF_{β} measurements (1959Ba22, 1959Ho02, 1969Al20, 1969Ga17, 1972Ga35). A BF_{β} of 0.831 (3) was derived in terms of LWM, with the uncertainty extended to the minimum value measured (± 0.003); this parameter was adopted in preference to the equivalent LWM calculation for the β^{-}/EC ratio (i.e. 4.88 (8) compared with a value of 4.92 (9) calculated from the weighted mean BF_{β}).

β^{-}/EC ratio and BF_{β} (Branching fraction).

Reference	BF_{β}	β^{-}/EC
1955Ba31	0.82	4.6
1955Ho67	0.81	4.2
1959Ba22	0.836 ± 0.008*	5.1 ± 0.2
1959Ho02	0.836 ± 0.003	5.1 ± 0.1*
1960As05	0.836*	5.1
1969Al20	0.82 ± 0.01*	4.6 ± 0.3
1969Ga17	0.828 ± 0.004	4.8 ± 0.1*
1972Ga35	0.827 ± 0.003*	4.78 ± 0.08
Recommended value	0.831 ± 0.003	[4.88 ± 0.08]

* Emphasis of the publication, and assumed to be the primary measurement.

Baranov and Shlyagin determined the conversion-electron emission intensities separately for both the electron-capture and beta decay processes, along with the β^{-} decay in equivalent units (1955Ba31) to furnish the following ratios:

P_{ce}(EC component)/$P_{\beta-}$ = 153.5/1200, and

P_{ce}(β^{-} component)/$P_{\beta-}$ = 661/1200.

One problem involves the assignment of uncertainties to the $P_{ce}/P_{\beta-}$ values as determined by Baranov and Shlyagin. Both parameters are the ratios of two equivalent measurements, and the resulting uncertainty for each of these ratios was assumed to be approximately 5 %:

P_{ce}(EC component)/$P_{\beta-}$ = 153.5/1200 = 0.128 (6)

P_{ce}(β^{-} component)/$P_{\beta-}$ = 661/1200 = 0.551 (28).

Using these data and BF_{β} of 0.831 (3):

$P_{ce}(\beta^{-})$ = 0.551 (28) × 0.831 (3) = 0.458 (23) for the 42.13-keV gamma ray,
and P_{ce}(EC) = 0.128 (6) × 0.831 (3) = 0.106 (5) for the 44.54-keV gamma ray.

These values were then used in conjunction with the theoretical internal conversion coefficients to calculate the absolute gamma-ray emission probabilities.

Quite remarkably, the resulting gamma-ray emission probabilities are in good agreement with the tabulated spectroscopic data of Vylov *et al.* (1980VyZZ) which are listed as 42.129 (7) keV and 0.039 (5) %, and 44.542 (25) keV and 0.015 (3) %. Accurate, high-resolution gamma-ray measurements are required to confirm the validity of the proposed decay scheme.

Gamma-ray emissions: recommended energies, emission probabilities, multipolarities and theoretical internal conversion coefficients (frozen orbital approximation).

	E_γ (keV)	P_γ^{abs}	Multi	α_K	α_L	α_{M+}	α_{tot}
$\gamma_{1,0}$ (Cm)	42.13 (5)	0.040 ± 0.002	E2	-	836 (12)	319 (5)	1155 (17)
$\gamma_{1,0}$ (Pu)	44.54 (2)	0.014 ± 0.001	E2	-	544 (8)	204 (3)	748 (11)

Multipolarities and Internal Conversion Coefficients

The nuclear level scheme specified by Akovali has been used to define the multipolarities of the gamma transitions on the basis of known spins and parities (2002Ak06). Recommended internal conversion coefficients have been determined from the theoretical tabulations of Band *et al.* (2002Ba25, 2002Ra45) by means of the methodology of Kibedi *et al.* (2008Ki07).

Beta-particle Emissions

Energies and emission probabilities

Beta-particle energies were calculated from the nuclear level energies of Akovali (2002Ak06) and a Q_{β^-} value of 664.5 ± 0.4 keV taken from Audi *et al.* (2003Au03).

Assuming virtually full internal conversion of the 42.13-keV gamma transition, the beta-particle emission probabilities were calculated from BF_β of 0.831 (3) and $P_{ce}(\beta^-)$ of 0.458 (23):

Beta-particle Emission Probabilities per 100 Disintegrations of ^{242}Am.

	E_β (keV)	av. E_β (keV)	P_β	Transition type	log *ft*
$\beta^-_{0,1}$	622.4 ± 0.4	185.92 ± 0.14	45.8 ± 2.3	1st forbidden non-unique	6.84
$\beta^-_{0,0}$	664.5 ± 0.4	200.17 ±. 0.14	37.3 ± 2.3	1st forbidden non-unique	7.03

EC Transitions

Energies and transition probabilities

EC transition energies were calculated from the nuclear level energies of Akovali (2002Ak06) and a Q_{EC} value of 751.3 ± 0.7 keV from Audi *et al.* (2003Au03).

Assuming virtually full internal conversion of the 44.54-keV gamma transition, the EC transition probabilities were calculated from BF_{EC} of 0.169 (3) and $P_{ce}(EC)$ of 0.106 (5):

EC Transition Probabilities per 100 Disintegrations of ^{242}Am.

	E_{EC} (keV)	P_{EC}	Transition type	log *ft*	P_K	P_L	P_M
$EC_{0,1}$	706.8 ± 0.7	10.6 ± 0.5	1st forbidden non-unique	7.26	0.7261 (23)	0.2016 (15)	0.0532 (10)
$EC_{0,0}$	751.3 ± 0.7	6.3 ± 0.6	1st forbidden non-unique	7.55	0.7303 (22)	0.1987 (15)	0.0522 (10)

Atomic Data

The x-ray and Auger-electron data have been calculated using the evaluated gamma-ray data, and atomic data from 1996Sc06, 1998ScZM and 1999ScZX. Both the x-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.01, 28 January 2003, with the emission.101 database extended to Z = 96 to calculate component L x-ray data of daughter Cm). This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

K and L X-ray Emission Probabilities per 100 Disintegrations of ^{242}Am.

			Energy keV	Photons per 100 disint.
XL		(Pu)	12.124 – 22.153	10.8 (5)
	XL_l	(Pu)	12.124	0.293 (11)
	XL_α	(Pu)	14.087 – 14.282	4.56 (16)
	XL_η	(Pu)	16.333	0.084 (4)
	XL_β	(Pu)	16.498 – 18.541	4.64 (15)
	XL_γ	(Pu)	21.420 – 22.153	1.03 (4)
XK_α	$XK_{\alpha 2}$	(Pu)	99.525	3.55 (17)
	$XK_{\alpha 1}$	(Pu)	103.734	5.6 (3)
$XK'_{\beta 1}$	$XK_{\beta 3}$	(Pu)	116.244	)
	$XK_{\beta 1}$	(Pu)	117.228	) 2.06 (11)
	$XK_{\beta 5}''$	(Pu)	117.918	)
$XK'_{\beta 2}$	$XK_{\beta 2}$	(Pu)	120.540	)
	$XK_{\beta 4}$	(Pu)	120.969	) 0.72 (4)
	$XKO_{2,3}$	(Pu)	121.543	)
XL		(Cm)	12.633 – 23.527	18.0 (11)
	XL_l	(Cm)	12.633	0.451 (22)
	XL_α	(Cm)	14.746 – 14.961	6.8 (3)
	XL_η	(Cm)	17.314	0.194 (11)
	XL_β	(Cm)	17.286 – 19.688	8.7 (4)
	XL_γ	(Cm)	22.735 – 23.527	2.09 (10)

Electron energies were determined from electron binding energies tabulated by Larkins (1977La19) and the evaluated gamma-ray energies. Absolute electron emission probabilities were calculated from the evaluated absolute gamma-ray emission probabilities and associated internal conversion coefficients.

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^{242m}Am - Comments on evaluation of decay data

by A. L. Nichols

Evaluated: April 2007/April 2010

Evaluation Procedure

Limitation of Relative Statistical Weight Method (LWM) was applied to average the decay data when appropriate.

Decay Scheme

A simple IT-decay mode dominates the decay scheme of ^{242m}Am. The small α branch is complex, and many features of this decay mode remain unresolved despite the extensive study of Hoff *et al.* (1990Ho02).

Some confusion arose during the course of the 1950s as to the correct identity of the ground and metastable states of ^{242}Am. This problem was resolved in 1960 by Asaro *et al.* (1960As05) when the 16-hour half-life activity was shown to be the ground state and the longer-lived 140-year isomer was defined as the metastable state. The α branch has been determined by Barnes *et al.* (1959Ba22) and Zelenkov *et al.* (1979Ze05) to be 0.46 (1) %. Hoff *et al.* have studied the emissions from the α-decay mode in considerable detail (1990Ho02), and the more modest measurements of Baranov *et al.* (1979Ba67) and Vylov *et al.* (1980VyZZ) show reasonable agreement with this extensive data set. A small spontaneous fission branch of 1.5 (6) × 10^{-8} % has been quantified by Caldwell *et al.* (1967Ca04), while an upper limit of 4.8 × 10^{-9} % has been specified by Zelenko *et al.* (1986Ze06).

Nuclear Data

The decay characteristics of ^{242m}Am need to be better defined for improved quantification of the production and decay heat contributions of ^{242}Cm and ^{244}Cm.

Half-life

A recommended half-life of 143 (2) years has been adopted from the two known measurements (1959Ba22, 1979Ze05). This limited data set is unsatisfactory, and further studies are required to determine the half-life with much greater confidence.

Half-life measurements

Reference	Half-life (years)
1959Ba22	152 ± 7
1979Ze05	141.9 ± 1.7
Recommended value	143 ± 2

Branching Fractions

Barnes *et al.* and Zelenkov *et al.* have determined the α branching fraction for ^{242m}Am (1959Ba22, 1979Ze05), and these data were used to derive an α branch of 0.46 (1) % and IT branch of 99.54 (1) %.

Reference	BF_α
1959Ba22	0.004 76 ± 0.000 14
1979Ze05	0.004 5 ± 0.000 1
Recommended value	0.004 6 ± 0.000 1
α branch	(0.46 ± 0.01) %

A spontaneous fission branch of 1.5 (6) × 10^{-8} % can be determined from the recommended total half-life of 143 (2) years and measured spontaneous fission half-life of 9.5 (35) × 10^{11} years (1967Ca04). Similarly, an upper limit of 4.8 × 10^{-9} % for the spontaneous fission branch can be derived from equivalent studies of the spontaneous fission half-life of > 3 × 10^{12} years (1986Ze06). Under these uncertain circumstances, a recommended value of < 4.8 × 10^{-9} % has been adopted for the spontaneous fission branch of ^{242m}Am.

Q values

Q_{IT} of 48.60 (5) keV and Q_α of 5637.10 (25) keV were adopted from the evaluated tabulations of Audi *et al.* (2003Au03).

Alpha Particles

Alpha-particle measurements reveal a relatively complex α-decay mode (1979Ba67, 1980VyZZ, 1990Ho02). The Q_α of 5637.10 (25) keV (2003Au03) and nuclear level energies as defined by Chukreev *et al.* (2002Ch52) were used to calculated the alpha-particle energies, while the alpha-particle emission probabilities were primarily adopted from the measurements of Hoff *et al.* (1990Ho02) and fortified by the introduction of a number of minor transitions observed by Baranov *et al.* (1979Ba67), all expressed in terms of decay per 100 alphas. Small adjustments were made to some of the low-intensity alpha-particle emission probabilities after consideration of the observed differences between the two sets of measurements (i.e., 5091.9-, 5248.15/5248.21- and 5272.96-keV alpha-particle emission probabilities). Some of the proposed daughter nuclear levels of comparable energy were also judged to be populated by alpha-particle transitions that were not experimentally resolved (i.e., alpha-particle transitions to nuclear levels with energies of 297.03/299.23, 300.68/300.743 and 374.7/376.7 keV). Under these circumstances, the observed alpha-particle emission was arbitrarily shared between the two nuclear levels of relevance. An unweighted mean value of 1.508 (5) was adopted for the radius parameter $r_0(^{238}\mathrm{Np})$ as derived from the equivalent data for neighboring doubly-even nuclei (1998Ak04), and used in the calculation of α-hindrance factors (HF):

$$r_0(^{238}\mathrm{Np}) = [r_0(^{240}\mathrm{Pu}) + r_0(^{242}\mathrm{Pu}) + r_0(^{242}\mathrm{Cm}) + r_0(^{244}\mathrm{Cm})] / 4$$

$$= [1.5168\ (3) + 1.5143\ (9) + 1.5013\ (10) + 1.4979\ (7)] / 4 = 1.508\ (5)$$

All of the available alpha-particle decay data were assessed in conjunction with the gamma-ray measurements of Hoff *et al.* These extremely significant gamma-ray studies do not furnish gamma-ray energy and emission probability data that can be adopted to depopulate the major alpha-populating nuclear levels of ^{238}Np in a consistent and satisfactory manner (i.e., nuclear levels at 407.59 keV and 342.439 keV populated by alpha particles with emission probabilities of 5.6 (2) % and 89.0 (7) % per 100 alphas, respectively). These two seriously incomplete features within the decay scheme are also observed to impact in various ways throughout the gamma-ray decay to the ground state of ^{238}Np. While the recommended alpha-particle emissions are believed to be reasonably sound, the related gamma-ray data remain significantly incomplete.

Alpha-particle emissions: energies, emission probabilities and hindrance factors.

1979Ba67		1980VyZZ		1990Ho02		Recommended		
E_α (keV)	*P_α (x100α)*	*E_α (keV)*	*P_α (x100α)*	*E_α (keV)*	*P_α (x100α)*	*E_α (keV)*	*P_α (x100α)*	*HF*
4974.9	~ 0.002	-	-	-	-	4975 (3)	0.002 (1)	2400
5027.1	0.02	-	-	5031 (5)	0.02 (1)	5027.3 (15)	0.02 (1)	540
5064.2	0.22	5065 (5)	0.23	5072 (3)	0.25 (7)	5068 (3)	0.25 (7)	81
5082	0.03	5082 (5)	) 0.34	-	-	5082.6 (12)	0.03 (1)	840
5088.4	0.19		)	5093 (4)	0.21 (7)	5091.9 (7)	0.20 (7)	146
5141.6 (5)	5.82	5142.35 (104)	6.601 (163)	5144.4 (9)	5.6 (2)	5143.07 (26)	5.6 (2)	11.2

1979Ba67		1980VyZZ		1990Ho02		Recommended		
E_α (keV)	*P_α (x100α)*	*E_α (keV)*	*P_α (x100α)*	*E_α (keV)*	*P_α (x100α)*	*E_α (keV)*	*P_α (x100α)*	*HF*
5153.3	0.02	-	-	-	-	5153.2 (15)	0.02 (1)	3600
~ 5173	) 0.04	-	-	-	-	5173.45 (26)	0.02 (1)	4900
5173.7	)	-	-	-	-	5175.4 (10)	0.02 (1)	5000
5206.8 (5)	89.84	5205.92 (72)	100.00 (167)	5208.4 (8)	89.0 (7)	5207.15 (25)	89.0 (7)	1.80
5214.7 ?	0.03	-	-	-	-	5215.4 (7)	0.03 (1)	6000
5248.2	~ 0.11	5248 (5)	0.67	5248.4 (22)	1.0 (1)	) 5248.15 (25)	0.4 (1)	730
						) 5248.21 (26)	0.4 (1)	730
5250.0	0.04	-	-	-	-	) 5249.64 (26)	0.02 (1)	14800
						) 5251.80 (25)	0.02 (1)	15300
~ 5273	0.86	5284	~ 0.34	5271 (3)	1.1 (1)	5272.96 (25)	1.0 (1)	414
5313.5	0.69	5312 (5)	0.90	5316 (3)	0.6 (1)	5314.95 (25)	0.6 (1)	1250
-	-	-	-	5331 (5)	0.15 (10)	5331.97 (25)	0.15 (10)	6400
5367.2	1.17	5364 (5)	1.67	5369.1 (18)	1.1 (2)	5367.73 (25)	1.1 (2)	1430
5409.3	1.04	5408 (5)	1.35	5412.4 (21)	1.0 (2)	5410.13 (25)	1.0 (2)	2820
5458.2	0.14	-	-	-	-	5458.68 (25)	0.14 (4)	39000
5517.3	0.006	-	-	-	-	5517.93 (25)	0.003 (3)	4000000

Σ 100.025

Gamma Rays

Energies

All gamma-ray transition energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of Akovali and Chukreev *et al.* were adopted (2002Ak06, 2002Ch52), and used to determine the energies and associated uncertainties of the gamma-ray transitions that populate and depopulate the excited nuclear levels of ^{238}Np and ^{242m}Am.

Emission Probabilities

Dedicated measurements of the gamma-ray emission probabilities of ^{242m}Am are limited to the significant studies of Hoff *et al.* (1990Ho02). Under these rather unsatisfactory circumstances, these gamma-ray decay data were adopted wholesale, although some comparison could be made with the limited data set of Vylov *et al.* (1980VyZZ). Hoff *et al.* have directly identified over 60 gamma-rays with the α-decay mode which has a branch of only 0.46 (1) %, while the major IT decay mode involves only one highly-converted gamma transition (48.60 keV).

Hoff *et al.* report the emission probabilities of a number of unresolved gamma rays in terms of what is believed to be the upper limit for each: 4.0 (3) per 100 α for both 109.61 (1) and 109.618 (3) keV; 0.024 (7) per 100 α for both 139.05 (3) and 139.11 (2) keV; 0.150 (8) per 100 α for both 152.70 (2) and 152.73 (1) keV; 3.50 (10) per 100 α for both 163.1 (5) and 163.29 (1) keV; and 0.122 (10) per 100 α for both 250.33 (3) and 250.37 (2) keV. These data have been adopted and both entries carried forward as values less or equal (≤) to the specified emission probability, as well as being incorporated into the database of recommended emission probabilities and transition probabilities.

The 26.427-keV gamma transition is particularly problematic, with a measured emission probability of 1.36 (1) per 100 α (1990Ho02). Combining this value with the internal conversion coefficients for an E2 transition generates an unrealistic absolute transition probability for this single gamma from the

26.427-keV nuclear level to the ground state of 2.12 %. There is a good possibility that this particular γ line arises partially from the alpha decay of ^{241}Am (isotopic content of 0.79 %, and γ-ray emission energy of 26.345 keV), and/or consists of a number of unresolved transitions that could not be identified nor located elsewhere within the incomplete decay scheme of ^{242m}Am. Therefore, the emission probability per 100 α of the 26.427-keV gamma transition has been significantly reduced to < 0.154, and is primarily based on α and γ transition probabilities per 100 α that are known to populate the 26.427-keV nuclear level.

Np K X-rays complicate the interpretation of the gamma-ray emission probability data over the energy ranges from 97 to 101 keV (Kα) and 113.3 to 118.5 keV (Kβ). Hoff *et al.* observed gamma rays with energies in the vicinity of 97 keV and between 113.7 and 118 keV. While many of these particular emissions can be incorporated into the proposed decay scheme, their emission probabilities and existence in this form are doubtful.

A limited number of the gamma rays observed by Hoff *et al.* could not be placed in the proposed and incomplete alpha-decay scheme: 89.60 (5) keV with P_γ per 100 α of 0.29 (7), 160.61 (2) keV with P_γ per 100 α of 0.09 (4), 165.97 (15) keV with P_γ per 100 α of 0.010 (5), and 233.69 (10) keV with P_γ per 100 α of 0.028 (7).

Gamma-ray emissions: measured and recommended energies and emission probabilities.

1980VyZZ			1990Ho02				**Adopted**	
E_γ (keV)	P_γ^{rel}	*P_γ per 100α*	*E_γ (keV) α decay*	*P_γ per 100α*	*E_γ (keV) (n,γ)*	*P_γ per 100n*	***E_γ (keV)***	***P_γ per 100α***
-	-	-	-	-	24.37 (2)	0.0064 (10)	24.34 (1)	-
-	-	-	26.32 (3)	1.36 (10)	26.43 (2)	0.104 (15)	26.427 (2)	< 0.154*
-	-	-	-	-	32.67 (3)	0.026 (4)	32.64 (1)	-
-	-	-	-	-	34.97 (3)	0.082 (11)	34.97 (1)	-
-	-	-	-	-	35.90 (2)	0.0109 (15)	35.90 (1)	-
-	-	-	-	-	43.11 (3)	0.044 (7)	43.11 (1)	-
-	-	-	-	-	43.32 (3)	0.0046 (7)	43.33 (1)	-
-	-	-	-	-	43.84 (3)	0.075 (11)	43.83 (2)	-
-	-	-	-	-	43.98 (4)	0.058 (8)	43.89 (2)	-
-	-	-	-	-	46.84 (3)	0.111 (17)	46.833 (3)	-
-	-	-	-	-	-	-	48.60 (5)	IT decay
49.367 (4)	100	[29.1]	49.35 (2)	29.1 (9)	49.372 (2)	8.57 (14)	49.371 (3)	29.1 (9)
-	-	-	-	-	52.98 (7)	0.029 (4)	53.2 (6)	-
-	-	-	53.69 (3)	0.45 (6)	53.70 (7)	0.038 (6)	53.67 (1)	0.45 (6)
-	-	-	-	-	53.88 (4)	0.017 (3)	53.85 (2)	-
-	-	-	57.54 (6)	0.21 (5)	-	-	57.51 (1)	0.21 (5)
-	-	-	-	-	59.31 (4)	0.0082 (13)	59.32 (1)	-
-	-	-	60.13 (6)	1.19 (11)	60.243 (4)	0.68 (5)	60.247 (3)	1.19 (11)
-	-	-	-	-	62.33 (3)	0.0100 (15)	62.330 (4)	-
66.808 (20)	11.2	3.26	66.89 (2)	3.25 (10)	66.919 (5)	0.23 (3)	66.92 (1)	3.25 (10)
67.9	3.9	1.1	67.93 (3)	0.87 (7)	-	-	67.92 (2)	0.87 (7)
73.3	3.2	0.93	73.66 (2)	1.71 (12)	73.715 (4)	0.49 (15)	73.72 (1)	1.71 (12)
-	-	-	-	-	75.97 (7)	0.0051 (8)	75.98 (1)	-
-	-	-	-	-	79.483 (17)	0.17 (3)	79.48 (1)	-
-	-	-	-	-	79.74 (3)	0.019 (3)	79.73 (2)	-
-	-	-	84.9 (2)	0.21 (7)	-	-	85.16 (7)	0.21 (7)
86.680 (36)	19.5	5.67	86.65 (2)	4.97 (15)	86.676 (2)	2.3 (4)	86.674 (2)	4.97 (15)
-	-	-	89.60 (5)	0.29 (7)	-	-	89.60 (5)	0.29 (7)#
92.5	2.2	0.64	92.52 (3)	0.61 (7)	92.486 (7)	0.19 (4)	92.48 (1)	0.61 (7)
-	-	-	93.82 (3)	0.79 (9)	93.67 (5)	0.19 (4)	93.88 (1)	0.79 (9)
-	-	-	-	-	95.22 (2)	0.046 (6)	95.22 (1)	-
-	-	-	95.7 (6)	-	-	-	96.204 (3)	-
-	-	-		-	96.82 (5)	0.025 (4)	96.78 (1)	-
97.077	$K_{\alpha2}$ (Np)	-	-	-	-	-	-	-
-	-	-	98.0 (6)	-	97.22 (5)	0.046 (6)	97.18 (2)	-
101.068	$K_{\alpha1}$ (Np)	-	-	-	-	-	-	-

1980VyZZ			1990Ho02				**Adopted**	
E_γ (keV)	P_γ^{rel}	*P_γ per 100α*	*E_γ (keV) α decay*	*P_γ per 100α*	*E_γ (keV) (n,γ)*	*P_γ per 100n*	***E_γ (keV)***	***P_γ per 100α***
109.6	12.9	3.75	109.61 (2)	4.0 (3)	109.614 (4)	1.09 (24)	109.61 (1)	≤ 4.0 (3)
			109.62 (2)	4.0 (3)	109.614 (4)	1.09 (24)	109.618 (3)	≤ 4.0 (3)
111.1	1.5	0.44	111.16 (5)	0.55 (9)	111.197 (15)	0.19 (4)	111.18 (1)	0.55 (9)
113.3-114.9	K_β (Np)	-	-	-	-	-	-	-
-	-	-	113.7 (6)	-	-	-	113.9 (5)	-
			114.3 (6)	-	-	-	-	-
117.5-118.4	K_β (Np)	-	-	-	-	-	-	-
-	-	-	117.2 (6)	-	-	-	117.2 (6)	-
-	-	-	117.8 (6)	-	-	-	117.80 (7)	-
-	-	-	117.85 (60)	-	-	-	117.85 (7)	-
-	-	-	121.3 (6)	-	-	-	121.59 (2)	-
-	-	-	-	-	121.69 (4)	0.076 (11)	121.645 (9)	-
-	-	-	122.5 (6)	-	122.76 (7)	0.019 (8)	122.81 (1)	-
-	-	-	126.83 (5)	0.028 (14)	-	-	126.92 (1)	0.028 (14)
-	-	-	131.49 (8)	0.059 (14)	-	-	131.50 (5)	0.059 (14)
-	-	-	132.6 (6)	-	-	-	132.07 (6)	-
135.17 (6)	5.6	1.63	135.19 (2)	1.47 (8)	-	-	135.21 (2)	1.47 (8)
137.02 (6)	5.1	1.48	136.03 (2)	2.05 (6)	136.045 (10)	0.68 (11)	136.045 (2)	2.05 (6)
-	-	-	139.05 (2)	0.024 (7)	-	-	139.05 (3)	≤ 0.024 (7)
-	-	-	139.05 (2)	0.024 (7)	-	-	139.11 (2)	≤ 0.024 (7)
-	-	-	151.07 (5)	0.018 (4)	-	-	151.01 (3)	0.018 (4)
152.75 (6)	0.7	0.2	152.70 (2)	0.150 (8)	152.69 (3)	0.29 (4)	152.70 (2)	≤ 0.150 (8)
-	-	-	152.73 (2)	0.150 (8)	152.69 (3)	0.29 (4)	152.73 (1)	≤ 0.150 (8)
			-	-	153.192 (12)	0.43 (5)	153.19 (1)	-
153.84 (6)	2.4	0.70	153.85 (2)	0.721 (22)	153.870 (9)	0.45 (10)	153.87 (1)	0.721 (22)
-	-	-	156.46 (2)	0.059 (10)	156.452 (2)	4.23 (22)	156.451 (3)	0.059 (10)
-	-	-	160.61 (2)	0.09 (4)	-	-	160.61 (2)	0.09 (4)[#]
163.24 (4)	12.7	3.70	163.25 (2)	3.50 (10)	163.29 (5)	0.28 (4)	163.1 (5)	≤ 3.50 (10)
-	-	-	163.25 (2)	3.50 (10)	-	-	163.29 (1)	≤ 3.50 (10)
-	-	-	164.67 (7)	-	-	-	164.64 (7)	-
-	-	-	165.97 (15)	0.010 (5)	-	-	165.97 (15)	0.010 (5)[#]
-	-	-	170.50 (1)	0.136 (10)	-	-	170.7 (8)	0.136 (10)
-	-	-	174.76 (6)	0.038 (10)	-	-	174.76 (6)	0.038 (10)
-	-	-	176.68 (15)	0.006 (3)	176.62 (5)	0.17 (3)	176.66 (2)	0.006 (3)
-	-	-	182.86 (2)	0.199 (7)	182.876 (2)	13.9 (16)	182.878 (2)	0.199 (7)
-	-	-	189.01 (3)	0.059 (10)	189.099 (6)	0.44 (4)	189.10 (1)	0.059 (10)
-	-	-	190.88 (5)	0.023 (5)	-	-	190.88 (5)	0.023 (5)
194.63 (5)	-	-	194.61 (2)	0.308 (10)	-	-	194.59 (2)	0.308 (10)
-	-	-	196.46 (10)	0.021 (10)	-	-	196.52 (1)	0.021 (10)
206.34 (5)	2.0	0.58	206.37 (2)	0.34 (4)	-	-	206.39 (1)	0.34 (4)
-	-	-	213.20 (14)	0.012 (4)	-	-	213.19 (1)	0.012 (4)
-	-	-	215.52 (2)	0129 (21)	215.517 (5)	0.81 (4)	215.522 (4)	0.129 (21)
-	-	-	232.40 (3)	0.122 (7)	232.433 (8)	0.29 (5)	232.43 (1)	0.122 (7)
-	-	-	233.69 (10)	0.028 (7)	233.650 (6)	0.243 (22)	233.69 (10)	0.028 (7)[#]
-	-	-	237.02 (10)	0.010 (5)	-	-	236.90 (6)	0.010 (5)
-	-	-	238.53 (5)	0.0035 (18)	-	-	238.35 (7)	0.0035 (18)
-	-	-	250.33 (3)	0.122 (10)	-	-	250.33 (3)	≤ 0.122 (10)
-	-	-	250.33 (3)	0.122 (10)	250.40 (4)	0.35 (6)	250.37 (2)	≤ 0.122 (10)
-	-	-	270.55 (6)	0.0063 (18)	-	-	270.55 (7)	0.0063 (18)
-	-	-	272.75 (7)	0.0081 (18)	-	-	272.80 (6)	0.0081 (18)
-	-	-	280.04 (5)	0.0130 (14)	-	-	280.11 (1)	0.0130 (14)
-	-	-	299.20 (14)	0.006 (3)	-	-	299.23 (6)	0.006 (3)

[*] emission probability per 100 α has been significantly reduced to < 0.154, based on the α branching fraction and γ transition probabilities per 100 α of the γ transitions populating the 26.427-keV nuclear level.

[#] not placed in the proposed partial decay scheme.

Placements of gamma-ray transitions.

Adopted E_γ (keV)	Proposed location in decay scheme (^{238}Np nuclear levels)	Adopted E_γ (keV)	Proposed location in decay scheme (^{238}Np nuclear levels)
24.34 (1)	86.674 (2) – 62.330 (4)	121.645 (9)	121.645 (9) – 0
26.427 (2)	26.427 (2) – 0	122.81 (1)	258.853 (8) – 136.045 (2)
32.64 (1)	215.522 (4) – 182.878 (2)	126.92 (1)	342.439 (8) – 215.522 (4)
34.97 (1)	121.645 (9) – 86.674 (2)	131.50 (5)	297.03 (5) – 165.532 (15)
35.90 (1)	62.330 (4) – 26.427 (2)	132.07 (6)	407.59 (6) – 275.519 (9)
43.11 (1)	179.154 (7) – 136.045 (2)	135.21 (2)	300.743 (16) – 165.532 (15)
43.33 (1)	258.853 (8) – 215.522 (4)	136.045 (2)	136.045 (2) – 0
43.83 (2)	106.155 (15) – 62.330 (4)	139.05 (3)	300.743 (16) – 161.69 (2)?
43.89 (2)	165.532 (15) – 121.645 (9)	139.11 (2)	165.532 (15) – 26.427 (2)
46.833 (3)	182.878 (2) – 136.045 (2)	151.01 (3)	312.70 (2) – 161.69 (2)?
49.371 (3)	136.045 (2) – 86.674 (2)	152.70 (2)	258.853 (8) – 106.155 (15)
53.2 (6)	218.7 (6) – 165.532 (15)	152.73 (1)	179.154 (7) – 26.427 (2)
53.67 (1)	232.828 (8) – 179.154 (7)	153.19 (1)	215.522 (4) – 62.330 (4)
53.85 (2)	312.70 (2) – 258.853 (8)	153.87 (1)	275.519 (9) – 121.645 (9)
57.51 (1)	179.154 (7) – 121.645 (9)	156.451 (3)	182.878 (2) – 26.427 (2)
59.32 (1)	121.645 (9) – 62.330 (4)	160.61 (2)	not placed in decay scheme
60.247 (3)	86.674 (2) – 26.427 (2)	163.1 (5)	328.6 (5) – 165.532 (15)
62.330 (4)	62.330 (4) – 0	163.29 (1)	342.439 (8) – 179.154 (7)
66.92 (1)	342.439 (8) – 275.519 (9)	164.64 (7)	300.68 (7) – 136.045 (2)
67.92 (2)	300.743 (16) – 232.828 (8)	165.97 (15)	not placed in decay scheme
73.72 (1)	136.045 (2) – 62.330 (4)	170.7 (8)	389.4 (5) – 218.7 (6)
75.98 (1)	258.853 (8) – 182.878 (2)	174.76 (6)	407.59 (6)– 232.828 (8)
79.48 (1)	215.522 (4) – 136.045 (2)	176.66 (2)	312.70 (2) – 136.045 (2)
79.73 (2)	106.155 (15) – 26.427 (2)	182.878 (2)	182.878 (2) – 0
85.16 (7)	300.68 (7) – 215.522 (4)	189.10 (1)	215.522 (4) – 26.427 (2)
86.674 (2)	86.674 (2) – 0	190.88 (5)	297.03 (5) – 106.155 (15)
89.60 (5)	not placed in decay scheme	194.59 (2)	300.743 (16) – 106.155 (15)
92.48 (1)	179.154 (7) – 86.674 (2)	196.52 (1)	258.853 (8) – 62.330 (4)
93.88 (1)	215.522 (4) – 121.645 (9)	206.39 (1)	342.439 (8) – 136.045 (2)
95.22 (1)	121.645 (9) – 26.427 (2)	213.19 (1)	275.519 (9) – 62.330 (4)
96.204 (3)	182.878 (2) – 86.674 (2)	215.522 (4)	215.522 (4) – 0
96.78 (1)	232.828 (8) – 136.045 (2)	232.43 (1)	258.853 (8) – 26.427 (2)
97.18 (2)	312.70 (2) – 215.522 (4)? X-ray?	233.69 (10)	not placed in decay scheme
109.61 (1)	342.439 (8) – 232.828 (8)	236.90 (6)	299.23 (6) – 62.330 (4)
109.618 (3)	136.045 (2) – 26.427 (2)	238.35 (7)	300.68 (7) – 62.330 (4)
111.18 (1)	232.828 (8) – 121.645 (9)	250.33 (3)	250.33 (3) – 0
113.9 (5)	389.4 (5) – 275.519 (9); X-ray?	250.37 (2)	312.70 (2) – 62.330 (4)
114.3 (6)	not placed in decay scheme; X-ray?	270.55 (7)	376.70 (7) – 106.155 (15)
117.2 (6)	459.6 (6) – 342.439 (8); X-ray?	272.80 (6)	299.23 (6) – 26.427 (2)
117.80 (7)	300.68 (7) – 182.878 (2)? X-ray?	280.11 (1)	342.439 (8) – 62.330 (4)
117.85 (7)	376.70 (7) – 258.853 (8)? X-ray?	299.23 (6)	299.23 (6) – 0
121.59 (2)	300.743 (16) – 179.154 (7)		

Measurements have also been carried out by Hoff *et al.* on the gamma-ray emissions following thermal-neutron capture on ^{237}Np – when judged appropriate, some of these (n,γ) data have been used to develop the proposed decay scheme of ^{242m}Am. The (n,γ) data were inspected in detail, and the opportunity taken to utilize these gamma-ray emission probabilities in a relative sense if their equivalent gamma-ray data had also been detected and quantified in the ^{242m}Am studies. For example, consider the depopulation of the 258.853-keV nuclear level:

Proposed depopulating γ-ray transition (keV)	P_γ per 100n (1990Ho02)	P_γ per 100α (1990Ho02)	P_γ per 100α calculated	P_γ per 100α adopted
43.33	0.0046 (7)	–	0.0019 (3)	0.0019 (3)
75.98	0.0051 (8)	–	0.0021 (3)	0.0021 (3)
122.81	0.019 (8)	–	0.008 (4)	0.008 (4)
152.70	≤ 0.29	≤ 0.150	–	≤ 0.150
196.52	–	0.021 (10)	–	0.021 (10)
232.43	0.29 (5)	0.122 (7)	–	0.122 (7)

Unobserved P_γ per 100 α data can be calculated on the reasonable assumption that the relative emission probabilities of these six depopulating gamma rays would be the same irrespective of the mode of feeding to that nuclear level. The emission probability of the 232.43-keV gamma ray has been measured for both the ^{237}Np(n,γ) reaction and the α decay of ^{242m}Am, and this ratio can be used to determine the equivalent relative emission probabilities of the 43.33-, 75.98- and 122.81-keV gamma-ray transitions in the α-decay mode. Thus, P_γ per 100 α for the 75.98-keV gamma ray can be calculated:

$$(0.122/0.29) \times 0.0051\ (8) = 0.0021\ (3)$$

This approach was adopted for a number of specific gamma transitions, as noted in the relevant footnote of the table below.

Despite the introduction of gamma-ray data as outlined above, additional gamma transitions are required to create a more comprehensive and consistent decay scheme for the ^{242m}Am alpha-decay mode. While some of these possibilities can be gleaned from the ^{237}Np(n,γ) reaction data, they cannot be quantified in terms of P_γ per 100 α because of commensurate limitations in the (n,γ) measurements – these particular gamma rays are denoted by a dash (–) within the column entitled "Adopted P_γ per 100 α" in the table below.

Gamma-ray emissions: multipolarities and theoretical internal conversion coefficients (frozen orbital approximation).

Adopted E_γ (keV)	Adopted P_γ per 100 α[*]	Multipolarity	α_K	α_L	α_{M+}	α_{total}	
24.34 (1)	0.014 (2)[#]	M1+0.01%E2 δ = 0.01	–	242 (4)	80	322 (5)	α
26.427 (2)	< 0.154[‡]	M1+1%E2 δ = 0.10	–	252 (4)	86	338 (5)	α
32.64 (1)	0.0041 (6)[#]	M1+0.02%E2 δ = 0.014	–	102.6 (15)	33.8	136.4 (20)	α
34.97 (1)	–	M1+1%E2 δ = 0.10	–	98.7 (14)	33.2	131.9 (19)	α
35.90 (1)	–	M1+1.8%E2 δ = 0.135	–	101.5 (15)	34.5	136.0 (19)	α
43.11 (1)	0.014 (3)[#]	M1+0.2%E2 δ = 0.045	–	46.1 (7)	15.2	61.3 (9)	α
43.33 (1)	0.0019 (3)[#]	M1+9.1%E2 δ = 0.32	–	93.5 (14)	33.2	126.7 (18)	α
43.83 (2)	–	M1+0.9%E2 δ = 0.095	–	47.3 (7)	15.8	63.1 (9)	α
43.89 (2)	–	M1+1.3%E2 δ = 0.115	–	49.2 (7)	16.5	65.7 (10)	α
46.833 (3)	0.0016 (3)[#]	M1+0.4%E2 δ = 0.063	–	36.7 (6)	12.1	48.8 (7)	α
48.60 (5)	IT decay	E4	–	3.33 (5) x 10^5	3.71 (6) x 10^5	7.04 (8) x 10^5	IT
49.371 (3)	29.1 (9)	E1	–	0.615 (9)	0.206	0.821 (12)	α
53.2 (6)	–	(M1+E2)	–	–	–	–	α

Adopted E_γ (keV)	Adopted P_γ per 100 α[*]	Multipolarity	α_K	α_L	α_{M+}	α_{total}	
53.67 (1)	0.45 (6)	M1+5.9%E2 δ = 0.25	–	34.2 (5)	11.8	46.0 (7)	α
53.85 (2)	0.0006 (3)[#]	M1+2.4%E2 δ = 0.16	–	27.8 (4)	9.4	37.2 (6)	α
57.51 (1)	0.21 (5)	E1	–	0.412 (6)	0.137	0.549 (8)	α
59.32 (1)	–	M1+E2	–	–	–	–	α
60.247 (3)	1.19 (11)	M1+0.5%E2 δ = 0.07	–	17.34 (25)	5.76	23.1 (4)	α
62.330 (4)	–	E2	–	98.9 (14)	37.1	136.0 (19)	α
66.92 (1)	3.25 (10)	E1	–	0.277 (4)	0.091	0.368 (6)	α
67.92 (2)	0.87 (7)	M1+11%E2 δ = 0.35 (6)	–	18 (2)	6	24 (3)	α
73.72 (1)	1.71 (12)	E1	–	0.214 (3)	0.071	0.285 (4)	α
75.98 (1)	0.0021 (3)[#]	E2	–	38.4 (6)	14.4	52.8 (8)	α
79.48 (1)	0.027 (5)[#]	M1+50%E2 δ = 1.0 (2)	–	19 (3)	7	26 (4)	α
79.73 (2)	–	E2	–	30.6 (5)	11.5	42.1 (6)	α
85.16 (7)	0.21 (7)	M1+50%E2 δ = 1.0 (2)	–	14 (2)	5	19 (3)	α
86.674 (2)	4.97 (15)	M1+1%E2 δ = 0.10	–	5.98 (9)	1.97	7.95 (12)	α
89.60 (5)	0.29 (7)	–	–	–	–	–	α
92.48 (1)	0.61 (7)	E1	–	0.1184 (17)	0.0390	0.1574 (22)	α
93.88 (1)	0.79 (9)	E1	–	0.1138 (16)	0.0375	0.1513 (22)	α
95.22 (1)	–	M1+E2	–	–	–	–	α
96.204 (3)	–	E1	–	0.1068 (15)	0.0352	0.1420 (20)	α
96.78 (1)	0.072 (12)[#]	E2	–	12.28 (18)	4.62	16.90 (24)	α
97.18 (2)	0.0016 (8)[#]	E2	–	12.05 (17)	4.53	16.58 (24)	α
109.61 (1)	≤ 4.0 (3)	M1+50%E2 δ = 1.0 (2)	–	4.9 (5)	1.8	6.7 (7)	α
109.618 (3)	≤ 4.0 (3)	E1	–	0.0760 (11)	0.0250	0.1010 (15)	α
111.18 (1)	0.55 (9)	E1	–	0.0733 (11)	0.0241	0.0974 (14)	α
113.9 (5)	–	E2	–	5.77 (15)	2.17	7.94 (20)	α
114.3 (6)	–	–	–	–	–	–	α
117.2 (6)	–	E1	–	0.0639 (13)	0.0211	0.0850 (17)	α
117.80 (7)	–	(M1+E2)	–	–	–	–	α
117.85 (7)	–	E2	–	4.93 (7)	1.85	6.78 (10)	α
121.59 (2)	–	E2	0.178 (3)	4.27 (6)	1.612	6.06 (9)	α
121.645 (9)	–	E2	0.179 (3)	4.27 (6)	1.601	6.05 (9)	α
122.81 (1)	0.008 (4)[#]	M1+50%E2 δ = 1.0 (2)	5.4 (12)	3.11 (22)	1.09	9.6 (9)	α
126.92 (1)	0.028 (14)	E2	0.196 (3)	3.51 (5)	1.324	5.03 (7)	α
131.50 (5)	0.059 (14)	E1	0.205 (3)	0.0475 (7)	0.0155	0.268 (4)	α
132.07 (6)	–	E1	0.203 (3)	0.0470 (7)	0.0150	0.265 (4)	α
135.21 (2)	1.47 (8)	E1	0.192 (3)	0.0443 (7)	0.0147	0.251 (4)	α
136.045 (2)	2.05 (6)	E1	0.190 (3)	0.0436 (6)	0.0137	0.247 (4)	α
139.05 (3)	≤ 0.024 (7)	E1	0.180 (3)	0.0412 (6)	0.0135	0.235 (4)	α
139.11 (2)	≤ 0.024 (7)	E2	0.211 (3)	2.32 (4)	0.869	3.40 (5)	α
151.01 (3)	0.018 (4)	E1	0.1495 (21)	0.0334 (5)	0.0111	0.194 (3)	α
152.70 (2)	≤ 0.150 (8)	E1	0.1458 (21)	0.0325 (5)	0.0107	0.189 (3)	α
152.73 (1)	≤ 0.150 (8)	E1	0.1457 (21)	0.0324 (5)	0.0107	0.189 (3)	α
153.19 (1)	0.068 (8)[#]	E1	0.1447 (21)	0.0322 (5)	0.0101	0.187 (3)	α
153.87 (1)	0.721 (22)	M1+1.9%E2 δ = 0.14	5.53 (8)	1.123 (16)	0.367	7.02 (10)	α
156.451 (3)	0.059 (10)	E1	0.1379 (20)	0.0305 (5)	0.0100	0.1784 (25)	α
160.61 (2)	0.09 (4)	–	–	–	–	–	α
163.1 (5)	≤ 3.50 (10)	M1+50%E2 δ = 1.0 (2)	2.5 (5)	1.04 (3)	0.36	3.9 (5)	α

Adopted E_γ (keV)	Adopted P_γ per 100 α[*]	Multipolarity	α_K	α_L	α_{M+}	α_{total}	
163.29 (1)	≤ 3.50 (10)	M1+50%E2 δ = 1.0 (2)	2.5 (5)	1.04 (3)	0.36	3.9 (5)	α
164.64 (7)	–	(M1 + E2)	–	–	–	–	α
165.97 (15)	0.010 (5)	–	–	–	–	–	α
170.7 (8)	0.136 (10)	(M1+50%E2) δ = 1.0 (2)	2.2 (5)	0.882 (23)	0.318	3.4 (5)	α
174.76 (6)	0.038 (10)	M1+50%E2 δ = 1.0 (2)	2.1 (5)	0.809 (17)	0.191	3.1 (4)	α
176.66 (2)	0.006 (3)	E2	0.181 (3)	0.804 (12)	0.300	1.285 (18)	α
182.878 (2)	0.199 (7)	E1	0.0965 (14)	0.0206 (3)	0.0067	0.1238 (18)	α
189.10 (1)	0.059 (10)	E1	0.0894 (13)	0.0190 (3)	0.0062	0.1146 (16)	α
190.88 (5)	0.023 (5)	E1	0.0875 (13)	0.0185 (3)	0.0061	0.1121 (16)	α
194.59 (2)	0.308 (10)	E1	0.0837 (12)	0.01768 (25)	0.00582	0.1072 (15)	α
196.52 (1)	0.021 (10)	E1	0.0819 (12)	0.01725 (25)	0.00565	0.1048 (15)	α
206.39 (1)	0.34 (4)	E2	0.1454 (21)	0.412 (6)	0.1536	0.711 (10)	α
213.19 (1)	0.012 (4)	M1+50%E2 δ = 1.0 (2)	1.19 (24)	0.401 (11)	0.139	1.73 (25)	α
215.522 (4)	0.129 (21)	E1	0.0664 (10)	0.01376 (20)	0.00454	0.0847 (12)	α
232.43 (1)	0.122 (7)	E1	0.0560 (8)	0.01145 (16)	0.00375	0.0712 (10)	α
233.69 (10)	0.028 (7)	–	–	–	–	–	α
236.90 (6)	0.010 (5)	M1+50%E2 δ = 1.0 (2)	0.89 (18)	0.280 (12)	0.100	1.27 (19)	α
238.35 (7)	0.0035 (18)	E1	0.0530 (8)	0.01078 (16)	0.00352	0.0673 (10)	α
250.33 (3)	≤ 0.122 (10)	(M1+50% E2) δ = 1.0 (2)	0.77 (15)	0.233 (12)	0.077	1.08 (16)	α
250.37 (2)	≤ 0.122 (10)	E1	0.0475 (7)	0.00958 (14)	0.00312	0.0602 (9)	α
270.55 (7)	0.0063 (18)	E1	0.0400 (6)	0.00798 (12)	0.00262	0.0506 (7)	α
272.80 (6)	0.0081 (18)	M1+50%E2 δ = 1.0 (2)	0.61 (12)	0.176 (11)	0.064	0.85 (13)	α
280.11 (1)	0.0130 (14)	E1	0.0371 (6)	0.00735 (11)	0.00235	0.0468 (7)	α
299.23 (6)	0.006 (3)	M1+50%E2 δ = 1.0 (2)	0.48 (9)	0.131 (9)	0.039	0.65 (10)	α

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[*] gamma rays with emission probabilities denoted by a dash (–) are believed to be relevant to the α-decay scheme, but could not be quantified in terms of P_γ per 100 α, and are omitted from the final recommendations.

[#] not observed in γ-ray measurements of the α-decay mode of ^{242m}Am – derived from equivalent (n,γ) studies (1990Ho02).

[‡] reported emission probability of 1.36 (10) per 100 α decays exceeds expectations considerably from the point of view of the proposed decay scheme and the internal conversion coefficients of this (M1 + 1 % E2) transition – value was reduced to < 0.154 to maintain a satisfactory balance for depopulation of the 26.427(2)-keV nuclear level and population to the ground state of ^{238}Np.

Multipolarities and Internal Conversion Coefficients

The nuclear level schemes specified by Akovali and Chukreev *et al.* have been used to define the multipolarities of the gamma transitions on the basis of known spins and parities (2002Ak06, 2002Ch52). Mixing ratios for many of the (M1 + E2) transitions up to gamma-ray energies of 153.87-keV are the assignments proposed by Hoff *et al.* (1990Ho02), while others were arbitrarily assigned mixing ratios of 1.0 with an uncertainty of 20 %. Others were derived from consideration of population-depopulation of the relevant nuclear levels. Recommended internal conversion coefficients have been determined from the frozen orbital approximation of Kibédi *et al.* (2008Ki07), based on the theoretical model of Band *et al.* (2002Ba85, 2002Ra45).

Significant conflict and inconsistencies remain in the proposed decay scheme for the rather small α branch, despite the impressive work of Hoff *et al.* (1990Ho02). Emphasis has been placed on the validity and comprehensive nature of the α-spectroscopy studies of Baranov *et al.* and Hoff *et al.* (1979Ba67, 1990Ho02) that may be of questionable merit. There are also very strong indications that the known gamma-ray data are unable to support the significant γ depopulation of the 407.59- and 342.439-keV nuclear levels of ^{238}Np. Arguably, further accurate high-resolution gamma-ray spectroscopy studies are required to develop and complete the rather complex α-decay mode with much greater confidence.

Atomic Data

The x-ray and Auger-electron data have been calculated using the evaluated gamma-ray data, and atomic data from 1996Sc06, 1998ScZM and 1999ScZX. Both the x-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.01, 28 January 2003, with the emission.101 database extended to Z = 96 to calculate component L x-ray data for IT decay to ^{242}Am). This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data. A number of the gamma-ray emission probabilities can only be quantified in terms of recommended upper limits (≤ and <) – EMISSION calculations have been undertaken with these values reduced by a factor of approximately two and assigned uncertainties of the same magnitude.

K and L X-ray emission probabilities per 100 disintegrations of ^{242m}Am.

			Energy (keV)	Photons per 100 disint.
XL		(Np)	11.871 – 21.491	0.37 (4)
	XL_l	(Np)	11.871	0.0090 (9)
	XL_α	(Np)	13.761 – 13.946	0.143 (13)
	XL_η	(Np)	15.861	0.0022 (4)
	XL_β	(Np)	16.109 – 17.992	0.164 (13)
	XL_γ	(Np)	20.784 – 21.491	0.040 (3)
XK_α	$XK_{\alpha 2}$	(Np)	97.069	0.019 (9)
	$XK_{\alpha 1}$	(Np)	101.059	0.030 (14)
$XK'_{\beta 1}$	$XK_{\beta 3}$	(Np)	113.303	0.011 (5)
	$XK_{\beta 1}$	(Np)	114.234	
	$XK_{\beta 5}''$	(Np)	114.912	
$XK'_{\beta 2}$	$XK_{\beta 2}$	(Np)	117.463	0.0037 (17)
	$XK_{\beta 4}$	(Np)	117.876	
	$XKO_{2,3}$	(Np)	118.429	
XL		(Am)	12.377 – 22.836	25.0 (11)
	XL_l	(Am)	12.377	0.608 (18)
	XL_α	(Am)	14.414 – 14.620	9.33 (24)
	XL_η	(Am)	16.819	0.274 (9)
	XL_β	(Am)	16.890 – 19.110	12.2 (3)
	XL_γ	(Am)	22.072 – 22.836	2.90 (8)

Electron energies were determined from electron binding energies tabulated by Larkins (1977La19) and the evaluated gamma-ray energies. Absolute electron emission probabilities were calculated from the evaluated absolute gamma-ray emission probabilities and associated internal conversion coefficients.

Data Consistency

An effective Q-value of 74.31 (5) keV has been adopted from the atomic mass evaluation of Audi *et al*. (2003Au03) while in the course of formulating the decay scheme of ^{242m}Am. This value has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{242m}Am alpha- and IT-decay processes (i.e. α, conversion electrons, γ, etc.):

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 72.9\ (12)\ \text{keV}$$

Percentage deviation from the effective Q-value of Audi *et al.* is (1.9 ± 1.6) %, which supports the derivation of a reasonably consistent decay scheme with a large variant. Much of this deviation can be attributed to the incompleteness of the recommended alpha- and gamma-transition data within the small alpha-decay mode.

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^{242}Cm - Comments on evaluation of decay data
by V.P. Chechev

This evaluation was completed in February 2005 (see 2006Ch34) and then corrected in October 2009 with a literature cut-off by the same date.

1 Decay Scheme

The decay scheme is based on the evaluation of Chukreev *et al.* (2002Ch52) and can be considered essentially complete although some weak gamma-ray transitions have not been observed in ^{242}Cm alpha decay. Such gamma rays were taken from ^{238}Am→^{238}Pu, ^{238}Np→^{238}Pu decays and have been included in the decay scheme.

2 Nuclear Data

Q(α) is from 2003Au03.

The evaluated half-life of ^{242}Cm is based on the experimental results given in Table 1. Re-estimated values were used for averaging when needed.

Table 1. Experimental values of the ^{242}Cm half-life (in days)

Reference	Author(s)	Original value	Re-estimated value	Measurement method
1950Ha14	Hanna et al.	162.5 (20)	-	α-counting with low geometry counter
1954Gl37	Glover and Milsted	162.46 (14) [a]	162.46 (32) [c]	α-counting with low geometry counter
1954Hu32	Hutchinson and White	163.0 (18)	-	Calorimetry
1957Treiman	Treiman et al.	162.7 (1)	-	Calorimetry
1965Fl02	Flynn et al.	164.4 (4)	163.1 (4) [d]	2π α counting
1975Ke02	Kerrigan and Banick	163.2 (2) [b]	-	Calorimetry
1977Di04	Diamond et al.	162.76 (4)	162.76 (8) [c]	Intermediate geometry α-counting
1979Ch41	Chang et al.	163.02 (11)	163.02 (18) [c]	α-counting with low geometry counter
1980Jadhav	Jadhav et al.	162.13 (215)	162.13 (225)	α-spectrometry with solid state detector
1981Us03	Usuda and Umezawa	161.35 (20)	161.35 (30) [c]	α-counting with 2π proportional counter
1982Ag02	Aggarwal et al.	163.17 (6)	163.17 (11) [c]	α-counting with proportional counter
1982Ag02	Aggarwal et al.	162.82 (21)	162.82 (26) [c]	α-spectrometry with solid state detector
1984Wi14	Wiltshire et al.	163.0 (2)	-	α-counting with low geometry counter

[a] The uncertainty of 0.27 quoted by authors, which corresponds to 95 % confidence level, has been reduced by a factor 2.

[b] The uncertainty of 0.4 quoted by authors, which corresponds to 95 % confidence level, has been reduced by a factor 2.

[c] Quoted uncertainties have been re-estimated in 1986LoZT.

[d] The value has been recalculated in 1977Di04.

The LWEIGHT and EV1NEW computer programs identified two outliers in the above data set. These are the values from 1981Us03 and 1980Jadhav. Omitting these values in the calculation and using the remaining 11 results produced a weighted mean of 162.86 with an internal uncertainty of 0.05 and an external uncertainty of 0.06 ($\chi^2/\nu = 1.6$). The EV1NEW program has chosen the smallest experimental uncertainty of 0.08 as the uncertainty of the weighted average.

Thus the recommended value of the ^{242}Cm half-life is 162.86 (8) days.

The evaluated spontaneous fission partial half-life of ^{242}Cm is based on the experimental results given in Table 2. Re-estimated values were used for averaging when needed.

Table 2. Experimental values of the ^{242}Cm spontaneous fission half-life (in 10^6 years)

Reference	Author(s)	Original value	Re-estimated value [a]	Measurement method
1951Ha87	Hanna et al.	7.2 (2)	-	Fission fragment counting, ionization chamber
1967Ar09	Armani and Gold	6.09 (18)	6.82 (18)	Fission neutron counting, LiI detector
1979Ch41	Chang et al.	7.46 (6)	-	Mica fission track detector
1982Ra33	Raghuraman et al.	7.15 (15)	-	Solid state detector
1982UmZZ	Umezawa et al.	6.89 (17)	-	Mica fission track detector
1986Ze06	Zelenkov et al.	6.9 (3)	6.98 (33)	α/SF, Si(Au) detectors
1989Us04	Usuda et al.	6.96 (18)	-	Absolute fission track counting

[a] Recalculated in 2000Ho27

Omitting the value of 1979Ch41 (outlier) the weighted mean of the six remaining values becomes 7.005 with an internal uncertainty of 0.076 and an external uncertainty of 0.063 ($\chi^2/\nu = 0.69$).

The recommended value of the ^{242}Cm spontaneous fission half-life is 7.01 (15) 10^6 years, where the uncertainty is the smallest quoted uncertainty of 6 experimental results.

2.1 α Transitions

The energies of the alpha-particle transitions given in Section 2.1 have been deduced from the Q value and the level energies given in Table 3 from 2002Ch52.

Table 3. ^{238}Pu levels populated in the ^{242}Cm α-decay

Level number	Energy (keV)	Spin and parity	Half-life	Probability of α-transition (%)
0	0.0	0^+	87.74 (3) a	74.06 (7)
1	44.08 (3)	2^+	177 (5) ps	25.94 (7)
2	146.00 (5)	4^+		0.034 (2)
3	303.42 (7)	6^+		0.0046 (5)
4	513.62 (16)	8^+		2×10^{-5}
5	605.08 (7)	1^-		$2.5 (5)\times10^{-4}$
6	661.28 (11)	3^-		$1.3 (3)\times10^{-5}$
7	763.22 (12)	5^-		$\leq 2.2\times10^{-7}$
8	941.44 (9)	0^+		$3.5 (7)\times10^{-5}$
9	962.72 (8)	1^-		$1.13 (21)\times10^{-6}$
10	983.00 (9)	2^+		$1.7 (5)\times10^{-6}$
11	1018.6 (3)	1^-		$\leq 2\times10^{-7}$
12	1028.62 (5)	2^+		$3.7 (10)\times10^{-6}$
13	1125.79 (17)	(4^+)		$3.1 (10)\times10^{-7}$
14	1228.69 (22)	0^+		$5.5 (15)\times10^{-7}$
15	1264.29 (22)	2^+		$5.2 (14)\times10^{-7}$

The emission probabilities of the most intensive transitions $\alpha_{0,i}$ (i = 0 to 4) have been obtained by averaging experimental data (Table 4). The emission probabilities of the remaining α-particle transitions have been deduced either from the P(γ+ce) decay-scheme balances or by averaging experimental and deduced values (for example, $\alpha_{0,5}$).

Table 4. Experimental, calculated and recommended α-transition probabilities (%) in the ^{242}Cm decay

	α-particle energy (keV)	1953As14	1958Ko87	1963Dz07	1966Ba07	1998Ya17	Deduced from decay-scheme balance c	Recommended
$\alpha_{0,0}$	6113	73.7 (5)	73.5 (5)	74 (2)	74.2 (5) [a]	74.08 (7)		74.06 (7) [d]
$\alpha_{0,1}$	6069	26.3 (5)	26.5 (5)	26.0 (9)	25.8 (5) [a]	25.92 (6)		25.94 (7) [d]
$\alpha_{0,2}$	5969	0.035 (2)[a]	0.030 (2) [b]	0.035 (2)	0.036 (2) [a]			0.034 (2) [e]
$\alpha_{0,3}$	5816		0.0046 (5)		0.0046			0.0046 (5) [f]
$\alpha_{0,4}$	5608			1963Bj01	$2\cdot10^{-5}$			$2\cdot10^{-5}$ [g]
$\alpha_{0,5}$	5518			$2.8\ (5)\cdot10^{-4}$	$2.5\ (6)\cdot10^{-4}$		$2.6\ (7)\cdot10^{-4}$	$2.5\ (5)\cdot10^{-4}$ [e]
$\alpha_{0,6}$	5462						$1.3\ (3)\cdot10^{-5}$	$1.3\ (3)\cdot10^{-5}$ [c]
$\alpha_{0,7}$	5366						$2.2\cdot10^{-7}$	$2.2\cdot10^{-7}$ [c]
$\alpha_{0,8}$	5187			$3.4\ (8)\cdot10^{-5}$	$2.5\ (8)\cdot10^{-5}$		$3.5\ (7)\cdot10^{-5}$	$3.5\ (7)\cdot10^{-5}$ [c]
$\alpha_{0,9}$	5166						$1.13\ (21)\cdot10^{-6}$	$1.13\ (21)\cdot10^{-6}$ [c]
$\alpha_{0,10}$[h]	5146				$\leq 5\cdot10^{-6}$		$1.7\ (5)\cdot10^{-6}$	$1.7\ (5)\cdot10^{-6}$ [c]

[a] No uncertainties are quoted by the authors. The uncertainties have been adopted by the evaluator based on the similarity of the spectra measured with magnetic spectrometers in 1953As14, 1958Ko87 and 1966Ba07.
[b] The uncertainty of 0.001 quoted by authors has been increased by a factor of 2 by the evaluator (see [a]).
[c] Deduced from P(γ+ce) decay-scheme balances for corresponding ^{238}Pu levels.
[d] Weighted average of experimental values The experimental data of 1998Ya17 have been obtained by the most accurate method (using a semiconductor detector).
[e] Weighted average of experimental and deduced values.
[f] Adopted experimental value from 1958Ko87.
[g] Adopted experimental value from 1966Ba07.
[h] The probabilities of remaining alpha-transitions ($\alpha_{0,11}$ and $\alpha_{0,15}$) have been deduced from P(γ+ce) decay-scheme balances.

2.2 γ Transitions and Internal Conversion Coefficients

The recommended energies of gamma-ray transitions are essentially the same as the gamma-ray energies because nuclear recoil is negligible.

The probabilities, P(γ+ce), for gamma-ray transitions of 44-($\gamma_{1,0}$), 102- ($\gamma_{2,1}$), 157-($\gamma_{3,2}$), and 210-keV ($\gamma_{4,3}$) have been deduced from transition- probability balances, using the emission intensities of α-transitions directly measured.

For E0- gamma transitions 941-($\gamma_{8,0}$) and 1229-keV ($\gamma_{14,0}$) the P(γ+ce) values have been taken from data on the electron capture decay ^{238}Am → ^{238}Pu (see 2002Ch52 and references therein).

The remaining P(γ+ce) values have been obtained from the gamma-ray emission probabilities and the total internal conversion coefficients (ICC's). The experimental values of ICC's have been adopted for (E0+E2) gamma-ray transitions 939-($\gamma_{10,1}$) and 1220-keV ($\gamma_{15,1}$). The remaining ICC's have been interpolated using the BrIcc package with the so called "*Frozen Orbital*" approximation (2008Ki07). The relative uncertainties of α_K, α_L, α_M, α_T for pure multipolarities have been taken as 2 %.

The multipolarities and E2/M1, M2/E1 mixing ratios have been taken from 2002Ch52. These are based on conversion electron measurements of 1952Du12, 1956Ba95, 1956Sm18, 1960As10, and 1965Ak02 made in the ^{242}Cm α-decay.

3 Atomic Data

3.1 Fluorescence yields

Fluorescence yield data are from 1996Sc06 (Schönfeld and Janβen).

3.1.1 X rays

The Pu KX-ray energies and relative emission probabilities have been taken from 1999Schönfeld, where the calculated energy values are based on X-ray wavelengths from 1967Be65 (Bearden). In Table 5 the recommended values of Pu KX-ray energies are compared with experimental results.

Table 5. Experimental and recommended values of Pu KX-ray energies (keV)

	1980Di13	1982Ba56	Recommended
$K\alpha_2$	99.55 (3)	99.530 (2)	99.525
$K\alpha_1$	103.76 (3)	103.741 (2)	103.734
$K\beta_3$	116.27	116.242 (2)	116.244
$K\beta_1$	117.26	117.233 (2)	117.228
$K\beta_{2,4}$	120.60 (15)	-	120.553
$KO_{2,3}$	121.55 (6)	-	121.543

The Pu KX-ray energies in 1980Di13 were measured in the alpha decay of ^{245}Cm. The relative emission probabilities of KX-rays were given as:

$K\alpha_2 : K\alpha_1 : K\beta_3 : K\beta_1 : K\beta_{2,4}$ = 64.7 (23) : 100.0 (33) : 12.9 (7) : 23.1 (10) : 8.9 (5).

3.1.2 Auger Electrons

The energies of Auger electrons have been calculated from atomic electron binding energies.

The P(KLX)/P(KLL), P(KXY)/P(KLL) ratios have been taken from 1996Sc06.

4 α Emissions

The energy of the alpha-particle group to the ground state of ^{238}Pu, $E(\alpha_{0,0})$ is from the absolute measurement of 1971Gr17, with a correction of –0.20 keV recommended by A. Rytz in 1991Ry01.

The energies of all other α particles have been deduced from Q_α and the ^{238}Pu level energies including the recoil energy corrections (see 2002Ch52).

In Table 6 the recommended values of α-particle energies are compared with the experimental results obtained with magnetic alpha spectrometers.

Table 6. Experimental [a] and recommended α-emission energies in the decay of ^{242}Cm (keV)

	1953As14	1958Ko87	1963Dz07	1966Ba07 1971Bb10	1971Gr17	Recommended
$\alpha_{0,0}$	6113	6114	6113 (1)	6112.9 (3)	6112.72 (8)	6112.72 (8)
$\alpha_{0,1}$	6069	6070	6069 (1)	6069.5 (5)	6069.43 (12)	6069.37 (9)
$\alpha_{0,2}$	5968	5968 (2)	5969 (3)	5970		5969.24 (9)
$\alpha_{0,3}$	-	5816 (2)	-	5817		5816.39 (11)
$\alpha_{0,4}$	-	-	-	5609		5607.76 (16)
$\alpha_{0,5}$	-	-	-	5514		5517.75 (11)
$\alpha_{0,8}$	-	-	-	5189		5186.95 (12)
$\alpha_{0,10}$	-	-	-	5146		5146.07 (12)

[a] Authors' values have been adjusted for changes in calibration energies (see 1991Ry01)

5 Electron emissions

The energies of conversion electrons have been obtained using gamma-ray transition energies and electron binding energies. The emission probabilities of conversion electrons have been deduced from the evaluated P(γ) and ICC values.

The absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program (2000Schönfeld).

6 Photon emissions

6.1. X-Ray emissions

The absolute emission probabilities of U KX- and U LX-rays in decay of ^{242}Pu have been calculated using the EMISSION computer program (2000Schönfeld).

The calculated total absolute emission probability of LX-rays P(XL)= 9.92 (23) % agrees well with the experimental value of 9.70 (14) % from 1970By01 and disagrees with the value of 11.7 (3) % measured in 1971Swinth.

The relative Pu LX-ray emission probabilities in ^{242}Cm α-decay measured in 1990Po14 [4.9 (8)-Ll; 66 (7)-Lα; 100-Lηβ; 23 (3)-Lγ] agree well with the values calculated using the EMISSION computer program with the exception of $L\alpha/L\eta\beta^{calc.}$ = 79 (4) / 100. The latter agrees well with the experimental result from 1995Jo23, Lα/Lηβ (Pu) = 80.9 (9) / 100, obtained for LX-rays in the decay of other even-even curium isotope – ^{244}Cm.

6.2 Gamma emission

6.2.1. Gamma-ray energies

The energy of the 44-keV gamma ray ($\gamma_{1,0}$) is from ^{238}Np→^{238}Pu β^{-}decay (1972Wi22); it agrees with the less accurate measurements in ^{242}Cm α-decay (44.11 (5) keV - 1956Sm18) and in ^{238}Am ε-decay (44.1 (1) keV - 1972Ah04).

The energies of the 102-($\gamma_{2,1}$), 157-($\gamma_{3,2}$), 336-($\gamma_{8,5}$), 358-($\gamma_{9,5}$), 605-($\gamma_{5,0}$), 940-($\gamma_{10,1}$), and 941-($\gamma_{8,0}$) keV gamma rays have been obtained from the available experimental data of 1981Le15 (^{242}Cm α-decay and ^{238}Np β^{-}-decay), 1972Wi22, 1972Ah04, 1956Sm18, and 1971Po09 (^{238}Am ε-decay) using the adopted ^{238}Pu level energies.

The energies of the 210-($\gamma_{4,3}$), 617-($\gamma_{7,2}$), and 883-($\gamma_{12,2}$) keV gamma rays, which were not observed in the ^{242}Cm α-decay, have been deduced from the adopted level energies. The energies of the remaining gamma rays have been taken from the measurements of 1981Le15 (^{242}Cm α-decay).

6.2.2. Gamma-ray emission probabilities

The absolute emission probabilities for gamma-rays of 44-($\gamma_{1,0}$), 102- ($\gamma_{2,1}$), 157-($\gamma_{3,2}$), and 210-($\gamma_{4,3}$) keV have been deduced from decay-scheme probability balances using the intensities of α-transitions evaluated directly from experimental data.

The absolute emission probabilities of > 300 keV gamma-rays (except for 883- and 1229-keV γ-rays) have been obtained from relative gamma-ray emission probabilities P(γ)/P(γ 561keV) measured in 1981Le15. The normalization factor P(γ 561keV) = $1.5 \cdot 10^{-4}$ per 100 disintegrations, which was used here, was estimated in 1981Le15 using a previous αγ coincidence measurement of the sum of the absolute emission probabilities of the 515-, 561-, 605-, and 617-keV gamma-rays (1963Le17).

P(γ 883keV) and P(γ 1229keV) are from 2002Ch52, using the experimental data on ^{238}Np β^{-}-decay and ^{238}Am ε-decay, respectively.

7. Consistency of recommended data

The most accurate Q value, Q(M), is taken from the atomic mass adjustment table of Audi et al. (2003Au03). Comparison of Q(eff)(deduced as the sum of average energies per disintegration ($\sum E_i \times P_i$) for all emissions accompanying ^{242}Cm α- decay) with the tabulated decay energy Q(M) allows to check a consistency of the recommended decay-scheme parameters obtained in this evaluation.

Here E_i and P_i are the evaluated energies and emission probabilities of the i-th alpha particle, beta particle, gamma ray, X-ray, etc. Consistency (percentage deviation) is determined by {[Q(M) – Q(eff))]/ Q(M)} ×100. “Percentage deviations above 5 % would be regarded as high and imply a poorly defined decay scheme; a value of less than 5 % indicates the construction of a reasonably consistent decay scheme” (quoted from the article by A.L. Nichols in Appl. Rad. Isotopes 55 (2001) 23-70).

For the above ^{242}Cm decay data evaluation we have Q(M) = 6215.56 (8) keV and Q(eff) = 6217 (6) keV, i.e. consistency is better than 0.12 %.

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^{243}Am - Comments on evaluation of decay data
by E. Browne, M.-M. Bé, R.G. Helmer

This evaluation was completed in September 2004 and reviewed in 2009. The literature available by April 2009 was included. Half-life and conversion coefficients have been updated.

Several measurements of the α emission intensities were carried out and their results are in good agreement. However, the available experimental γ-ray emission intensities are mostly imprecise and in poor agreement with each other.
The decay scheme overall consistency is supported by the agreement between Q(eff) = 5439.6 (40) keV, deduced from average radiation energies and intensities, and Q(α) = 5438.8 (10) keV, from the atomic mass adjustment (2003Au03).

Evaluation Procedures

The *Limitation of Relative Statistical Weight* (LWM) [1985ZiZY] method, used for averaging numbers throughout this evaluation, provided a uniform approach for the analysis of discrepant data.

1 Decay Scheme

^{243}Am decays 100 % by emission of α particles, with a minute branch of 3.8 (7) × 10^{-9} % (2002Sa53) by spontaneous fission. Other value: 3.7 (9) × 10^{-9} % (1966Gv01). The α-particle intensities (in percent) to individual levels presented in the decay scheme are experimental values from α-spectroscopic measurements. α-hindrance factors given in the decay scheme have been calculated by using a radius parameter r_0 (^{239}Np) = 1.505, average of r_0 (^{238}U) = 1.5143 (9), r_0 (^{240}U) = 1.5062 (10), r_0 (^{238}Pu) = 1.5013 (10), and r_0 (^{240}Pu) = 1.4979 (7) (1998Ak04). The level energies, spins, parities, as well as γ-ray multipolarities shown in the decay scheme are recommended values from the evaluation 2003Br12.

Levels at 71- and 122 keV are based on α-γ coincidence experiments with γ rays (169-, 50.6-, and 195 keV) that feed such levels. The de-excitations of these two levels, however, have not been observed. The expected γ rays may have been masked by more intense ones, which de-excite other levels.

2 Nuclear Data

The recommended half-life of ^{243}Am is 7367 *a*, a weighted average of the values given in Table 1, the most accurate value (from 2007Ag02) contributes 54 % to the statistical weight. The calculated internal uncertainty is 17 *a*. However, the recommended uncertainty is the smallest uncertainty in the input values, i.e., 23 *a*. This half-life compares well with other recommended values such as 7370 (40) *a* (1992Ak06), 7366 (20) *a* (1991BaZS), and 7370 (15) *a* (1986LoZT).

Q_α = 5438.8 (10) keV is from the atomic mass adjustment 2003Au03.

Table 1. ^{243}Am measured half-life values

Reference	**Method**	**$T_{1/2}(^{243}Am)/T_{1/2}(^{241}Am)$**	**$T_{1/2}(^{243}Am)$ (*a*)**	**u_c**	**Remarks**
1959Ba22	Relative activity	16.85 (35)	7289.3 *	151.7	
1960Be10	Relative activity	16.70 (10)	7224.4 *	100.0	An uncertainty of 1.4 % (100 *a*) from 1960Be10 is mostly systematic. Thus, dividing this value by the square root of the number of measurements (5) is questionable and was not done in the evaluation of 1986LOZT. Omitted from analysis.
1968Br22	Relative activity	16.96 (13)	7336.9 *	57.2	
	Specific activity		7390	50	
1974Po17			7380	34	This value is the weighted mean result from specific $T_{1/2}(^{243}Am)$ determination and from measurements relative to $T_{1/2}(^{241}Am)$
1980Ag05	Relative activity	17.010 (95)	7359 *	42	Superseded by 2007Ag02
2007Ag02	Relative activity	17.022 (27)	7363.7 *	23	
	LWM		7367	17	χ^2 /n-1 = 0.2 , χ^2 crit = 3.3, int. uc. = 17
		Recommended value	**7367**	**23**	Weighted average. Some results depend on the $T_{1/2}(^{241}Am)$ and then are not independent so the uncertainty is the minimum value from input.

* Relative to $T_{1/2}(^{241}Am)$ = 432.6 (6) *a* (Chechev in 2004BeZQ).

3 Atomic Data

X-ray and Auger (relative and absolute) electron emission probabilities given in Sections 3 and 5, respectively, have been calculated by means of the computer code EMISSION (version 3,01, Nov. 3, 1999) [1], which makes use of the atomic data from 1996Sc06, from reference [2], and from the evaluated γ-ray data given in Sections 2.1 and 4.2. In addition, internal conversion electron energies and absolute emission probabilities for the strongest lines are presented in Section 5. Electron energies have been calculated using electron binding energies from 1977La19, and γ-ray energies from Section 2.1. Absolute electron emission probabilities have been calculated using absolute γ-ray emission probabilities given in Section 4.2 and conversion coefficients from Section 2.1.

4 Alpha Particles

α-Particle Energies

Most of the recommended α-particle energies in this evaluation are weighted averages (*Limited Relative Statistical Weight* method, LWM) of values from 1964Ba26 and 1968Ba25 (magnetic spectrograph), and from 1996Sa24 and 2002Da21 (semiconductor detectors). Values reported by 2002Da21 are from the analysis of an α-particle spectrum measured by 1992Ga01.

A. Rytz (1991Ry01) has critically evaluated the α-particle groups at 5233, 5275, and 5379 keV. His energies, also recommended in this evaluation, are virtually the same as the weighted average energies given in Table 2. This table shows the results of various measurements as well as the values recommended in this evaluation.

Table 2. ^{243}Am Alpha-Particle Energies

1964Ba26	1968Ba25	1996Sa24	2002Da21&	W. Average	Rec. Values
4695 (3)			[4697]#		4695 (3)
4919 (3)					4919 (3)
4930 (3)			[4936]#		4930 (3)
4946 (3)			[4951]#		4946 (3)
4997 (3)			[5001]#		4997 (3)
5008 (3)		5002(5)	5012 (5)	5008 (3)	5008 (3)
5029 (3)		5030 (5)		5029 (3)	5029 (3)
5035 (3)			5037 (5)	5035 (3)	5035 (3)
5088 (3)		5083 (5)	5091 (5)	5088 (5)	5088 (5)
5113 (1)		5109 (5)	5113 (5)	5113 (1)	5113 (1)
5181 (1)		5177 (5)	5178 (5)	5181 (1)	5181 (1)
5234 (1)	5232.9 (10)	5232 (5)	5233 (5)	5233.4 (10)	5233.3 (10)*
5276 (1)	5274.8 (10)	5275 (5)	5275 (5)	5275.3 (10)	5275.3 (10)*
5321 (1)		5319 (5)	5318 (5)	5321 (1)	5321 (1)
5350 (1)		5350 (5)	5349 (5)	5350 (1)	5349.4 (23)*

\# 2002Da21 did not measure the alpha spectrum of ^{243}Am. The alpha spectrum used was from 1992Ga01, who had not identified these very weak peaks. 2002Da21 reported for these peaks, intensities ranging from 2 to 13 times those given by 1964Ba26. Evaluators have interpreted this discrepancy as possibly caused by *spurious peaks* produced in the spectral peak-shape analysis of 2002Da21. Thus, they did not use these α-particle energies in the averaging process.

* From 1991Ry01.

& Rounded values. Uncertainties assigned by evaluators are typical values for spectra measured with semiconductor detectors.

α-Particle Emission Intensities

Table 3 shows the emission intensities measured by various authors. The uncertainties given by all of them (except one, 1996Sa24) are statistical values deduced from spectral peak-shape analysis. Such uncertainties do not include a constraint imposed by normalizing the sum of the emission probabilities to 100, that is, to absolute emission intensities (p_i(%)) per 100 α-particle disintegrations of the parent nuclide. The following formula (1988Br07) may be used to convert uncertainties (dI_i) in relative α-particle emission intensities (I_i) to values in the absolute emission intensities (dp_i(%)):

$$dp_i(\%)/p_i(\%) = [\ (dI_i/I_i)^2\,(1 - 2\ I_i/\Sigma I_k) + \Sigma dI_k^2/(\Sigma I_k)^2\ ]^{1/2} \qquad (1)$$

The uncertainties given by 1996Sa24 (see Table 3) are those in the absolute α-emission intensities (dp_i(%)), whereas the other authors give uncertainties only in the relative α-emission intensities (dI_i). This situation significantly affects only the two most intense α-particle groups for which 1996Sa24 give the same uncertainty of 0.03.

The energies and absolute emission intensities recommended in this evaluation are given in Section 2.2. The following description shows the procedure used here for determining these recommended absolute emission intensities:

1. Changing the uncertainty in the 5275-keV α-particle group before averaging from its absolute value of dp (%) = 0.03 (1996Sa24) to a relative value (estimated by evaluators) of dI = 0.06.

2. Averaging (i.e., weighted averages, LWM) the relative emission intensities given by various authors (1955St98, 1956Hu96, 1964Ba26, 1966Le13, 1992Ga01, 1996Sa24, 2002Da21) and depicted in Table 3. Relative emission probabilities from 1998Ya17 (also shown in Table 3) are in disagreement with those from these authors, thus significantly increasing χ^2/ν for most averages. Their uncertainties include a "non-statistical component." Unfortunately, 1998Ya17 give neither their values for these components nor the criteria used for estimating them. Therefore, data from 1998Ya17 have not been used for averaging.

3. Converting uncertainties in the recommended emission intensities (Table 3, column 9) to uncertainties in the absolute α-particle emission intensities by using formula (1). It should be noticed that only the uncertainties in the two most intense α-particle groups have been affected by this procedure.

Table 3. ^{243}Am Alpha particle emission intensities

Eα(keV)	1955St98	1956Hu96	1964Ba26	1966Le13	1992Ga01	1998Ya17	1996Sa24##	2002Da21$	Iα(avg)&&	χ^2/ν	Rec. Iα &&&
4695			0.000 6	0.001 7 (5)***				0.003 8 (4)^^			0.001 7 (5)
4919			0.000 085								0.000 085
4930			0.000 18					0.002 6 (3)^^			0.000 18
4946			0.000 34					0.002 8 (3)^^			0.000 34
4997			0.001 6#		0.001 6 (5)#		0.002 0 (4)#	0.003 1 (4)^^	0.001 8 (3)	0.39	0.001 8 (4)#
5008								0.005 2 (4)^^			
5029			0.002 2^		0.003 3 (5)^		0.004 4 (5)^	0.008 2 (5)^^	0.003 9 (4)	2.4	0.003 9 (6)^
5035											
5088			0.004		0.005 6 (7)		0.005 5 (6)	0.011 2 (6)^^	0.005 5 (5)	0.01	0.005 5 (6)
5113			0.005 4		0.010 (1)		0.010 1 (10)	0.019 (1)^^	0.010 0 (7)	0	0.010 (1)
5181	1.1 (3)&	1.3 (2)	1.1		1.36 (1)	0.98 (2)	1.388 (8)	1.391 (7)	1.383 (5)	2.0	1.383 (7)
5233	11.5 (3)*	11.5 (3)	10.6 (2)**		11.46 (3)	11.04 (7)	11.37 (3)	11.52 (2)	11.46 (6)	7.1	11.46 (5)$$
5275	87.1 (4)*	86.9 (4)	87.9 (3)**		86.74 (6)	87.42 (8)	86.79 (3)	86.60 (7)	86.74 (4)	4.1	86.74 (5)$$
5321	0.16	0.16	0.12		0.190 (7)	0.270 (6)	0.194 (3)	0.190 (3)	0.192 (2)	0.48	0.192 (3)
5349	0.17	0.17	0.16		0.230 (7)	0.298 (8)	0.243 (3)	0.240 (3)	0.240 (2)	1.5	0.240 (3)

$ 2002Da21 analyzed an α spectrum of 1992Ga01.

& Uncertainty assumed by evaluator.

* From 1955St98, quoted in 1991Ry01; uncertainties are from 1991Ry01.

4997α + 5008α

^ 5029α + 5035α

** From 1964Ba26, quoted in 1991Ry01; uncertainties are from 1991Ry01.

Uncertainties include the effect of covariances when normalizing ΣIα = 100.

^^ α-particle intensities are at least about twice those found by other authors, which suggest a possible systematic bias in the analysis of the spectrum. These values were not used for averaging.

*** Agrees well with Iα=0.001 48 (3) % from γ-ray transition intensity balance.

&& Weighted average using the Limitation of Relative Statistical Weights method. Data from 1998Ya17 have not been included. See text.

$$ Normalization of Iα to ΣIa=100 requires same values for these uncertainties. See text.

&&& Uncertainty is always greater than or equal to the smallest uncertainty in any of the experimental values used in the calculation

5 Gamma Rays

Energies

The recommended γ-ray energies given in Sections 2.1 and 4.2 are weighted averages (LWM) of values given in 1982Ah04 and 1975Pa04, complemented with values from 1996Sa23, 1969En02, and 1968Va09 (See table 4).

Table 4. ^{243}Am Gamma-ray Energies

E_γ (keV)	E_γ (keV)	E_γ (keV)	E_γ (keV)	E_γ (keV)	E_γ (keV)		E_γ (keV)
1996Sa23	1982Ah04	1975Pa04	1969En02	1968Va09	**W. Avg.***	**$\chi 2/\nu$**	**Rec. Eγ**
31.13	31.14 (3)	31.10 (15)		31.2	31.14 (3)	0.068	31.14 (3)
		43.1	43.1				43.1#
43.53	43.53 (2)	43.53 (15)		43.6	43.53 (2)		43.53 (2)
50.6				50.6			50.6&$
55.18			55.4	55.4			55.18&
74.66	74.66 (2)	74.67 (15)	74.7	74.8	74.66 (2)	0.004	74.66 (2)
86.71	86.71 (2)	86.79 (15)	86.7	86.7	86.71 (2)	0.27	86.71 (2)
98.5			98.5				98.5^
117.84		117.60 (15)	117.8	117.8			117.60 (15)#
141.89	141.89 (3)	142.18 (15)	142	142	141.90 (3)	3.6	141.90 (6)
169				169			169$
195				195			195$

* Weighted average of values in 1982Ah04 and 1975Pa04.
# From 1975Pa04
& From 1996Sa23
$ From 1968Va09
^ From 1969En02

The recommended absolute γ-ray emission (photons) and transition (photons + electrons) intensities given in Sections 4.2 and 2.2, respectively, are weighted averages (LWM) of values in 1996Sa23, 1996Wo05, 1984Va41, 1982Ah04, 1979Po20, 1977St35, 1975Pa04, 1972Ah02, 1969Al14 and 1960As02 (see Table 5).

The conversion coefficients used for deducing absolute transition probabilities (see section 2.2) are theoretical values interpolated from the Band's tables (2002Ba85) by using the computer code BrIcc (2008Ki07) with the so called "Frozen orbital" approximation.

The M1/E2 mixing ratio for $\gamma_{3,0}$(31.1 keV) $\delta =$ 0.17 was deduced from probability balance in ^{243}Am α- decay and in ^{239}U β^- -decay

The M1/E2 mixing ratios for $\gamma_{4,3}$(43.1 keV) $\delta =$ 0.38 (4) and $\gamma_{6,4}$(55,2 keV) $\delta =$ 0.75 (10) have been taken from Engelkemeir (1969En02).

The remaining M1/E2 mixing ratios are from 2003Br12 based on measurements of 1957Ho07, 1964Bl11, 1969En02.

Table 5. ^{243}Am γ-ray Absolute Emission Probabilities

Eγ (keV)	Iγ	Iγ$^{@}$	Iγ	Iγ	Iγ	Iγ	Iγ	Iγ	Iγ	Iγ	Iγ	W. Avg.	χ^2/ν	Iγ ^{a}
Rec. Value*	**1960As02**	**1968Va09**	**1969Al14**	**1972Ah02**	**1975Pa04**	**1977St35**	**1979Po20**	**1982Ah04**	**1984Va41**	**1996Wo05**	**1996Sa23**			**Rec. Value**
31.14 (3)								0.069 (7)			0.0477 (13)	0.0484 (13)	9	0.048 (4)
43.1		0.03												0.065^
43.53 (2)	4 (1)	5.3	5 (1)	5.5 (3)			5.3 (12)	6.20 (30)	6.04 (13)	5.93 (10)	5.72 (17)	5.89 (7)	1.4	5.89 (10)
50.6		0.0027									0.0062 (10)			0.0062 (10)#
55.18		0.0094									0.0168 (11)			0.0168 (11)#
74.66 (2)	69 (3)	61		66 (3)		59.1 (40)	60 (4)	68.0 (20)	68.5 (15)	66.7 (12)	68.4 (13)	67.2 (7)	1.4	67.2 (12)
86.71 (2)		0.37						0.340 (15)	0.35 (1)	0.342 (15)	0.344 (9)	0.346 (6)	0.2	0.346 (9)
98.5											0.0151 (21)			0.0151 (21)#
117.60 (15)		0.75			0.56 (8)						0.57 (5)			0.57 (5)#
141.90 (6)		0.13						0.128 (6)	0.13 (1)	0.117 (5)	0.1068 (26)	0.115 (2)	3.8	0.115 (8)
169		0.0012												0.0012$^{\&}$
195		0.00085												0.00085$^{\&}$

a Recommended absolute emission probabilities are weighted averages (LWM) of experimental values, unless otherwise noted. Uncertainty is always greater than or equal to the smallest uncertainty in any of the experimental values used in the calculation.

***** From Table 4

From 1996Sa23

& From 1968Va09

^ Estimated by 2003Br12 from α_M (43.1γ, exp.) = 31, I_M (ce, 43.1γ) / Iγ(117) = 3.56 (1969En02), and Iγ(117) = 0.57.

@ Uncertainties are at least 10 %.

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^{243}Cm -Comments on evaluation of decay data
by V.P. Chechev

This evaluation was done in October 2010 with a literature cut-off by the same date.

1. DECAY SCHEME

The structure of the adopted scheme of ^{243}Cm decay is based on the evaluations by E. Browne (2003Br12) and Y.A. Akovali (2004Ak21). The decay scheme includes two decay modes: α decay to ^{239}Pu (99.71 (3) %) and electron capture decay (EC) to ^{243}Am (0.29 (3) %).

EC branching was obtained from the EC decay half-life of 1.0 (1) × 10^4 a, as determined in 1958Ch38 from a ratio of ^{243}Am and ^{243}Cm α activities (correction for the half-lives of ^{243}Am and ^{243}Cm adopted by DDEP does not change this value), and from the total ^{243}Cm half-life of 29.1 (1) a (correction for the recommended below value of the ^{243}Cm half-life does not change the EC branching). The EC decay occurs 100 % to the ground state 5/2- of ^{243}Am (1958Ch38, 2004Ak21).

In the ^{243}Cm α decay to ^{239}Pu the intense population takes place only to levels in ^{239}Pu with energy less than 400 keV (8 excited levels and ground state) and in this part the decay scheme is well defined. Nevertheless, a number of gamma-ray transitions with energy less than 200 keV were not observed in the ^{243}Cm α decay, such as 7.86-keV, 49.4-keV, 61.5-keV, 67.8-keV, 88.1-keV, 102.0-keV, 106.1-keV, 106.5-keV, and 166.4-keV. These transitions, included in the ^{243}Cm decay scheme, have been derived from measurements of ^{239}Np and ^{239}Am decays.

For levels with higher energy, the decay scheme has not been completed since many gamma-ray transitions have not been observed yet. In addition, many levels were placed in the ^{243}Cm α decay scheme based only on questionable weak α transitions. Therefore, further measurements are needed to determine the γ transitions and ^{243}Cm α decay scheme with greater precision.

2. NUCLEAR DATA

Q(α) and Q(EC) values are from Audi *et al.* (2003Au03).

The recommended ^{243}Cm half-life is based on the experimental results given in Table 1.

Table 1. Experimental values of ^{243}Cm half-life (in years)

Reference	Author(s)	Original value	Re-estimated value	Comments
1950Th52	Thompson et al.	Roughly 100		Not used
1953As40	Asaro	35		Not used
1958Ch38	Choppin and Thompson	29.0 (8)	28.5 (2) [a]	Relative activity to ^{244}Cm
1986Ti03	Timofeev et al.	29.20 (12)	29.20 (13) [a]	Relative activity to ^{244}Cm

[a] Re-estimated by the evaluator to the ^{244}Cm half-life of 18.11 (3) a

The weighted average of 29.0 for this two re-estimated discrepant experimental data set is dominated by the accurate value of 1986Ti03. The LWEIGHT computer program, which uses a *Limitation of Relative Statistical Weights* (LRSW method), has expanded the 1986Ti03 uncertainty from 0.13 to 0.20 and used a weighted mean (28.85) and an external uncertainty (0.35) for the average of the adjusted data set ($\chi^2/\nu = 6.13$).

The recommended value of the ^{243}Cm half-life is **28.9 (4) years**.

The value of 5.5 (9) × 10^{11} years was adopted for ^{243}Cm spontaneous fission (SF) half-life from the measurement of 1987Po19. SF branching of 5.3 (9) ×10^{-9} % has been obtained using the adopted values of SF half-life and total half-life of 28.9 (4) a.

2.1. Alpha Transitions

The energies of the alpha transitions have been obtained from the Q(α) value and ^{239}Pu level energies given in Table 2 from 2003Br12 where they were deduced from a least-squares fit to gamma ray energies.

Table 2. ^{239}Pu levels populated in ^{243}Cm α-decay

Level	Energy (keV)	Spin and parity	Half-life	Probability of α-transition (%)
0	0	1/2+	24100 (11) a	1.3 (2)
1	7.861 (2)	3/2+	36 (3) ps	4.4 (2)
2	57.275 (2)	5/2+	101 (5) ps	1.05 (12)
3	75.705 (3)	7/2+	83 (8) ps	5.7 (2)
4	163.76 (3)	9/2+	73 (4) ps	0.1
5	192.8 (10)	11/2+		0.7
6	285.460 (2)	5/2+	1.12 (5) ns	73.4 (4)
7	330.124 (4)	7/2+		11.3 (2)
8	387.42 (2)	9/2+		1.6 (1)
9	391.584 (3)	7/2-	193 (4) ns	0.2
10	427 (3) ?			0.03
11	434 (3)	(9/2-)		0.14
12	451 (5) ?			0.06
13	462 (3)	(11/2+)		0.03
14	469.8 (4)	(1/2-)		≤ 0.01
15	481 (3) ?			0.01
16	487 (3)	(11/2-)		0.02
17	492.1 (3)	3/2-		0.009
18	499 (3)			0.007
19	505.6 (2)	(5/2-)		0.007
20	538 (3)			0.002
21	543 (3) ?			0.006
22	556.2 (5)	(7/2-)		0.002
23	746 (3)			0.003
24	756 (3)			0.003
25	763 (3)			0.001
26	813 (3)			0.0015
27	850 (15)			0.00039

The probabilities of the most intense α-transitions ($I_\alpha > 1$ %) have been obtained by averaging experimental values from the spectrometric measurements (Table 3). Probabilities of the rest of alpha transitions have been adopted from the magnetic spectrometer measurements of 1966Ba07. The probability of the $\alpha_{0,9}$ transition (0.2 %) from 1966Ba07 disagrees with the value deduced from the gamma-ray transition intensity balance (> 0.4 %).

The α-decay hindrance factors have been calculated using the ALPHAD computer program from the ENSDF evaluation package with r_0 (^{239}Pu) = 1.4996 fm (see 2003Br12).

Table 3. Experimental (per 100 α decays) and recommended probabilities (per 100 decays) of the most intense α-transitions (I_α > 1 %) observed in ^{243}Cm α decay

	α-part. energy	1957 As83	1963 Dz07	1966Ba07	1973 Ah04	2009 KoZV	Evaluated from α measurement results (per 100 α decays)	Deduced from P(γ+ce) balance	Recommended (per 100 (α+ EC) decays)
$\alpha_{0,0}$	6066	1.0 (2) [a]		1.5 (2) [a]			1.3 (2) [a]		1.3 (2)
$\alpha_{0,1}$	6058	5		4.7 (3) [a]	4.3 (2)	4.5 (3)	4.4 (2) [a]		4.4 (2)
$\alpha_{0,2}$	6010		0.95		1.05 (5)	1.1 (2)	1.05 (12) [b]		1.05 (12)
$\alpha_{0,3}$	5992	6.0 (2) [a]	5.4 (2)	5.63 (20) [a]	5.6 (2)	5.8 (2)	5.7 (2) [a]		5.7 (2)
$\alpha_{0,6}$	5785	73 (4) [a]	73 (4)	73.54 (40) [a]	74.2 (8)	72.9 (12)	73.6 (4) [a]	73.8 (26)	73.4 (4)
$\alpha_{0,7}$	5742	11.5 (6) [a]	12.3 (6)	10.65 (60) [a]	11.1 (2)	11.6 (4)	11.3 (2) [a]	11	11.3 (2)
$\alpha_{0,8}$	5686		1.7	1.6	1.52 (5)	1.8 (1)	1.6 (1) [a]		1.6 (1)

[a] Weighted average, uncertainty is the smallest experimental one.

[b] Weighted average, uncertainty is external.

2.2. Gamma Transitions and Internal Conversion Coefficients

The recommended energies of the gamma-ray transitions are virtually the same as those of the gamma-ray energies because the nuclear recoil is negligible for ^{239}Pu.

The intensities of gamma-ray transitions $\gamma_{1,0}$ (7.86 keV), $\gamma_{3,2}$ (18.43 keV), $\gamma_{2,0}$ (57.27 keV), $\gamma_{3,1}$ (67.84 keV), $\gamma_{4,2}$ (106.47 keV), and $\gamma_{5,3}$ (117.1 keV) have been deduced from intensity balances at the ^{239}Pu levels “0” (0 keV), “3” (75.7 keV), “2” (57.3 keV), “1” (7.86 keV), “4” (163.8 keV), and “5” (192.8 keV), respectively.

The rest of gamma-ray transition intensities (P_γ) have been deduced from their evaluated gamma-ray emission probabilities and total internal conversion coefficients (ICCs).

ICCs have been interpolated using the BrIcc computer program, version v2.2a, data set BrIccFO (2008Ki07). Multipolarities of the gamma-ray transitions and E2/M1 mixing ratios (δ) are based on the measurements of conversion electrons (ce) in ^{239}Am, ^{239}Np and ^{243}Cm decays and $\gamma(\theta)$ measurements by 1972Kr07, 1990Si12 from polarized ^{239}Np. The multipolarities have been taken from 2003Br12. The δ values have been adopted mainly from 2003Br12, except as noted below.

The δ values for $\gamma_{6,3}$ (209.75 keV), $\gamma_{6,2}$ (228.18 keV), and $\gamma_{6,1}$ (277.60 keV) have been taken from $\gamma(\theta)$ measurements of 1972Kr07, 1990Si12. Asymmetric uncertainties of 1972Kr07, 1990Si12 were symmetrized by transformation to equivalent symmetric normal distribution using a method described in 2003Au03 (p. 21): for $\gamma_{6,3}$ δ = -0.004 (+1 -24) → δ = -0.019 (15) and for $\gamma_{6,2}$ δ = + 0.004 (+9 -1) → δ = +0.009 (6). The value of δ = 0.24 (4) has been adopted for $\gamma_{7,6}$ (44.66 keV) to provide more accurate probability balances at the levels “6” (285.46 keV) and “7” (330.12 keV).

ICCs for the E1(+M2) anomalously converted 106.1-keV gamma-ray transition are from conversion electron measurements of 1959Ew90.

3. ATOMIC DATA

The fluorescence yields, X-ray energies and relative probabilities, and Auger electrons energies and relative probabilities are from the SAISINUC software.

4. ALPHA EMISSIONS

The recommended energies of alpha particles have been deduced from the energies of alpha transitions taking into account the recoil energies for ^{239}Pu.

In Table 4 the deduced (recommended) values of α-particle energies for the four intense α-transitions are compared with the experimental results from spectrometric measurements of 1957As83, 1963Dz07 and 1966Ba07. Other measurement results can be found in 1953As14, 1957As70, 1962Iv01, 1963Le17, 1970By01, 1971Bb10, 1976BaZZ, and 1977VaZW. Most of them have lesser accuracy in comparison with the recommended values.

Table 4. Experimental and recommended values of α -particle energies (keV) in the decay of ^{243}Cm

	Measured [a]			Evaluated in 1991Ry01	Recommended
	1957As83	1963Dz07	1966Ba07		
$\alpha_{0,0}$	6061 (3) [b]		6067 (2) [b]	6066.2 (17)	6067.2 (10)
$\alpha_{0,3}$	5987 (3) [b]	5992 (3)	5993 (2) [b]	5991.8 (15)	5992.7 (10)
$\alpha_{0,6}$	5780 (3) [b]	5785 (3)	5784.5 (10)	5785.2 (9)	5786.4 (10)
$\alpha_{0,7}$	5736 (3) [b]	5740 (3)	5741.6 (10)	5742.1 (9)	5742.5 (10)

[a] Original values have been adjusted for changes in calibration energies as suggested in 1991Ry01.

[b] Uncertainty deduced or guessed by A. Rytz.

5. ELECTRON EMISSIONS

The energies of the conversion electrons have been obtained from the gamma-ray transition energies and the atomic electron binding energies.

The emission probabilities of the conversion electrons were deduced using the evaluated P_γ and ICC values. The total absolute emission probabilities of K and L Auger electrons were calculated using the EMISSION computer program.

6. PHOTON EMISSIONS

6.1 X - Ray emissions

The absolute emission probabilities of Pu KX- and LX-rays were calculated using the EMISSION computer program (Table 5).

Table 5. Measured (1972Ah02) and calculated absolute Pu KX-ray emission probabilities (%).

	1972Ah02	Calculated
Kα_2 (Pu)	13.5 (5)	13.34 (28)
Kα_1 (Pu)	20.8 (8)	21.1 (5)
Kβ'_1 (Pu)	7.6 (3)	7.75 (21)
Kβ'_2 (Pu)	2.6 (1)	2.69 (8)

The good agreement between measured and calculated KX-ray emission probabilities supports the recommended γ-ray emission probabilities and assigned multipolarities.

6.2. Gamma emissions

6.2.1. Gamma ray energies

The gamma ray energies have been taken mainly from 2003Br12. They are based on measurements of γ-ray transitions observed in ^{239}Np and ^{239}Am decays by 1959Ew90, 1964Ba31, 1965Ma17, 1972Po04, 1979Bo30, and 1982Ah04. The energies of gamma rays $\gamma_{9,8}$ (4.16 keV), $\gamma_{1,0}$ (7.86 keV), $\gamma_{3,2}$ (18.43 keV), $\gamma_{2,1}$ (49.41 keV), $\gamma_{8,7}$ (57.30 keV), $\gamma_{5,3}$ (117.1 keV), and $\gamma_{22,2}$ (498.9 keV) have been deduced directly from the adopted ^{239}Pu level energies.

Earlier measurement results can be found in 1953As14, 1955Sc08, and 1956Ne17.

The gamma rays reported in 1963Le17 only, have not been placed in the decay scheme.

6.2.2. Gamma ray emission probabilities

The absolute gamma ray emission probabilities (Pγ) were adopted from the experimental values given by 1972Ah02 multiplied by 0.9971 (3), except when noted below.

Pγ of gamma rays $\gamma_{1,0}$ (7.86 keV), $\gamma_{3,2}$ (18.43 keV), $\gamma_{2,0}$ (57.27 keV), $\gamma_{3,1}$ (67.84 keV), $\gamma_{4,2}$ (106.47 keV), and $\gamma_{5,3}$ (117.1 keV) have been obtained from P(γ+ce) values deduced from intensity balances (see section 2.2).

Pγ of gamma ray $\gamma_{7,6}$ (44.66 keV) has been deduced using the ratio Iγ(44.66 keV) / Iγ(254.4 keV) = 0.13 (1) / 0.1091 (22) in ^{239}Np β^- decay (2005Tr08, 2008BeZV) and P$\gamma_{7,3}$ (254.4 keV) = 0.11 (1) % measured in 1972Ah02.

Pγ of gamma ray $\gamma_{8,7}$ (57.30 keV) has been deduced from the total intensity of doublet P$\gamma_{2,0}$ (57.27 keV) + P$\gamma_{8,7}$ (57.30 keV) = 0.14 (1) % measured in 1972Ah02 and P$\gamma_{2,0}$ (57.27 keV) = 0.06 % from transition probability balance at the 57 keV level.

Pγ of gamma ray $\gamma_{9,7}$ (61.46 keV) has been deduced using the ratio Iγ(61.46 keV) / Iγ(334.31 keV) = 1.29 (2) / 2.05 (2) in ^{239}Np β^- decay (2005Tr08, 2008BeZV) and P$\gamma_{9,2}$ (334.31 keV) = 0.024 (2) % measured in 1972Ah02.

Pγ of gamma ray $\gamma_{4,3}$ (88.06 keV) has been deduced using from the ratio Iγ(88.06 keV) / Iγ(106.47 keV) = 0.006 (2) / 0.049 (2) in ^{239}Np β^- decay (2005Tr08, 2008BeZV) and P$\gamma_{4,2}$ (106.47 keV) = 0.015 %.

Pγ of gamma ray $\gamma_{8,6}$ (101.96 keV) has been deduced using data from ^{239}Am ε decay (1972Po04).

Pγ of gamma ray $\gamma_{9,6}$ (106.12 keV) has been deduced using data from ^{239}Np β^- decay of the relative intensity Iγ(106.12 keV) / Iγ(334.31 keV) = 25.32 (17) / 2.055 (13) as measured in 2005Tr08 and P$\gamma_{9,2}$ (334.31 keV) = 0.024 (2) % measured in 1972Ah02.

Pγ of gamma ray $\gamma_{7,4}$ (166.39 keV) has been deduced using the ratio Iγ(166.39 keV) / Iγ(254.4 keV) = 0.016 (7) / 0.1091 (22) in ^{239}Np β^- decay (2005Tr08, 2008BeZV) and P$\gamma_{7,3}$ (254.4 keV) = 0.11 (1) % measured in 1972Ah02.

7. CONSISTENCY OF RECOMMENDED DATA

The most accurate Q(α) value, Q_α (M), is taken from the atomic mass adjustment table of Audi et al. (2003Au03). Comparison of Q_α (eff) (deduced as the sum of average energies per disintegration ($\sum E_i \times P_i$) for all emissions accompanying ^{243}Cm α- decay) with the tabulated decay energy Q_α (M) × 0.9971 allows to check a consistency of the recommended decay-scheme parameters obtained in this evaluation.

Here E_i and P_i are the evaluated energies and emission probabilities of the i-th alpha particle, γ- ray, X-ray, etc. Consistency (percentage deviation) is determined by $\{[Q_\alpha\ (M) \times 0.9971 - Q(eff))] / Q_\alpha\ (M) \times 0.9971\ \} \times 100$. “Percentage deviations above 5 % would be regarded as high and imply a poorly defined decay scheme; a value of less than 5 % indicates the construction of a reasonably consistent decay scheme” (quoted from the article by A.L. Nichols in Appl. Rad. Isotopes 55 (2001) 23-70).

For the current ^{243}Cm decay data evaluation we have Q_α (M) × 0.9971 = 6150.9 (10) keV and Q(eff) = 6171 (35) keV, i.e. consistency is better than 1.0 %.

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^{244}Am - Comments on evaluation of decay data
by A. L. Nichols

Evaluated: January 2007/February 2009

Evaluation Procedure

Limitation of Relative Statistical Weight Method (LWM) was applied to average the decay data when appropriate (but see below).

Decay Scheme

A relatively simple decay scheme was constructed from the gamma-ray studies of 1962Va08, 1963Ha29, 1967Sc34 and 1984Ho02. Only the gamma-ray measurements of Hoff *et al*. provide any estimates of the uncertainties in the gamma-ray probabilities expressed in terms of their relative intensity per 100 neutron captures in a high-flux reactor (1984Ho02). All other studies contained no information with respect to their overall uncertainties. Thus, no weighted mean data could be derived, and the data of 1984Ho02 were adopted wholesale and re-adjusted when seemed necessary (expressed in terms of the 743.977-keV gamma-ray emission probability (100 %)). Further measurements are merited to quantify the gamma-ray emission probabilities and decay scheme with greater certainty.

Nuclear Data

^{244}Am is an important actinide for high burn-up fuel within the reactor core, and needs to be better characterized for improved assessments of accelerator-driven systems (ADS) and ^{244}Cm decay heat contribution.

Half-life

The recommended half-life has been adopted from the single known measurement of Vandenbosch and Day (1962Va08). Further measurements are required to determine this half-life with much greater confidence.

Half-life measurement.

Reference	Half-life (hours)
1962Va08	10.1 ± 0.1

Gamma Rays

<u>Energies</u>

All gamma-ray transition energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of Akovali were adopted (2003Ak04), and used to determine the energies and associated uncertainties of the gamma-ray transitions between the various populated-depopulated levels. However, Akovali recommended the gamma-ray energies determined by Hoff *et al.* (1984Ho02) by means of two curved-crystal spectrometers – minor differences do occur between the calculated energies of the higher energy transitions (538.402 (16), 743.977 (5) and 897.840 (7) keV) and those observed by Hoff *et al*.

Emission Probabilities

Relative emission probabilities and their uncertainties were determined from measurements of Hoff *et al.* (1984Ho02). These data were estimated to be in reasonably good agreement with the earlier measurements of Vandenbosch and Day, and Schuman (1962Va08, 1967Sc34), although these latter two sets of data possessed no uncertainties. Under these unsatisfactory circumstances, the data of Hoff *et al.* had to be adopted wholesale as the only suitable starting point in the attempted construction of a consistent decay scheme. Adjustments were made to the relative emission probabilities of the 99.383-, 153.863- and 205.575-keV gamma rays (adjusted from 7.0 (12) to 7.5 (13), 25 (5) to 28.6 (60), and 0.52 (12) to 0.53 (12), respectively) to conform with respect to the expected population-depopulation balance for the 501.79-, 296.21- and 142.35-keV nuclear levels of ^{244}Cm. Furthermore, a relative emission probability had to be calculated for the 42.96-keV gamma ray for which there were no data at all (from a population-depopulation balance of the 42.96-keV nuclear level of ^{244}Cm (populated by the 99.38-keV gamma ray and depopulated by the 42.96-keV gamma ray). Downward adjustments were made to the uncertainties of specific gamma-ray transitions and emissions through consideration of these and other data that are judged to be heavily correlated (99.383- and 153.863-keV gamma rays compared with 743.977-keV gamma ray and each other).

Measured relative gamma-ray emission probabilities.

		1962Va08	**1967Sc34**	**1984Ho02**
	E$_\gamma$ (keV)	$P_\gamma^{Abs} \rightarrow P_\gamma^{rel}$	$P_\gamma^{Abs} \rightarrow P_\gamma^{rel}$	$P_\gamma^{Abs} \rightarrow P_\gamma^{rel}$
$\gamma_{1,0}$ (Cm)	42.965 (10)	-	-	-
$\gamma_{2,1}$ (Cm)	99.383 (4)	-	-	0.23 (4) → 7.0 (12)
$\gamma_{3,2}$ (Cm)	153.863 (2)	72 → 100	-	0.82 (16) → 25 (5)
$\gamma_{4,3}$ (Cm)	205.575 (4)	0.4 → 0.6	-	0.017 (4) → 0.52 (12)
$\gamma_{9,4}$ (Cm)	538.402 (16)	0.4 → 0.6	-	0.033 (7) → 1.0 (2)
$\gamma_{9,3}$ (Cm)	743.977 (5)	72 → 100	66.2 → 100	3.3 (9) → 100 (27)
$\gamma_{9,2}$ (Cm)	897.840 (7)	28 → 39	27.6 → 42	1.4 (4) → 42 (12)

Gamma-ray emissions: recommended energies, relative emission probabilities, multipolarities and theoretical internal conversion coefficients (frozen orbital approximation).

γ **(keV)**	P_γ^{rel}	**Multipolarity**	α_K	α_L	α_{M+}	α_{tot}
42.965 (10)	0.145 (12)*	E2	-	760 (11)	290 (4)	1050 (15)
99.383 (4)	7.5 (13)§	E2	-	13.9 (2)	5.4 (1)	19.3 (3)
153.863 (2)	28.6 (60)§	E2	0.174 (3)	1.90 (3)	0.74 (1)	2.81 (4)
205.575 (4)	0.53 (12)§	E2	0.141 (2)	0.541 (8)	0.205 (3)	0.887 (13)
538.402 (16)	1.0 (2)	E2	0.0292 (4)	0.0149 (2)	0.0054 (1)	0.0495 (7)
743.977 (5)	100 (27)	M1 + E2 $\delta = -0.92$ (8)	0.059 (4)	0.0130 (7)	0.0050 (3)	0.077 (5)
897.840 (7)	42 (12)	E2	0.0122 (2)	0.00358 (5)	0.00124 (2)	0.0170 (3)

* Determined from the calculated theoretical internal conversion coefficients and the transition probability of the 99.383-keV gamma ray feeding the 42.965-keV nuclear level of ^{244}Cm.

§ Adjusted to conform with respect to the expected population-depopulation balances for the 501.79-, 296.21- and 142.35-keV nuclear levels of ^{244}Cm.

A normalisation factor of 0.66 (14) was calculated from the relative emission probabilities of the three gamma rays that depopulate the 1040.188-keV nuclear level:

$$\sum^{3} P_\gamma (1+\alpha_{tot}) \times F \quad = \quad 100\%$$

$$[P^{rel}(897.84\,keV)\,(1+\alpha_{tot}) + P^{rel}(743.97keV)(1+\alpha_{tot}) + P^{rel}(538.40keV)(1+\alpha_{tot})] \times F$$

$$= \quad 100$$

$$F \quad = \quad 100/151\ (32) \quad = \quad 0.66 \pm 0.08$$

Multipolarities and Internal Conversion Coefficients

The nuclear level scheme specified by Akovali has been used to define the multipolarities of the gamma transitions on the basis of known spins and parities (2003Ak04). Hansen *et al.* undertook angular correlation measurements to confirm the assignment of the 1040.2-keV nuclear level as the only ^{244}Cm nuclear level populated directly by β^- decay (1963Ha29), in which the depopulating 743.977-keV gamma ray was defined as (46 ± 4) % quadrupole [E2] and (54 ± 4) % dipole [M1] to give a mixing ratio (δ) of - 0.92 (8) for this transition. Recommended internal conversion coefficients have been determined from the theoretical tabulations of Band *et al.* (2002Ba25, 2002Ra45) by means of the methodology of Kibédi *et al.* (2008Ki07).

Beta-particle Emission

Energy and emission probability

The single beta-particle energy was calculated from the structural detail of the proposed decay scheme. A nuclear level energy of 1040.188 (12) keV from Akovali (2003Ak04) and a Q_{β^-} value of 1427.3 ± 1.0 keV from Audi *et al.* (2003Au03) were used to determine the energy and uncertainty of the beta-particle transition. By definition, this single beta transition was assigned an emission probability of 100 %.

Beta-particle Emission Probability per 100 Disintegrations of ^{244}Am.

	E_β (keV)	P_β	Transition type	log *ft*
$\beta^-_{0,9}$	387.1 ± 1.0	100	(1st forbidden non-unique)	5.63

Atomic Data

The x-ray and Auger-electron data have been calculated using the evaluated gamma-ray data, and atomic data from 1996Sc06, 1998ScZM and 1999ScZX. Both the x-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.01, 28 January 2003, with the emission.101 database extended to Z = 96 to calculate component L x-ray data of daughter Cm). This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

K and L X-ray Emission Probabilities per 100 Disintegrations of ^{244}Am.

			Energy (keV))	Photons per 100 disint.
XL		(Cm)	12.633 – 23.527	100 (10)
	XL_l	(Cm)	12.633	2.36 (24)
	XL_α	(Cm)	14.746 – 14.961	36 (4)
	XL_η	(Cm)	17.314	1.15 (15)
	XL_β	(Cm)	17.286 – 19.688	51 (5)
	XL_γ	(Cm)	22.735 – 23.527	12.5 (13)
XK_α	$XK_{\alpha2}$	(Cm)	104.590	2.2 (3)
	$XK_{\alpha1}$	(Cm)	109.271	3.4 (4)
$XK'_{\beta1}$	$XK_{\beta3}$	(Cm)	122.304	)
	$XK_{\beta1}$	(Cm)	123.403	) 1.29 (16)
	$XK_{\beta5}''$	(Cm)	124.124	)
$XK'_{\beta2}$	$XK_{\beta2}$	(Cm)	126.889	)
	$XK_{\beta4}$	(Cm)	127.352	) 0.45 (6)
	$XKO_{2,3}$	(Cm)	127.970	)

Electron energies were determined from electron binding energies tabulated by Larkins (1977La19) and the evaluated gamma-ray energies. Absolute electron emission probabilities were calculated from the evaluated absolute gamma-ray emission probabilities and associated internal conversion coefficients.

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^{244}Am^{m} - Comments on evaluation of decay data

by A. L. Nichols

Evaluated: January 2007/February 2009

Evaluation Procedure

Limitation of Relative Statistical Weight Method (LWM) was applied to average the decay data when appropriate (but see below).

Decay Scheme

A relatively simple decay scheme was constructed from the branching fraction measurements of Fields *et al*. and Gabeskipiya *et al*. (1955Fi36, 1976Ga31) and the gamma-ray studies of Hoff *et al*. (1984Ho02). Only the gamma-ray studies of Hoff *et al*. provide estimates of the gamma-ray emission probabilities and their uncertainties per 100 neutron captures. Thus, no weighted mean data could be derived, and the data of 1984Ho02 were adopted as published.

Nuclear Data

^{244}Am^{m} is an important actinide for high burn-up fuel within the reactor core, and needs to be better characterized for assessments of accelerator-driven systems (ADS) and ^{244}Cm production and decay heat contribution.

Half-life

The recommended half-life has been adopted from two known measurements that did not quantify the uncertainties (1950St61, 1954Gh24). Thus, the assigned uncertainty is a crude estimate of ~ 10 %. This situation is extremely unsatisfactory, and further measurements are required to determine the half-life and uncertainty with much greater confidence.

Half-life measurements.

Reference	Half-life (min)
1950St61	~ 25
1954Gh24	26
Recommended value	26 ± 3

Branching Fractions (BF)

Fields *et al.* and Gabeskipiya *et al.* have determined the EC/β^- ratio (1955Fi36, 1976Ga31).

Reference	EC/β^-
1955Fi36	0.000 38 ± 0.000 03*
1976Ga31	0.000 361 ± 0.000 013
Recommended value	0.000 36 ± 0.000 01

* Adjusted from 0.000 39 (3) on consideration of ^{244}Cm half-life (18.11 (3) years).

Recommended EC/β^- ratio was used to derive BF$_{\beta-}$ of 0.999 64 (1) and BF$_{EC}$ of 0.000 36 (1).

Gamma Rays

Energies

All gamma-ray transition energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 2003Ak04 were adopted, and used to determine the energies and associated uncertainties of the gamma-ray transitions between the various populated-depopulated levels.

Emission Probabilities

Relative emission probabilities and their uncertainties were determined from the studies of Hoff *et al.* (1984Ho02). There are no other known measurements of these important decay characteristics. Under such unsatisfactory circumstances, the data of Hoff *et al.* had to be adopted wholesale, and further measurements are required to confirm the validity of the proposed decay scheme.

Measured gamma-ray emission probabilities per 100 neutron captures.

	E$_\gamma$ (keV)	P_γ	**Multipolarity**
		1984Ho02	
$\gamma_{1,0}$ (Cm)	42.965 (10)	(0.029)*	E2
$\gamma_{6,1}$ (Cm)	941.95 (3)	0.33 (11)	E2
$\gamma_{7,1}$ (Cm)	977.80 (4)	not detected	E0 (+ M1 + E2)
$\gamma_{6,0}$ (Cm)	984.91 (2)	not detected	E0
$\gamma_{10,1}$ (Cm)	1041.22 (3)	0.18 (6)	(M1 + E2)
$\gamma_{11,1}$ (Cm)	1062.95 (3)	0.26 (8)	E1
$\gamma_{10,0}$ (Cm)	1084.181 (14)	0.34 (11)	(E2)
$\gamma_{11,0}$ (Cm)	1105.91 (2)	0.04 (2)	(E1)

* Calculated from experimental electron emission probabilities and theoretical internal conversion coefficients

Vandenbosch *et al.* have measured the ^{243}Am(n,γ) cross-section ratio for ^{244}Am^{m} and ^{244}Am production (1964Va04), and this value has been used to convert the P$_\gamma$ per 100 neutron captures to P$_\gamma$ per 100 disintegrations of ^{244}Am^{m}:

$$\frac{\sigma(^{243}Am(n,\gamma)^{244}Am^{m})}{\sigma(^{243}Am(n,\gamma)^{244}Am)} = 18.6(19)$$

$$^{244}Am^{m} = 18.6(19) \times {}^{244}Am \qquad (1)$$

Consider (n,γ) reaction to produce ^{244}Am, and expressing the generation of ^{244}Am and ^{244}Am^{m} in the following manner:

$$\sum(^{244}Am + {}^{244}Am^{m}) = 100\% \qquad (2)$$

Substituting Eqn. (1) in (2):

$$^{244}Am = 100/19.6(19) = (5.1 \pm 0.5)\%$$

$$\text{and} \quad {}^{244}Am^{m} \quad = \quad (94.9 \pm 0.5)\%$$

Absolute Pγ per 100 disintegrations of ^{244}Am^{m} were obtained by multiplying the Pγ per 100 neutron capture data of Hoff *et al.* by a factor of 1/0.949 (5).

There is considerable ambivalence in the quantification of the transition probabilities of the E0 977.80- and 984.91-keV gammas that cannot be satisfactorily resolved on the basis of the available measurements. While Hoff *et al.* found no evidence for any gamma-ray emissions with these particular energies (1984Ho02), von Egidy *et al.* observed a 977.92-keV gamma ray in their neutron capture studies with the following emission probability ratio (1984Vo07):

$$\frac{P_{\gamma}(977.92\,keV)}{P_{\gamma}(1084.18\,keV)} \quad = \quad \frac{0.12(4)}{0.52(16)},$$

and substituting $P_{\gamma}(1084.18\,keV) = 0.36(12)$ in this equation from the β^{-} decay of ^{244}Am^{m},

$$P_{\gamma}(977.92\,keV) \quad = \quad \frac{0.12(4)}{0.52(16)} \times 0.36(12) \quad = \quad 0.083(28),$$

with the recommended uncertainty reflecting only the uncertainty in P_{γ}(1084.18 keV). This value is in good agreement with equivalent calculations involving the 1041.22- and 1062.95-keV gamma rays (0.084 (27) and 0.081 (24), respectively) that were also observed by von Egidy *et al* (1984Vo07).

Gamma-ray emissions: recommended energies, absolute emission probabilities, multipolarities and theoretical internal conversion coefficients (frozen orbital approximation).

E_{γ} (keV)	P_{γ}^{abs}	Multipolarity	α_K	α_L	α_{M+}	α_{tot}
42.965 (10)	0.030 (9)*	E2	-	760 (11)	290 (4)	1050 (15)
941.95 (3)	0.35 (12)	E2	0.011 20 (16)	0.003 18 (5)	0.001 09	0.015 47 (22)
977.80 (4)	-	E0 (+ M1 + E2)	-	-	-	-
984.91 (2)	-	E0	-	-	-	-
1041.22 (3)	0.19 (6)	(M1 + E2)	-	-	-	-
1062.95 (3)	0.27 (8)	anomalous E1+	0.09 (3)	0.015 (4)	0.005	0.11 (3)
1084.181 (14)	0.36 (12)	anomalous (E2)+	0.030 (8)	0.008 (2)	0.003	0.041 (11)
1105.91 (2)	0.04 (2)	anomalous (E1)+	0.14 (3)	0.024 (6)	0.006	0.17 (4)

* Uncertainty of 30 % assigned on the basis of total transition probability of 30 (9), as defined by Hoff *et al.* (1984Ho02).

\+ Anomalous internal conversion coefficients derived from the measurements of Hoff *et al.* (1984Ho02), with the components adjusted to match theoretical data on a relative basis.

Hoff *et al.* used a beta spectrometer to study the conversion electrons and determine the internal conversion coefficients of the various gamma transitions (1984Ho02). Total transition probability (TP_{total}) per 100 neutron captures were also derived by Hoff *et al.* for the two gamma transitions: 977.80-keV TP_{γ} per 100 disintegrations of ^{244}Am^{m} approximated to 0.08 (2), and 984.91-keV TP_{γ} per 100 disintegrations of ^{244}Am^{m} approximated to 1.0 (1). Anomalous internal conversion coefficients were observed for the 1062.95-, 1084.181- and 1105.91-keV gamma rays. A combination of the TP_{γ} and TP_{total} measurements of Hoff *et al.* and von Egidy *et al.* were adopted (1984Ho02, 1984Vo07), while complete sets of anomalous internal conversion coefficients were determined on the basis of the theoretical data derived from Kibédi *et al.* (2008Ki07) and adjusted in terms of the studies of Hoff *et al.* (1984Ho02). The emission probability of the 42.965-keV gamma ray was estimated from Hoff *et al.* to be 0.029 per 100 neutron captures from TP_{total} of 30 (9) and the theoretical internal conversion coefficients. This transition probability of 30 (9) was corrected for the ^{244}Am contribution to derive a TP_{total} of 32 (9) and P_{γ}(42.96 keV) of 0.030 (9) per 100 disintegrations of ^{244}Am^{m}.

Multipolarities and Internal Conversion Coefficients

The nuclear level scheme specified by Akovali has been used to define the multipolarities of the gamma transitions on the basis of known spins and parities (2003Ak04). Recommended internal conversion coefficients have been determined from the theoretical tabulations of Band *et al.* (2002Ba25, 2002Ra45) by means of the methodology of Kibédi *et al.* (2008Ki07). Some of these data were judged to be anomalous from the studies of Hoff *et al.* (1984Ho02), and were adjusted accordingly (ICC data for the 1062.95-, 1084.181- and 1105.91-keV gamma transitions).

Beta-particle Emissions

Energies and emission probabilities

The ^{244}Am^{m} nuclear level was estimated to have an energy of (89 ± 2) keV from S(n) of 5366.5 (17) keV (2003Au03) and a gamma-ray energy of 5277.6 (4) keV from the neutron capture state to ^{244}Am^{m} (1984Vo07). Energies of the ^{244}Cm nuclear levels adopted from Akovali (2003Ak04), Q_{β^-} value of (1427.3 ± 1.0) keV from Audi *et al.* (2003Au03), and ^{244}Am^{m} nuclear level energy of (89 ± 2) keV were used to determine the energies and uncertainties of the beta-particle transitions.

Adopted Nuclear Levels of ^{244}Cm: J$^{\pi}$ and Origins (2003Ak04).

Nuclear level number	Nuclear level energy (keV)	J$^{\pi}$	Origins
0	0.0	0+	^{244}Bk EC decay, ^{244}Am β^- decay, **^{244}Am^{m} β^- decay**, ^{248}Cf α decay, Coulomb excitation
1	42.965 ± 0.010	2+	^{244}Am β^- decay, **^{244}Am^{m} β^- decay**, ^{248}Cf α decay, Coulomb excitation
2	142.348 ± 0.011	4+	^{244}Am β^- decay, ^{248}Cf α decay, Coulomb excitation
3	296.211 ± 0.011	6+	^{244}Am β^- decay
4	501.786 ± 0.012	8+	^{244}Am β^- decay
5	970 ± 4	(2+, 3–)	Coulomb excitation
6	984.914 ± 0.021	0+	**^{244}Am^{m} β^- decay**
7	1020.76 ± 0.03	(2+)	**^{244}Am^{m} β^- decay**
8	1038 ± 6	(2+, 3–)	Coulomb excitation
9	1040.188 ± 0.012	6+	^{244}Am β^- decay
10	1084.181 ± 0.014	1, 2+	**^{244}Am^{m} β^- decay**
11	1105.91 ± 0.02	(1, 2–)	**^{244}Am^{m} β^- decay**

Beta-particle emission probabilities were determined by balancing the proposed decay scheme through consideration of the βγ-population and γ-depopulation of the nuclear levels of daughter ^{244}Cm. The recommended absolute gamma-ray emission probabilities and theoretical internal conversion coefficients derived from Kibédi *et al.* (2008Ki07) were used in this process, with the theoretical internal conversion coefficients adjusted if identified as anomalous on the basis of the measurements by Hoff *et al.*

Beta-particle Emission Probabilities per 100 Disintegrations of ^{244}Am^{m}.

	^{244}Cm level energy (keV)	E_β (keV)	P_β	Transition type	log *ft*
$\beta^-_{0,11}$	1105.91 ± 0.02	410 ± 3	0.35 ± 0.09	(1st forbidden non-unique)	6.8
$\beta^-_{0,10}$	1084.181 ± 0.014	432 ± 3	0.56 ± 0.13	(allowed)	6.67
$\beta^-_{0,7}$	1020.76 ± 0.03	496 ± 3	0.08 ± 0.02	(allowed)	7.7
$\beta^-_{0,6}$	984.914 ± 0.021	531 ± 3	1.36 ± 0.16	allowed	6.58
$\beta^-_{0,1}$	42.965 ± 0.010	1473 ± 3	31 ± 9	allowed	6.74
$\beta^-_{0,0}$	0.0	1516 ± 3	67 ± 9	allowed	6.45

Σ 100.35

EC Transition

Energy and transition probability

The EC transition energy was assigned a value of (164 ± 9) keV commensurate with Q_{EC} calculated from Audi *et al.* (2003Au03), while the transition probability was adopted from the recommended BF_{EC} of 0.00036 (1).

EC Transition Probability per 100 Disintegrations of ^{244}Am^{m}.

	E_{EC} (keV)	P_{EC}	Transition type	log *ft*	P_K	P_L	P_M
$EC_{0,0}$	164 ± 9	0.036 ± 0.001	allowed	6.37	0.24 (5)	0.53 (4)	0.168 (12)

Atomic Data

K and L X-ray Emission Probabilities per 100 Disintegrations of ^{244}Am^{m}.

			Energy keV	Photons per 100 disint.
XL		(Cm)	12.633 – 23.527	12.3 (27)
	XL_l	(Cm)	12.633	0.43 (8)
	XL_α	(Cm)	14.746 – 14.961	4.6 (11)
	XL_η	(Cm)	17.314	0.13 (4)
	XL_β	(Cm)	17.286 – 19.688	6.0 (14)
	XL_γ	(Cm)	22.735 – 23.527	1.4 (4)
XK_α	$XK_{\alpha 2}$	(Cm)	104.590	0.013 (4)
	$XK_{\alpha 1}$	(Cm)	109.271	0.020 (6)
$XK'_{\beta 1}$	$XK_{\beta 3}$	(Cm)	122.304	)
	$XK_{\beta 1}$	(Cm)	123.403	) 0.0076 (21)
	$XK''_{\beta 5}$	(Cm)	124.124	)
$XK'_{\beta 2}$	$XK_{\beta 2}$	(Cm)	126.889	)
	$XK_{\beta 4}$	(Cm)	127.352	) 0.0027 (8)
	$XKO_{2,3}$	(Cm)	127.970	)

The x-ray and Auger-electron data have been calculated using the evaluated gamma-ray data, and atomic data from 1996Sc06, 1998ScZM and 1999ScZX. Both the x-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.01, 28 January 2003, with the emission.101 database extended to Z = 96 to calculate component L x-ray data of daughter Cm). This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

Electron energies were determined from electron binding energies tabulated by Larkins (1977La19) and the evaluated gamma-ray energies. Absolute electron emission probabilities were calculated from the evaluated absolute gamma-ray emission probabilities and associated internal conversion coefficients.

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^{244}Cm - Comments on evaluation of decay data
by V. P. Chechev

This evaluation was completed in February 2005 (see 2006Ch34) and then corrected in October 2009 with a literature cut-off by the same date.

1 Decay Scheme

The decay scheme is based on the evaluation of 2004Ch64. It can be considered essentially complete although some weak gamma-ray transitions have not been observed in ^{244}Cm alpha decay. Such gamma-rays were taken from the ^{240}Np β^--decay and the ^{240}Am electron capture and have been included in the decay scheme.

2 Nuclear Data

Q(α) value is from 2003Au03.

The evaluated half-life of ^{244}Cm is based on the experimental values given in Table 1.

Table 1. Experimental values of the ^{244}Cm half-life (in years).

Reference	Author(s)	Value	Measurement method
1954Fr19	Friedman et al.	17.9 (5)	α-activity relative to ^{242}Cm
1954St33	Stevens et al.	19.2 (6)	α-activity relative to ^{242}Cm
1961Cao1	Carnall et al.	17.59 (6)	Specific activity
1968Be26	Bentley	18.099 (32) [a]	2π α-counting
1972Ke29	Kerrigan and Dorsett	18.13 (4)	Calorimetry
1982Po14	Polyukhov et al.	18.24 (25)	Specific activity

[a] Revised value, recalculated in 2000Ho27.

The EV1NEW program has led to successive rejections of values from 1961Ca01 and 1954St33 due to their too large contribution to χ^2-value (more than 80 %). The LRSW method has increased 1.03 times the uncertainty of the value from 1968Be26. The weighted mean of the data set including only the four remaining values is 18.115, with the internal uncertainty 0.028 and $\chi^2/\nu = 0.25$. The smallest experimental uncertainty is 0.032, thus the recommended value of ^{244}Cm half-life is **18.11 (3) a**.

The recommended spontaneous fission partial half-life of ^{244}Cm is based on the experimental values given in Table 2.

Table 2. Experimental values of the ^{244}Cm spontaneous fission half-life (in 10^7 years).

Reference	Author(s)	Value	Measurement method
1952Gh27	Ghiorso et al.	1.4 (2) [a]	Ionization chamber
1963Ma56	Malkin et al.	1.46 (6)	Gas scintillator
1965Me02	Metta et al.	1.345 (8) [a]	α/SF counting, α with low geometry counter, SF with 2π parallel plate chamber
1967Ar09	Armani and Gold	1.33 (3)	Fission neutron counting, LiI detector
1970Ba11	Barton and Koontz	1.250 (7)	Low geometry fission fragment counting
1972Ha80	Hastings and Strohm	1.343 (6) [a]	α/SF counting, Si(Au) detector
1993Pa29	Pandey et al.	1.263 (5)	α/SF counting by sequential etching of alpha and fission tracks

[a] Revised value, recalculated in 2000Ho27.

The data set in Table 2 is discrepant. The LWEIGHT computer program has chosen the unweighted mean of 1.342 and expanded the uncertainty to 0.079 so its range includes the most precise value of 1993Pa29.

The recommended value of ^{244}Cm spontaneous fission half-life is 1.34 (8) × 10^7 years.

2.1 α Transitions

The energies of the alpha transitions have been obtained from the Q value and the ^{240}Pu level energies given in Table 3 from 2004Ch64.

Table 3. ^{240}Pu levels populated in the ^{244}Cm α-decay.

Level number	Energy (keV)	Spin and parity	Half-life	Probability of α-transition (%)
0	0.0	0^+	6561 (7) a	76.7 (4)
1	42.824 (8)	2^+	164 (5) ps	23.3 (4)
2	141.690 (15)	4^+		0.0204 (15)
3	294.319 (24)	6^+		0.00352 (18)
4	497.6 [a]	8^+		4×10^{-5}
5	597.34 (4)	1^-		$5.5\ (9) \times 10^{-5}$
6	648.85 (4)	3^-		$4.2\ (30) \times 10^{-6}$ [b]
7	860.71(7)	0^+		$1.49\ (16) \times 10^{-4}$
8	900.32 (4)	2^+		$5.0\ (5) \times 10^{-5}$
9	938.06 (6)	(1^-)		$4.7\ (11) \times 10^{-6}$ [b]

[a] Energy has been taken from ^{238}U(α, 2n γ)-reaction measurements of 1972Sp06.

[b] Deduced from P(γ+ce) decay-scheme probability balances.

The probabilities of the transitions $\alpha_{0,i}$ (i = 0, 1, 2, 3, 7) have been obtained by averaging experimental data (Table 4). The experimental results from 1998Ga19 agree well with the evaluated probabilities of the most intense alpha-transitions. The probabilities of the remaining α-transitions have been deduced using the experimental values and the values obtained from P(γ+ce) decay-scheme balances (see footnotes).

Table 4. Experimental and recommended α-transition probabilities (%) in the ^{244}Cm decay.

	α-energy (keV)	1956 Hu96	1960 As11, 1984 Asaro	1963 Dz07	1966 Ba07	1984 BuZJ	1996 Bu50	1996 Sa24	1997 Ka59	1998 Ga19	1998 Ya17	2002 Da21	Recommended
$\alpha_{0,0}$	5805	76.7 (6)	-	76.2 (20)	76.4 (20) [a]	76.98 (5)	76.8 (7)	76.9 (5)	-	76.63 (18)	76.31 (5)	77.16 (11)	76.7 (4) [b]
$\alpha_{0,1}$	5763	23.3 (6)	-	23.8 (9)	23.6 (9) [a]	23.00 (5)	23.2 (5)	23.1 (5)	-	23.34 (18)	23.69 (6)	22.80 (5)	23.3 (4) [c]
$\alpha_{0,2}$	5664	0.017 (3)	0.023 (2)	0.021 (2)	0.02	0.0163 (7)	-	0.0135 (2)	-	0.0205 (15)	-	0.020 (1)	0.0204 (15) [d]
$\alpha_{0,3}$	5515	-	0.0036 (3)	0.003 (1)	0.0034	-	-	-	0.003 42 (9)	0.0038 (5)	-	0.012 (1)	0.003 52 (18) [e]
$\alpha_{0,4}$	5315		~ 1.5 10^{-4}		~ 4 10^{-5}								4 10^{-5} [f]
$\alpha_{0,5}$	5215	-	1.5 10^{-4}	-	1 10^{-4}	-	-	-	4.2 (9) 10^{-5}	-	-	-	5.5 (9) 10^{-5} [g]
$\alpha_{0,7}$	4960	-	1.55 (16) 10^{-4}	-	3 10^{-4}	-	-	-	1.42 (16) 10^{-4}	-	-		1.49 (16) 10^{-4} [h]
$\alpha_{0,8}$	4920	-	5.0 (5) 10^{-5}	-	1.3 10^{-4}	-	-	-	4.9 (8) 10^{-5}	-	-	-	5.0 (5) 10^{-5} [i]

[a] No uncertainties are quoted by the authors. The uncertainties have been adopted by the evaluator based on the analogy of the spectra obtained with magnetic spectrometers in 1963Dz07and 1966Ba07.

[b] This set of experimental values is discrepant. The LWEIGHT computer program has recommended a weighted average and expanded the uncertainty so the range includes the most precise value from 1998Ya17.

[c] Obtained from the relation $P(\alpha_{0,1}) = 100 - P(\alpha_{0,0})$ per 100 disintegrations. An unweighted average of the discrepant set of the experimental values is 23.31, a weighted average is 23.11.

[d] Weighted average of the values from 1956Hu96, 1960As11, 1963Dz07, 1998Ga19 and 2002Da21. The lower values from 1984BuZJ and 1996Sa24 have been omitted as outliers. These values conflict greatly with the ratio $P(\gamma_{2,1})/ P(\gamma_{1,0})$ = 0.067 (7) measured in 1972Sc01. The uncertainty of the evaluated $\alpha_{0,2}$ probability has been adopted from the experimental result of 1998Ga19.

[e] Average of values from 1960As11, 1963Dz07, 1997Ka59 and 1998Ga19. The EV1NEW computer program using a limitation of relative statistical weights of 0.5 has expanded the uncertainty from 1997Ka59 to 0.00025 and recommended a weighted average and an internal uncertainty.

[f] Adopted from 1966Ba07.

[g] Deduced from the P(γ+ce)-probability balance at the 597-keV level (“5”).

[h] Weighted average of values from 1960As11, 1997Ka59.

[i] Weighted average of values from 1960As11, 1997Ka59 and a value of 5.2 (7) × 10^{-5}, calculated from P(γ+ce)-probability balance at the 900-keV level (“8”). The uncertainty is the smallest experimental one.

2.2 γ Transitions

The evaluated energies of gamma-ray transitions are virtually the same as the photon energies because nuclear recoil is negligible.

The probabilities, P(γ+ce), for gamma-ray transitions of 42.8-keV ($\gamma_{1,0}$), 98.9-keV ($\gamma_{2,1}$), 152.6-keV ($\gamma_{3,2}$), and 202-keV ($\gamma_{4,3}$) have been deduced from intensity balances, using the probabilities of α-particle transitions evaluated directly from experimental data.

For the 861-keV ($\gamma_{7,0}$) E0 transition its P(ce) value has been obtained from the (α–ce)-coincidence measurement of 1963Bj03: P(ce $\gamma_{7,0}$) + P(ce $\gamma_{7,1}$) = 9.5 (20) × 10^{-6} per 100 disintegrations.

The remaining P(γ+ce) values have been calculated from the gamma-ray emission probabilities and the total internal conversion coefficients (ICC’s). The ICC’s have been interpolated using the BrIcc package with the so called “*Frozen Orbital*” approximation (2008Ki07). The fractional uncertainties of α_K, α_L, α_M, α_T for pure multipolarities have been taken as 2 %.

Multipolarities are from 2004Ch64. These are based on conversion electron measurements of 1956Sm18, 1963Bj03, 1968Du06 and 1990Pe03.

3 Atomic Data

3.1. Fluorescence yields

The fluorescence yields are from 1996Sc06 (Schönfeld and Janβen).

3.2 X radiations

The Pu KX-ray energies and relative emission probabilities are from 1999Schönfeld, where the calculated energy values are based on X-ray wavelengths from 1967Be65 (Bearden). In Table 5 the recommended values of U KX-ray energies are compared with experimental values.

Table 5. Experimental and recommend values of Pu KX-ray energies (keV).

	1980Di13	1982Ba56	Recommended
$K\alpha_2$	99.55 (3)	99.530 (2)	99.525
$K\alpha_1$	103.76 (3)	103.741 (2)	103.734
$K\beta_3$	116.27	116.242 (2)	116.244
$K\beta_1$	117.26	117.233 (2)	117.228
$K\beta_{2,4}$	120.60 (15)	-	120.553
$KO_{2,3}$	121.55 (6)	-	121.543

In 1980Di13 the Pu KX-ray energies were measured in the alpha decay of ^{245}Cm. The relative emission probabilities of KX-rays were obtained as:

$K\alpha_2 : K\alpha_1 : K\beta_3 : K\beta_1 : K\beta_{2,4}$ = 64.7 (23) : 100.0 (33) : 12.9 (7) : 23.1 (10) : 8.9 (5).

3.3. Auger Electrons

The energies of Auger electrons have been calculated from atomic electron binding energies.

The P(KLX)/P(KLL), P(KXY)/P(KLL) ratios have been taken from 1996Sc06.

4 α Emissions

The energy of alpha particles to the ground state of ^{240}Pu, E($\alpha_{0,0}$), are from the absolute measurement of 1971Gr17 but including the correction of –0.19 keV recommended by A. Rytz in 1991Ry01.

The energies of all other α-particles have been deduced from Q_α and ^{240}Pu level energies including the recoil energy corrections.

In Table 6 the recommended values of α-particle energies are compared with experimental results obtained with magnetic alpha spectrometers.

Table 6. Experimental [a] and evaluated α-particle energies in the decay of ^{244}Cm (keV).

	1960 As11	1963 Dz07	1966 Ba07	1971 Gr17	1992 Fr04	1998 Ga19	Recommended
$\alpha_{0,0}$	5805	5805 (3)	5805 (1)	5804.77 (5)	5803.6 (22)	-	5804.77 (5)
$\alpha_{0,1}$	5763	5762	5763 (1)	5762.16 (3)	-	-	5762.65 (5)
$\alpha_{0,2}$	5666	5665	5664 (3)	-	-	5664 (2)	5665.41 (5)
$\alpha_{0,3}$	5514	5514	5513 (3)	-	-	5515 (3)	5515.29 (6)
$\alpha_{0,4}$	5316	-	5313	-	-	-	5315.3
$\alpha_{0,5}$	5215	-	5215 (3)	-	-	-	5217.24 (7)
$\alpha_{0,7}$	4956	-	4960 (3)	-	-	-	4958.20 (9)
$\alpha_{0,8}$	4916	-	4920 (3)	-	-	-	4919.24 (7)

[a] Authors' values have been adjusted for changes in calibration energies (see 1991Ry01).

5 Electron emissions

The energies of conversion electrons have been obtained from gamma transition energies and relevant electron binding energies. The emission probabilities of conversion electrons have been deduced from the evaluated P(γ) and ICC values.

The absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program (2000Schönfeld).

6 Photon emissions

6.1 X-ray emissions

The absolute emission probabilities of U KX- and U LX-rays in decay of ^{242}Pu have been calculated using the EMISSION computer program (2000Schönfeld).

The calculated total absolute emission probability of LX-rays P(XL)= 8.92 (23) % agrees with the experimental value of 8.77 (6) % from 1995Jo23.

In 1990Po14 the relative LX-ray emission probabilities in ^{244}Cm α-decay were measured:
[5.3 (8) : Ll; 72 (7) : Lα; 100: Lηβ; 22.4 (23) : Lγ].

These values agree with the recommended ones with the exception of the (Lα/Lηβ)-ratio.

6.2 Gamma-ray emissions

6.2.1. Gamma-ray energies

The energies of the 43-keV ($\gamma_{1,0}$), 99-keV ($\gamma_{2,1}$), and 153-keV ($\gamma_{3,2}$) gamma rays are from ^{244}Cm α-decay (1972Sc01). Other, less accurate measurements of ^{244}Cm α-decay (1956Sm18), ^{240}Np β^--decay (1981Hs02) and ^{240}Am ε-decay (1972Ah07) agree with data from 1972Sc01.

The energies of remaining gamma rays have been obtained from the adopted ^{240}Pu level energies. In Table 7 the recommended gamma ray energies are compared with the available experimental data.

Table 7. Experimental and recommended gamma-ray energies (keV).

	1967Lederer (1978LeZA)	1972Ah07	1972Sc01	1981Hs02	Recommended
$\gamma_{1,0}$		42.9 (1)	42.824 (8)	-	42.824 (8)
$\gamma_{2,1}$	-	98.9 (1)	98.860 (13)	-	98.860 (13)
$\gamma_{3,2}$	-	-	152.630 (20)	-	152.630 (20)
$\gamma_{8,6}$	251.20 (20)	-	-	251.5 (1)	251.47 (6)
$\gamma_{7,5}$	263.34 (15)	-	-	263.4 (1)	263.37 (8)
$\gamma_{8,5}$	302.99 (15)	-	-	303.0 (1)	302.98 (6)
$\gamma_{6,2}$	506.9 (3)	-	-	507.2 (1)	507.16 (5)
$\gamma_{5,1}$	554.5 (2)	-	-	554.6 (1)	554.52 (4)
$\gamma_{5,0}$	597,2 (2)	-	-	597.4 (1)	597.34 (4)
$\gamma_{6,1}$	605.8 (2)	-	-	606.1 (1)	606.03 (4)
$\gamma_{8,2}$	758.6 (2)	-	-	758.6 (1)	758.63 (5)
$\gamma_{7,1}$	817.8 (2)	-	-	817.9 (1)	817.89 (7)
$\gamma_{8,1}$	857.5 (2)	-	-	857.5 (1)	857.50 (4)
$\gamma_{9,1}$	894.7 (5)	-	-	895.3 (1)	895.24 (6)
$\gamma_{8,0}$	900.1 (5)	-	-	900.3 (1)	900.32 (4)
$\gamma_{9,0}$	937.6 (10)	-	-	938.0 (1)	938.06 (6)

6.2.2. Gamma-Ray Emission Probabilities

The absolute emission probabilities for gamma rays of 43-keV ($\gamma_{1,0}$), 99-keV ($\gamma_{2,1}$), 153-keV ($\gamma_{3,2}$) and 202-keV ($\gamma_{4,3}$) have been deduced from intensity balances, using the experimental α-particle probabilities. The relative emission probabilities for the first three gamma rays were measured in 1972Sc01 as [100 - $\gamma_{1,0}$, 6.7 (7) - $\gamma_{2,1}$,and 4.1 (1) - $\gamma_{3,2}$]. The measured $P(\gamma_{2,1})/P(\gamma_{1,0})\times100$ ratio disagrees with the evaluated 5.3 (4), and the measured $P(\gamma_{3,2})/P(\gamma_{1,0})\times100$ ratio agrees with the evaluated 3.95 (23).

The recommended relative emission probabilities of gamma rays with energies greater than 150-keV, obtained by averaging the experimental data from 1967Lederer (1978LeZA) and 1969Sc18 (1970Sc39), are given in Table 8.

Table 8. Experimental and recommended relative emission probabilities of > 150-keV gamma rays from the decay of ^{244}Cm.

	Energy (keV)	1967Lederer 1978LeZA	1969Sc18 1970Sc39	Recommended
$\gamma_{3,2}$	152.6	-	1240 (150)	1170 (160) [a]
$\gamma_{8,6}$	251.5	14 (3)	12.7 (20)	13.1 (20) [b]
$\gamma_{7,5}$	263.4	73 (5)	68 (6)	71 (5) [b]
$\gamma_{8,5}$	303.0	23 (4)	21.0 (20)	21.4 (20) [b]
$\gamma_{6,2}$	507.2	10 (3)	-	10 (3) [c]
$\gamma_{5,1}$	554.5	100	100	100
$\gamma_{5,0}$	597.3	61 (2)	62 (4)	61 (2) [b]
$\gamma_{6,1}$	606.0	10 (2)	9.1 (11)	9.3 (20) [b]
$\gamma_{8,2}$	758.6	15.6 (8)	18.3 (21)	15.9 (8) [b]
$\gamma_{7,1}$	817.9	75 (4)	91 (8)	78 (4) [b]
$\gamma_{8,1}$	857.5	6.6 (4)	< 7.5	6.6 (4) [c]
$\gamma_{9,1}$	895.2	2.1 (6)	< 1.3	2.1 (6) [c]
$\gamma_{8,0}$	900.3	1.5 (6)	< 0.4	1.5 (6) [c]
$\gamma_{9,0}$	938.1	0.5 (5)	< 0.75	0.5 (5) [c]

[a] Deduced from the evaluated absolute emission probabilities P(γ 153 keV) and P(γ 555 keV).

[b] Weighted average, uncertainty is the smallest experimental value reported.

[c] Adopted from 1967Lederer (1978LeZA).

The deduced absolute emission probabilities of gamma-rays with energies greater than 250 keV are based on our recommended relative gamma-ray emission probabilities P(γ)/P(γ 555 keV) in Table 8 and a normalization factor obtained from decay scheme.

The absolute gamma-ray emission probability $P^{(1)}(\gamma\ 555\ \mathrm{keV}) = 9.1\ (11) \times 10^{-5}$ per 100 disintegrations (used for decay-scheme normalization) has been obtained from the intensity balance at the 861-keV level ("7") using the alpha-transition probability $P(\alpha_{0,7}) = 1.49\ (16) \times 10^{-4}$ per 100 disintegrations, deduced from the experimental data of 1960As11 and 1997Ka59:

$$P(\gamma\ 555\ \mathrm{keV}) = [P(\alpha_{0,7}) - P(\mathrm{ce}\ 861\ \mathrm{keV})] / [P'(\gamma\ 263\ \mathrm{keV})\times(1+\alpha_T^{263}) + P'(\gamma\ 818\ \mathrm{keV})\times(1+\alpha_T^{818}],$$

where P'(γ) is a gamma-ray emission probability relative to that of the 555-keV transition (i.e., P(γ)/P(γ 555 keV)).

Another way of deducing a normalization factor is by using the relative gamma-ray emission probability P(γ 153 keV)/P(γ 555 keV) = 12.4 (15) measured in 1969Sc18 (1970Sc39) and the absolute probability P(γ 153 keV) obtained from the intensity balance for the level 294-keV level ("3"):

$$P^{(2)}(\gamma\ 555\ \mathrm{keV}) = 8.2\ (11) \times 10^{-5}\ \text{per 100 disintegrations.}$$

The average of the two P(γ 555 keV) values, $8.7\ (11) \times 10^{-5}$ per 100 disintegrations, was used as a normalization factor for calculating absolute emission probabilities of gamma-rays with energy greater than 250 keV.

The absolute emission probabilities for the 289-keV ($\gamma_{9,6}$) and 341-keV ($\gamma_{9,5}$) gamma rays have been deduced using the ratios P(γ 895 keV)/P(γ 289 keV) = 3.6 (15) and P(γ 895 keV)/P(γ 341 keV) = 1.0 (3) measured in ^{240}Np β^--decay (1981Hs02, 2004Ch64).

The absolute emission probability of the 202-keV ($\gamma_{4,3}$) gamma ray has been obtained using the adopted $\alpha_{0,4}$-transition probability. The 202-keV E2-gamma-ray transition was not observed in the ^{244}Cm alpha decay; however, it is expected from theoretical considerations and by analogy with the ^{242}Cm decay scheme.

7 Consistency of recommended data

The most accurate Q value, Q(M), is taken from the atomic mass adjustment table of Audi et al. (2003Au03). Comparison of Q(eff)(deduced as the sum of average energies per disintegration ($\sum E_i \times P_i$) for all emissions accompanying ^{244}Cm α- decay) with the tabulated decay energy Q(M) allows to check a consistency of the recommended decay-scheme parameters obtained in this evaluation.

Here E_i and P_i are the evaluated energies and emission probabilities of the i-th alpha particle, beta particle, gamma ray, X-ray, etc. Consistency (percentage deviation) is determined by {[Q(M) − Q(eff))] / Q(M)} ×100. “Percentage deviations above 5 % would be regarded as high and imply a poorly defined decay scheme; a value of less than 5 % indicates the construction of a reasonably consistent decay scheme” (quoted from the article by A.L. Nichols in Appl. Rad. Isotopes 55 (2001) 23-70).

For the above ^{244}Cm decay data evaluation we have Q(M) = 5901.74 (5) keV and Q(eff) = 5903 (33) keV, i.e. consistency of (0.02 ± 0.56) % is not superior, but better than 0.6 %.

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^{245}Cm -Comments on evaluation of decay data
by V.P. Chechev

Evaluated in November 2010 with a literature cut-off by the same date.

1. DECAY SCHEME

^{245}Cm decays 100 % to levels of ^{241}Pu by emission of α particles and, with a very small branch of 5.9 (9) × 10^{-7} % by spontaneous fission. The adopted ^{241}Pu levels populated in the ^{245}Cm α decay are based generally on the evaluation by Martin (2005Ma88). Questionable ^{241}Pu levels with energies of 260.5 and ≈ 376 keV as reported from α spectrometric measurements of 1975Ba65 were not included into the current evaluation. The 260.5-keV nuclear level was judged in 1975Ba65 as belonging possibly to ^{243}Am α decay, while the 376-keV nuclear level was not identified by 1975Ba65 and may belong to ^{239}Pu α decay along with the ≈ 384-keV energy level. However, the latter has been identified as $13/2^+$ belonging to the ^{241}Pu 7/2 [624] rotational band populated in the ^{245}Cm α decay (1975Ba65), and therefore has been included in the proposed decay scheme.

The decay scheme overall consistency is supported by the agreement between Q(calc) = 5640 (30) keV, deduced from the evaluated average energies and intensities of all emissions, and Q(α) = 5622.3 (5) keV, deduced from measured α-particle energies. Percentage deviation of Q(calc) from the adopted Q(α) and the Q(α) value of Audi *et al.* (2003Au03) is –(0.3 ± 0.5) %.

2. NUCLEAR DATA

Q(α) value has been deduced from the five alpha transition energies obtained from the α particle energies measured in 1975Ba65 and adjusted for changes in calibration energies by Rytz (1991Ry01). This approach (Table 1) similar to the evaluation by Martin (2005Ma88) is due to absence of an adjusted Q(α) value for ^{245}Cm in 2003Au03. Audi *et al.* (2003) chose Q(α) = 5623 (1) keV reported in 1975Ba65.

Table 1. ^{245}Cm Q(α) values deduced from α-transition energies

Energy of ^{241}Pu level (keV)	Energy of α particles (keV) (experimental)	Energy of α-transition (keV)	Deduced Q(α) value (keV)
41.9722 (9)	$\alpha_{0,1}$ 5488.5 (5)	5579.7 (5)	5621.7 (5)
95.7795 (12)	$\alpha_{0,2}$ 5436.1 (5)	5526.4 (5)	5622.2 (5)
175.0523 (14)	$\alpha_{0,5}$ 5361.8 (12)	5450.9 (12)	5625.9 (12)
231.935 (9)	$\alpha_{0,6}$ 5303.6 (12)	5391.7 (12)	5623.6 (12)
301.172 (16)	$\alpha_{0,7}$ 5234.4 (12)	5321.4 (12)	5622.5 (12)

The weighted average of the deduced Q(α) data set is 5622.3 keV, the internal uncertainty is 0.31, the external uncertainty is 0.55, $\chi^2/\nu = 3.05$, χ^2/ν (critical) = 3.30. The smallest value of experimental uncertainties is ± 0.5 keV. The recommended **Q(α)** value is **5622.3 (5) keV**.

The ^{245}Cm half-life is based on the experimental results given in Table 2.

Table 2. Experimental values of ^{245}Cm half-life (in 10^3 years)

Reference	Author(s)	Original value	Re-estimated value	Comments
1954Hu50	Hulet *et al.*	≈ 20		Not used
1954Fr19	Friedman *et al.*	11.5 (50)	11.3 (50) [a]	Relative specific activity to ^{244}Cm - not used.
1955Br02	Browne *et al.*	14.3 (29)		α counting - not used.
1957Hu76	Huizenga *et al.*	7.5 (19)		H. Diamond, Priv. Com. no details - outlier.
1961Ca01	Carnall *et al.*	9.32 (28)	9.60 (29) [a]	Relative specific activity to ^{244}Cm - outlier.
1969Me01	Metta *et al.*	8.265 (180)	8.270 (180) [a]	Relative specific activity to ^{244}Cm
1971Ma32	MacMurdo *et al.*	8.532 (53)	8.537 (71) [a,b]	Relative specific activity to ^{244}Cm
1982Po14	Polyukhov *et al.*	8.445 (100)	8.450 (100) [a]	Relative specific activity to ^{244}Cm
2009KoZV	Kondev *et al.*	8.245 (70)		Daughter in-growth from ^{249}Cf sample

[a] Re-estimated by the evaluator on the basis of the recommended ^{244}Cm half-life of 18.11 (3) years.
[b] Uncertainty has been revised in 1989Ho24.

In the six values adopted in the data analysis, the LWEIGHT computer program identified two outliers (1957Hu76 and 1961Ca01), and indicated that the four remaining experimental values are discrepant: there are two separate groups of measured values at 8.5×10^3 and 8.25×10^3 years. A similar situation for measurements of ^{239}Pu half-life by the specific activity method (24 400 and 24 100 years) was resolved to the benefit of the lower value on the basis of the detected presence of impurities leading to overestimations of half-life. This method involves the determination of the number of atoms and disintegration rate of the radionuclide with good accuracy, and thereby requires absolute efficiencies (2009KoZV). Daughter growth in a sample in which the parent is shorter lived does not require such efficiencies, and has been successfully adopted recently to determine the ^{240}Pu half-life (2008KoZP). Therefore, for statistical processing the evaluator has chosen two consistent experimental results obtained with different methods: 1969Me01 (re-estimated) and 2009KoZV, and omitted the other two measurements. The weighted average for this limited set of only two measurements is 8.25×10^3 years with an internal uncertainty of 0.065 and external uncertainty of 0.0084 ($\chi^2/\nu = 0.02$).

The recommended value for the **^{245}Cm half-life** is **8.25 (7) × 10^3 years**.

A value of 1.4 (2) × 10^{12} years was adopted for ^{245}Cm spontaneous fission (SF) half-life from the measurement of 1985Dr10. SF branching of 5.9 (9) × 10^{-7} % has been derived from the adopted SF half-life and total half-life of 8.25 (7) × 10^{3} years.

2.1. Alpha Transitions

The energies of alpha transitions $\alpha_{0,1}$, $\alpha_{0,2}$, $\alpha_{0,5}$, $\alpha_{0,6}$ and $\alpha_{0,7}$ have been obtained from the experimental α particle energies taking into account the recoil energies for ^{241}Pu (Table 1). The energies of the remaining alpha transitions have been obtained from Q(α) value and ^{241}Pu level energies given in Table 3 from the Adopted Levels, Gammas of 2005Ma88 where they were deduced from a least-squares fit to gamma-ray energies.

Table 3. ^{241}Pu levels populated in ^{245}Cm α-decay

Level	Energy (keV)	Spin and parity	Half-life	Probability of α- transition (%)
0	0.0	5/2+	14.33 (4) a	0.58
1	41.9722 (9)	7/2+		0.83
2	95.7795 (12)	9/2+		0.04
3	161.314 (4)	11/2+		0.39 (22)
4	161.6852 (9)	1/2+	0.88 (5) μs	0.0210 (9)
5	175.0523 (14)	7/2+		93.2 (5)
6	231.935 (9)	9/2+		5.0 (1)
7	301.172 (16)	11/2+		0.32
8	385 (3)	(13/2+)		≤0.005

The experimental values for the α-transition probabilities of ^{245}Cm from spectrometric measurements are presented in Table 4. Uncertainties were not reported in the cited references, but these for the most intense α-transitions $\alpha_{0,5}$ (5362 keV) and $\alpha_{0,6}$ (5304 keV) observed in 1975Ba65 were estimated in 1976BaZZ. The data of 1966Ba07 for ^{245}Cm are not given in Table 4 as those were superseded in 1975Ba65 by the same group. The probabilities of the α-transitions $\alpha_{0,3}$ and $\alpha_{0,4}$ (observed as a doublet with an energy of ~5370 keV) have been deduced from intensity balances at the ^{241}Pu levels "3" (161.3 keV) and "4" (161.7 keV), respectively. Probabilities of the remaining alpha transitions have been adopted from the magnetic spectrometer measurements of 1975Ba65.

Table 4. Experimental and recommended probabilities (per 100 decays) of alpha transitions observed in ^{245}Cm α decay

	α-particle energy	1960As11	1963Dz07	1966Fr03	1975Ba65	Deduced from P(γ+ce) balance	Recommended
$\alpha_{0,0}$	5529			1.1	0.58		0.58
$\alpha_{0,1}$	5488			0.9	0.83		0.83
$\alpha_{0,2}$	5436			0.2	0.04		0.04
$\alpha_{0,3}$	5372					0.39 (22)	0.39 (22)
$\alpha_{0,4}$	5371					0.0210 (9)	0.0210 (9)
$\alpha_{0,5}$	5362	93	90	91	93.2 (5)	95.3 (21)	93.2 (5)
$\alpha_{0,6}$	5303	7	7	6.2	5.0 (1)		5.0 (1)
$\alpha_{0,7}$	5234		2	0.5	0.32		0.32
$\alpha_{0,8}$	5152				≤ 0.005		≤ 0.005

The α decay hindrance factors have been calculated using the ALPHAD computer program from the ENSDF evaluation package with $r_0(^{241}Pu) = 1.4969\ (12)$ fm (2005Ma88).

2.2. Gamma Transitions and Internal Conversion Coefficients

The recommended energies of the gamma-ray transitions are the same as those of the gamma-ray energies with correction to the minor nuclear recoil for ^{241}Pu.

The gamma-ray transition probabilities ($P_{\gamma+ce}$) have been deduced from their evaluated gamma-ray emission probabilities (P_γ) and total internal conversion coefficients (ICCs), apart from $P_{\gamma+ce}$ values for the gamma-ray transitions $\gamma_{6,5}$ (56.9 keV) and $\gamma_{7,6}$ (69.2 keV). The latter values have been deduced directly from intensity balances at the ^{241}Pu levels “6” (231.9 keV) and “7” (301.2 keV), respectively.

ICCs have been interpolated using the BrIcc computer program, version v2.2a, data set BrIccFO (2008Ki07). Multipolarities of the gamma-ray transitions and E2/M1 mixing ratios (δ) are based on the measurements of conversion electrons (ce) in the ^{240}Pu (n,γ)-reaction and have been taken from 2005Ma88, except as noted below.

The δ values for $\gamma_{6,5}$ (56.9 keV) and $\gamma_{7,6}$ (69.2 keV) have been obtained from the total ICC deduced using the expression $1+ \alpha_T = P_{\gamma+ce} / P_\gamma$.

3. ATOMIC DATA

The fluorescence yields, X-ray energies and relative probabilities, and Auger electrons energies and relative probabilities are from the SAISINUC software.

4. ALPHA EMISSIONS

The recommended energies of alpha particles for the five transitions ($\alpha_{0,1}$, $\alpha_{0,2}$, $\alpha_{0,5}$, $\alpha_{0,6}$, $\alpha_{0,7}$) used for obtaining Q(α) have been adopted from the most precise measurements of 1975Ba65. The remaining α particle energies have been deduced from the Q(α) value, taking into account the recoil energies for ^{241}Pu.

The recommended α-particle energies are compared in Table 5 with the experimental results from spectrometric measurements (1960As11, 1963Dz07, 1966Fr03 and 1975Ba65).

Table 5. Experimental and recommended α-particle energies (keV) in the decay of ^{245}Cm [a]

	1960As11	1963Dz07	1966Fr03	1975Ba65	Recommended
$\alpha_{0,0}$			5530 (3)	5529.0 (5)	5530.4 (5)
$\alpha_{0,1}$			5497 (5)	5488.5 (5)	5488.5 (5)
$\alpha_{0,2}$			5447 (5)	5436.1 (5)	5436.1 (5)
$\alpha_{0,3}$				5370	5371.7 (5)
$\alpha_{0,4}$				5370	5371.4 (5)
$\alpha_{0,5}$	5360	5361	5359 (2)	5361.8 (12)	5361.8 (12)
$\alpha_{0,6}$	5305	5305	5306 (2)	5303.6 (12)	5303.6 (12)
$\alpha_{0,7}$		5245	5239 (3)	5234.4 (12)	5234.4 (12)
$\alpha_{0,8}$				≈ 5151	5152 (3)

[a] Authors’ experimental values have been adjusted for changes in calibration energies, as suggested in 1991Ry01.

5. ELECTRON EMISSIONS

The energies of the conversion electrons have been obtained from the gamma-ray transition energies and the atomic electron binding energies from 1977La19.

The emission probabilities of the conversion electrons have been deduced using the evaluated P_γ and ICC values. Measurements of the ^{241}Pu conversion electrons following thermal neutron capture in ^{240}Pu were carried out by 1998Wh01.

The total absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program (1996Sc06, 2000Sc47).

6. PHOTON EMISSIONS

6.1 X - Ray emissions

The absolute emission probabilities of Pu KX- and LX-rays were calculated using the EMISSION computer program (Table 6). In 1980Di13 the emission probabilities of Pu KX-rays were measured relatively to P_γ ($\gamma_{5,0}$ 175.0 keV). The experimental absolute P(KX) values are given in Table 6 using the evaluated P_γ ($\gamma_{5,0}$ 175.0 keV) = 9.83 (22) %.

Table 6. Experimental (1980Di13) and calculated absolute Pu KX-ray emission probabilities (%)

	1980Di13	Calculated
$K\alpha_2$ (Pu)	20.0 (7)	19.0 (5)
$K\alpha_1$ (Pu)	30.9 (11)	30.1 (7)
$K\beta'_1$ (Pu)	11.1 (5)	11.1 (3)
$K\beta'_2$ (Pu)	3.7 (2)	3.84 (12)

The good agreement between measured and calculated KX-ray emission probabilities supports the recommended γ-ray emission probabilities and assigned multipolarities.

6.2. Gamma emissions

6.2.1. Gamma-ray energies

The gamma-ray energies (E_γ) have been taken from 2005Ma88 (^{241}Pu, Adopted Levels, Gammas). They are based mainly on measurements of γ rays from ^{245}Cm α decay by 1980Di13, 1992Daniels, 1994Sh31, 1998Wh01 and γ rays from thermal neutron capture in ^{240}Pu by 1998Wh01 (Table 7). The gamma-ray energies for $\gamma_{7,6}$ (69.2 keV), $\gamma_{5,2}$ (79.3 keV), $\gamma_{2,0}$ (95.8 keV), $\gamma_{6,2}$ (136.1 keV), $\gamma_{7,2}$ (205.4 keV), and $\gamma_{6,0}$ (231.9 keV) have been deduced directly from the adopted ^{241}Pu level energies. Other, less accurate measurements of E_γ can be found in 1955Pe32, 1966Ba07, 1991Po17.

6.2.2. Gamma-ray emission probabilities

The relative gamma-ray emission probabilities (I_γ) are weighted averages of the experimental values from 1980Di13 and 1992Daniels, except as noted otherwise in Table 7. The LWEIGHT computer program was used for statistical processing, with the uncertainty assigned to the average value always greater than or equal to the smallest uncertainty of the values used to calculate the average.

The normalization factor (N) was obtained from the intensity balance to the ground state of ^{241}Pu:

$$\Sigma(1+\alpha_T)I_\gamma\,(\gamma_{1,0}\,,\gamma_{2,0}\,,\gamma_{4,0}\,,\gamma_{5,0}\,,\gamma_{6,0}\,) + P(\alpha_{0,0}\,) = 1$$

assuming $P(\alpha_{0,0}) = 0.006$ (1) (1975Ba65, 2005Ma88),

$N = P_\gamma$ (175.0 keV) = 0.0983 (22).

This adopted value agrees with the directly measured P_γ (175.0 keV) of 0.095 (7) (1980Di13) and 0.101 (1) (1992Daniels).

The absolute gamma-ray emission probabilities (P_γ) have been deduced from the evaluated relative gamma-ray emission probabilities (Table 7) using the derived normalization factor of 0.0983 (22).

Table 7. Experimental (E_γ^{exp}) and recommended gamma-ray energies and experimental and evaluated relative emission probabilities (I_γ^{exp}) in the decay of ^{245}Cm

	E_γ^{exp} from ^{245}Cm decay	**Recommended E_γ (keV)**	I_γ^{exp} (1980Di13)	I_γ^{exp} (1992Daniels)	I_γ^{exp} (1998Wh01)	**Evaluated I_γ**
$\gamma_{1,0}$	41.93 (3) [a]	**41.972 (1)**	3.68 (18)	4.10 (39)		**3.75 (18)** [a]
$\gamma_{2,1}$	53.72 (4) [a]	**53.807 (1)**	0.70 (4)	0.77 (4)		**0.74 (4)** [a]
$\gamma_{6,5}$	56.89 (3) [b]	**56.89 (3)**	0.38 (2)	0.325 (32)		**0.365 (20)** [a]
$\gamma_{3,2}$	65.44 (8) [a]	**65.535 (3)**	0.12 (4)	0.20 (2)		**0.18 (2)** [a]
$\gamma_{7,6}$	69.17 (6) [c]	**69.237 (18)**	0.07 (3)	-		**0.07 (3)**
$\gamma_{5,2}$	79.27 (4) [a]	**79.2728 (18)**	1.58 (9)	1.22 (7)		**1.22 (7)** [d]
$\gamma_{2,0}$	95.786 (3) [b, d]	**95.7795 (12)**				**0.111 (23)** [e]
$\gamma_{7,5}$	126.09 (4) [b]	**126.09 (4)**			0.07 (2)	**0.07 (2)** [b]
$\gamma_{5,1}$	133.05 (8) [a]	**133.081 (2)**	29.2 (15)	28.6 (4)		**28.6 (4)** [a]
$\gamma_{6,2}$	136.127 (20) [b]	**136.156 (9)**	1.18 (7)	1.15 (3)		**1.15 (3)** [a]
$\gamma_{7,3}$	139.87 (4) [b]	**139.858 (16)**	0.06 (2)	0.06 (3)	0.09 (1)	**0.08 (9)** [f]
$\gamma_{4,0}$	161.72 (8) [a]	**161.685 (1)**	0.09 (4)	0.067 (2)		**0.072 (2)** [a]
$\gamma_{5,0}$	175.01 (9) [a]	**175.0523 (14)**	100	100	100	**100**
$\gamma_{6,1}$	189.965 (10) [b]	**189.965 (10)**	2.03 (13)	2.07 (4)		**2.07 (4)** [a]
$\gamma_{7,2}$	205.404 (20) [a]	**205.393 (16)**	-	0.115 (19)	0.08 (1)	**0.09 (1)** [g]
$\gamma_{6,0}$	231.96 (3) [b]	**231.935 (9)**	0.16 (4)	0.117 (18)	0.11 (2)	**0.119 (18)** [h]
$\gamma_{-1,1}$	388.16 (5) [b]	**388.16 (5)**			0.19 (1)	**0.19 (1)** [b]

[a] Weighted averages of experimental values from 1980Di13 and 1992Daniels (see also1994Sh31, 2005Ma88).

[b] Experimental value from 1998Wh01.

[c] Reported only in 1980Di13, but also adopted in the level scheme of 1994Sh31.

[d] From 1992Daniels; higher value leads to a large intensity imbalance at the 96-keV and 175-keV levels

[e] Obscured by the Pu $K\alpha_2$ X-ray; I_γ is from I_γ/I_γ(53.8 keV) = 0.15 (3) in Adopted Gammas (2005Ma88).

[f] Weighted averages of experimental values from 1980Di13, 1992Daniels and 1998Wh01.

[g] Weighted averages of experimental values from 1992Daniels and 1998Wh01.

[h] Weighted averages of experimental values from 1980Di13, 1992Daniels and 1998Wh01.

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^{246}Cm - Comments on evaluation of decay data
by F.G. Kondev

This evaluation was completed in December 2006 with a literature cut off by the same date. The Saisinuc software (2002BeXX) and associated supporting programs were used in assembling the data following the established protocol within the DDEP collaboration.

1. Decay Scheme

The deformed ^{246}Cm nucleus disintegrates by α emissions and spontaneous fission. The strongest α–decay branch populates the ground state of the daughter nuclide ^{242}Pu, which is also deformed. The level schemes of ^{242}Pu and ^{246}Cm are based on the evaluations of Akovali (2002Ak06) and Artna -Cohen (1998Ar12), respectively. The recent experimental work of Kondev *et al.* (2007Ko01) reported a weak α–decay branch to the 4^+ level of the ground-state band of ^{242}Pu.

2. Nuclear Data

Q(α) value is obtained from the adopted $\alpha_{0,0}$ energy (see section 2.1 for details) and by taking into account the relevant recoil energy. This value differs from that of 5475.1 (9) keV (2003Au03), deduced as a weighted mean of Q(α)=5475.2 (10) keV and 5474.9 (20) keV, which were determined from the $\alpha_{0,0}$ energies of 1984Sh31 and 1966Ba07, respectively. It should be noted that no uncertainty to the $E_{\alpha0,0}$ value was reported in the original publication of 1966Ba07, but it was assigned by 2003Au03.

The experimental data on α/SF and $T_{1/2\ SF}$, together with results from the earlier evaluation of Holden (2000Ho27), are presented in Table 1.

Table 1. Experimental and evaluated data for the α/SF ratio and the SF half-life of ^{246}Cm

Author	a/**SF**	$T_{1/2SF}$, **(10^7 a)**	**Method**	**Used in the evaluation**
1956Fi11	2740 (140)	> 1.24	From α/SF	No
1956FrXX		2.0 (8)	relative to ^{246}Pu weight and the α–counting technique	No
1965Me02	0.139 (9) $10^{6\ a)}$	1.66 (10)	relative to ^{244}Cm α–decay data $^{b)}$	No
1969Me01	3822 (10)	1.80 (1)	From α/SF	Yes
1971Ma32	3833 (32)	1.85 (2)	From α/SF	Yes
2000Ho27		1.81 (2)	Evaluated value	No

$^{a)}$ Net (^{246}Cm fissions)/(^{244}Cm α–disintegrations).
$^{b)}$ Using $T_{1/2,\alpha}$ (^{244}Cm) = 18.11 (7) a, mole ratio (^{244}Cm/^{246}Cm) = 7.82 (9) and (^{246}Cm fissions)/(^{244}Cm α–disintegrations) = 0.139 (9) 10^6.

The %α and %SF values were deduced using α/SF = 3823 (10), a weighted mean of 3822 (10) (1969Me01) and 3833 (32) (1971Ma32):

$$\%SF = \frac{1}{1 + a / SF} \times 100, \text{ with } \%a = 100 - \%SF \qquad (1)$$

Then %SF = 0.02615 (7) % and %α = 99.97385 (7) %
The mean number of neutrons emitted by spontaneous fission is: 2.948 (from ENDF/B-VII)

The recommended partial SF half -life of $T_{1/2\ SF}$ = 1.81 (2) 10^7 a, was determined as a weighted mean of 1.80 (1) 10^7 a (1969Me01) and 1.85 (2) 10^7 a (1971Ma32).

The experimental data for the partial α–decay half-life of ^{246}Cm are presented in Table 2.

Table 2. Experimental data for the partial α–decay half-life of ^{246}Cm

Author	**Method** a)	**$T_{1/2\ a}$, (a)** b)	**$T_{1/2\ a}$, (a)** c)	**$T_{1/2\ a}$, (a)** d)	**Used in the evaluation**
1954Fr19	RSA to ^{244}Cm	4000 (600)	18.44 (5)	3928 (589)	No
1955Br02	IA to ^{246}Pu	2300 (460)			No
1956Bu91	IA to ^{250}Cf	6620 (320)	9.3 (9)	9311 (623)	No
1961Ca01	RSA to ^{244}Cm	5480 (170)	17.59 (6)	5642 (175)	No
1969Me01	RSA to ^{244}Cm	4711 (22)	18.099 (15)	4714 (22)	Yes
1971Mc19	ASA	4654 (40)			Yes
1971Ma32	RSA to ^{244}Cm	4820 (20)	18.099 (15)	4823 (20)	Yes
1977Po20	RSA to ^{244}Cm	4852 (76)	18.099 (15)	4855 (76)	Yes
2007Ko01	IA to ^{250}Cf	4706 (40)	13.08 (9)		Yes

a) RSA-relative specific activity method; ASA – absolute specific activity method; IA in -growth activity method.

b) Value reported in the original publication.

c) Half-life value for the reference ^{244}Cm or ^{250}Cf nuclide used in the original publication.

d) Corrected ^{246}Cm half-life values using $T_{1/2}$(^{244}Cm) = 18.11 (3) a (2005ChXX) and $T_{1/2}$(^{250}Cf) = 13.08 (9) a (2001Ak11))

Since in all cases, except 1971Mc19, relative methods were used to deduce $T_{1/2\,\alpha}$, the values reported in the original publications were corrected using the most recently adopted $T_{1/2\,\alpha}$ of the reference nuclides ^{244}Cm and ^{250}Cf, as summarized in Table 2. Results from the early work of 1954Fr19, 1955Br02, 1956Bu91 and 1961Ca01 are inaccurate and discrepant (with half -life values spanning between 2300 (460) a and 9311 (623) a), and hence, these data were excluded from the present analysis.

Although the remaining five $T_{1/2\,\alpha}$ values have better accuracy, these data are also discrepant. For example, while the data of 1969Me01, 1971Mc19 and 2007Ko01 give a weighted mean of $T_{1/2\,\alpha}$ = 4701 (17) a, the results of 1971Ma32 and 1977Po20 are clustered around the weighted mean value of $T_{1/2\,\alpha}$ = 4825 (19) a. In the present work, detailed evaluatio ns of $T_{1/2\,\alpha}$ were carried out using specially developed techniques that deal with discrepant data (see references 1992Ra08, 1994Ka08 and 2004MaXX for example) and the results are presented in Table 3. The weighted mean (WM) value (external uncertainty) is $T_{1/2\,\alpha}$ = 4756 (32) a, but χ^2_ν = 6.16 (where $\chi^2_\nu = \chi^2$/N-1) is larger than the critical value of $\chi^2_{\nu\ crit}$ = 3.32 (99 % confidence level) because the data are discrepant.

The Limitation of Relative Statistical Weight (LRSW) method adopts $T_{1/2\,\alpha}$ = 4756 (67) a, which is the WM value, but the uncertainty is extended in order to include "the most precise" value of 4823 (20) a (1971Ma32) (uncertainty of 0.41 %). It should be noted, however, that the determined by the LRSW method "the most precise" value is as accur ate as that of 4714 (22) a (1969Me01) (uncertainty of 0.47 %). Hence, if the value from 1969Me01 is adopted as "the most precise" one, then the LRSW would give $T_{1/2\,\alpha}$ = 4756 (42) a. In the LRSW case, χ^2_ν is also larger than $\chi^2_{\nu\ crit}$. The Normalized Residual Method (NRM) evaluates a value of $T_{1/2\,\alpha}$ = 4723 (27) a, while the Rajeval method (RM) adopts $T_{1/2\,\alpha}$ = 4713 (17) a. In both cases χ^2_ν is smaller than $\chi^2_{\nu\ crit}$.

Table 3. Evaluated values of the half-life of ^{246}Cm.

Method/Author [a)]	**Evaluated $T_{1/2}$, (a)**	c^2/N-1	
UWM	4750 (38)	6.21	
WM (external)	4756 (32)	6.16	
LRSW	4756 (67)	6.16	
NRM	4723 (27)	2.78	Adopted
RM	4713 (17)	1.24	
1989Ho24	4760 (40)	7.48	
1998Ar12	4760 (40) [b)]		

[a)] UWM – Unweighted Mean; WM – Weighted Mean; LRSW – Limitation of Relative Statistical Weight; NRM – Normalized Residual; RM – Rajeval.
[b)] Value adopted from 1989Ho24

The NRM value is recommended in the present evaluation since the relative statistical weights of the uncertainties (note that only the uncertainty reported in 1971Ma32 has been adjusted by the this method) are less than 50 %, while the RM value (uncertainties of 1971Ma32, 1971Mc19 and 1977Po20 were adjusted by this method) is biased towards that of $T_{1/2\,\alpha} = 4714$ (22) a (1969Me01) (with a relative statistical weight of 62 %).

2.1 Alpha Transitions

The ^{242}Pu level energies were deduced by a least-square fit to the adopted γ–ray energies (see section 2.2 and Table 7 for details) using the computer program GTOL from the ENSDF evaluation package. The $\alpha_{0,0}$ energy was taken from the evaluation of Rytz (1991Ry01), while the $\alpha_{0,1}$ and $\alpha_{0,2}$ energies were obtained from the adopted $E_{\alpha0,0} = 5387.5$ (9) keV, the 2^+ and 4^+ level energies of ^{242}Pu, respectively, and by taking into account the relevant recoil energies.

Table 4. Experimental and evaluated values of the α–particle energies in decay of ^{246}Cm

Authors	**$E_{a0,0}$, (keV)**	**$E_{a0,1}$, (keV)**	**$E_{a0,2}$, (keV)**	**Comment** [a)]
1963Be48	5387	5345		MS
1963Dz07	5387 (4)	5345 (4)		MS
1966Ba07	5385	5342		MS
1984Sh31	5386.5 (10)	5343.5 (10)		MS
2007Ko01	5386 (3)	5342 (3)	5242 (3)	SD
1991Ry01	5387.5 (9)	5342.7 (9)		evaluated
Adopted	**5387.5 (9)**	**5343.7 (9)**	**5242.5 (10)**	**Evaluated**

a) MS – magnetic α–spectrometer; SD – semiconductor detector

The experimental values for the α–transition probabilities of ^{246}Cm are presented in Table 5. It should be noted that uncertainties were not reported in the work of 1963Be48 and 1966Ba07, but these were estimated by Rytz (1991Ry01).

Table 6 contains the evaluated $P_{\alpha0,0}$ values using two different data sets, one that excludes values reported without uncertainty in the original publications ("limited data") and the second that includes all experimental values with uncertainties estimated by Rytz (1991Ry01) in cases where those were missing in the original publications ("all data"). The evaluated values deduced using both data sets are consisted and the WM value from the so-called "all data" set is recommended ($\chi^2_\nu = 1.69$ is smaller than the critical value of $\chi^2_{\nu\ \mathrm{crit}} = 3.32$ (99 % confidence level)). The recommended $P_{\alpha0,2}$ value was deduced using the branching ratios of 2007Ko01 and the adopted here $P_{\alpha0,0} = 79.17$ (22) %. The $P_{\alpha0,1}$ value was determined as:

$$P_{a\,0,1} = 100 - P_{a\,0,0} - P_{a\,0,2} \qquad (2)$$

Table 5. Experimental and evaluated α–transition probabilities in decay of ^{246}Cm.

Authors	**$P_{a0,0}$, (%)**	**$P_{a0,1}$, (%)**	**$P_{a0,2}$, (%)**	**Comment** [a]
1963Be48	78	22		MS
1963Dz07	78 (5)	22 (5)		MS
1966Ba07	79	21		MS
1984Sh31	82.2 (12)	17.8 (12)		MS
2007Ko01	79.08 (22)	20.9 (4)	0.020 (2)	SD
1991Ry01	80.7 (11) [b]	19.3 (11) [b]		evaluated
Adopted	**79.17 (22)**	**20.81 (22)**	**0.020 (2)**	**Evaluated**

[a] MS – magnetic α–spectrometer; SD – semiconductor detector

[b] Rytz (1991Ry01) assigned uncertainties to the original 1963Be48 and 1966Ba07 values as follow: $P_{\alpha 0,0} = 78$ (3) and $P_{\alpha 0,1} = 22$ (3) (1963Be48) and $P_{\alpha 0,0} = 79$ (2) and $P_{\alpha 0,1} = 21$ (2) (1966Ba07).

The α–decay hindrance factors were calculated using the computer program ALPHAD from the ENSDF evaluation package with $r_0 = 1.4954$ (10) fm.

Table 6. Evaluated $P_{\alpha 0,0}$ values in the α–decay of ^{246}Cm

Method/Author [a]	**"limited data"**		**"all data"**	
	$P_{a0,0}$, (keV)	**c^2/N-1**	**$P_{a0,0}$, (keV)**	**c^2/N-1**
UWM	79.8 (13)		79.26 (78)	
WM	79.18 (22)	3.30	79.17 (22)	1.69
LRSW	79.18 (22)	3.30	79.17 (22)	1.69
NRM	79.15 (22)	2.31	79.17 (22)	1.69
RM	79.10 (22)		79.10 (22)	
1991Ry01			80.7 (11)	

[a] UWM – Unweighted Mean; WM – Weighted Mean; LRSW – Limitation of Relative Statistical Weight; NRM – Normalized Residual; RM – Rajeval.

2.2 Gamma-Ray Transitions and Electron Internal Conversion Coefficients

The energy of the $2^+ \rightarrow 0^+$ ground state band γ–ray transition of ^{242}Pu was taken from 1972Sc01. The $4^+ \rightarrow 2^+$ γ–ray transition was not observed in the α–decay of ^{246}Cm and its energy was taken from the Coulomb excitation data of 1983Sp03 (note that the uncertainty in this value comes from the work of 1971EiZS). Gamma-ray transition multipolarities were taken from the ENSDF evaluation of 1998Ar12. Since absolute γ–ray emission probabilities were not measured directly for any of the γ–ray transitions that follow α–decay of ^{246}Cm, the absolute transition probabilities, $P_{\gamma+ce}$, were deduced from the relative α–transition probabilities, presented in Table 5, after a correction for the α–decay branching was applied:

$$P_{g+ce}(g_{2,0}) = \frac{\%a}{100} \times P_{a0,2} \text{ and } P_{g+ce}(g_{1,0}) = \frac{\%a}{100} \times (P_{a0,1} + P_{a0,2}) \qquad (3)$$

The electron internal conversion coefficients were calculated by a program supplied with the Saisinuc software (2002BeXX) that uses interpolated values of Band *et al.* (2002Ba85) with the hole being taken into account.

Table 7. Energies, multipolarities and electron internal conversion coefficients for γ–ray transitions following α–decay of ^{246}Cm

	Energy, (keV)	Multipolarity	α_K	α_L	α_M	α_N	α_O	α_T
$\gamma_{1,0}$	44.545 (9)	E2	-	542 (16)	152 (5)	41.6 (12)	9.8 (3)	746 (22)
$\gamma_{2,1}$	102.8 (1)	E2	-	10.1 (3)	2.82 (8)	0.775 (23)	0.183 (5)	13.9 (4)

3. Atomic Data

The Atomic data (Fluorescence yields, X-Ray energies and Relative probabilities, and Auger electrons energies and Relative probabilities) were provided by the Saisinuc software (2002BeXX). Details regarding the origin of these data can be found in 1996Sc06, 1998ScZM, 1999ScZX, 2000ScXX and 2003DeXX.

4. Alpha Emissions

Details are given is section 2.1. The number of alphas per 100 disintegrations was obtained by multiplying the corresponding α–transition probabilities that are presented in Table 5 by the α–decay branching ratio of 0.999 738 5 (7).

5. Photon Emissions

5.1 X-Ray Emissions

The X-ray emissions per 100 disintegrations were calculated using the computer program EMISSION (2000ScXX).

	Energy, (keV)	(%)
Ll	12.125	0.195 (8)
Lα	14.083 – 14.279	3.03 (11)
Lη	16.334	0.082 (4)
Lβ	16.499 – 19.331	3.76 (14)
Lγ	20.708 – 21.984	0.87 (4)

5.2 Gamma-Ray Emissions

The number of γ rays per 100 disintegrations was obtained from the $P_{\gamma+ce}(\gamma_{i,k})$ values, described in section 2.2, and the total electron internal conversion coefficients, $\alpha_T(\gamma_{i,k})$ that are presented in Table 7:

$$P_\gamma(\gamma_{i,k}) = \frac{P_{\gamma+ce}(\gamma_{i,k})}{1+\alpha_T(\gamma_{i,k})} \qquad (4)$$

6. Electron Emissions

The energies of the conversion electrons have been calculated from the γ–ray transition energies presented in Table 7 and the corresponding electron shell binding energies (1977La19). The number of conversion electrons of type x=T,L,M,N and O, where T stands for total, L for L -shell electrons, etc., per 100 disintegrations have been determined from the evaluated numbers of photons per 100 disintegrations, $P_\gamma(\gamma_{i,k})$, and the corresponding electron internal conversion coefficients, $\alpha_x(\gamma_{i,k})$

$$ec_{i,kx} = P_\gamma(\gamma_{i,k}) \times \alpha_x(\gamma_{i,k}) \qquad (5)$$

The number of L Auger electrons per 100 disintegrations was obtained from the computer program EMISSION (2000ScXX).

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^{252}Cf - Comments on evaluation of decay data
by M.M. Bé and V. Chisté

This evaluation was completed in November 2007. The literature available by October 2007 was included.

1 Decay Scheme

^{252}Cf disintegrates by α emissions mainly to the ^{248}Cm ground state level, and by spontaneous fission for 3,086 (8) %.
In the Tables part, the data are then normalized to 96,914 (3) alpha decays (see §2.2).
The calculated Q value of 6217(26) keV deduced from the decay scheme data, for the α decay, is in agreement with the value of 6216,87 (4) keV from Audi *et al.* (2003Au03).

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).
The level energies, spins and parities are based on the evaluation of Y.A. Akovali (1999Ak02).

2.1 Total half-life

A theoretical calculation of the α-decay half-life of Cf-252, by M. Balasubramaniam *et al.* (1999Ba03) leads to a value of 2,592 *a*.

The measured half-life are, in years:

Reference	half-life	Uc	Comments
Mehta (1965Me02)	2,646	0,004	
De Volpi (1969De23)	2,621	0,006	Rejected by Chauvenet criterion
Mijnheer (1973Mi05)	2,659	0,010	Rejected by Chauvenet criterion
V.Spiegel (1974Sp02)	2,638	0,007	
V.T. Shchebolev (1974Sh15)	2,628	0,010	Superseded by 1992Sh33
Mozhaev (1976Mo30)	2,637	0,005	
Lagoutine (1982La25)	2,639	0,007	
J.R.Smith (1984SmZW)	2,651	0,003	
W.G.Alberts (1983Al**)	2,648	0,002	
E.J. Axton (1985Ax**)	2,6503	0,0031	
Chen Keliang (1988Ke**)	2,64	0,13	
V.T. Shchebolev (1992Sh33)	2,645	0,003	
Weighted mean	2,6470	0,0014	χ^2 = 1,3 ; χ^2 crit = 2,5

(See also 1994Ka08, 1994KhZW for previous evaluated values.)
In the set of data listed above, two values were rejected in application of the Chauvenet's criterion. A value from 1974Sh15 has been superseded by a more recent one by the same author (1992Sh33). The remaining set of 9 values is consistent with a reduced χ^2 of 1,3. Then the weighted mean is 2,6470 with an external uncertainty of 0,0014. The largest contribution to the statistical weight (35 %) is from Alberts ; Axton,

Shchebolev and Smith give about 15 % each.
However, in the references listed above the uncertainty budget, in most cases, was not given. Some of them include the statistical part of the uncertainty only and did not take into account the systematic components as the associated presence of Cf-250 for example. So, as recommended in the study of Kharitonov (1994KhZW) an uncertainty of 0,1 % has been applied on the final result.

The adopted value is *2,6470 (26) a*.

2.2 Spontaneous fission half-life

The spontaneous fission decay constant λ_{sf} is determined by :

$\lambda_{sf} = \lambda / [(N\alpha/N_{sf}) + 1]$

where $(N\alpha /N_{sf})$ is the ratio between the number of α-decays and N_{sf} the number of spontaneous fission events and, λ is the total ^{252}Cf decay constant.

Measured values of the ratio $N\alpha/N_{sf}$:

Reference	Value	Uc
D.Mehta (1965Me02)	31,3	0,2
B.M.Aleksandrov (1970Al23)	31,39	0,26
J.D.Hastings (1971Ha**)	31,5	0,2
A.K. Pandey (1993Pa29)	31,56	0,35
Y.S.Popov (1990Po24)	31,38	0,12
Weighted mean	31,40	0,08

The 5 data sets given above are consistent (reduced χ^2 =0,2).

From this value and the total half-life above (§ 2.1), a **spontaneous fission half-life of *85,76 (23) a*** is deduced.

From $N\alpha/N_{sf}$ = 31,40 (8) and $N\alpha + N_{sf}$ = 100 Cf-252 decays, the **percentage of spontaneous fissions in the decay of Cf-252 is *3,086 (8) %*.**

Then the percentage of alpha transitions is: 96,914 (8) %.

2.3 Average number of neutrons

The average number of neutrons $\bar{\nu}$ emitted by spontaneous fission is:
$\bar{\nu}$ = 3,7675 (40)
as evaluated in the study of M. Divadeenam *et al.* (1984Di08) where relevant experimental data are taken into account and a least-squares fitting program was used to obtain an overall fit.

The average number of neutrons emitted per 100 disintegrations is:
n = 3,086 (8) × 3,7675 (40) = 11,627 (33) %

2.4 a Transitions

See Alpha-particle emissions (§ 4)

2.5 g Transitions

Multipolarities of these γ-ray transitions are from 1999Ak02.

The internal conversion coefficients for the 43- and 100-keV gamma transitions were calculated with the BrIcc code for the Frozen Orbital approximation (2005KiZW).

3 Atomic Data

Atomic values, ω_K, ϖ_L and n_K, are from Schönfeld and Janβen (1996Sc33).

4 a-Particle Emissions

4.1 a-Particle Energies

From the measured values of Rytz (1986Ry04) and Baranov (1976BaZZ, 1971Ba10, 1970Ba18), Rytz (1991Ry01) made some adjustments taking into account variations in the energies used as calibration standards. This leads, for the two main groups, to the recommended values of :
6118,10 (10) keV and 6075,64 (11) keV

The other energies : 5976,6 ; 5826,3 and 5615,6-keV are from Baranov (1970Ba18 and 1971Ba10)

Recorded spectra are also shown in Glover (1984Gl03) and Wiltshire (1985Wi14).

4.2 a-Particle Intensities

Measured alpha intensities, per 100 alpha decays :

Energy (keV)	Reference	Intensity (%)	Uc	Comments
6118,10	Asaro (1955As42)	84,5		
	Baranov (1976BaZZ)	84,1	0,4	See also 1970Ba18
	Adopted	84,3	0,3	Unweighted mean
6075,64	Asaro (1955As42)	15,5		
	Baranov (1976BaZZ)	15,8	0,1	See also 1970Ba18
	Adopted	15,6	0,3	Unweighted mean
5976,6	Baranov (1970Ba18)	0,2		See also 1985Wi14
	Asaro (1958As64)	0,28		
	Adopted	0,24	0,04	Unweighted mean
5826,3	Baranov (1970Ba18)	$2\ 10^{-3}$		
5616	Baranov (1970Ba18)	$\sim 6\ 10^{-5}$		

The number of measurements is very scarce moreover the results given by Asaro are without uncertainties. To try to make the most of this limited data, the unweighted mean is adopted, for the 6118-, 6075-, 5976-keV groups, with uncertainty covering the two existing values.
The intensity of the 5826-keV group is from Baranov (1970Ba18).
The weak group with energy 5615-keV, possibly feeding a 505-keV level, is not adopted, because no photons depopulating this level have been observed in the Cf-252 decay.

In the Tables part, these data are normalized to 96,914 (8) alpha decays (see §2.2).

5 Photon Emissions

5.1 g-Ray Emissions

Measured gamma-ray intensities, per 100 alpha decays :

Energy (keV)	Reference	Intensity (%)	Uc	Comments
42	Asaro (1955As42)	0,014		
43,399 (25)	Watson (1971Wa28)	0,0153	0,0009	
	Adopted	0,0157	0,0004	From decay scheme
100,2 (4)	Asaro (1955As42)	0,013		Adopted Eγ (1999Ak02)
	Adopted	0,0123	0,0021	From decay scheme
154,5 (2)	Piercey (1993Pi07)			Adopted Eγ (1993Pi07)
	Adopted	0,00053	0,00001	From decay scheme

The gamma ray intensities were deduced from the gamma-ray transition probabilities (see §2.5) and the theoretical ICC values.

In the Tables, these data are normalized to 100 decays of Cf-252 (see §2.2).

5.2 X-ray emissions

Asaro (1955As42) measured a K X-ray intensity of 0,007 %. This value disagrees with an expected KX-ray intensity of 0,000 086 % from the internal conversion electrons of the 154,5-keV gamma ray.

Relative intensities were measured by Popov *et al.* (1990Po14).

Total L X-ray intensity following the Cf-252 decay to Cm-248 was measured by Watson (1971Wa28) as 7,83 (40) % per 100 alpha decays.

The L X-ray total intensity calculated from the decay scheme data is 6,26 (14) % per 100 alpha decays. This result is in reasonable agreement with the measured value of Watson.

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