Monographie BIPM-5

Table of Radionuclides
(Comments on evaluation)

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TABLE DE RADIONUCLÉIDES
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COMMENTS ON EVALUATIONS

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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 inclus les commentaires sur les évaluations des radionucléides figurant dans le rapport Monographie BIPM-5 :

^{7}Be, ^{11}C, ^{13}N, ^{15}O, ^{18}F, ^{24}Na, ^{32}P, ^{33}P, ^{44}Sc, ^{44}Ti, ^{46}Sc, ^{51}Cr, ^{54}Mn, ^{56}Mn, ^{57}Co, ^{57}Ni, ^{59}Fe, ^{64}Cu, ^{66}Ga, ^{67}Ga, ^{85}Kr, ^{85}Sr, ^{88}Y, ^{89}Sr, ^{93}Nb^{m}, ^{99}Mo, ^{99}Tc^{m}, ^{109}Cd, ^{110}Ag, ^{110}Ag^{m}, ^{123}I, ^{123}Te^{m}, ^{125}Sb, ^{129}I, ^{131}I, ^{131}Xe^{m}, ^{133}Ba, ^{140}Ba, ^{140}La, ^{152}Eu, ^{153}Gd, ^{153}Sm, ^{154}Eu, ^{155}Eu, ^{166}Ho, ^{166}Ho^{m}, ^{169}Yb, ^{170}Tm, ^{177}Lu, ^{186}Re, ^{198}Au, ^{201}Tl, ^{203}Hg, ^{204}Tl, ^{208}Tl, ^{212}Bi, ^{212}Pb, ^{212}Po, ^{216}Po, ^{220}Rn, ^{224}Ra, ^{226}Ra, ^{227}Th, ^{228}Th, ^{238}Pu, ^{240}Pu, ^{241}Am, ^{242}Pu.

Summary

Over the past years, an informal group 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. These evaluators have agreed on the methodologies to be used. 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 :

^{7}Be, ^{11}C, ^{13}N, ^{15}O, ^{18}F, ^{24}Na, ^{32}P, ^{33}P, ^{44}Sc, ^{44}Ti, ^{46}Sc, ^{51}Cr, ^{54}Mn, ^{56}Mn, ^{57}Co, ^{57}Ni, ^{59}Fe, ^{64}Cu, ^{66}Ga, ^{67}Ga, ^{85}Kr, ^{85}Sr, ^{88}Y, ^{89}Sr, ^{93}Nb^{m}, ^{99}Mo, ^{99}Tc^{m}, ^{109}Cd, ^{110}Ag, ^{110}Ag^{m}, ^{123}I, ^{123}Te^{m}, ^{125}Sb, ^{129}I, ^{131}I, ^{131}Xe^{m}, ^{133}Ba, ^{140}Ba, ^{140}La, ^{152}Eu, ^{153}Gd, ^{153}Sm, ^{154}Eu, ^{155}Eu, ^{166}Ho, ^{166}Ho^{m}, ^{169}Yb, ^{170}Tm, ^{177}Lu, ^{186}Re, ^{198}Au, ^{201}Tl, ^{203}Hg, ^{204}Tl, ^{208}Tl, ^{212}Bi, ^{212}Pb, ^{212}Po, ^{216}Po, ^{220}Rn, ^{224}Ra, ^{226}Ra, ^{227}Th, ^{228}Th, ^{238}Pu, ^{240}Pu, ^{241}Am, ^{242}Pu.

TABLE DE RADIONUCLÉIDES – COMMENTAIRES SUR LES ÉVALUATIONS

De nombreuses applications nécessitent la connaissance des données liées à la désintégration des radioéléments, telles que la période radioactive, les énergies et les intensités des divers rayonnements. Pour répondre aux demandes des utilisateurs, le Laboratoire National Henri Becquerel (BNM - 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, inclus : 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 détails 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 volume regroupe les commentaires liés à l'évaluation des radionucléides suivants :

^{7}Be, ^{11}C, ^{13}N, ^{15}O, ^{18}F, ^{24}Na, ^{32}P, ^{33}P, ^{44}Sc, ^{44}Ti, ^{46}Sc, ^{51}Cr, ^{54}Mn, ^{56}Mn, ^{57}Co, ^{57}Ni, ^{59}Fe, ^{64}Cu, ^{66}Ga, ^{67}Ga, ^{85}Kr, ^{85}Sr, ^{88}Y, ^{89}Sr, ^{93}Nb^{m}, ^{99}Mo, ^{99}Tc^{m}, ^{109}Cd, ^{110}Ag, ^{110}Ag^{m}, ^{123}I, ^{123}Te^{m}, ^{125}Sb, ^{129}I, ^{131}I, ^{131}Xe^{m}, ^{133}Ba, ^{140}Ba, ^{140}La, ^{152}Eu, ^{153}Gd, ^{153}Sm, ^{154}Eu, ^{155}Eu, ^{166}Ho, ^{166}Ho^{m}, ^{169}Yb, ^{170}Tm, ^{177}Lu, ^{186}Re, ^{198}Au, ^{201}Tl, ^{203}Hg, ^{204}Tl, ^{208}Tl, ^{212}Bi, ^{212}Pb, ^{212}Po, ^{216}Po, ^{220}Rn, ^{224}Ra, ^{226}Ra, ^{227}Th, ^{228}Th, ^{238}Pu, ^{240}Pu, ^{241}Am, ^{242}Pu.

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 (BNM - 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 volume contains the procedures and comments relevant to the evaluation for the following radionuclides :

^{7}Be, ^{11}C, ^{13}N, ^{15}O, ^{18}F, ^{24}Na, ^{32}P, ^{33}P, ^{44}Sc, ^{44}Ti, ^{46}Sc, ^{51}Cr, ^{54}Mn, ^{56}Mn, ^{57}Co, ^{57}Ni, ^{59}Fe, ^{64}Cu, ^{66}Ga, ^{67}Ga, ^{85}Kr, ^{85}Sr, ^{88}Y, ^{89}Sr, ^{93}Nb^{m}, ^{99}Mo, ^{99}Tc^{m}, ^{109}Cd, ^{110}Ag, ^{110}Ag^{m}, ^{123}I, ^{123}Te^{m}, ^{125}Sb, ^{129}I, ^{131}I, ^{131}Xe^{m}, ^{133}Ba, ^{140}Ba, ^{140}La, ^{152}Eu, ^{153}Gd, ^{153}Sm, ^{154}Eu, ^{155}Eu, ^{166}Ho, ^{166}Ho^{m}, ^{169}Yb, ^{170}Tm, ^{177}Lu, ^{186}Re, ^{198}Au, ^{201}Tl, ^{203}Hg, ^{204}Tl, ^{208}Tl, ^{212}Bi, ^{212}Pb, ^{212}Po, ^{216}Po, ^{220}Rn, ^{224}Ra, ^{226}Ra, ^{227}Th, ^{228}Th, ^{238}Pu, ^{240}Pu, ^{241}Am, ^{242}Pu.

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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AUTORES PARA CORRESPONDENCIA

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 relativos a datos recomendados y la manera de establecerlos 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 by specialists and compiled (e.g., Q-values); if a new experimental study exists, the resulting measured value may be taken into account, 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 1s 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:

$$u_c = \sqrt{s_A^2 + s_B^2} \qquad (1)$$

where u_c is the combined standard uncertainty,
s_A is the type A standard deviation, and
s_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:

$$\bar{a} = \sum_{i=1}^{n} \frac{a_i}{n} \qquad (2)$$

with type A standard deviation:

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

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

$$s_B(\bar{a}) = \left[\sum_{j=1}^{m} s_{Bj}^2 \right]^{1/2} \qquad (4)$$

Combined standard uncertainty:

$$u_c(\bar{a}) = \sqrt{s_A^2(\bar{a}) + s_B^2(\bar{a})} \qquad (5)$$

Recommended value:

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

(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.

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

The associated values σ$_A$, σ$_B$ are:

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

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

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

σ$_A$ and σ$_B$ are combined quadratically to determine u_c:

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

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]:

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

The internal variance $s_{int}^{2}\left(a_w\right)$ 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:

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

The external variance $s^{2}_{ext}(a_w)$ 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]:

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

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

n	**critical** **c²/(n – 1)**	n	**critical** **c²/(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	$1 + 2.33\sqrt{2/n}$

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

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

If $c^{2}/(n-1) >$ critical $c^{2}/(n-1)$, 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 $c^{2}/(n-1)$ are then recalculated:

> if $c^{2}/(n-1) \leq$ critical $c^{2}/(n-1)$, the recommended value is given by:
>
> $$a = a_w \pm (\text{the larger of } s_{int}(a_w) \text{ and } s_{ext}(a_w)) \tag{16}$$
>
> if $c^{2}/(n-1) >$ critical $c^{2}/(n-1)$, 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 $P(rel)_{g_i}$ are known, the absolute emission probability $P(abs)_{gi}$ can be obtained from the equation:

$$P(abs)_{gi} = P(rel)_{gi} \times N \qquad (17)$$

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

$$N \sum_{i} P(rel)_{gi} \left(1 + a_{t_i}\right) = 1 - B, \qquad (18)$$

  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. b 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. g-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.

a_p 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 w_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 $\overline{w}_L$ 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 $\overline{w}_M$ are obtained from the fitting of experimental data by Hubbell [28, 30].

Relative X-ray emission rates (Kß/Ka) are taken from Schönfeld and Janßen [25], and Ka_1/Ka_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 510.998902(21) keV, as given by the CODATA Group [34].

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Table of contents

^{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 (1967Ca21), 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 ($I_{\gamma511}$) is $P_{\beta+}$ (=99.750(13)%), multiplied by 2, without the correction factor for the annihilation-in-flight process in the medium. That is, $I_{\gamma511}$ = 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 ($I_{\gamma511}$) is $P_{\beta+}$ (= 99,818 (13)), multiplied by 2, without the correction factor for the annihilation-in-flight processus in the medium. That is, $I_{\gamma511}$ = 199,636 (26) %.

4) Atomic Data

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

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^{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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1995Au04 – G. Audi, A.H. Wapstra, Nucl. Phys. A595 (1995) 409 [Q].
2000Co21 – Codata Group, Revs. Modern Phys. 72 (2000) 351 [m_0c^2].

^{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 ± 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 ($I_{\gamma511}$) is $P_{\beta+}$ (=96.86(19) %), multiplied by 2, without the correction factor for the annihilation-in-flight process in the medium. That is, $I_{\gamma511} = 193.72(27)$ %.

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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 $Q_{\beta-}$ value is taken from the 1995Au04 evaluation.

2.1 b^{-} Transitions

The energies are calculated from the $Q_{\beta-}$ 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	**1950Gr01**	**1951Tu12**	**Present evaluation**
(keV)	Grant(1950)	Turner (1951)	
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) < 5x10^{-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-χ^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-χ^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-χ^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-χ^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 value 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 uncertainty 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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^{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:

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

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	$\langle\beta^+\rangle^*$ 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 < β^+>/β^+(%)

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

$^@$ Fraction (in %) of β^+ transitions that annihilate in flight = 0.01xβ^+(%)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 χ^2/ν = 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	$\alpha_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 ε(0) < 0.04%. Using ε(0)=0.04% and ε(146) = 99.6 (11)% gives ε(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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^{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), $\leq$ 0.06 (1950Mo62), and $\leq$ 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$^\pi$ 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 about 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, $\alpha(2009)$ has been neglected.

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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 $P_\gamma(320)$ 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, a = 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-χ^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.

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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 1σ 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 ≤ 8x10^{-5}% (1968Be01), ≤ 4.4x10^{-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 834-keV 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(β^-) ≤ 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
24.7 (9)	1973MuAA
25.93 (14)	1978Ma06
25.1 (7)	1980Co22

which are slightly lower than the calculated values, but generally are within the uncertainties.

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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.

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

$101.163(23) \times NF = 100$

$NF = 0.9885(3)$

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 ($\Delta J=3$, $\Delta\pi$ = 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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^{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 relative 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 deduced Iγ 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 Iβ(*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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^{64}Cu - Comments on evaluation of decay data
by R. G. Helmer

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 (1996Si12).

The decay scheme for the electron capture to ^{64}Ni is consistent since the sum of the average energies of all of the radiations, as computed by RADLST, is 1020 (10) keV compared to the value of 1020 (8) from the Q_e value and the branching fraction.

2 Nuclear Data

Q values from 1995Au04 are for ß$^-$ decay 578.7 (9) and for e decay 1675.10 (20) keV.

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 half-life values considered are, in hours:

10	(1935Am01)	omitted, no uncertainty
12.8 (1)	(1936Va02)	
12.5	(1937He05)	omitted, no uncertainty
12.8 (3)	(1938Ri)	as cited in 1968Ke12
12.8 (3)	(1939Sa02)	as cited in 1968Ke12
11.9 (10)	(1943Hu03)	
11.9 (10)	(1944Hu05)	omitted, same data as 1943Hu03
12.80 (4)	(1950Ra62)	as cited in 1968Ke12
12.74 (7)	(1951Sc56)	
12.88 (3)	(1951Si91)	
12.80 (3)	(1955To07)	as cited in 1968Ke12
12.90 (6)	Rudstam	as cited in 1968Ke12
12.87 (5)	(1957Wr37)	superseded by 1972Em01
12.85 (5)	(1959Po64)	
13.9	(1965He08)	omitted, no uncertainty
12.86 (3)	(1965Pa18)	
12.70 (3)	(1966Fu14)	
12.86 (3)	(1966Li09)	

12.8	(1967Vi08)	omitted, no uncertainty
12.701 (11)	(1968He20)	as cited in 1973De56
12.80 (4)	(1968Ke12)	
12.65 (17)	(1969Bo11)	
12.715 (7)	(1972Em01)	
12.701 (7)	(1972MeZM)	as cited in 1996Si12
12.72 (4)	(1972WyZZ)	superseded by 1972Em01
12.6 (10)	(1973ArZI)	
12.699 (2)	(1973De56)	
12.82 (4)	(1973Ne02)	
12.704 (6)	(1974Ry01)	
12.701 (3)	(1980RuZY, 1982RuZV)	
12.701 (2)	**Adopted value**	

The set of 23 unsuperseded values with uncertainties is inconsistent. The unweighted average is 12.73 (4) hours and the weighted average is 12.7029 with an internal uncertainty of 0.0015, a reduced-χ^2 of 6.8, and an external uncertainty of 0.0039. 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) given by 1973De56, and used here, differs slightly from the weighted average of 12.6973 (16) computed by the evaluator for 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 adopted half-life was taken from the weighted average of the 6 values (those from 1968He20, 1972Em01, 1972MeZM, 1973De56, 1974Ry01, and 1980RuZY) with uncertainties less than 0.03 hours. This average is 12.7007 with internal and external uncertainties of 0.0015 and a reduced-χ^2 of 1.04. 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 0.002.

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**	Dl/l·$\mathbf{10^4}$
1972Au Auric	Cu phtalocyanine in two forms	10.0 (16)
1972Em01 Emery	Cu metal Cu(NO$_3$)$_2$	15 (15)

Reference and first author	Forms compared		Dl/l·10^4
1973Ha60	Cu metal	CuO	0 (3)
Harbottle			
1973De56	Cu phtalocyanine in two forms		0.4 (20)
Dema			
1974Je	Cu metal	$Cu(H_2O)_6SO_4$	1.12 (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 0.00037 (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.

2.1 ß$^-$ Transitions

See comments in section 2.3.

2.2 ß$^+$ Transitions

See comments in section 2.3.

2.3 Electron Capture Transitions

The probabilities of the ß$^-$, ß$^+$, and e branches have been determined by a series of separate, but partially correlated, measurements by 1983Ch47 and 1986Ka03. These measurements include the ß$^-$ spectrum, the ß$^+$ spectrum, 4pß-γ coincidences, liquid scintillation counting, and the γ-ray spectrum. The analysis of 1983Ch47 included a least-squares fit to the various measured quantities and ratios of quantities. Since over 90% of the decays are to the ground states of ^{64}Ni and ^{64}Zn, this set of data provides very accurate results. The results are: %ε = 43.1 (5) [from 43.10 (46) (1983Ch47) and 43.2 (5) (1986Ka03)], %ß$^-$ = 39.0 (3) [from 1986Ch47, other: 38.3 (6) (1986Ka03)], and %ß$^+$ = 17.86 (14) [from 1986Ch47, other: 17.93 (20) (1986Ka03)].

A recent, and unpublished, determination of %ß$^-$ has been made by mass spectrometric measurements of the number of atoms of ^{64}Ni and ^{64}Zn produced in the decay of a ^{64}Cu sample (2002We). Their results is 38.06 (3). This result suggests that future evaluations may result in a small decrease in this value and the corresponding increase in %ε.

From ß$^-$ and ß$^+$ spectra, the ratio of their emission rates is 2.181 (6) (1986Ch47) and 2.138 (32) (1986Ka03). (Earlier and less precise measurements of these quantities are tallied in 1983Ch47.) The average particle energies to the ^{64}Ni and ^{64}Zn ground states are 278.21 (9) and 190.4 (4), respectively, and are from the LOGFT code. The log ft values to the ^{64}Ni ground state and 1345 level are 4.973 (3) and 5.506 (10), respectively, and to the ^{64}Zn ground state 5.294 (4), all of which are consistent with being allowed transitions from the 1$^+$ parent.

2.4 Gamma Transitions

The γ-ray energy is 1345.77 (16) from 1974HeYW and its emission intensity is 0.475% (10), a weighted average of 0.471% (11) (1983Ch47) and 0.487 (20) (1986Ka03).

The J$^\pi$ assignments are from the Adopted Levels in the Nuclear Data Sheets (1996Si12) and these imply the γ-ray has E2 multipolarity. The internal-conversion coefficients were interpolated from the tables of Band et al. (1976Ba63) and are α_K =0.000 112, α_L = 0.0000108, and α_T = 0.000126.

The internal-pair-formation coefficient was interpolated from the theoretical values (1979Sc31) and is IPFC(1345) = 0.000034.

3 Atomic Data

The data are from 1996Sc06.

3.1 and 3.2

None

4 Radiation Emissions

4.1 Electron Emissions

Auger electron emission intensities are deduced from the evaluated data set.

4.2 Photon Emissions

See section 2.4.
X-ray emission intensities are deduced from the evaluated data set.

5 Main production modes

They are taken from : Table de Radionucléides, F; Lagoutine, N. Coursol, J. Legrand. ISBN 2 7272 0078-1

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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 < $2\text{x}10^{-4}$) 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, $\chi^2/\nu=2.9$) 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 $Q(\varepsilon) = 5175(3)$ 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 ($E(\varepsilon) = Q(\varepsilon) - E(\mathrm{keV})$) are evaluator's values deduced using $Q(\varepsilon) = 5175(3)$ 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.	1970Ph01	1970Ph01*	1971Ca14	1971Ca14*	1994En02	1994En02*	2000Ra00	Berkeley	Budapest	Recomm.	Remarks
Eg (keV)	**Ig**	**Ig(Corr.)**	**Ig**	**Ig(Corr.)**	**Ig**	**Ig(Corr.)**	**Ig**	**Ig**	**Ig**	**Ig**	
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.	1970Ph01	1970Ph01*	1971Ca14	1971Ca14*	1994En02	1994En02*	2000Ra00	Berkeley	Budapest	Recomm.	Remarks
E_g (keV)	I_g	I_g(Corr.)	I_g	I_g(Corr.)	I_g	I_g(Corr.)	I_g	I_g	I_g	I_g	
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 V.P. Chechev and N.K. Kuzmenko

This evaluation was completed in March 2000, the half-life value has been updated in March 2004.

1. Decay Scheme

Up to the recent time a main uncertainty of evaluations of the ^{67}Ga decay scheme was connected with the lack of measurements of the absolute intensity of the internal conversion electron component $P(ec_{1,0})$ from the 93 keV gamma-transition (2000Si03). This value determines directly the probability of the allowed, but l-forbidden electron capture transition to the ground state of ^{67}Zn. In many evaluations including 1991Bh06 it has been adopted equal zero.

This evaluation of the ^{67}Ga decay scheme has taken into account two recent measurements of $P(ec_{1,0})$ (1998At04 and 2000Si03) as well as an analysis 2000Si03 and based on the average of the above two measurement results which gives $P(ec_{1,0}) = 32.5 \pm 0.4$ per 100 disintegrations (see comments in 4.2) and leads to the probability of the electron capture transition to the ^{67}Zn ground state $P(\varepsilon_{0,0}) = 3.6 \pm 2.0$ per 100 disintegrations.

There are two levels 604.5 keV and 814.8 keV among the adopted levels in 1991Bh06 which are placed below the decay energy and which could be fed by the 3rd and 2nd EC transitions, respectively. From the lg *ft* systematics their corresponding lg *ft* should be more than 17.6 and 11. From here the upper limits on the EC branch intensities are obtained negligible: $< 4 \cdot 10^{-12}$ % and 10^{-6} %.

2 Nuclear Data

Q value is from Audi and Wapstra (1995Au04)

Since 1972 the eight accurate measurements of the ^{67}Ga half-life have been carried out. They gave the following values, in days:

3.261(1)	1972Le37
3.264(1)	1978La21
3.261(1)	1978Me10
3.2594(12)	1979De42
3.2607(8)	1980Ho17
3.26154(54)	1982HoZJ, 1992Un01, 2002Un02
3.2623(15)	2003Schrader
3.2634(16)	2003Silva

The other available values are, in days: 3.29(8) (1938MA01); 3.46 (1948HO04); 3.26(2) (1948MC32); 3.33 (1950HO26); 3.246(13) (1955TO27); 3.30(7) (1964RU06); 3.27(6), 3.26(5), 3.53(10), 3.30(6), 2.90(15), 3.51(5), 3.78(18), 3.49(18) (1972CR02). These values were omitted due to their large uncertainties.

Statistical processing of the above data set leads to the unweighted mean (UWM) of 3.2616(6) and weighted mean (WM) of 3.2613(6) with an internal uncertainty of 0.00033 and an external uncertainty of 0.00038. The LWEIGHT computer program has chosen WM and the internal uncertainty. The EV1NEW computer program has chosen WM and the minimum input uncertainty of 0.00054.

The adopted value for the ^{67}Ga half-life is 3.2613(5) days.

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 computed from the tables of Schönfeld (1998Sc28).

The experimental values of P_K are available for $\varepsilon_{0,2}$ and $\varepsilon_{0,3}$ being obtained in 1988Be55 for ω_K=0.479(30) from 72Bb16; $P_K(\varepsilon_{0,2}) = 0.89(4)$; $P_K(\varepsilon_{0,3}) = 0.88(3)$.

The electron capture probabilities have been calculated from the balance of the evaluated $P_{\gamma+ce}$ values taking into account the evaluated absolute intensity $P(ec_{1,0})$ = 32.5±0.4 per 100 disintegrations (see comments in 1. and 4.2) that allows normalizing the total ground-state gamma transition probability to 96.4(20) per 100 disintegrations.

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 experimental information on the multipolarity admixture coefficients (see the table below) and the theoretical values from 1978Ro22.

Most of gamma-transitions have the multipolarity of M1+E2. The multipolarities of the $\gamma_{1,0}$ and $\gamma_{4,1}$ transitions are pure E2 (for $\gamma_{4,1}$ the admixture of M3 is possible). Below the measured admixture coefficients δ(E2/M1) and adopted $|\delta|$ are given. The values $|\delta|$ have been adopted mainly from the most accurate gamma-gamma directional-correlation measurements of 1973Ba54 and 1978Lo06.

	1962 Ri09	1964 Al28	1966 Fr12	1973 Ba54	1974 Ni01	1975 Th01	1975 We08	1978 Du04	1978 Lo06	Adopted $\|\delta\|$
$\gamma_{2,1}$	$\|\delta\| \leq 0.07$		+ 0.1(1)			+ 0.06(5)	-0.15(3), 2.6(3)			0.06(5)
$\gamma_{2,0}$	+ 0.51(7)	$+ 0.415^{+0.085}_{-0.07}$	+ 0.38(8)	- 0.350(35)	- 0.8 < δ δ < -0.1	+ 0.48(11)	-0.17(7)	+ 0.08(4), - 5.0(8)		0.35(4)
$\gamma_{3,2}$			- 0.02(2)	+ 0.035(21)	+ 0.02(4)	+ 0.01(20)	+ 0.08(5), - 5.7(20)	- 0.10(6), + 3.6(8)		0.035(21)
$\gamma_{3,1}$			- 0.1(2)	- 0.178(5)	- 0.21(5)	+ 0.05(7)	- 0.11(4), 2.3(3)	+ 0.20(8), 3.1(4)		0.18(1)
$\gamma_{3,0}$			+ 0.07(8)	+ 0.043(10)	+ 0.11(6)	- 0.01(18)	0.09(2), 3.2(2)	- 0.17(8), - 2.1(3)		0.043(10)
$\gamma_{4,3}$			- 0.14(8)		$+ 1.9^{+0.8}_{-0.3}$	0.57	0.06(4), 2.8(4)	- 0.17(8), - 1.7(6)	0.14(3)	0.14(3)
$\gamma_{4,1}$ M3/ E2					$- 0.04^{+0.22}_{-0.10}$	0.46(11)		- 0.1(1)	0.04(4)	0.04(4)
$\gamma_{4,0}$						- 0.81(47)		+ 0.9(3)	- 0.96(9)	0.96(9)

The measurements of ICC(α_K) have been made in 1966Fr12. Below their results are compared with the adopted α_K.

	Measured α_K	Adopted α_K
$\gamma_{1,0}$	0.77(8)	0.751(15)
$\gamma_{2,0}$	0.0156(10)	0.0158(6)
$\gamma_{3,2}$	0.0075(7)	0.00811(17)
$\gamma_{3,1}$	0.00337(30)	0.00356(15)
$\gamma_{3,0}$	0.00192(15)	0.00174(4)
$\gamma_{4,3}$	0.0019(15)	0.00104(3)
$\gamma_{4,0}$	$3.4(7) \cdot 10^{-4}$	$3.2(3) \cdot 10^{-4}$

As seen from this table the adopted α_K agree satisfactorily with the measured ones.

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 KX-ray emission probabilities are taken from 1996Sc06.

3.3. Auger Electrons

The energies of Auger electrons are from 1977La19 (Larkins) and 1987Table (Table de Radionucleides).

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 probability of KX-rays (P_{XK}) has been computed using the adopted value of ω_K, the evaluated total absolute emission probabilities 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 96Sc06.

Below the measured in 1979De42 the P(XKα)/P($\gamma_{2,0}$) and P(XKβ)/P($\gamma_{2,0}$) values are given in comparison with our calculated (evaluated) values:

	Measured 1979De42	Calculated (evaluated)
P(XKα)/P($\gamma_{2,0}$)	2.37(5)	2.38(8)
P(XKβ)/P($\gamma_{2,0}$)	0.331(7)	0.338(11)

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 Emissions

The gamma ray energies have been adopted from 1978Me10 as the most accurate with corrections to the revised energetic scale in 2000He14 (lowering by 5.80 ppm). The complete list of the gamma ray energy measurements is given below in Table 1.

Table 1. Measured energies of gamma-rays in the decays of ^{67}Ga → ^{67}Zn and ^{67}Cu → ^{67}Zn

	1958Ch08	1966Fr12	1969Ra15	1974Ar22	1974HeYW*	1974HeYW	1978Du04	1978Me10	1990Me15	Adopted
$\gamma_{2,1}$	91.22(4)	91.275(20)	91.26(10)		91.31(3)	91.31(5)		91.266(5)	91.237(35)	91.265(5)
$\gamma_{1,0}$	93.26(4)	93.317(20)	93.25(10)	93.2(2)	93.32(2)	93.32(2)	93.30(5)	93.311(5)	93.291(30)	93.310(5)
$\gamma_{2,0}$	184.46(27)	184.60(4)	184.53(10)	184.0(2)	184.56(2)	184.56(2)	184.63(3)	184.577(10)	184.569(30)	184.576(10)
$\gamma_{3,2}$		208.96(6)	208.95(10)		208.93(2)	208.93(2)	208.91(4)	208.951(10)	208.970(30)	208.950(10)
$\gamma_{3,1}$		300.24(7)	300.22(10)		300.24(6)	300.18(2)	300.24(5)	300.219(10)	300.230(25)	300.217(10)
$\gamma_{3,0}$		393.65(6)	393.60(10)		393.56(7)	393.47(3)	393.54(3)	393.529(10)	393.539(25)	393.527(10)
$\gamma_{4,3}$		494.31(10)				494.19(8)	494.10(6)	494.169(15)	494.132(30)	494.166(15)
$\gamma_{4,2}$		703.6(2)					703.2(3)	703.110(15)	703.078(50)	703.106(15)
$\gamma_{4,1}$		794.7(2)				794.49(20)	794.39(8)	794.386(15)	794.378(50)	794.381(15)
$\gamma_{4,0}$		888.0(2)				887.68(15)	887.67(7)	887.693(15)	887.664(40)	887.688(15)

) In 74HeYW the gamma ray energies have been measured in the decay of ^{67}Cu → ^{67}Zn

The gamma ray absolute emission probabilities have been computed from the evaluated relative emission probabilities given in Tables 2, 3 and the absolute emission probability of $\gamma_{1,0}$(93 keV). The latter has been obtained from the evaluated P($ec_{1,0}$)=32.5(4) per 100 disintegrations and the total ICC from 1978Ro22 for E2 gamma-transition $\gamma_{1,0}$: P($\gamma_{1,0}$)=P($ec_{1,0}$)/α_T($\gamma_{1,0}$)=37.8(9).

The evaluated value of P($ec_{1,0}$) is based on measurements 1998At04 and 2000Si03. In 2000Si03 two measurement results are given for two experimental data sets: 32.13(14) and 31.82(27). The weighted mean of them with the external uncertainty increased by Student's factor is 32.06(23). In fact, this is a final experimental result of Simpson and Ntsoane (2000Si03). Combining it with the somewhat discrepant value of Attie et al. (1998At04) of 32.9(4) we have an evaluation for P($ec_{1,0}$)=32.5(4) which is the unweighted average and obtained also on other statistical procedures (Limitation of Relative Statistical Weight, Chauvenet's Criteria and Permanent Inflation methods). The Uniform Chi-Square Inflation method gives 32.5(3), the Iterative Extensive Weighting method – 32.5(5). (See 1994Ka08). Simpson and Ntsoane recommended P($ec_{1,0}$)=32.5(1) but such an uncertainty does not correspond to discrepancy of the two experimental results and evidently is underestimated.

The results of statistical data processing for the relative gamma emission probabilities are given in Table 3.

Table 2. Relative emission probabilities of gamma rays in the decay of ^{67}Ga

		1966 Fr12	1967 Vr03	1974 HeYW	1975 Th01	1978 Me10	1979 De42	1990 Me15	1991 HiZZ**	Evaluated
$\gamma_{2,1}$	91	7.4(26)*		21.0(19)*	15.1(6)	14.49(10)	15.0(5)	13.8(11)	14.9(7)	14.7(2)
$\gamma_{1,0}$	93	314(22)*		161(11)		181.2(11)	185(6)	169(10)	184(5)	181(3)
$\gamma_{2,0}$	184	100	100	100	100	100	100	100	100	100
$\gamma_{3,2}$	208	10.8(13)	10.9(5)	11.5(9)		11.38(8)	11.35(15)	11.1(7)	11.3(4)	11.34(9)
$\gamma_{3,1}$	300	70(5)	75.6(50)	81(6)		81.2(5)	79.9(11)	76.5(37)	79.2(11)	80.2(6)
$\gamma_{3,0}$	393		20.4(12)	22.6(19)		22.72(15)	22.0(3)	20.7(10)	22.1(3)	22.3(2)
$\gamma_{4,3}$	494	0.43(4)	0.24(3)	0.60(6)*		0.332(4)	0.322(7)	0.32(5)	0.326(7)	0.328(7)
$\gamma_{4,2}$	703	0.065(10)	0.05(1)			0.0529(10)	0.060(5)	0.046(5)	0.050(4)	0.053(2)
$\gamma_{4,1}$	794	0.26(5)	0.23(2)	0.24(3)		0.248(9)	0.251(8)	0.244(17)	0.255(9)	0.249(8)
$\gamma_{4,0}$	888	0.69(9)	0.58(6)	0.69(7)		0.612(10)*	0.712(11)	0.69(4)	0.703(15)	0.703(11)

* Omitted as outliers. For $\gamma_{4,0}$ the value of 1978Me10 has been omitted as it increases considerably χ^2 for the data set.

** In 1991HiZZ the absolute emission probabilities have been given but the details of the measurements are absent. Photons per 100 disintegrations: $\gamma_{2,1}$-3.16(9); $\gamma_{1,0}$- 39.3(10); $\gamma_{2,0}$-21.20(28); $\gamma_{3,2}$-2.40(7); $\gamma_{3,1}$-16.80(22); $\gamma_{3,0}$-4.68(6); $\gamma_{4,3}$-0.061(14); $\gamma_{4,2}$-0.0106(9); $\gamma_{4,1}$-0.0540(18); $\gamma_{4,0}$-0.149(3) .

Table 3. The results of statistical data processing for the relative gamma emission probabilities

	Eγ	n	WM	σ	S	χ^2		Final uncertainty and its type
						set	table	
$\gamma_{2,1}$	91	5	14.7	0.23	0.16	2.0	9.5	0.2 (σ) *
$\gamma_{1,0}$	93	5	181	2.4	2.8	5.5	9.5	3 (S) *
$\gamma_{3,2}$	208	7	11.34	0.09	0.04	1.2	12.6	0.09 (σ)
$\gamma_{3,1}$	300	7	80.2	0.52	0.63	8.8	12.6	0.6 (S) *
$\gamma_{3,0}$	393	6	22.3	0.14	0.21	10.7	11.1	0.2 (S) *
$\gamma_{4,3}$	494	6	0.328	0.0034	0.0062	16.6	11.1	0.007 (tS) *
$\gamma_{4,2}$	703	6	0.053	0.0018	0.0019	6.0	11.1	0.002 (S) *
$\gamma_{4,1}$	794	7	0.249	0.0046	0.0024	1.6	12.6	0.008 (σ)
$\gamma_{4,0}$	888	6	0.703	0.0094	0.0092	4.8	5.0	0.011 (σ_{min}) **

*Limitation of Relative Statistical Weight (LRSW) method increased the uncertainty of 1978Me10.
**LRSW method increased the uncertainty of 1979De42.

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.

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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:

$\alpha_T(M1) * \%(M1) + \alpha_T(E2) * \%(E2) = (0.00479(14) * 0.9948(4)) + (0.213(6) * 0.0052(4)) = 0.0488(14)$

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, ϖ_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 $P_{\gamma+\mathrm{ce}}$ (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 $P_{\gamma+\mathrm{ce}}$ 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 keV 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 probabilities 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_{γ} = 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 χ^2 = 0,57; 2734 keV: LWM of values 1, 3, 5, 6, reduced χ^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_γ(rel)·$(1 + \alpha_t)$·$(1 + \alpha_\pi)$	$P_{\gamma+ce}$ (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 rays is calculated to be 0,9932(3) photons per disintegration and $P_{\gamma+ce}$ 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 $P_{\gamma+\mathrm{ce}}$ 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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^{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* ≥ 8, the β^- branches to 1205 keV and 1321 keV levels, if they exist, would be expected ≤ 0,010% and ≤ 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.

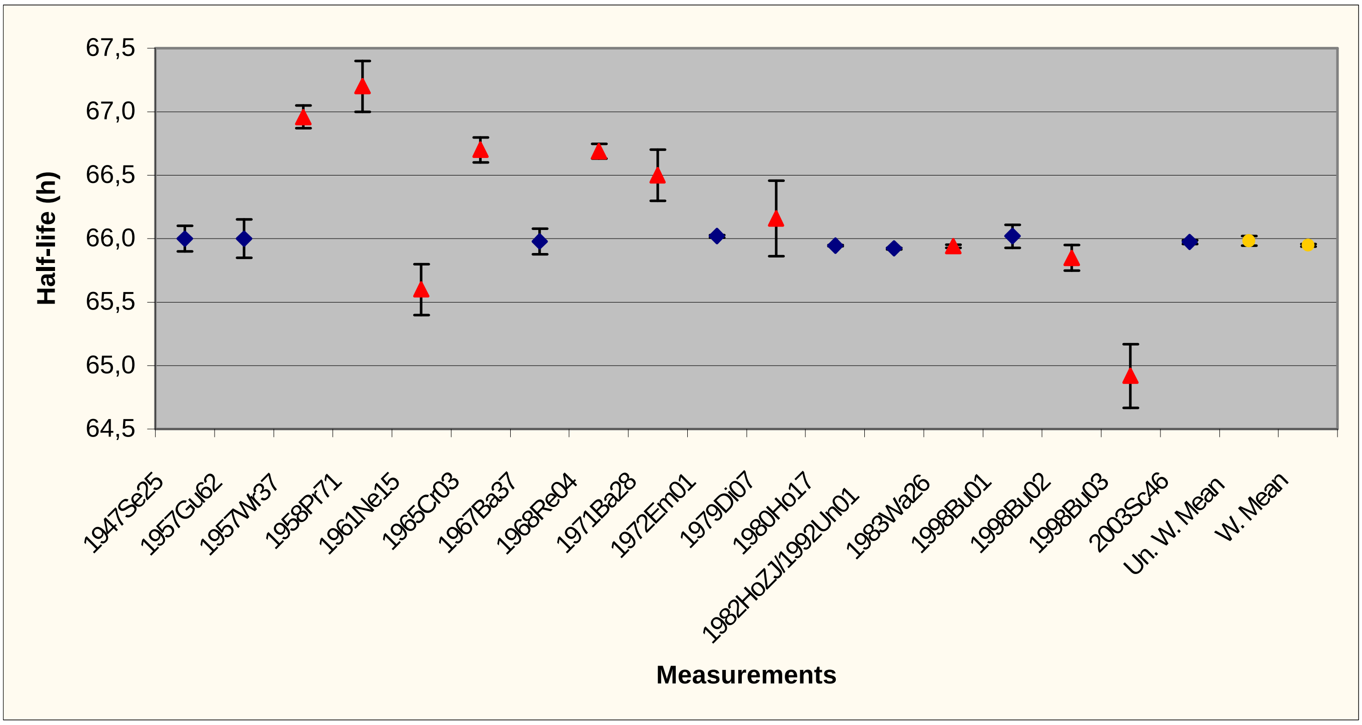
For this evaluation Mo-99 and Tc-99m are considered being in equilibrium. Therefore, the ratio of their activities is 1,1.

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)	ic
	Unterweger *et al.* (1992Un01)	
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 (1969) 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 ($\delta=-0,119(8)$) 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 δ = 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 and type
					table	set	
$\gamma_{3,1}$	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 $\Sigma P_\beta=1$ 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^{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_γ(142,7)/ I_γ(140,5) = 0,00026(2) and P_γ(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:
$\omega_K = 0{,}796(4)$, $\varpi_L = 0{,}0453(11)$, $n_{KL} = 1{,}000(4)$

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	$0{,}97 \times 10^{-6}$ (15)		Jones and Griffin (1970Jo24)
	$1{,}10 \times 10^{-6}$ (10)		Decombaz *et al.* (1972De76)
	$1{,}13 \times 10^{-6}$ (9)		Alburger *et al.*.(1980Al02)
	$1{,}09 \times 10^{-6}$ (6)	$0{,}96 \times 10^{-4}$(6)	LWEIGHT reduced-χ^2 = 0,42 weighted mean and internal uncertainty
232	$0{,}95 \times 10^{-7}$ (17)	$0{,}84 \times 10^{-5}$ (15)	Alburger *et al.*. (1980)
89		$1{,}04 \times 10^{-3}$ (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) × 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 × 10^{-6}/0,93= **1,06(6) ´ 10^{-4}.**

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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_γ < 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)
$K_{\alpha2}/K_{\alpha1}$	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

$K_{\alpha2}$	0,198 (12)
$K_{\alpha1}$	0,372 (22)
K_β	0,121 (7)

Cd KX-rays per 100 decays of the parent

$K_{\alpha2}$	0,153 (9)
$K_{\alpha1}$	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	ΔJ,Δπ	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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^{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 ($\delta^2(440)=0,149$) was calculated with $\delta^2(159) = 0,0119$ (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:

$$\text{Normalization} = \frac{100}{(\Sigma(1 \quad + a_T)P_{rel})}$$

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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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

Normalization factor = 83,25 (21)

exp.unc. = LWM expanded the uncertainty so range includes the most precise value.

int.unc. = internal uncertainty

ext.unc. = external uncertainty

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)

^{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

- 88-keV gamma transition

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.

- 247-keV gamma transition

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).

- 159-keV gamma transition

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 $\bar{\omega}_L$ 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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^{125}Sb -Comments on evaluation

by R. G. Helmer

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 population of the isomer is 23.9 (9)% calculated from this adopted 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	15.2(9)	unique 1st forb.	9.77
321	7.10 (10)	1st forb.	9.34
443	0.087 (10)	2nd forb.	11.06
463	39.8 (4)	allowed	8.04
525	1.585 (24)	1st forb.	9.12
636	17.95 (22)	allowed	7.23
642	5.75 (6)	allowed	7.66
671	13.42 (15)	allowed	6.93

For comparison, the measured values to the 144-keV 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.

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			364	186
117	E1			0.127	0.109
144	[E5]			265	39.8
172	M1(+E2)	-0.004 (8)	<0.014	0.151	0.130
176	M1+E2	-0.60 (2)	26.5 (18)	0.167	0.130
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)	0.091	0.079
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	0.00420
606	E2			0.00485	0.00413
635	M1+E2	+0.332 (3)	9.9 (2)	0.00526	0.00455
672	E2			0.00373	0.00320

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 [γγ(θ)], 1998Ro20 [γγ(θ)], 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 g-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, 6.45 (28); KLX, 2.92 (13); and KXY, 0.331 (16).

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.

The relative emission probabilities are: $K_{\alpha2}$, 0.5370 (25); $K_{\alpha1}$, 1.0000; and K_{β}, 0.3483 (35) and the absolute probabilities (in %) are $K_{\alpha2}$, 19.5 (6); $K_{\alpha1}$, 36.3 (11); and K_{β}, 12.7 (4).

4.2 γ 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)

Energy	68An15[a]	68Se11[b]	69Ch09	70Na12	73Gu10	74Il02[c]	76Wa13	77Ar10	77Ge12
408.1	0.9 (4)	0.6		0.62 (6)	0.59 (3)	0.50 (3)	0.62 (2)	0.59 (3)	
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)

Energy	79Pr08	80Ro22	83Si14	84Iw03	86Wa35	93Fa02	98Sa55	90He05
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)
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

Energy	Adopted	wtd. avg.	s $_{int}$	reduced-χ^2	σ_{ext}	σ_{LWM}	P_γ (%) x0.292 (3)	90Lo03 eval.	1999Ka26 eval.
19.9	0.0683 (16)	0.0683	0.0016	0.14			0.0199 (5)	0.068 (2)	0.069 (3)
35.5	20.0 (2) [i]	16.0	0.13	43	0.9	1.7	5.84 (8)	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		0.0675 (14)	0.233 (5)	
110.8	0.0037 (3)	0.00373	0.00017	3.6	0.00033		0.00108 (9)	0.0036 (6)	0.0035 (4)
117	0.890 (9)	0.890	0.006	2.5	0.009		0.260 (4)	1.03 (4)	0.887 (9)
172.6	0.65 (3)	0.649	0.007	4.6	0.014	0.031	0.190 (9)	0.75 (5)	0.646 (24)
176.3	23.09 (15)	23.09	0.09	2.6	0.15		6.74 (8)	23.06 (14)	23.11 (5)
178.7	0.116 (5)	0.116	0.002	5.0	0.005		0.0339 (15)	0.110 (9)	0.114 (8)
198.6	0.0448 (24)	0.0448	0.0024	0.9			0.0131 (7)	0.054 (11)	0.0432 (20)
204.1	1.06 (5)	1.061	0.007	4.6	0.015	0.047	0.310 (15)	1.105 (11)	1.070 (21)
208.1	0.833 (27)	0.833	0.006	2.3	0.009	0.027	0.243 (8)	0.808 (9)	0.837 (14)
227.9	0.443 (9)	0.443	0.005	0.5			0.129 (3)	0.437 (12)	0.443 (6)
315	0.0144 (9)	0.0144	0.0009	0.8			0.0042 (3)	0.0138 (9)	0.0136 (16)
321	1.409 (8)	1.409	0.008	0.9			0.411 (5)	1.40 (2)	1.404 (9)
380.4	5.145 (13)	5.145	0.012	1.2	0.013		1.502 (15)	5.13 (4)	5.124 (19)
408.1	0.617 (5)	0.617	0.005	0.7			0.1802 (24)	0.611 (12)	0.623 (6)
427.9							29.2 (3)	100	100
443.5	1.033 (7)	1.033	0.007	1.0			0.302 (4)	1.03 (2)	1.035 (6)

Energy	Adopted	wtd. avg.	s $_{int}$	reduced-χ^2	σ_{ext}	σ_{LWM}	P_γ (%) x0.292 (3)	90Lo03 eval.	1999Ka26 eval.
463.4	35.47 (4)	35.47	0.04	1.0			10.36 (10)	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	17.55 (21)	60.36 (11)	59.62 (16)
606.6	16.997 (27)	19.997	0.027	1.0			4.96 (5)	17.03 (3)	16.83 (6)
635.9	38.31 (14)	38.31	0.05	4.7	0.11	0.14	11.19 (12)	38.36 (15)	37.9 (3)
671.4	6.036 (17)	6.036	0.014	1.5	0.017		1.763 (19)	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. A portion of the feeding of this γ ray is via the 58-day isomer. Most papers to not give sufficient experimental detail to know if their source was at equilibrium. The value adopted was chosen by the evaluator to give an intensity balance at the 35-keV level.

[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 normalization of the relative γ-ray emission probabilities has been done by setting the total feeding of the ground state to 100%; this gives a normalization factor of 0.292 (3). The resulting γ-ray emission probabilities are given in the third from the last column. The last two columns give the relative probabilities from the evaluations of 1990Lo03 and 1999Ka26. The agreement is very good except for the lines at 35 keV, where this evaluator has taken a value from the intensity ballance, and 117 and 172 where 1990Lo03 gives larger values.

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 23.9 (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	0.180 (7)
	M	18.79	0.0362 (14)
	N	19.63	0.0076 (3)
35.49	K	3.675	71 (3)
	L	30.55	9.6 (4)
	M	34.48	1.93 (9)
	N	35.35	0.406 (16)
109.28	K	77.46	12.6 (5)
	L	104.33	9.3 (4)
	M	108.27	2.18 (8)

γ energy (keV)	shell	electron energy	emission prob. (%)
	N	109.11	0.451 (18)
116.96	K	85.14	0.0284 (11)
	L	112.02	0.00367 (15)
172.72	K	140.90	0.0247 (10)
	L	167.78	0.0032 (1)
176.31	K	144.50	0.94 (3)
	L	171.37	0.149 (6)
	M	175.30	0.030 (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	0.347 (14)
	L	422.94	0.0450 (18)
	M	426.87	0.0090 (3)
443.56	K	411.74	0.00302 (12)
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)

γ energy (keV)	shell	electron energy	emission prob. (%)
	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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^{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:

$$\mathrm{N} = \left(\frac{100 - P_{abs}(163 keV)}{(\Sigma(1 \ + a_T)P_{rel})} \right) \times 100$$

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.

Additional Reference

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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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^{133}Ba - Comments on evaluation of decay data

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

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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^{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. × 10^{-4} % ; < 1. × 10^{-5} %, ; and < 1. × 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 α(pair)/α_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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^{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 been 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	138.5	132.9	144.6	141.0	140.6	136.9	136.7	139.0	136.2	136.6		133.5	136.9
	4.1	6.4	4.0	4.7	4.0	2.8	1.3	0.7	1.0	1.6	1.8		1.8	3.9
125.7										0.057	0.115			
										0.009	0.013			
148.0			0.077			0.154				0.190	0.218		0.231	
			0.026			0.013				0.040	0.026		0.026	
166.9											0.051		0.010	
											0.013		0.004	
173.1										0.002	0.038		0.081	
										0.001	0.013		0.003	
192.6										0.033	0.023	0.031	0.029	
										0.001	0.006	0.008	0.005	
202.6										0.018	0.028			
										0.009	0.006			
207.6			0.064	0.035		0.038				0.021	0.031	0.022	0.035	
			0.038	0.012		0.013				0.006	0.006	0.003	0.003	
209.4			0.077	0.038		0.026				0.021	0.038	0.027	0.026	
			0.038	0.026		0.013				0.006	0.013	0.003	0.013	
212.6		0.086	0.103	0.097		0.103				0.094	0.115		0.077	
		0.037	0.026	0.029		0.026				0.003	0.026		0.026	
237.3			0.051							0.045	0.064		0.012	
			0.026							0.004	0.026		0.004	
239.4				0.321							0.051		0.019	
				0.154							0.013		0.004	
244.7	39.4	36.2	35.8	36.4	36.6	35.8	36.2	36.5	36.5	35.9	38.0			36.8
	1.3	1.8	1.0	1.2	1.1	0.6	0.3	0.4	0.3	0.6	0.5			0.9
251.6		0.333	0.372	0.359		0.359				0.300	0.321		0.308	
		0.051	0.064	0.051		0.013				0.010	0.026		0.026	
269.9				0.015						0.039				
				0.006						0.004				

Eg(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

Eγ(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	1.3	
	0.25		
125.7	0.09	9.9	
	0.03		
148.0	0.166	5.8	
	0.024		
166.9			[18]
173.1			[18]
192.6	0.0326	1.1	
	0.0010		
202.6			[18]
207.6	0.0285	2.1	
	0.0019		
209.4	0.0266	0.60	
	0.0025		
212.6	0.094	0.23	
	0.003		
237.3	0.012		[1]
	0.004		
239.4	0.036	3.2	
	0.016		
244.7	36.23	1.5	
	0.08		
251.6	0.322	2.4	
	0.007		
269.9	0.029	8.0	
	0.012		
271.1	0.374	1.9	[2]
	0.014		
275.5	0.155	2.3	
	0.008		
286.0	0.048	1.2	
	0.003		
295.9	2.123	1.6	
	0.013		
315.2	0.238	1.1	[3]
	0.008		
316.2	0.015		[3]
	0.005		
320.0	0.008		[13]
	0.003		
324.8	0.354	0.27	
	0.007		
329.4	0.62	11	
	0.03		
330.5	0.029		[4]
	0.008		
340.4	0.151	4.6	
	0.016		
344.3	127.53	0.66	
	0.20		
351.7	0.067	2.2	
	0.011		
357.3	0.0194	4.0	
	0.0024		
367.8	4.136	0.77	
	0.018		
379.4	0.004		[5]
	0.001		
385.7	0.024		[6]
	0.003		
387.9	0.0142		[5]
	0.0010		
391.3	0.006		[13]
	0.001		
395.0			[18]
406.7	0.004		[13]
	0.001		
411.0	10.735	0.95	
	0.020		
416.0	0.523	0.4	
	0.008		
423.5	0.0155	1.7	
	0.0023		
440.9	0.064	2.5	
	0.005		
444.0	13.46		[7]
	0.09		
444.0	1.53		[7]
	0.09		
444.0	14.99	1.2	[7]
	0.03		
482.3	0.141	1.3	
	0.008		
488.7	1.985	1.8	
	0.008		

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 0.005	2.2	
919.3	2.06 0.02	1.1	
926.3	1.309 0.019	0.73	
930.6	0.350 0.009	0.37	
937.1	0.013 0.003	1.4	
958.6	0.101 0.009	1.10	
963.4	0.644 0.009		[14]
964.1	69.55 0.10	0.62	[14]
974.1	0.066 0.004	0.76	
990.2	0.151 0.006	0.39	
1001.1	0.022 0.005	0.15	
1005.3	3.19 0.11	9.6	
1086.0	48.63 0.20	1.9	[17]
1089.7	8.30 0.03	0.78	
1109.2	0.892 0.018	 1.7	[15]
1112.0	64.30 0.09		[15]
1112.0			[18]
1139	0.006 0.002		[13]
1170.9	0.175 0.006	2.2	
1206.1	0.065 0.004	1.7	
1212.9	6.79 0.03	0.95	
1249.9	0.894 0.015	0.89	
1261.3	0.161 0.005	0.56	
1292.8	0.499 0.015	1.6	
1299.1	7.83 0.03	0.48	
1314.7	0.023 0.003	0.73	
1348.1	0.084 0.004	1.2	
1363.8	0.123 0.004	0.75	
1390.4	0.023 0.003	0.36	
1408.0	100.00 0.12	0.22	
1457.6	2.388 0.017	0.82	
1486.0			[18]
1528.1	1.349 0.021	4.4	
1537.4			[18]
1605.6	0.0388 0.0020	0.54	
1608.4	0.0255 0.0016	0.38	
1635.2	0.0007 0.0002		[13]
1643.6	0.0070 0.0020	0.89	[16]
1647.4	0.0305 0.0019	1.1	
1674.3	0.029 0.004		[13]
1769.0	0.0441 0.0016	0.63	

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]. $I\gamma$ = weighted average ($I\gamma$(271) doublet) - $I\gamma$(269) = 0.403 (7) - 0.029 (12) = 0.374 (14). $\chi2/\nu$ = 1.9.
[3]. $I\gamma$ = weighted average ($I\gamma$(315) doublet) - $I\gamma$(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]. $I\gamma$ = weighted average ($I\gamma$(444) doublet) - $I\gamma$(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]. $I\gamma$ = weighted average ($I\gamma$(556.5) doublet) - weighted average $I\gamma$(557.8) = 0.106 (5) - 0.021 (4) = 0.085 (6)
[10]. $I\gamma$ = weighted average (Ig(563.8) doublet) - Ig(562.9) = 2.37 (2) - 0.18 (6) = 2.19 (6). $\chi2/\nu$ = 0.64.
$I\gamma$(562.9) = 2.37 (2) from transition intensity balance.
[11]. From 1993Ka30, close to upper limit of 92Ya12.
[12]. $I\gamma$ = weighted average ($I\gamma$(719) doublet, $\chi2/\nu$ = 3.4) - weighted average $I\gamma$(719.4) = 1.57 (2) - 0.282 (35) = 1.29 (6).
[13]. From 1990Me15.
[14]. $I\gamma$ = weighted average ($I\gamma$(964) doublet) - $I\gamma$(963) = 70.19 (10) - 0.644 (9) = 69.55 (10).
$I\gamma$(963) = 0.644 (9) is from 152Eu(9.3h) EC decay branching.
[15]. $I\gamma$ = weighted average ($I\gamma$(1112) doublet, $\chi2/\nu$ = 1.5) - weighted average $I\gamma$(1109, $\chi2/\nu$ = 1.7) = 65.19 (9) - 0.895 (18) = 64.30 (9)
[16]. Weighted average of values from 1980Sh15 and 1993Ka30.
[17] $I\gamma$ = $I\gamma$ (1084)+ $I\gamma$ (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)

* 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}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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^{153}Sm - Comments on evaluation of decay data
by R. G. Helmer and E. Schönfeld

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

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

The half-life values available are, in hours:

47 (1)	1942Ku03	as quoted in 1990Le13
46	1946Mi06	as quoted in 1990Le13
46.5 (10)	1952Ru10	as quoted in 1990Le13
47.0 (3)	1954Le08	as quoted in 1990Le13
47.1 (1)	1958Co76	
46.7 (16)	1958Gu09	
45 (8)	1960Wi10	
46.2 (1)	1961Gr18	
46.8 (1)	1961Wy01	
47.1 (1)	1962Ca24	
46.5 (5)	1963Ho15	
46.75 (9)	1970Ch09	
46.44 (8)	1971Ba28	
46.27 (1)	1987Co04	superseded by 1992Un01
46.70 (5)	1989Ab05	
45.6 (16)	1989Po21	
46.2853 (14)	1992Un01 & 1994Co02	
46.29 (4)	1996ScZX	superseded by 1999Sc12
46.285 (4)	1998Bo18	
46.274 (7)	1999Sc12	

46.2838 (26) h or 1.92849 (11) d Adopted

Data are very discrepant, ranging from 46.2853(14) to two values of 47.1(1), a difference of about 8σ. For a weighted average of the twelve unsuperseded values with $\sigma < 1.0$ hours, the result is 46.2857 with a σ_{int} of 0.0013, a reduced-χ^2 of 24.3, and an σ_{ext} of 0.0064. For this average, the value of 1992Un01 contributes 86% of the weight. (The values with $\sigma \geq 1.0$ would have very small weights and would not significantly influence the result.) In the Limitation of Relative Statistical Weight, LRSW, analysis (1985ZiZY, 1992Ra08), the uncertainty for the 1992Un01 value is increased by a factor of 2.5 from 0.0014 to 0.0034 in order to reduce the relative weight to 50%. Then, the values of 1992Un01 and 1998Bo18 contribute 87% of the relative weight and the weighted average is 46.2866 with a σ_{int} of 0.0024, a reduced-χ^2 of 24.3, and a σ_{ext} of 0.012. If one considers only the unsuperseded measurements since 1970 with uncertainties < 1.0 hours, the reduced-χ^2 is still 20.4.

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. After the uncertainty of the 1992Un01 value is increased by a factor of 2.5 to reduce its relative weight from 86% to 50%, the weighted average of these three values is 46.2838 with a σ_{int} of 0.0025, a reduced-χ^2 of 1.12, and a

σ_{ext} of 0.0026. This weighted average and the external uncertainty are adopted. Although the weighted average is almost independent of the data selection process, the final uncertainty changes from 0.012 to 0.0026 as a result of this selection.

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 emission probabilities for the 69- and103-keV γ-rays (1987Co04, 1998Bo18, 1999Sc12).

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 18.4(18).
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 49.6(19)% from the intensity 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 31.1(10)% from the intensity balance.

2.2 Gamma Transitions

The multipolarities are from the adopted gamma data in the Nuclear Data Sheets (1998He06) and they are based on the internal-conversion electron data of 1961Mo07, 1962Su01, 1969Sm04, and 1970PaZI.

3 Atomic Data

The fluorescence yields and K x-ray relative intensities are from 1996Sc06.
The calculated with EMISSION and measured (1999Sc12) x-ray emission probabilities (in %) are

	Decay scheme	Measured
L	11.3 (6)	10.04 (15)
K_α	49.1 (16)	45.6 (5)
K_β	12.5 (4)	11.56 (18)

The measured values were adopted with the components calculated from the theoretical ratios.

4 Emissions

4.1 Electron Emission

Data were computed by RADLST for the Auger and conversion 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)	521.3 (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 used in the averaging 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. 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 > 1.0 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 ≤ 1.0, 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 column.

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, and 1999Sc12. Of the five γ rays that are given in all three 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 three values [4.85(7), 4.67(5), 4.65(5), respectively] is 4.70 γ's per 100 decays with an internal uncertainty of 0.03, a reduced-χ^2 of 2.97, and an external uncertainty of 0.05. The latter uncertainty was adopted. For the 103-keV γ ray, the weighted average of the three values [29.8(4), 28.5(5), 29.23(18), respectively] is 29.26 γ's per 100 decays with an internal uncertainty of 0.22, a reduced-χ^2 of 2.07, and an external uncertainty of 0.32. The value of 29.26(32) was adopted. In the latter average, the LRSW method increased the uncertainty of 0.18 to 0.31 in order to decrease its relative weight from 75% to 50%.

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Table 2: Gamma relative emission intensities

γ-ray energy	1964Al09	1966Bl06	1969Pa03	1969Sm04	1969Un03	1974HeYW	1985Ab08	1987Co04	1992Ch44	1998Bo18	1999Sc12	Weighted average				Adopted
(keV)	(x100)	(x0.010)			(x3.546)	(x100)	(x365.4)		(x100)	(x35088)	(x34211)	value σ_{int}	χ_R^2	σ_{ext}	σ_{LRSW}	
L x																3430 (50)
K α																15600 (170)
K β x									3693 (104)		4000 (44)					3950 (60)
14.0																
54.1	0.58 (12)				12.4		0.73									0.65 (12)
68.2	0.43 (12)						<1.1									0.43 (12)
69.6	1730 (100)			2080 (146)	1433	1620 (140)	1930	1626 (21)	1620 (50)	1639 (18)	1591 (17)	1618 (10)	1.06	(11)	(-)	1618 (11)
75.4	61 (4)			75 (4)	213	110 (12)	50.4	117 (5)	55 (2)[a]	65 (4)	80 (7)	66.4 (16)	29	(87)	(114)	66 (9)
83.3	75 (4)			85 (4)	50	63 (6)	55	68 (4)	63 (2)	58 (4)	72 (4)	65.5 (14)	2.8	(23)	(25)	65.5 (25)
89.4	58 (3)			62 (4)	46	32 (4)	51		59 (2)		53.4 (24)	54.4 (13)	13	(46)	(-)	54 (5)
96.8					2.5		<2.2									2.5
97.4	263 (13)			254 (8)	252	233 (20)	222	284 (4)	255 (4)	279 (6)	258.3 (24)[a]	264.3 (18)	8.8	(52)	(60)	264 (6)
103.1	10000	same	same	same	same	same	same	same	same	same	same					10000
118.1					0.11		<0.13		0.06 (1)							0.08 (2)
151.6	3.2 (5)		5.1 (16)		4.08	3.0 (5)	4.38		3.5 (1)[a]		3.93 (21)	3.62 (13)	1.43	(15)	(-)	3.62 (15)
166.5					0.21		<0.25		0.21 (1)							0.21 (2)
172.3					0.14		<0.19									0.14
172.8	21 (2)		24 (5)	22.9 (18)	28	28 (3)	29.6	27.0 (4)	25.0 (4)	25.3 (11)	24.50 (24)[a]	25.19 (19)	5.4	(44)	(69)	25.2 (7)
412.0[b]		0.64 (20)	0.73 (13)	0.7 (3)	0.82	0.8 (1)	0.98		0.65 (2)[c]		0.65 (4)	0.656 (17)	0.63	(-)	(-)	0.656 (17)
424.4		0.75 (20)	0.60 (12)		0.82	0.7 (1)	0.84		0.65 (2)[c]		0.62 (4)	0.646 (17)	0.29	(-)	(-)	0.646 (17)
436.9		0.48 (12)	0.5 (1)		0.64	0.8 (1)	0.77		0.53 (2)		0.57 (3)[a]	0.58 (4)	1.56	(5)	(-)	0.58 (5)
443.2							0.132		0.030 (5)							0.030 (5)
462.0			0.5 (1)[c]						0.7 (2)			0.54 (9)	0.80	(-)	(-)	0.54 (9)
463.6		5.1 (8)	4.7 (4)		5.50	5.3 (4)	5.30		4.3 (8)		4.34 (6)[a]	4.64 (18)	1.17	(19)	(-)	4.64 (19)
485.0		0.12 (6)	0.12 (6)		0.14		0.150		0.13 (1)[c]		0.12 (3)	0.129 (9)	0.03	(-)	(-)	0.129 (9)
487.7							0.124									0.124
509.1		0.85 (16)	0.61 (20)		0.78	1.0 (1)	0.84		0.62 (3)[a]		0.63 (6)	0.68 (3)	3.4	(6)	(-)	0.68 (6)
521.3		3.5 (7)	2.5 (9)	2.1 (4)	2.66	2.8 (2)	2.81		2.3 (1)		2.31 (4)[a]	2.36 (6)	2.05	(9)	unw	2.36 (9)
531.4		22.3 (20)	23 (3)	15.0 (12)	22.7	23.8 (20)	19.9		18.9 (13)[a]	19.3 (21)	18.37 (21)	18.70 (15)	3.06	(25)	unw	18.7 (3)
533.2		11.6 (10)	8.8 (25)		11.3	11.9 (8)	11.6		10.4 (1)	9.8 (21)	10.02 (9)[a]	10.23 (7)	2.81	(12)	(21)	10.23 (21)
539.1		9.1 (14)	8.2 (25)	5.4 (8)	7.1	8.6 (6)	7.3		7.2 (2)		7.04 (9)[a]	7.21 (13)	2.04	(19)	unw	7.21 (19)
542.7			0.6 (5)		0.96	1.4 (1)	1.06		0.77 (8)		0.75 (6)[a]	1.06 (7)	7.6	(19)	(31)	1.1 (3)
545.7					0.35	0.3 (1)	0.48		0.26 (1)		0.41 (17)	0.261 (10)	0.47	(-)	(-)	0.261 (10)

554.9	1.93 (30)	1.60 (13)		1.81	2.0 (2)	1.51	1.61 (4)	1.62 (3)[a]	1.624 (26)	1.19	(29)	(-)	1.62 (3)
574.1				0.04		<0.09	0.053 (18)						0.053 (18)
578.7	1.38 (20)	1.15 (23)		1.17	1.3 (2)	1.21	1.07 (3)	1.17 (3)	1.125 (21)	2.00	(30)	unw	1.12 (3)
584.5	0.54 (10)	0.45 (15)		0.30	0.4 (1)	0.39	0.36 (1)[c]	0.352 (27)	0.361 (9)	0.96	(-)	(-)	0.361 (9)
587.6		0.1 (1)		0.121	0.20 (3)	0.18	0.16 (4)	0.161 (27)	0.172 (18)	0.55	(-)	(-)	0.172 (18)
590.9		0.45 (15)		0.32	0.5 (1)	0.34	0.38 (1)[a]	0.421 (27)	0.403 (18)	0.76	(-)	(-)	0.403 (18)
596.7	4.4 (7)	4.2 (6)	2.1 (4)	4.08	4.5 (3)	3.22	3.8 (1)	3.56 (10)	3.74 (7)	2.9	(11)	unw	3.74 (11)
598.3[b]				0.53	0.4 (1)	0.99	0.61 (9)	0.70 (3)	0.61 (5)	3.1	(8)	(9)	0.61 (9)
603.6[b]	2.0 (4)	1.8 (3)		1.10	1.9 (2)	1.43	1.53 (5)	1.49 (3)[a]	1.53 (3)	1.58	(4)	(-)	1.53 (4)
609.5[b]	5.5 (8)	5.2 (8)	3.6 (5)	4.50	5.1 (4)	5.08	4.5 (1)[a]	4.04 (14)	4.36 (9)	3.2	(16)	unw	4.36 (25)
615.8[b]	0.60 (12)	0.21 (10)		0.28	0.3 (1)	0.33	0.14 (2)[a]	0.233 (24)	0.188 (16)	3.1	(28)	(48)	0.19 (5)
617.9		0.32 (14)		0.39	0.3 (1)	0.25	0.20 (2)[a]	0.304 (24)	0.252 (16)	3.4	(30)	(50)	0.25 (5)
630.5		0.04 (2)		0.04		0.040	0.034 (5)[c]		0.034 (5)	0.08	(-)	(-)	0.034 (5)
634.8				0.11	0.20 (3)	0.17	0.20 (5)	0.15 (3)	0.179 (20)	0.80	(-)	(-)	0.179 (20)
636.5	0.81 (15)	0.74 (8)		0.67	0.7 (1)	0.84	0.70 (2)[a]	0.595 (27)	0.660 (17)	2.7	(28)	(40)	0.66 (4)
657.5[b]	0.13 (3)	0.12 (3)		0.14	0.10 (3)	0.130	0.14 (1)[c]	0.140 (24)	0.135 (8)	0.48	(-)	(-)	0.135 (8)
662.4		0.03 (1)					0.007 (2)[a]		0.018 (7)	2.6	(12)	(-)	0.018 (12)
677.0		<0.005		0.004		0.014	0.016 (5)						0.015 (5)
682.0	0.09 (3)	<0.005					0.009 (3)[a]		0.049 (21)	3.6	(40)	(-)	0.05 (4)
686.0		0.09 (1)		0.082		0.066	0.077 (8)	0.072 (21)	0.081 (6)	0.62	(-)	(-)	0.081 (6)
694.1		<0.005		0.007		0.028	0.007 (2)						0.007 (2)
701.8		<0.005		0.0087		0.029	0.010 (2)						0.010 (2)
706.8		<0.005		0.0053		0.012							0.008 (4)
713.9	0.11 (3)	0.066 (20)		0.067	0.10 (3)	0.080	0.077 (8)[c]	0.09 (4)	0.079 (7)	0.54	(-)	(-)	0.079 (7)
719.0		0.007 (4)		0.007		0.023	0.009 (2)[c]		0.0086 (18)	0.20	(-)	(-)	0.0086 (18)
760.5	0.013 (4)	0.027 (15)		0.0089		0.023	0.010 (2)[c]		0.0108 (18)	0.81	(-)	(-)	0.0108 (18)
763.8		0.011 (6)					0.017 (5)		0.015 (4)	0.59	(-)	(-)	0.015 (4)

[a] Uncertainty increased in LRSW analysis to reduce the relative weight to 50%.

[b] γ is doubly placed.

[c] Value, dominates weighted average, but since the reduced-$\chi^2 \leq 1.00$, the uncertainty is not increased.

^{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→^{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 $5 \cdot 10^{-5}$ % and less than $3 \cdot 10^{-7}$ %, 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 3rd forbidden and its intensity is expected to be less than $5 \cdot 10^{-10}$ % (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→^{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) - Σ $P_{\beta i}$, 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 $P_{\gamma 1,0}$ (123,07 keV) =40,4(5)% agrees well with the value of 40,6(7)% measured in 1991ZaZZ.

The evaluated value of $P_{\gamma 16,1}$ (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 $P_{\gamma 2,1}$ (247,93 keV)=6,96(8) % and $P_{\gamma 6,0}$ (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

by V. P. Chechev and V. O. Sergeev

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_γ^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 γγ(θ)-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 γγ, ^{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′γ) are shown in Table 4.

The evaluated values of P′γ 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 α_{L3}($\gamma_{4,2}$) and α_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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^{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:

α_K = 1,650(33)
α_L = 3,983(170)
α_M = 0,990(50)
α_N = 0,200(12)
α_{OP} = 0,048(3)
α_t = 6,87(18)

The total conversion coefficient of this transition was determined by Brandtley et al. (1966) to be α = 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 $P(K_{ß})/P(K_{\alpha})$ 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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^{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 $P_ß$ 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 KX-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 ($\gamma_{4,0}$):

$$f_N \, [P_{\mathrm{rel}}(\gamma_{1,0}) \, (1 + \alpha_t) + P_{\mathrm{rel}}(\gamma_{4,0}) \, (1 + \alpha_t)] = 100$$

The conversion coefficient is, of course, to put for the assigned gamma transition. This yields for the transition $\gamma_{1,0}$

$P_{g+\mathrm{ce}} = 100 - f_\mathrm{N}\, P_\mathrm{rel}(\gamma_{4,0})\ (1 + \alpha_\mathrm{t})$

With $f_\mathrm{N} = 0{,}725(3)$, $P_\mathrm{rel}(\gamma_{4,0}) = 0{,}026(5)$, $\alpha_\mathrm{t}\ (\gamma_{4,0}) = 0{,}00566(12)$

we obtain :

$P_{\gamma+\mathrm{ce}}(\gamma_{1,0}) = 99{,}981(4)$ 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 :

$\gamma_{i,f}$	E_γ (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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A. Alzner, E. Bodenstedt. B. Gemünden. J. van den Hoff and H. Reif, *Z. Phys.* A322 (1985) 467 [δ]

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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 ($\gamma 8,4 + L_{\beta 2,15}$) = 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

References not used

Von W. Bothe. Z. Naturforschg. 1 (1946) 173
J. M. Cork *et al.* Phys. Rev. 78,2 (1950) 95
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M. C. Michel *et al.* Phys. Rev. 93 (1954) 1422
J. M. Cork *et al.* Phys. Rev. 101,3 (1956) 1042
E. N. Hatch *et al.* Phys. Rev. 104,3 (1956) 745

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 $\alpha_M/\ \alpha_{NO}$ = 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 $K\beta/K\alpha$, $K\alpha_2/K\alpha_1$, $K'\beta_2/K'\beta_1$ 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)·10^{-3}	7,7 (3)·10^{-3}	0,0077 (3)
$K'\beta_2$	1,45 (6)·10^{-3}	2,2 (1)·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}(Er)=0,113(6) and P_{XK}(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}(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 $\alpha_K(\gamma79)$ 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 ω_K(Yb) and theoretical value of $\alpha_K(\gamma84)$ 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-χ^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-χ^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

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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)**	c**2/(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	$\lvert\delta(\gamma_{3,0})\rvert$	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	$\lvert\delta(\gamma_{3,1})\rvert$	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	$\lvert\delta(\gamma_{3,2})\rvert$	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 (1999ScZX), 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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^{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 $P_{\gamma+ce}$ (which is also the transition probability of the electron capture branch to the 122 keV level) is obtained to be $P_{\gamma+ce} = P_{EC}$ (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

$$P(\text{W KX}) = \left\{ P_{EC}(0{,}1)\left[P_K(0{,}1) + a_K / \left(1 + a_t\right)\right] + P_{EC}(0{,}0)\, P_K(0{,}0)\right\} w_K .$$

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 $P_{EC}(0,0)$ can be extracted from the above expression. Using P(W KX) = 0,0602(8) as determined by Schönfeld et al. (1994), one obtains $P_{EC}(0,0)$ = 0,0584(12).

Thus, the total electron capture probability amounts to $P_{EC}(0,1) + P_{EC}(0,0)$ = 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

Taken from the „Table des Radionucléides“, LMRI, 1982.

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For additional references see also § References in the Tables Part.

^{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 χ^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 Metskhvarisvili. 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 $\alpha_K(412) = 0{,}0317$; 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:

$$P_g\left(676\right) = \frac{ce_K(676)}{ce_K(412)} \cdot \frac{a_K(412)}{a_K(676)} \cdot P_g\,(412)$$

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_γ(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*(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*(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

$$\left[P_g(412)\left(1+a_t(412)\right)+P_g(1088)\left(1+a_t(1088)\right)\right]\cdot f_N = 1-P_b(1372)$$

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
$P(K_\alpha)/P_\gamma(412)$	0,0229(5)	0,0228(2)
$P(K_\beta)/P_\gamma(412)$	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)	-
L_{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)
K_{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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^{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 $L_I/L_2/L_3$ 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 determined 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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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 multipolarity, 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$^-$ --> 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$^-$ → 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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^{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 σ × 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- $K_{\alpha 2}$	0,474	0,020
	Hg- $K_{\alpha 1}$	0,812	0,034
	Hg- K_{β} 1	0,273	0,010
	Hg- K_{β} 2	0,081	0,003
	Pb- $K_{\alpha 2}$	$4,4\ 10^{-3}$	0,3
	Pb- $K_{\alpha 1}$	$6,1\ 10^{-3}$	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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^{208}Tl – 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 consistent decay scheme has been derived, assuming no direct beta decay to the 2614.55 keV and ground states of ^{208}Pb (based on spin-parity considerations). This decay scheme is primarily based on the gamma-ray measurements of 1960Em01, 1960Sc07, 1961Si11, 1969Au10, 1969Pa02, 1969La23, 1972Ja25, 1972DaZA, 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. Further measurements are merited to confirm the recommended value of 3.060(8) min.

Reference	Half-life (min)
1957Ba05	3.090(15)
	3.099(12)
1967La20	3.055(6)
1970Mu21	3.17(5)
1971Ac02	3.0527(33)*
Recommended Value	3.060(8)#

* Uncertainty adjusted to ± 0.0050 to reduce weighting below 0.5.
\# 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 1986Ma17 were adopted, and used to determine the energies and associated uncertainties of the gamma-ray transitions between the various populated-depopulated levels.

Emission Probabilities
A consistent decay scheme has been constructed from the gamma-ray measurements of 1960Em01, 1960Sc07, 1961Si11, 1969Au10, 1969Pa02, 1969La23, 1972Ja25, 1972DaZA, 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 2614.51 keV transition, and specific sets of data were adjusted accordingly (some of the original measurements were quantified relative to the 583.19 keV gamma ray or as absolute emission probabilities, while minor modifications were made to the relevant emission probabilities for the partially resolved 277.37, 510.7 and 583.19 keV gamma rays as reported by 1983Sc13). 1993El08 observed additional gamma rays (808.3 and 835.9 keV) that were introduced into the proposed decay scheme, along with the previously unplaced 1125.7 and 1647.5 keV gamma rays.

Published Gamma-ray Emission Probabilities

E_g (keV)	**P_g**						
	1960Em01	1960Sc07	1961Si11		1969Au10*	1969La23	1969Pa02
211.4(2)	-	-	-	-	-	0.20(5)	0.17(8)
233.3(1)	-	0.3	-	-	-	0.30(5)	0.33(17)
252.5(2)	1.5(7)	1.1	-	-		0.8(1)	0.70(11)
277.37(3)	6.9(8)	8.6	-	7.2(7)	-	6.9(5)	6.5(4)
485.8(1)	-	0.1(1)	-	-	-	0.07(4)	0.05(2)
510.7(1)	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)
587.8(2)	-	-	-	-	-	-	-
650.2(2)	-	-	-	-	-	-	-
705.3(2)	-	-	-	-	-	-	-
722.0(1)	-	-	)	-	-	0.3(1)	0.27(8)
748.7(2)	-	-	) 22.5(20)	-	-	-	-
763.2(1)	1.9(5)	3.4(2)	)	3.6(7)	-	2.0(2)	1.68(8)
808.3(2)	-	-	-	-	-	-	-
821.1(2)	-	-	-	-	-	-	0.09(4)
835.9(2)	-	-	-	-	-	-	-
860.56(3)	11.4(12)	14.2(6)	15.3(20)	15.2(15)	-	13(1)	12.0(8)
883.4(2)	-	-	-	-	-	-	-
927.6(2)	-	-	-	-	-	0.15(5)	0.13(3)
982.7(2)	-	-	-	-	-	0.20(5)	0.20(3)
1004(2)	-	-	-	-	-	-	~ 0.01
1093.9(1)	-	0.7(1)	~ 2	-	-	0.5(1)	0.38(5)
1125.7(4)	-	-	-	-	-	-	-
1160.8(2)	-	-	-	-	-	-	-
1185.2(3)	-	-	-	-	-	-	-
1282.8(3)	-	-	-	-	-	-	0.05(2)
1381.1(5)	-	-	-	-	-	-	0.02(1)
1647.5(7)	-	-	~ 3	-	-	-	~ 0.01
1743.9(2)	-	-	-	-	-	-	-
2614.511(10)	100	(100)	100	100	116.7(24)	100	100

Published Gamma-ray Emission Probabilities (cont.)

E_g (keV)	**P_g** (cont.)					
	1972DaZA	1972Ja25	1975Ko02	1977Ge12[*]	1978Av01	1982Sa36[†]
211.4(2)	0.16(4)	-	0.17(2)	-	-	-
233.3(1)	~ 0.2	-	0.31(3)	-	-	-
252.5(2)	0.8(2)	-	0.80(5)	-	0.62(4)	0.28(3)
277.37(3)	6.6(13)	6.2(7)	6.8(3)	-	6.1(2)	2.4(1)
485.8(1)	0.04(1)	-	0.050(5)	-	-	-
510.7(1)	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)
587.8(2)	~ 0.04	-	0.04(2)	-	-	-
650.2(2)	-	-	0.036(5)	-	-	-
705.3(2)	~ 0.02	-	0.022(4)	-	-	-
722.0(1)	0.21(6)	-	0.203(14)	-	0.27(2)	-
748.7(2)	0.05(1)	-	0.043(4)	-	-	-
763.2(1)	1.7(3)	-	1.64(9)	-	1.82(9)	0.7(1)
808.3(2)	-	-	-	-	-	-
821.1(2)	0.04(1)	-	0.040(4)	-	-	-
835.9(2)	-	-	-	-	-	-
860.56(3)	11.8(12)	11.5(10)	12.0(4)	14.79(15)	13.9(6)	4.2(2)
883.4(2)	~ 0.025	-	0.031(3)	-	-	-
927.6(2)	0.13(4)	-	0.125(1)	-	-	-
982.7(2)	0.20(6)	-	0.197(15)	-	-	-
1004(2)	-	-	< 0.005	-	-	-
1093.9(1)	0.37(7)	-	0.37(4)	-	-	-
1125.7(4)	-	-	0.005(2)	-	-	-
1160.8(2)	-	-	0.011(3)	-	-	-
1185.2(3)	-	-	0.017(5)	-	-	-
1282.8(3)	~ 0.05	-	0.052(5)	-	-	-
1381.1(5)	-	-	0.007(3)	-	-	-
1647.5(7)	-	-	0.002(1)	-	-	-
1743.9(2)	-	-	0.002(1)	-	-	-
2614.511(10)	100	(100)	100	118.5(16)	(100)	-

Published Gamma-ray Emission Probabilities (cont.)

E_g (keV)	**P_g** (cont.)				
	1983Sc13[‡]	1983Va22[#]	1984Ge07[*]	1992Li05	1993El08[¶]
211.4(2)	-	-	0.228(20)	-	0.18(1)
233.3(1)	-	-	0.31(4)	-	0.30(1)
252.5(2)	-	-	0.955(13)	-	0.77(2)
277.37(3)	2.33(7)	2.29(4)	7.55(6)	2.54(7)[§]	6.88(12)
485.8(1)	-	-	-	-	0.055(11)
510.7(1)	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)
587.8(2)	-	-	-	-	0.07(1)
650.2(2)	-	-	-	-	0.065(11)
705.3(2)	-	-	-	-	-
722.0(1)	-	-	0.31(6)	-	0.27(2)
748.7(2)	-	-	-	-	0.054(9)
763.2(1)	0.73(5)	-	2.15(2)	0.651(40)	1.72(8)
808.3(2)	-	-	-	-	0.029(7)
821.1(2)	-	-	-	-	0.041(17)
835.9(2)	-	-	-	-	0.075(11)
860.56(3)	4.55(12)	-	14.78(9)	4.32(15)	12.6(7)
883.4(2)	-	-	-	-	-
927.6(2)	-	-	-	-	0.13(1)
982.7(2)	-	-	-	-	0.21(1)
1004(2)	-	-	-	-	-
1093.9(1)	-	-	0.525(8)	-	0.47(4)
1125.7(4)	-	-	-	-	-
1160.8(2)	-	-	-	-	-
1185.2(3)	-	-	-	-	-
1282.8(3)	-	-	-	-	0.049(13)
1381.1(5)	-	-	-	-	-
1647.5(7)	-	-	-	-	-
1743.9(2)	-	-	-	-	-
2614.511(10)	35.6(11)	-	119.1(21)	-	98.1(13)

[*] Emission probabilities relative to P_γ(583.19 keV) of 100.

[†] Emission probabilities relative to P_γ(583.19 keV) of 30.0.

[‡] Emission probabilities relative to P_γ(583.19 keV) of 30.7.

[#] Emission probabilities relative to P_γ(583.19 keV) of 30.8.

[¶] Absolute emission probabilities.

[§] Unresolved overlap with another gamma-ray emission.

Specific emission probabilities deviated significantly from the equivalent measurements from other laboratories:

252.5 keV gamma ray: 1960Em01 and 1978Av01;
485.8 keV gamma ray: 1960Sc07;
510.7 keV gamma ray: 1960Sc07;
583.19 keV gamma ray: 1961Si11;
763.2 keV gamma ray: 1960Sc07 and 1961Si11;
860.56 keV gamma ray: 1960Sc07, 1961Si11 and 1978Av01;
927.6 keV gamma ray: 1969La23;
1093.9 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 583.19 keV gamma-ray emission in 1978Av01; these data were also not included in the weighted-mean analyses. 1982Sa36 and 1983Va22 reported measurements that did not include the main 2614.511 keV gamma-ray transition: the evaluated relative emission probability of the 583.19 keV gamma ray was adopted to create data sets comparable with the other studies, hence the assumed $P\gamma$(583.19 keV) was not included in the analyses under these circumstances.

An uncertainty of 2% was determined for the relative emission probability of the 2614.511 keV gamma ray, as derived from the emission probabilities and uncertainties reported by 1969Au10, 1977Ge12, 1983Sc13, 1984Ge07 and 1993El08:

Reference	**P_g(2614.551 keV)**
1969Au10	100(2)
1977Ge12	100.0(14)
1983Sc13	100(3)
1984Ge07	100(2)
1993El08	100.0(13)
Recommended Value	100(2)

Gamma-ray Emission Probabilities: Relative to P_g(2614.551 keV) of 100

E_g (keV)	**P_g^{rel}**							
	1960Em01	1960Sc07	1961Si11		1969Au10	1969La23	1969Pa02	
211.4(2)	-	-	-	-	-	0.20(5)	0.17(8)	
233.3(1)	-	0.3§	-	-	-	0.30(5)	0.33(17)	
252.5(2)	1.5(7)†	1.1§	-	-		0.8(1)	0.70(11)	
277.37(3)	6.9(8)	8.6§	-	7.2(7)	-	6.9(5)	6.5(4)	
485.8(1)	-	0.1(1)†	-	-	-	0.07(4)	0.05(2)	
510.7(1)	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)	
587.8(2)	-	-	-	-	-	-	-	
650.2(2)	-	-	-	-	-	-	-	
705.3(2)	-	-	-	-	-	-	-	
722.0(1)	-	-	)	-	-	0.3(1)	0.27(8)	
748.7(2)	-	-	) 22.5(20)‡	-	-	-	-	
763.2(1)	1.9(5)	3.4(2)†	)	3.6(7)†	-	2.0(2)	1.68(8)	
808.3(2)	-	-	-	-	-	-	-	
821.1(2)	-	-	-	-	-	-	0.09(4)	
835.9(2)	-	-	-	-	-	-	-	
860.56(3)	11.4(12)	14.2(6)†	15.3(20)†	15.2(15)†	-	13(1)	12.0(8)	
883.4(2)	-	-	-	-	-	-	-	
927.6(2)	-	-	-	-	-	0.15(5)†	0.13(3)	
982.7(2)	-	-	-	-	-	0.20(5)	0.20(3)	
1004(2)	-	-	-	-	-	-	~ 0.01	
1093.9(1)	-	0.7(1)†	~ 2	-	-	0.5(1)	0.38(5)	
1125.7(4)	-	-	-	-	-	-	-	
1160.8(2)	-	-	-	-	-	-	-	
1185.2(3)	-	-	-	-	-	-	-	
1282.8(3)	-	-	-	-	-	-	0.05(2)	
1381.1(5)	-	-	-	-	-	-	0.02(1)	
1647.5(7)	-	-	~ 3	-	-	-	~ 0.01	
1743.9(2)	-	-	-	-	-	-	-	
2614.511(10)	100	(100)	100	100	100(2)	100	100	

Gamma-ray Emission Probabilities: Relative to P_g(2614.551 keV) of 100 (cont.)

E_g (keV)	**P_g^{rel}** (cont.)					
	1972DaZA	1972Ja25	1975Ko02	1977Ge12	1978Av01	1982Sa36
211.4(2)	0.16(4)	-	0.17(2)	-	-	-
233.3(1)	~ 0.2	-	0.31(3)	-	-	-
252.5(2)	0.8(2)	-	0.80(5)	-	0.62(4)†	0.80(9)
277.37(3)	6.6(13)	6.2(7)	6.8(3)	-	6.1(2)	6.8(3)
485.8(1)	0.04(1)	-	0.050(5)	-	-	-
510.7(1)	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)]$^{\#}$
587.8(2)	~ 0.04	-	0.04(2)	-	-	-
650.2(2)	-	-	0.036(5)	-	-	-
705.3(2)	~ 0.02	-	0.022(4)	-	-	-
722.0(1)	0.21(6)	-	0.203(14)	-	0.27(2)	-
748.7(2)	0.05(1)	-	0.043(4)	-	-	-
763.2(1)	1.7(3)	-	1.64(9)	-	1.82(9)	2.0(3)
808.3(2)	-	-	-	-	-	-
821.1(2)	0.04(1)	-	0.040(4)	-	-	-
835.9(2)	-	-	-	-	-	-
860.56(3)	11.8(12)	11.5(10)	12.0(4)	12.48(13)	13.9(6)†	11.9(6)
883.4(2)	~ 0.025	-	0.031(3)	-	-	-
927.6(2)	0.13(4)	-	0.125(1)	-	-	-
982.7(2)	0.20(6)	-	0.197(15)	-	-	-
1004(2)	-	-	< 0.005	-	-	-
1093.9(1)	0.37(7)	-	0.37(4)	-	-	-
1125.7(4)	-	-	0.005(2)	-	-	-
1160.8(2)	-	-	0.011(3)	-	-	-
1185.2(3)	-	-	0.017(5)	-	-	-
1282.8(3)	~ 0.05	-	0.052(5)	-	-	-
1381.1(5)	-	-	0.007(3)	-	-	-
1647.5(7)	-	-	0.002(1)	-	-	-
1743.9(2)	-	-	0.002(1)	-	-	-
2614.511(10)	100	(100)	100	100.0(14)	(100)	-

Gamma-ray Emission Probabilities: Relative to P_g(2614.511 keV) of 100 (cont.)

E_g (keV)	P_g^{rel} (cont.)				
	1983Sc13	1983Va22	1984Ge07	1993El08	Recommended Values*
211.4(2)	-	-	0.19(2)	0.18(1)	0.18(1)
233.3(1)	-	-	0.26(3)	0.31(1)	0.31(1)
252.5(2)	-	-	0.80(1)	0.78(2)	0.78(2)
277.37(3)	6.5(2)	6.3(1))	6.34(5)	7.01(12)	6.6(3)
485.8(1)	-	-	-	0.056(11)	0.049(4)
510.7(1)	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)	88(3)	85.2(3)
587.8(2)	-	-	-	0.07(1)	0.06(2)
650.2(2)	-	-	-	0.066(11)	0.05(2)
705.3(2)	-	-	-	-	0.022(4)
722.0(1)	-	-	0.26(5)	0.28(2)	0.24(4)
748.7(2)	-	-	-	0.055(9)	0.046(3)
763.2(1)	2.05(14)	-	1.81(2)	1.75(8)	1.79(3)
808.3(2)	-	-	-	0.030(7)	0.030(7)
821.1(2)	-	-	-	0.042(17)	0.041(4)
835.9(2)	-	-	-	0.076(11)	0.076(11)
860.56(3)	12.8(3)	-	12.41(8)	12.8(7)	12.5(1)
883.4(2)	-	-	-	-	0.031(3)
927.6(2)	-	-	-	0.13(1)	0.125(1)
982.7(2)	-	-	-	0.21(1)	0.205(8)
1004(2)	-	-	-	-	-
1093.9(1)	-	-	0.441(7)	0.48(4)	0.43(2)
1125.7(4)	-	-	-	-	0.005(2)
1160.8(2)	-	-	-	-	0.011(3)
1185.2(3)	-	-	-	-	0.017(5)
1282.8(3)	-	-	-	0.050(13)	0.052(5)
1381.1(5)	-	-	-	-	0.007(3)
1647.5(7)	-	-	-	-	0.002(1)
1743.9(2)	-	-	-	-	0.002(1)
2614.511(10)	100(3)	-	100(2)	100.0(13)	100(2)

* Weighted mean values adopted when appropriate; remainder derived from proposed decay scheme; normalisation factor of 0.9979(1) calculated from total theoretical internal conversion coefficient of 2614.511 keV (0.00210(6)) and transition probability of 100% (1.00), with no direct β^- decay to the ground state of ^{208}Pb.

† Data rejected as outliers, and not included in weighted-mean analyses.

§ No uncertainty quoted; data not included in the weighted-mean analyses.

‡ 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 583.19 keV gamma ray was used to convert all other data in this study to comparable relative values – under these circumstances, P_γ(583.19 keV) was not included in the weighted-mean analysis.

Ψ unresolved overlap with another gamma-ray emission, and measurement did not include 2614.51-keV γ ray; therefore relative emission probability of 85.2 (3) was used for the 583.19-keV γ ray to convert other data in this study to comparable relative values – under these circumstances, P_γ(583.19 keV) were not included in the weighted-mean analysis.

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Multipolarities and Internal Conversion Coefficients

The major 583.19 and 2614.51 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 were used to determine specific multipolarities and theoretical internal conversion coefficients: ((98%M1 + 2%E2) for 211.4, 233.3 and 252.5 keV, (99.73%M1 + 0.27%E2) for 510.7 keV, (91.2%M1 + 8.8%E2) for 722.0 keV, (99.99%M1 + 0.01%E2) for 763.2 keV, and (66.5%M1 + 33.5%E2) for 860.56 keV gamma rays). The assigned multipolarity of the 860.56 keV gamma ray is particularly important in achieving the desired population-depopulation balance for the 2614.55 keV nuclear level.

A normalisation factor of 0.9979(1) was calculated for the relative emission probabilities of the gamma rays, assuming no direct beta decay to the ground state of ^{208}Pb:

transition probability of 2614.511 keV gamma ray = 100% (1.00)

total theoretical internal conversion coefficient (2614.511 keV E3 transition) = 0.00210(6) [78Ro22] → $100/[(1 + 0.00210(6))\ P_\gamma^{rel}(2614.51 \text{ keV})] = 0.9979(1)$.

Beta-particle Emissions

Energies

All beta-particle energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 1986Ma17 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 probability balances, using the recommended gamma-ray emission intensities and the theoretical internal conversion coefficients of 1978Ro22. All beta-particle transitions were classified as or assumed to be first forbidden non-unique.

Beta-particle Emission Probabilities per 100 Disintegrations of ^{208}Tl

E_b(keV)	P_b			
	1960Em01	1960Sc07	1967Os01	Recommended Values*
521(2)	-	-	-	0.053(5)
618(2)	-	-	-	0.017(5)
643(2)	-	-	4.5(15)	0.045(7)
678(2)	-	-	-	0.005(2)
690(2)	-	-	-	0.076(11)
705(2)	-	-	-	0.048(6)
718(2)	-	-	-	0.030(7)
739(3)	-	-	-	0.002(1)
821(2)	-	-	-	0.231(9)
876(2)	-	-	-	0.18(2)
1005(3)	-	-	-	0.007(3)
1040(2)	3.6	4.6(2)	< 0.6	3.26(7)
1055(2)	-	-	-	0.048(3)
1081(2)	-	-	-	0.64(6)
1293(2)	24.3	23.9(8)	21(2)	24.1(3)
1526(2)	20.6	22.7(7)	22(2)	22.2(7)
1803(2)	51.3	48.8(27)	52(1)	49.0(9)

* 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 1986Ma17 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) [α]	-	-	-	-	-	-	-	0.9(1)
180.2(2) [β^-]	-	-	-	-	-	-	-	-
288.08(6) [α]	-	0.775(40)[#]	-	0.82(2)	-	0.9(2)	0.97(5)	0.32(3)
327.94(6) [α]	-	0.299(23)[#]	-	0.33(1)	-	0.36(7)	-	-
433.7(2) [α]	-		-	0.04(1)	-	~ 0.025	-	-
452.8(1) [α]	-		-	0.84(2)	-	0.88(17)	1.10(6)	0.42(5)
		1.18(5)[#]						
473.6(2) [α]	-		-	0.122(8)	-	0.10(3)	-	-
492.7(1) [α]	-		-	< 0.008	-	-	-	-
580.5(3) [α]	-	-	-	-	-	-	-	-
620.4(3) [α]	-	-	-	-	-	-	-	-
727.33(1) [β^-]	11.1(7)		11.8(24)	-	-	17.6(17)	21.0(8)	6.9(4)
759(1) [α]	-	100[†]	-	-	-	-	-	-
785.37(9) [β^-]	1.70(26)		-	-	-	2.8(6)	3.26(16)	1.01(7)
807(1) [α]	-	-	-	-	-	-	-	-
893.41(2) [β^-]	0.66(7)	4.9(3)[†]	0.5(1)	-	-	0.94(19)	-	0.49(8)
952.12(2) [β^-]	0.16(4)	-	-	-	-	0.46(9)	-	-
1073.6(2) [β^-]			-	-	-	~ 0.03	-	-
	0.99(8)	10.1(4)[†]						
1078.63(11) [β^-]			0.7(1)	-	-	1.4(2)	-	-
1512.70(8) [β^-]	0.49(5)	3.4(3)[†]	-	-	0.99(15)	0.8(1)	-	-
1620.74(1) [β^-]	2.81(20)	20.0(6)[†]	3.0(6)	-	4.85(50)	3.9(4)	-	-
1679.45(1) [β^-]	-	-	-	-	0.230(7)	0.16(3)	-	-
1800.9(2) [β^-]				-	-	-	-	-
	0.17(3)	1.4(2)[†]	0.5(1)					
1805.96(10) [β^-]				-	0.41(10)	0.25(5)	-	-

Published Gamma-ray Emission Probabilities (cont.)

E_g (keV)	P_g (cont.)			
	1983Sc13[Ψ]	1983Va22[Ψ]	1984Ge07[Δ]	1992Li05[Ψ]
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]	M1 + E2
	452.8(1) [α decay]	72%M1 + 28%E2
	727.33(1) [β^- decay]	E2
	785.37(9) [β^- decay]	98%M1 + 2%E2
1982Be09	785.37(9) [β^- decay]	99.2%M1 + 0.8%E2
	893.41(2) [β^- decay]	M1 (+ ≤ 0.25%E2)
	952.12(2) [β^- decay]	70%M1 + 30%E2
	1078.63(11) [β^- decay]	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 $\beta^-\alpha$ 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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1996Sc06 - E. Schönfeld and H. Janβen, Evaluation of Atomic Shell Data, Nucl. Instrum. Meth. Phys. Res. A369(1996)527. [X_K, X_L, Auger electrons]

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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)	M1 $[L_I:L_{II}:L_{III} \rightarrow 100 : 10.4(3) : 0.88(10)]$
	238.632(2)	M1 $[L_I:L_{II}:L_{III} \rightarrow 100 : 10.4(2) : 0.74(5)]$
1960Ro16	115.183(5)	M1 $[\alpha_K = 5.8(9)]$
	238.632(2)	M1 $[\alpha_K = 0.74(7)]$
1963Da11	238.632(2)	M1
	415.27(1)	M1 $[\alpha_K \sim 0.35]$
1969Kr06	238.632(2)	M1
1978Av01	115.183(5)	E2
	238.632(2)	M1 (+ E2)
	300.09(1)	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:

[$\Sigma P_{\gamma i} (1 + \alpha_i)$ 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:

{[$\Sigma P_{\gamma i} (1 + \alpha_i)$ 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
$\Sigma P_{\gamma i} (1 + \alpha_i)$ 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: [$\Sigma P_{\gamma i} (1 + \alpha_i)$ 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}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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^{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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1995Au04 - G. Audi and A. H. Wapstra, The 1995 Update to the Atomic Mass Evaluation, Nucl. Phys. A595(1995)409. [Q value]

1996Sc06 - E. Schönfeld and H. Janβen, Evaluation of Atomic Shell Data, Nucl. Instrum. Meth. Phys. Res. A369(1996)527. [X_K, X_L, Auger electrons]

1998ScZM - E. Schönfeld and G. Rodloff, Tables of the Energies of K-Auger Electrons for Elements with Atomic Numbers in the Range from Z = 11 to Z = 100, PTB Report PTB-6.11-98-1, October 1998. [Auger electrons]

1999ScZX - E. Schönfeld and G. Rodloff, Energies and Relative Emission Probabilities of K X-rays for Elements with Atomic Numbers in the Range from Z = 5 to Z = 100, PTB Report PTB-6.11-1999-1, February 1999. [X_K]

^{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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^{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)) - [$\Sigma\ P_{\gamma i}\ (1 + \alpha_i)$ 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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^{226}Ra - Comments on evaluation of decay data
by M.M. Bé, V. Chisté

Ra-226 disintegrates by alpha emissions to excited levels and to the ground state of Rn-222.
The alpha emission intensities were measured only once (Bastin-Scoffier) and the results were given without uncertainties in the original paper.
On the other hand, a certain number of measurements of the 186-keV gamma intensity were carried out, so this intensity can be considered to have a good level of confidence.
Therefore, the decay scheme given here was built using this 186-keV gamma-ray intensity.

Nuclear Data

Q value is from Audi and Wapstra (1995Au04).
Spin and parity of the nuclear levels are from Akovali (1996El01).

Half-life
Experimental values are, in years :

Reference	Half-life	Uncertainty
Ramthun (1966Ra13)	1599	7
Martin (1959Ma12)	1602	8
Gorshkov (1959Go80)	1577	9
Sebaoun (1956Se10)	1617	12
Kohman (1949Ko01)	1622	13
Weighted mean	1600	7

The five values are statistically consistent (reduced χ^2 of 2,9). The internal uncertainty is 4 and the external uncertainty is 7.
The recommended value is the weighted mean with the external uncertainty.

Alpha Transitions

The alpha transition intensities have been deduced from the Rn-222 decay scheme balance at each level.
Below, comparison is done between the one and only measured values by Bastin-Scoffier (1963Ba62) and the calculated ones :

Alpha emission energy (keV)	Measured intensities [c]	Calculated intensities
4784,34 (25) [a]	94,45 (5)	94,03 (8)
4601 (1) [a]	5,55 (5)	5,96 (8)
4340 [b]	0,0065 (3)	0,0065 (16)
4191 [b]	0,0010 (1)	0,0008
4160 [b]	0,00027 (5)	0,0002

[a] Energy data are from Rytz (1991Ry01)
[b] Energy data are from Bastin-Scoffier
[c] Intensities are from Bastin-Scoffier with uncertainties given by Rytz

Gamma transitions and internal conversion coefficients

The internal conversion coefficients were interpolated from the tables of Rösel (1978Ro21), uncertainties are assumed to be 3%. Theoretical values are compared with measured values below :

	De Pinho (1973De50)	Rösel
α_K	0,200(9)	0,190 (6)
$\alpha L1$	0,031 (6)	0,0327 (10)
$\alpha L2$	0,226 (16)	0,212 (6)
$\alpha L3$	0,124 (8)	0,122 (4)
α_L	0,380 (20)	0,367 (11)

The gamma transition probabilities were determined from the gamma emission intensities and the theoretical ICC data.

Photon emissions

Gamma emission intensities

186-keV γ-ray

The strongest γ-ray, namely 186-keV, absolute emission intensity is taken from Helmer (IAEA – CRP). This study was done for the ^{226}Ra decay chain, all available relative and absolute measurements of gamma rays were taken into account, the most intense line of this chain is the 609,3 keV line which occurs in the disintegration of ^{214}Bi. Its intensity was determined as : 45,16 (33)% by Helmer (IAEA – CRP).

The 186 keV line from Ra-226 and the 609 keV line from Bi-214 intensity measurements are given below in Tables 1 and 2 :

Table 1 - Absolute gamma-ray emission intensities, results of measurements :

Energy (keV)	1969Li11	1983Ol01	1983Sc13	1991Li11	1998Mo14	Weighted average	s_{int} ; s_{ext}	reduced-χ^2
186,1 (Ra-226)		3,50 (5)	3,51 (6)	3,59 (6)		3,53	0,03	0,74
609,3 (Bi-214)	42,8 (40)	45,0 (7)	44,6 (5)	46,1 (5)	44,8 (6)	45,16	0,28 ; 0,33	1,39

Table 2 - Relative gamma-ray emission intensity, results of measurements :

Energy (keV)	1975Ha31	1982Ak03	2000Sa32	2002De03	Molnar	Weighted average	s_{int}	reduced-χ^2
186,1	8,7 (11)	9,2 (10)	7,6 (8)	7,812 (31)	7,85 (5)	7,824	0,026	0,76

These data are relative to the 609-keV line in Bi-214.

Table 3 – Combination of absolute and relative emission probabilities :

Energy (keV)	P_γ - table 1	P_γ - table 2	Weighted average	s_{int}	reduced-χ^2
186,211 (13)	3,53 (3)	3,533 (12)	3,533	0,021	0,01
609,316 (3)	45,16 (33)	reference			

The absolute emission intensity recommended by Helmer, and adopted here, for the 186 keV emission intensity is then : 3,533 (21) %,

262-keV γ-ray

This line was measured relatively to the 609-keV line of Bi-214 :
- Sardari (2000Sa32) : 0,012 (4) converted to the absolute value of 0,0054 (18) %
- Diallo (1993Di09,) : 0,012 (4) converted to the absolute value of 0,0054 (18) %

The adopted value is the weighted mean : 0,0054 (13) %

414-, 449- and 600-keV γ-rays

These three γ-emissions were reported by Lourens (1971Lo19) and Stephens (1960St20), no uncertainties were given,

The adopted values are those of Lourens converted to absolute values using Iγ(186) = 3,533 (21)%

γ-ray energies

The γ-ray energies are from Lourens (1971Lo19).
Multipolarities are from Lagoutine *et al.* (1983La**).

X-ray emissions

Several measurements were carried out, they are summarized in the table below and compared to the calculated values deduced from the decay scheme :

	Delgado (2002De03)	Schötzig (1983Sc13)	De Pinho [a] (1973De50)	Calculated
Kα1	0,215 (3)			0,315 (11)
Kα2	0,156 (39)			0,191 (7)
Kα	0,371 (39)	0,418 (21)		0,505 (17)
Kβ1	0,079 (5)			0,109 (4)

Kβ2	0,020 (4)			0,0349 (14)
Kβ	0,099 (6)	0,145 (9)		0,144 (5)
XK	0,47 (4)	0,563 (23)	0,689 (25)	0,649 (21)
XL1			0,0180 (25)	0,0149 (5)
XL2			0,417 (28)	0,431 (14)
XL3			0,399 (14)	0,367 (11)
XL			0,837 (43)	0,813 (17)

[a] Calculated with Iγ(186) = 3,533 (21)

The calculated values based on the assumption that Iγ(186) = 3,533 (21) are significantly greater than those measured by Delgado or Schötzig, except for the Kβ ray.

Nevertheless, with Iγ(186) = 3,28 (3) %, based on an α- transition to the 186-keV level of 5,55 (5)% and with the same calculation method, we obtain : XK = 0,603 (20) %, This value is consistent with those of Schötzig but the Delgado's value remains unexplained, It can be noted that Schötzig gave an absolute intensity of 3,51 (6)% for the 186-keV line, consistent with the recommended one.
The calculated data are in agreement, within the uncertainty values, with the experimental ones of De Pinho, who used a Ra-226 source from which the descendants were removed. Schötzig and Delgado, however, carried out measurements with sources in equilibrium with their daughters radionuclides.

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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 $I_{avg}(50.13\ \gamma) = 8.20(17)\%$, weighted average of the following measured absolute γ-ray emission probabilities: $I_\gamma(50.13) = 8.18(17)\%$ (1990Ko40) and $I_\gamma(50;13) = 8.4(6)\%$ (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(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)
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}Th – 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

^{228}Th ($T_{½}$ = 698.6 days) decays 100% by alpha-particle emission ($Q(\alpha)$ = 5520.12(22) keV) to various excited levels and the ground state of ^{224}Ra ($T_{½}$ = 3.64 days). A reasonably well-defined decay scheme was derived from the alpha-particle studies of 1970Ba20, 1976BaZZ, 1969Pe17, and 1993Ba72, and the gamma-ray measurements of 1977Ku15, 1982Sa36 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 131.61, 166.41, 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. Estimates were made of the uncertainties of the 700.4 and 992.65 keV gamma rays.

Cluster decay has also been observed, and reviewed by 1995Ar33 and 1997Tr17. O-20 emissions were detected, with an estimated branching fraction of 1.1(2)E-13. 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). ^{208}Tl in particular emits high-energy gamma rays that represent a well-defined spectroscopic signature for this decay chain.

Half-life

Half-life was 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 1956Ki16, 1971Jo14 and 1992Un01 were considered.

Reference	Half-life (d)
1956Ki16	697.8(7)
1971Jo14	698.77(32)*
1992Un01	698.60(36)
Recommended Value	698.60(23)

*Uncertainty adjusted to ± 0.33 to reduce weighting below 0.5.

Woods evaluation for IAEA-CRP (2004WoZZ): recommended half-life of 698.60(23) days (using above dataset).

Gamma Rays

Energies

All gamma-ray transition energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 1997Ar05 were adopted, and used to determine the energies and associated uncertainties of the gamma-ray transitions between the various populated-depopulated levels.

Emission Probabilities

Gamma-ray emission probabilities have been partially or fully determined in the measurements of 1977Ku15, 1982Sa36 and 1984Ge07. Weighted mean relative emission probabilities were calculated for the 131.61, 166.41, 205.99 and 215.985 keV gamma rays, while equivalent data for the other gamma transitions were directly adopted from the measurements of 1977Ku15. An additional gamma transition was added to the proposed decay scheme from equivalent studies of ^{224}Fr decay by 1981Ku02 as 908.28 keV gamma ray depopulating the 992.65 keV nuclear level of ^{224}Ra to maintain consistency. All of these relative emission probabilities were defined in terms of the 84.373 keV gamma ray. Estimates were made of the uncertainties of the 700.4 and 992.65 keV gamma rays.

Published Gamma-ray Emission Probabilities

E_g (keV)	**P_g**			
	1969Pe17	1977Ku15[†]	1982Sa36[‡]	1984Ge07
74.4(1)	-	4.0(14)	-	-
84.373(3)	1.21(6)	12100(600)	1.9(1)	100.0(16)
131.612(4)	-	1240(60)	0.17(2)	10.70(15)
142.7(1)	-	0.013(4)	-	-
166.410(4)	-	960(50)	0.13(1)	8.49(12)
182.3(1)	-	0.052(18)	-	-
205.99(4)	-	184(9)	-	-
215.985(4)	-	2390(130)	0.30(2)	1.61(5)
228.4(2)	-	0.18(3)	-	20.78(25)
700.4(1)	-	~ 0.03	-	-
741.87(1)	-	0.014(4)	-	-
832.0(1)	-	0.14(2)	-	-
908.28(1)	-	-	-	-
992.65(6)	-	~ 0.015	-	-

[†] 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%.

Gamma-ray Emission Probabilities: Relative to Pg(84.373 keV) of 100

E_g (keV)	**P_g^{rel}**			
	1977Ku15	1982Sa36	1984Ge07	Recommended Values[*]
74.4(1)	0.033(12)	-	-	0.033(12)
84.373(3)	100(5)	100(5)	100.0(16)	100.0(16)
131.612(4)	10.25(50)	8.9(10)	10.70(15)	10.6(2)
142.7(1)	0.00011(3)	-	-	0.00011(3)
166.410(4)	7.9(4)	6.8(5)	8.49(12)	8.0(5)
182.3(1)	0.00043(15)	-	-	0.00043(15)
205.99(4)	1.52(7)	-	1.61(5)	1.58(5)
215.985(4)	19.8(11)	15.8(11)	20.78(25)	19.3(15)
228.4(2)	0.0015(3)	-	-	0.0015(3)
700.4(1)	~ 0.00025	-	-	0.00025(8)
741.87(1)	0.00012(3)	-	-	0.00012(3)
832.0(1)	0.0012(2)	-	-	0.0012(2)
908.28(1)	-	-	-	0.00014(4)
992.65(6)	~ 0.00012	-	-	0.00012(3)

[*] Weighted mean values adopted when judged appropriate; remainder derived from proposed decay scheme.

The normalisation factor was calculated for the gamma-ray emission probabilities by averaging the values determined by three different routes:

(i) from direct population of the ^{224}Ra ground state

$[\Sigma P_{\gamma i} (1 + \alpha_i)$ to ground state$]$ NF + 0. 732(2) = 1.00
NF = 0.000117(5)

(ii) population/depopulation of the 84.373 keV nuclear level of ^{224}Ra

$[P_{\gamma}$(84.373 keV)(1 + α(84.373 keV)) - $\Sigma P_{\gamma i} (1 + \alpha_i)$ to 84.373 keV level$]$ NF = 0.262(2)
NF = 0.000117(6)

(iii) all α transitions

ΣP_{α} NF = 1.00, and adopting α-particle emission probability to ^{224}Ra ground state of 0.732(2) (see section on alpha-particle emissions),
NF = 0.000117(7)

An average value of 0.000117(5) has been adopted.

Multipolarities and Internal Conversion Coefficients
The nuclear level scheme specified by 1997Ar05 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: E2 for both the 84.373 and 166.410 keV gamma rays (1953As31, 1966Co40, 1969Du06 and 1969Pe17). The 908.28 keV gamma ray was identified as the only mixed multipolarity transition, and was arbitrarily assigned 50%M1 + 50%E2.

All of the recommended internal conversion coefficients have been interpolated from the theoretical tabulations of 1978Ro22. Uncertainties of ± 2% were adopted for all of the E1 and E2 (+M3) gamma transitions (with minor upward adjustments associated with the significant figures for α_L and α_{M+}), while an uncertainty of ± 10 % was assigned to the ICCs for the 908.28-keV (50 %M1 + 50 %E2) gamma transition.

Internal Conversion Coefficients

Reference	**E$_g$ (keV)**	a				
		a_L	a_{LII}	a_{LIII}	a_{M+}	a_{total}
1953As31	84.373	-	-	-	-	16
	166.410	-	-	-	-	1.2
1966Co40	84.373	14(3)	7.6	6.3	3.8(9)	18(4)
1968Du06	84.373	-	-	-	-	19.6(14)
1969Pe17	84.373	-	-	-	-	21.4(9)

Alpha-particle Emissions

Energies
All alpha-particle energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 1997Ar05 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

An alpha-particle emission probability of 73.2(2) % was derived for the 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 0.0117(5), per 100 disintegrations, for the relative emission probabilities of the gamma rays (see above).

Published Alpha-particle Emission Probabilities per 100 Disintegrations of ^{228}Th

E_a(keV)	P_a				
	1953As31	1969Pe17	1970Ba20	1976BaZZ	1993Ba72
4448.0(3)	-	-	-	-	-
4523.0(3)	-	-	-	-	-
4952.5(4)	-	-	-	-	-
4997.8(3)	-	-	-	-	-
5138.01(26)	-	-	~ 0.05	-	-
5176.89(23)	20	-	0.18	-	-
5211.08(22)	40	-	0.36	-	-
5340.38(22)	28	26.7(2)	26.7	26.6(5)	26.0(8)
5423.28(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 normalisation to (100 – 0.38 – 0.20 – 0.036) = 99.384
(72.4 + 26.6) N = 99.384
N = 1.0039 to give P_α(5423.28 keV) of 72.7%, and uncertainty of ± 0.5;
and P_α(5340.38 keV) of 27.3%, and uncertainty of ± 0.5.

1993Ba72 studies also require normalisation to give P_α(5423.28 keV) of 73.5%
and uncertainty of ± 0.6;
and P_α(5340.38 keV) of 26.5%, and uncertainty of ± 0.6.

A weighted mean value of 73.2(2)% (0.732(2)) was determined for P_α(5423.28 keV), which has been matched with a value of 26.2(2)% (0.262(2)) for P_α(5340.38 keV).

Adjusted Alpha-particle Emission Probabilities per 100 Disintegrations of ^{228}Th

E_a(keV)	P_a					
	1953As31	1969Pe17	1970Ba20	1976BaZZ	1993Ba72	Recommended Values*
4448.0(3)	-	-	-	-	-	$4.4(12) \times 10^{-6}$
4523.0(3)	-	-	-	-	-	$1.7(3) \times 10^{-5}$
4952.5(4)	-	-	-	-	-	$2.5(5) \times 10^{-5}$
4997.8(3)	-	-	-	-	-	$1.0(3) \times 10^{-5}$
5138.01(26)	-	-	~ 0.05	-	-	0.036(7)
5176.89(23)	20	-	0.18	-	-	0.20(2)
5211.08(22)	40	-	0.36	-	-	0.38(3)
5340.38(22)	28	26.7(2)	26.7	27.3(5)	26.5(6)	26.2(2)
5423.28(22)	71	[73.3(2)]	72.7	72.7(5)	73.5(6)	73.2(2)

*P_α(5423.28 keV) of 73.2(2) is effectively the weighted mean of the normalised studies, which is subsequently matched against P_α(5340.38 keV) of 26.2(2); recommended emission probabilities of the low-intensity α transitions were derived from the evaluated
gamma-ray emission probabilities and theoretical internal conversion coefficients.

The absolute emission probabilities of all 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.

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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^{238}Pu – Comments on evaluation of decay data
by V. P. Chechev

This evaluation was completed in March 2003. The literature available by 2003 has been included here.

1. Decay Scheme

The decay scheme is based on the evaluation of Akovali (1994Ak05). It can be basically considered complete though several expected gamma transitions have not been observed in ^{238}Pu α-decay and thus have been adopted from the decay of ^{234}Pa and ^{234}Np and from the existing ^{234}U level scheme. These gamma transitions are weak, consequently they do not significantly influence the intensity balances.

2. Nuclear Data

Q(α) value is from 1995Au04.

The evaluated 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
1965Eichelberr	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 evaluator using the analysis of 1977Di06

[d] Re-estimated by evaluator

By omitting three values reported without uncertainties, the weighted average of the remaining 11 values is 87.73 with an internal uncertainty of 0.019 and $\chi^2/\nu = 2.0$. The average value of 87.73(3) could be adopted for the 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) (1974StYZ) 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 have been 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 adopted value of the ^{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 adopted value of the ^{238}Pu spontaneous fission is $4.74(12)\cdot10^{10}$ 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 a ^{238}Pu half-life of 87.77 yr. See also 2000Ho27

2.1. Alpha Transitions

The energies of the alpha transitions have been calculated from the Q value and the level energies given in Table 3 from 1994Ak05.

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 10^5 yr	71.04(6)
1	43.498(1)	2+	0.25 ns	28.85(6)
2	143.350(4)	4+		0.105(3)
3	296.070(4)	6+		0.00297(4)
4	497.04(4)	8+		$6.85(23)\cdot10^{-6}$
5	786.29(3)	1-		$8.21(16)\cdot10^{-6}$
6	809.88(3)	0+	<0.1 ns	$1.0(4)\cdot10^{-4}$
7	849.30(5)	3-		$7.4(22)\cdot10^{-8}$

8	851.70(10)	2+	>1.74 ps	$8.2(17)\cdot10^{-6}$
9	926.74(5)	2+	1.4 ps	$1.30(5)\cdot10^{-6}$
10	947.85(15)	4+		$1.7(4)\cdot10^{-7}$
11	989.45(5)	2-	0.76 ns	$1.52(16)\cdot10^{-7}$
12	1023.7(2)	4+		$\sim2.0\cdot10^{-7}$
13	1044.53(4)	0+		$1.17(7)\cdot10^{-6}$
14	1085.30(15)	2+		$\sim1.2\cdot10^{-6}$

The probabilities of the most intensive 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 for the relevant levels in ^{234}U.

Table 4. Experimental and evaluated 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	Evaluated
$\alpha_{0,0}$	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)	0.105 (3) [c]
$\alpha_{0,3}$	5208		0.005(1)	0.0018 [a]		0.036(5)	0.0030(1)				0.00297 (4) [d,e]
$\alpha_{0,4}$	5010			$\sim4\cdot10^{-6}$							$6.85(23)\cdot10^{-6}$ [e]
$\alpha_{0,5}$	4726			$2.2\cdot10^{-5}$							$8.21(16)\ 10^{-6}$
$\alpha_{0,6}$	4703			$5\cdot10^{-5}$							$1.0(4)10^{-4}$ [e,f]
$\alpha_{0,7}$	4664										$7.4(22)10^{-8}$ [e]
$\alpha_{0,8}$	4662			$<2\cdot10^{-5}$							$8.2(17)\cdot10^{-6}$ [e]
$\alpha_{0,9}$	4588			$(1,2\cdot10^{-5})$							$1.30(5)10^{-6}$ [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 calculated from P(γ+ce) balance is 0,1050(24); adopted value is 0,105(3)

[d] Agrees well with the experimental value from 1984Bo41

[e] Evaluated from P(γ+ce) balance

[f] A 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

Gamma-ray transition probabilities have been deduced from their emission probabilities and total internal conversion coefficients (ICC). ICC's are theoretical values from 1978Ro22 for the adopted energies and multipolarities taken from the analysis of Akovali (1994Ak05), and using 2% fractional uncertainties in α_K, α_L, and α_M for pure multipolarities.

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 (1994Ak05), as well as from α-decay of ^{238}Pu (1963Bj03, 1964Le17, 1964Le22).

3. ATOMIC DATA

3.1. Fluorescence yields

Fluorescence yield data are from 1996Sc06 (Schönfeld and Janßen).

3.2. X Radiations

The U KX-ray energies have been taken from 1999Schönfeld (E. Schönfeld and G. Rodloff - PTB-6.11-1999-1999-1, Braunschweig, Februar 1999) 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 K X-ray emission probabilities have been taken from 1999Schönfeld (see above).

Table 5. Experimental and adopted (calculated) values of K X-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 [a]	110.416(3)	110.42(3)	110.421
$K\beta_1$	111.30 [a]	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 [a]	-	114.50(3)	114.46
$KO_{2,3}$	115.40 [a]	-	115.40(5)	115.377

The energies of U LX-rays have been taken from 1994Le37 where the fine structure of LX-radiation was measured in decays of ^{239}Pu, ^{240}Pu. Other measurements of U LX-ray energies can be found in 1954As07, 1982GeZP, 1984BaYT, 1983Ah02, 1984Bo41, 1984DrZX, 1990Po14, 1992Ba08, 1994Le28 and 1995Jo23.

In 1983Ah02 the electron capture decay of ^{235}Np was investigated. The U LX-ray energies measured in 1984Bo41 are 11.6 keV (Ll), 13.5 keV (Lα), 17.4 keV (Lβ) and 20.4 keV (Lγ). In 1984DrZX and 1995Jo23 the energies and intensities of finer L X-ray lines were measured. These agree with theoretical estimates.

3.3. Auger Electrons

The energies of Auger electrons are from 1977La19 (Larkins) and 1987Lagoutine (F. Lagoutine, N. Coursol and J. Legrand, ISBN-2-7272-0078-1 (LMRI, 1982-1987)).

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 the ground state of ^{234}U, $E(a_{0,0})$ has been adopted from the absolute measurement of 1971Gr17 by using 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 $E(a_{0,0})$ and the level energies taking into account the recoil energies (see also 1994Ak05).

In Table 6 the deduced (evaluated) values of a – emission energies are compared with the experimental results obtained by using magnetic spectrometry.

Table 6. Experimental and evaluated α emission energies (keV) in the decay of ^{238}Pu.

	Measured [a]						Evaluated
	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)	5456,26(20)
$\alpha_{0,2}$	5358	5358,6(10)	5362(1)		5357,7		5358,09(20)
$\alpha_{0,3}$		5215(5)			5205,6		5207,94(20)
$\alpha_{0,4}$					≈5015		5010,36(21)
$\alpha_{0,5}$					4724		4725,98(21)
$\alpha_{0,6}$					4704		4702,79(21)
$\alpha_{0,7}$					-		4664,03(21)
$\alpha_{0,8}$					4661		4661,67(23)
$\alpha_{0,9}$					≈4590		4587,89(21)

[a] Original values have been adjusted for changes in calibration energies as suggested in 1991Ry01

[b] Absolute measurement; this value has been adopted as recommended in1991Ry01 (see text above)

[c] Value is from 1962Le11; adopted in 1970Ba72 as calibration energy

5. ELECTRON EMISSIONS

Energies of conversion electrons have been deduced from the gamma transition energies given in section 2.2 using atomic-electron binding energies.

The emission probabilities of conversion electrons have been deduced from the evaluated P(γ) and ICC values. I am comparing below experimental L1:L2:L3 conversion electron subshell intensities (1969Am02) with theoretical values for the most intense E2 transition of 43,498 keV.

Calculated	Measured
3,82(11):112(3):100	3,99(22):114,7(20):100

The total absolute emission probabilities of K Auger electrons have been computed by using the evaluated total P(XK) and the adopted ω_K from section 3.

The total absolute emission probability of L Auger electrons have been computed using the total evaluated P(XL) and the adopted ϖ_L from section 3.

6. Photon Emissions

6.1. X-Ray Emissions

6.1.1. M X-Rays

The total absolute emission probability of M X–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 L X–rays [P(XL)] using the adopted value ϖ_L = 0.500(19) from section 3.1 and the evaluated total absolute emission probability of L conversion electrons, namely, P(ce_L) = 21.2(6) % leads to the value P(XL) = 10.6 (5) %. The analogous calculation using the computer code EMISSION 2000Schönfeld (E. Schönfeld and H.Janβen, Appl. Rad. Isot. 52(2000) 595) gives P(XL) = 10.62(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 a value from 1984DrZX where also the fine structure of L X-radiation was measured. The value from 1995Jo23 has been adopted as the recommended absolute emission probability of U LX–rays from the decay of ^{238}Pu: P(XL) = 10.63(8) % (per 100 disintegrations).

For the evaluation of emission probabilities of the L X–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 LX rays from the 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 theoretical absolute emission probabilities of LX rays from the α decay of ^{238}Pu

	1976Va23	1977Bemis	1984Bo41	1995Jo23	Evaluated	Calculated (1995Jo23) (theory)
Ll	-	0.24(1)	0.239(7)	0.231(3)	0.235(4) [b]	0.234
Lα	3.77(5)	3.88(7)	3.74(6)	3.81(3)	3.80(3) [c]	3.78
L$\beta\eta$	5.53(7) [a]	5.24(7)	5.38(8)	5.31(4)	5.31(4) [c]	5.42
Lγ	1.10(2) [a]	1.27(2)	1.27(2)	1.29(1)	1.28(1) [c]	1.26

[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 KX-ray emission probability (P(Kα_2)) with energy 98.44 keV (U Kα_2) has been adopted from 1976GuZN. The uncertainty of P(Kα_2) includes a 2 % from the detector efficiency. The absolute emission probabilities of all other X-rays have been computed from their relative emission probabilities using the adopted P(Kα_2) = 1.69 (4) $\cdot 10^{-4}$ %.

The total absolute K X –ray emission probability P(XK) = 3.56(5) 10^{-4} %, obtained by summing the individual K X-ray emission probabilities, 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 conversion electron intensities from E0 and E0+E2 transitions in the decay of ^{238}Pu.

6.2. Gamma-Ray Emissions

6.2.1. Gamma-Ray Energies

The energies of prominent gamma-rays such as $\gamma_{1,0}$(43.5 keV), $\gamma_{2,1}$(99.9 keV) and $\gamma_{3,2}$(152.7 keV) have been taken from 1984He19, which includes a correction of 5.8 ppm in the gamma-ray energy scale (2000He14The energy of $\gamma_{4,3}$(201.0 keV) has been taken from the decay of 6.75-h ^{234}Pa β^- decay (1994AK05). The energies of $\gamma_{14,7}$ (235.9 keV) and $\gamma_{14,5}$(299.2 keV) have been adopted from 1969LeZX. The energies of $\gamma_{13,5}$(258.2 keV) and $\gamma_{5,1}$(742.8 keV) are from 2000Ni13 (Y. Nir-El, Radiochim. Acta 88(2000)83). The energies of unobserved gamma-rays from ^{238}Pu α-decay have been taken from the decay of ^{234}Pa and ^{234}Np ,and from the existing ^{234}U level energies (1994Ak05). The energies of gamma-rays with energy greater than 700 keV have been adopted from the decay of ^{234}Pa and ^{234}Np (1969LeZX). The experimental gamma-ray energy from 1971GuZY and 1976GuZN agree with values in 1969LeZX and with those adopted here (Table 9).

Table 9. Experimental and recommended gamma-ray energies (keV) from ^{238}Pu[a] α decay

	1969LeZX	1971GuZY	1972Sc01	1976GuZN	1984He19	Adopted
$\gamma_{1,0}$		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)					299.2(2)
$\gamma_{7,2}$	706.1(3)	705.6		705.6		705.9(1)
$\gamma_{8,2}$	708.4(2)	708.4		708.4		708.4(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)
$\gamma_{9,1}$	883.23(10)	883.21				883.24(4)
$\gamma_{10,1}$	904.37(15)	904.34				904.3(2)
$\gamma_{9,0}$	926.72(15)	926.73				926.74(5)
$\gamma_{14,2}$	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 measurements results can be find in 1954As07, 1955Ch02, 1956Ne17, 1971Cl03 and 1971Ma68. They agree with those given in Table 9.

6.2.2. Gamma-Ray Emission Probabilities

Experimental and evaluated gamma-ray emission probabilities for γ-rays with energies < 200 keV are given in Table 10. The evaluated P(γ) values have been obtained by averaging several experimental results. They agree well with calculated values obtained from intensity balances in ^{234}U levels using P(α) and total ICC.

Table 10. Experimental and evaluated absolute emission probabilities (per 10^4 α-decays) for < 200-keV gamma-rays from the decay of ^{238}Pu

	Energy (keV)	1976 GuZN	1976 Um01	1979 Vaninbroukx	1984 Bo41	1984 He19	1984 Ov01	1994 Ba91	Evaluated [a]	Calculated [b]
$\gamma_{1,0}$	43.5	3.93(8)	4.11(8)	3.,93 (12)	3.96 (10)	3.82 (8)			3.97 (8)	3.96 (8)
$\gamma_{2,1}$	99.8	0.724 (14)			0.730 (11)	0.743 (8)	0.631 (38) [c]		0.735 (8)	0.735 (30)
$\gamma_{3,2}$	152.7	0.0956 (20)			0.0928 (14)	0.0936 (10)	0.086 (4) [c]	0.0923 (7)	0.0930 (7)	0.094 (4)

[a] Weighted averages; uncertainties are the smallest experimental values

[b] Calculated from P(α) values and adopted total ICC's

[c] Omitted based on statistical considerations

The emission probabilities of $\gamma_{14,7}$(235.9 keV), $\gamma_{13,8}$(258.2 keV) and $\gamma_{14,5}$(299.2 keV) have been adopted from 1969LeZX.

The P(γ) of gamma-rays that were not observed in the ^{238}Pu α-decay have been deduced from the decay of ^{234}Pa and ^{234}Np (1994Ak05) using experimental relative gamma ray emission probabilities.

The absolute emission probabilities of all other weak gamma-rays (most of them with energies > 700 keV) have been computed from their evaluated relative emission probabilities given in Table 11. The value P(γ766) = 2.19(5) $\cdot 10^{-7}$ measured in 1976GuZN (the uncertainty includes a 2% detector efficiency uncertainty) was used as a normalization factor. This value agrees well with 2.19(6)$\cdot 10^{-7}$, calculated from the results in 1979Ce04(P(γ786) = 3.16(9)$\cdot 10^{-8}$) and the relative intensity ratio of $\gamma_{766}/\gamma_{786}$; as well as with the value of 2.21(15) $\cdot 10^{-7}$ measured in 1984Ov01. The latter value has been obtained by evaluator from authors' Pγ renormalized to P(γ153) = 9.30(7) $\cdot 10^{-6}$.

Table 11. Experimental and evaluated relative emission probabilities of > 200-keV gamma-rays from the decay of ^{238}Pu

		1969LeZX	1971GuZY	1971Ma68	1976GuZN	1979Ce04	1984Ov01	Evaluated
$\gamma_{4,3}$	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)
$\gamma_{14,5}$	299.2	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)
$\gamma_{8,2}$	708.4	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)

		1969LeZX	1971GuZY	1971Ma68	1976GuZN	1979Ce04	1984Ov01	Evaluated
$\gamma_{9,1}$	883.2	3.43(15)	2.72(27)	3.3(5)		3.54(25)	3.2(6)	3.30(17)
$\gamma_{10,1}$	904.3	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.

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^{240}Pu – Comments on evaluation of decay data
by V. P. Chechev

This evaluation was completed in August 2003. The literature available by July 2003 was included.

1. DECAY SCHEME

The decay scheme is based on the evaluation of Schmorak (1991Sc08) and taken from 1996Firestone. It can be considered as basically completed though several weak gamma transitions were not observed in ^{240}Pu alpha decay. They have been taken from data on nuclear reactions and ^{236}Pa, ^{236}Np decays (1984Mi02, 1991Sc08).

The alpha transitions to ^{236}U highly excited levels with energy of 958, 960 and 967 keV were not observed either. They are expected from data on level spins and gamma rays de-excited the above levels.

2. NUCLEAR DATA

Q(α) value is from 1995Au04.

The evaluated 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 the ^{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	6240(120)		α-Particle Counting
1954Fa11	Farwell et al.	6300(600)		α-Particle Counting
1956Bu92	Butler et al.	6600(100)		α-Particle Counting
1959Do64	Dokuchaev	6620(50)	6610(55) [b]	α-Particle Counting
1968Oe02	Oetting	6524(10)	6537(15) [d]	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

[a] Quoted uncertainties, corresponding to 95% confidence level, have been reduced by a factor 2.

[b] Re-estimated in 1978Ja11.

[c] Re-estimated in 1986IAEA. According to the criterion adopted by the members of the CRP, a minimum uncertainty of 0,1% on the half-life of long-lived nuclides should be attributed to all measured values.

[d] Re-estimated in 1986IAEA. The quoted uncertainty has been increased since no measurements were made to demonstrate the absence of ^{238}Pu .

With omitting the value of 1951We21 as outlier the weighted mean of the remaining 10 values is 6561 yr with the internal uncertainty 3.1 yr and external uncertainty 4.0 yr.

According to the criterion adopted by the members of the CRP (1986IAEA) 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 evaluated spontaneous fission half-life of ^{240}Pu is based on the experimental results given in Table 2.

Table 2. Experimental values of the spontaneous fission ^{240}Pu half-life (in 10^{11}years)

Reference	Author(s)	Measurement 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 2p geometry	Yes
1989Dy01	Dytlewski et al.	1.12(2)	Neutron coincidences and low geometry α-counting	Yes
1991Iv01	Ivanov et al.	1.15(2)	$\lambda_{SF}/\lambda_{\alpha}$ in ^{240}Pu standards	Yes

[a] Re-estimated in Holden 2000. Original value is 1.170(25).

Early measurement values have been omitted from averaging according to analysis of Holden and Hoffman (2000Ho27). The weighted mean of 6 selected values is 1.15 with the internal uncertainty 0.010 and external uncertainty 0.0087.

The adopted value of the ^{240}Pu spontaneous fission is $1.15(2)\cdot10^{11}$ years where the uncertainty is the smallest quoted uncertainty.

2.1 Alpha Transitions

The energies of the alpha transitions have been calculated from the Q value and the level energies given in Table 3 from 1991Sc08, 1996Firestone.

Table 3. ^{236}U levels populated in the ^{240}Pu α-decay

Level number	Energy, keV	Spin and parity	Half-life	Probability of α-transition (x 100)
0	0.0	0^+	$2.342\cdot10^{7}$ yr	72.74(11)
1	45.242(3)	2^+	234 ps	27.16(11)
2	149.476(15)	4^+	124 ps	0.0863(18)
3	309.783(8)	6^+	58 ps	0.001082(18)
4	522.24(5)	8^+	24 ps	$4.7(5)\cdot10^{-5}$
5	687.60(5)	1^-	3.8 ns	$1.93(4)\cdot10^{-5}$
6	744.15(8)	3^-	< 0.1 ns	
7	919.21(17)	0^+		$\approx 6.5\cdot10^{-7}$
8	957.99(17)	(2^+)		$< 1.7\cdot10^{-7}$
9	960.3 (3)	(2^+)		$< 1.3\cdot10^{-7}$
10	966.63(9)	1^-		$< 1\cdot10^{-7}$

The probabilities of the most intensive 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 evaluated from the P(γ+ce) balances for corresponding levels of ^{236}U.

Table 4. Experimental and evaluated values of α-transition probabilities (× 100) in the decay of ^{240}Pu

	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	2003 Sibbens	Evaluated
$\alpha_{0,0}$	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(11) [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(11) [a]
$\alpha_{0,2}$	5021	0.091 (6)	0.085 (15)	0.1		0.096 (5)	0.090 (5)		0.10 (2)					0.0863(18) [b]
$\alpha_{0,3}$	4864	0.0032 (1)				0.001								0.001082(18) [b]
$\alpha_{0,4}$	4655													$4.7(5)\cdot10^{-5}$ [b]
$\alpha_{0,5}$	4492				$2.1(4)\ 10^{-5}$									$1.93(4)\cdot10^{-5}$ [b]

[a] MBAYS procedure was used for obtaining the final uncertainty as the data set is discrepant (see 2000Ch01)

[b] Calculated from (γ+ce)-intensity balance for corresponding levels

2.2. Gamma Transitions and Internal Conversion Coefficients

The gamma-ray transition probabilities have been deduced from their gamma-ray emission probabilities and total internal conversion coefficients (ICC). The experimental values of ICC have been adopted for gamma rays $\gamma_{5,1}$ (642.4 keV) and $\gamma_{5,0}$ (687.6 keV). The remaining ICC are theoretical values from1978Ro22 for the adopted energies and multipolarities. The latter ones have been taken from the analysis of Schmorak (1991Sc08) and 1996Firestone. The relative uncertainties of α_K, α_L, α_M for pure multipolarities have been adopted as 2%.

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 have been taken from 1994Le28 and 1994Le37 where the fine structure of LX radiation was measured in the decay of ^{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 have been taken from 1999Schönfeld and from data on α-decay of ^{238}Pu.

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 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. ALPHA EMISSIONS

The energy of the 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 α-emission energies have been calculated from E$\alpha_{0,0}$ and the level energies taking into account the recoil energies (see also 1994Ak05).

In Table 6 the calculated (evaluated) values of α-emission energies are compared with the experimental results obtained with using alpha spectrometry.

Table 6. Experimental and evaluated α-emission energies in the decay of ^{240}Pu, keV

	Measured [a]						Evaluated
	1956Ko67	1956Go43	1952As28 1957As83	1962Le11	1972Go33	1977Ba69	
$\alpha_{0,0}$	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)	5123.64(15)
$\alpha_{0,2}$	5021(2)	5020	5019			5021.3(5)	5021.15(15)
$\alpha_{0,3}$	4858(5)	4856				4863.4(5)	4863.51(15)

[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 in1991Ry01 (see text above)

It should be noted that Sibbens and Pomme (2003Sibbens) 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(1) keV and E($\alpha_{0,1}$)= 5124.10(2) keV discrepant with published data. However these results can depend on the spectrum de-convolution algorithm used. New experiments for pure ^{240}Pu sources need to be done.

5. ELECTRON EMISSIONS

The energies of the conversion electrons have been calculated from the gamma transition energies given in section 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 experimental spectrum of the conversion electrons in the decay of ^{240}Pu is given in 1958Sa21.

The absolute total emission probability of K Auger electrons have been computed by using the evaluated total emission probability of K–conversion electrons $P(ce_K) = 9.04(18)\cdot 10^{-5}$ % and the adopted ω_K from section 3.

The absolute total emission probability of L Auger electrons have been computed using the adopted total absolute emission probability of U LX–rays and the adopted ϖ_L from section 3.

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 1994Le28 and 1994Le37. The uncertainties are the smallest quoted uncertainties.

The total absolute emission probability of U LX–rays P(XL) = 9.9(5) % , calculated using the value $\varpi_L = 0.500(19)$ from section 3.1 and the evaluated total absolute emission probability of L conversion electrons $P(ce_L) = 19.8(6)$ %, differs slightly from the value P(XL) = 10.34(15) % adopted from measurements of 1994Le28, 1994Le37. The measurement result of 1970Swinth (11.5(3) %) disagrees with the adopted and calculated values.

6.1.2. KX-Rays

The total absolute KX –ray emission probability $P(XK) = 8.77(18)\cdot 10^{-5}$ % has been computed using the value $\omega_K = 0.970(4)$ from section 3.1 and the evaluated total emission probability of K–conversion electrons $P(ce_K) = 9.04(18)\cdot 10^{-5}$ %

6.2. Gamma Ray Emissions

6.2.1. Gamma Ray Energies

The energies of gamma rays accompanying α-decay of ^{240}Pu to levels with energy less than 700 keV have been obtained on the basis of the available experimental data from ^{240}Pu α-decay (Table 7) and data from ^{236}Pa, ^{236}Np decays (1984Mi02, 1991Sc08). The adopted gamma ray energies correspond to the decay scheme from 1991Sc08, 1996Firestone. Other much more inaccurate measurements results can be found in 1958Sa21, 1959Tr37 and 1972ClZS.

Table 7. Measured in the decay of ^{240}Pu and adopted values of gamma ray energies (keV)

	1969Le05	1971GuZY	1972Sc01	1974HeYW	1975OtZX	1976GuZN	1981He16	Adopted
$\gamma_{1,0}$		45.235(20)	45.242(6)			45.232(5)	45.244(3)	45.242(3)[a]
$\gamma_{2,1}$		104.233(10)	104.233(5)	104.15(2)		104.244(5)	104.234(6)	104.234(6)[b]
$\gamma_{3,2}$		160.35(50)	160.310(8)	160.27(2)	160.312(10)	160.280(15)	160.308(3)	160.307(3)[c]
$\gamma_{4,3}$			212.4(1)		212.48(5)			212.46(5)[a]
$\gamma_{5,2}$	538.05(30)				538.09(15)			538.11(10)[a]
$\gamma_{5,1}$	642.43(10)			642.48(15)	642.33(10)	642.48		642.35(9)[a]
$\gamma_{5,0}$	687.77(15)			688.01(15)	687.57(10)	687.7		687.60(5)[a]
$\gamma_{7,1}$	873.91(20)				873.92(15)			873.92(15)[a]

[a] .Obtained by averaging experimental data with corrections where necessary according to the adopted decay scheme

[b] Taken from 1981He16

[c] Taken from 1981He16 with the correction according to 2000He14

6.2.2. Gamma-Ray Emission Probabilities

The experimental and evaluated gamma ray emission probabilities for γ-rays with energy less than 200 keV are given in Table 8. The evaluated P(γ) values have been obtained by averaging several experimental results(except P($\gamma_{1,0}$) that calculated from intensity balance).

Table 8. Experimental and evaluated emission probabilities of gamma rays in the decay of ^{240}Pu 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	Evaluated
$\gamma_{1,0}$	45.24	4.50 (10)[a]	4.50[b]		4.53 (9)[d]	4.61 (14)[e]	4.35 (9)			4.50 (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 data of 1971GuZY have been revised in 1976GuZN

[b] Omitted from averaging as uncertainty is not quoted

[c] Omitted on statistical considerations

[d] The uncertainty quoted in 1976GuZN has been recalculated in 1986IAEA to include a 2% detector efficiency uncertainty

[e] The uncertainty quoted in 1976Um01 has been recalculated in 1986IAEA to include a 2% detector efficiency uncertainty and 1% from the sample isotopic composition

[f] Calculated from the P(α) values and the adopted total ICC $\alpha_T(\gamma_{1,0})$ = 604(12); agreed with the weighted mean of 1976GuZN, 1976Um01 and 1981He16: 4.47(10)

[g] Weighted mean of 1976GuZN and 1981He16; the uncertainty is the smallest quoted uncertainty

[h] Weighted mean of 5 experimental values; 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 evaluated 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 α-decays)

	Energy, keV	1969Le05	1971GuZY	1975OtZX	1975Dr05	1976GuZN	Evaluated
$\gamma_{5,2}$	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(16) [d]

[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 one increased by Student's coefficient (2000Ch01)

The emission probability of $\gamma_{7,1}$ (874 keV) has been obtained as a weighted average of measurement results from 1969Le05 and 1975OtZX.Weak gamma rays with energy more than 900 keV are reported in 1969Le05 and 1976GuZN. They are expected from the decay scheme but their emission probabilities (< 10^{-7} per 100 decays) have not been determined with a great accuracy.

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^{241}Am -Comments on evaluation of decay data
by V.P. Chechev and N.K. Kuzmenko

This evaluation was completed in October 2002 and revised in January 2004. The literature available by October 2002 was included.

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-transitions (1995Ak01). For high levels the decay scheme is not completed as great number of observed gamma transitions are not placed in the level scheme and some expected gamma transitions have not been seen.

However the intensive 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 of the decay scheme is mainly defined. Nevertheless here also there are gamma-transitions scarcely studied and expected but not certainly observed such as 27,02; 54,1; 96,7 keV. This leads to the not very good intensity balance for some levels.

The population of all higher levels does not exceed 0,1% in total.

2. Nuclear Data

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

The evaluated value of the ^{241}Am half-life has been obtained by averaging the experimental values, in years, given below:

432,7(7)	1967Oe01	Calorimetry
433(7)	1968Br22	Specific Activity Determination
436,6(30)	1968St02	Specific Activity Determination
426,3(21)	1972Jo07	Calorimetry
432,5(7)	1974StYG	Calorimetry
435,0(7)	1974StYZ	Specific Activity Determination
432,8(16)	1974Po16	Specific Activity Determination
432,0(2)	1975Ra35	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 y 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 (UWM) of 432,6(11) and weighted mean (WM) of 432,6 with an internal uncertainty of 0,27 and an external uncertainty of 0,51.

The EV1NEW computer program has chosen WM and the tS (or MBAYS) uncertainty of 0,55. The LWEIGHT program has also chosen WM and expanded the uncertainty so range includes the most precise value of 432,0 (1975Ra35) giving the value of 432,6(6) as result coinciding with the EV1NEW final value.

The adopted value of the ^{241}Am half-life is 432,6(6) years.

2.1. Alpha Transitions

The energies of the alpha transitions have been calculated from the Q value and the level energies given in Table 1 from 1995Ak01, with corrections for the 8 lower levels to take into account the adopted energies of gamma transitions from section 2.2.

Table 1. ^{237}Np levels displayed in the ^{241}Am α-decay

Level number	Energy, keV	Spin and parity	Half-life	Probability of α-transition (x100)
0	0,0	$5/2^+$	$2,14\ 10^6$ yr	0,38(1)
1	33,1963(3)	$7/2^+$	54(24) ps	0,23(1)
2	59,5409(1)	$5/2^-$	67(2) ns	84,45(10)
3	75,900(3)	$9/2^+$	~56 ps	<0,04
4	102,961(3)	$7/2^-$	80(40) ps	13,23(10)
5	130,00(3)	$11/2^+$		~0,01
6	158,49(2)	$9/2^-$		1,66(3)
7	191,44(10)	$13/2^+$		
8	225,96(2)	$11/2^-$		0,015(5)
9	267,54(2)	$3/2^-$	5,2(2) ns	$5 \cdot 10^{-4}$
10	281,35(2)	$1/2^-$		
11	305,06(4)	$13/2^-$		0,0022(3)
12	316,8(2) ?			
13	324,42(5)	$7/2^-$		0,0013
14	332,36(3)	$1/2^+$	≤1 ns	
15	359,7(1)	$(5/2^-)$		$6 \cdot 10^{-4}$
16	368,59(3)	$5/2^+$		$9 \cdot 10^{-4}$
17	370,93(3)	$3/2^+$		$3 \cdot 10^{-4}$
18	395,52(5)	$15/2^-$		$7 \cdot 10^{-4}$
19	418(4) ?			
20	434,12(16)	$(11/2^-)$		$4 \cdot 10^{-4}$
21	444,78(10) ?			
22	452,53(5)	$9/2^+$		$\sim 4 \cdot 10^{-4}$
23	459,69(4)	$7/2^+$		$\sim 4 \cdot 10^{-4}$
24	485,96(12)	$(9/2^-)$		$1,1 \cdot 10^{-4}$
25	497,02(6)	$17/2^-$		
26	514,19(6)	$(3/2^-)$		
27	545,59(16)	$(5/2^-)$		$1 \cdot 10^{-4}$
28	590,28(15)	$(7/2^-)$		
29	592,3(10)	$13/2^+$		
30	598,0(2)	$11/2^+$		
31	646,1(2)	(9/2-)		
32	666,2(2)	$(5/2^+, 7/2)$		
33	721,95(5)	$5/2^-$		$7 \cdot 10^{-4}$
34	756,00(10)	$7/2^-$		$8,6 \cdot 10^{-5}$
35	770,57(5)			
36	800,00(10)	$9/2^-$		$4(3) \cdot 10^{-5}$

37	805,8(2)	(7/2$^+$, 9/2)			
38	853,36(20)	11/2$^-$			
39	861,7(5)	(5/2$^+$, 7/2)			
40	920,9(5)				
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 measured values from spectrometric measurements (Table 2).

Table 2. Measured and adopted probabilities (x100) of the five most intensive alpha transitions

	1984Ah06 1993Ahmad	1987Bo25	1994Bl12	1996 Bueno	1996 Sanchez	1998Ya17	Adopted (WM)
$\alpha_{0,0}$	0,36(1)	0,34(5)	0,36(5)	0,5(2)	0,36(3)	0,394(9)	0,38(1)
$\alpha_{0,1}$	0,23(1)	0,22(3)	0,22(6)	-	0,28(3)	0,224(7)	0,23(1)
$\alpha_{0,2}$	84,6(2)	84,7(9)	84,69(28)	84,5(8)	84,5(3)	84,30(7)	84,45(10)
$\alpha_{0,4}$	13,1(1)	13,0(3)	13,08(24)	12,5(3)	13,2(3)	13,40(8)	13,23(10)
$\alpha_{0,6}$	1,65(8)	1,6(1)	1,66(6)	1,6(2)	1,65(7)	1,67(2)	1,66(3)

The $\alpha_{0,2}$ and $\alpha_{0,4}$ probability values of 1984Ah06 have been revised by the same author in 1993Ahmad cited in 1994Bl12. In Table 2 the revised values are given.

The probabilities of the alpha transitions $\alpha_{0,3}$, $\alpha_{0,5}$, $\alpha_{0,9}$, $\alpha_{0,13}$, $\alpha_{0,15} \div \alpha_{0,33}$ have been adopted from 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 computed from the intensity balance of gamma transitions.

2.2. Gamma Transitions and Internal Conversion Coefficients

The energies of gamma transitions are the energies of gamma rays.

The probabilities of the intensive anomalously converted gamma transitions $\gamma_{2,1}$ and $\gamma_{2,0}$ as well as that of $\gamma_{1,0}$ have been adopted from the analysis of Peter N. Johnston (1996Jo28) made in search of optimized values of parameters for low energy photons in the decay of ^{241}Am including LX-rays. The decay scheme balance for lower levels of ^{237}Np is better in 1996Jo28 than previous attempts.

ICC for $\gamma_{2,1}$ and $\gamma_{2,0}$ transitions have been obtained from the evaluation of the gamma ray and L-conversion electron probabilities in 1996Jo28. ICC for $\gamma_{1,0}$ transition have been taken from 1966Le13.

Multipolarities for all other gamma transitions have been adopted from measurements of 1959Sa10, 1964Wo03, 1966Ko06 and 1966Ya05. For these transitions the ICC have been evaluated using the above experimental information on the multipolarity admixture coefficients and the theoretical values from 1978Ro22.

The multipolarity admixture coefficient for $\gamma_{4,2}$ has been obtained by averaging four measurement results from 1963Wo03, 1966Ko06, 1966Ya05 and 1998Ko61.

The probabilities of the gamma transitions, $P_{\gamma+ce}$, have been computed using the evaluated absolute gamma -ray emission probabilities and the total internal conversion coefficients.

3. Atomic Data

3.1. Fluorescence yields

The ω_K and ϖ_L fluorescence yields are taken from 1996Sc06 (Schönfeld and Janβen).

ϖ_M is from 1989Hubbell.

3.1.1. X Radiations

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 measurement results of 1982Ba56 and 1983Ah02:

	Calculated (1999 Schönfeld)	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		}
Kβ_4	117,876		} 117,51(3)
KO$_{2,3}$	118,429	-	118,45(5)

The relative emission probabilities of XK -rays are taken from 1999Schönfeld.

3.1.2. Auger electrons

The energies of Auger electrons are from 1977Larkins.

The ratios P(KLX)/P(KLL) and P(KXY)/P(KLL) are taken from 1996Sc06.

4. Alpha Emissions

The energies of alpha particles, E_α , have been calculated from the energies of alpha transitions taking info account the recoil energies (see also 1995Ak01). The recommended energies of alpha-particles and emission probabilities of the most intensive alpha transitions are given also in 1991Ry01.

The experimental values E_α from spectrometric measurements are given in 1971GR17, 1968Ba25, 1968Ka09, 1965Mi06, 1964Ba26, 1962Le11, 1957Ro20, 1955Go57. They have the lesser accuracy in comparison with the calculated values.

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. The total emission probability of L-Auger electrons has been calculated from the evaluated P(XL) and ϖ_L.

6. Photon emissions

6.1 X - Ray emissions

The total absolute emission probability of MX - rays is the measurement result of 1971Ka48.

The absolute emission probabilities of LX - rays have been obtained by averaging of measurement results (per 100 disintegrations) shown in Table 3.

Table 3. Measured and evaluated absolute emission probabilities of LX rays in the decay of ^{241}Am

	1971 Ge11	1971 Wa28	1974 Ca16	1974 Ga40	1976 GuZN	1980 Cohen	1988 Co07	1992 Bl07	1994 Le37	Adopted (WM)
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)	0,848(10)[a]
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)	13,03(10)[a]
Lβ	19,1(14)	19,1(14)	19,25(40)	19,46(16)	19,2(10)	19,78(36)	18,3(6)	18,61(15)	18,39(19)	18,86(15)[b]
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)	4,81(4)[c]

[a] The smallest uncertainty of the measurement results.

[b] tS – external uncertainty (or MBAYS).

[c] Internal uncertainty of WM.

In 2001Sc08 also the measurement results of 1993Lepy (per 100 disintegrations) are given which are not included in averaging: Ll-0,875(18), Lα-13,10(21), Lβ-18,5(4), Lγ-4,84(8).

The total absolute emission probability of LX - rays is obtained by summing of the adopted data in the last column of Table 3: P(XL) = 37,6(3) per 100 disintegrations. This value can be compared with that calculated using total absolute sums Pce_L, Pce_K, and atomic data of sect.3 (ω_K, ϖ_L, n_{KL}). The latter is 38,6(16) per 100 disintegrations.

The absolute emission probabilities of XK -rays have been computed from the total XK - ray absolute emission probability P(XK) = 0,00389(8) per 100 disintegrations and the relative emission probabilities of XK - rays given in 1999Schönfeld. The above value P(XK) has been calculated using the adopted value of ω_K and the evaluated absolute emission probabilities of K conversion electrons from section 5. It agrees with measurements of 1976GuZN which give P(XK)=0,0040(1) per 100 disintegrations.

Below the experimental data of 1976GuZN are compared with the calculated (adopted) values of absolute emission probability of KX – ray components:

	1976GuZN (measured)	Calculated (adopted)
Kα_2	0,00118(3)	0,00116(3)
Kα_1	0,00189(5)	0,00185(4)
Kβ_3	2,4(1)·10^{-4}	2,14(5)·10^{-4}
Kβ_1	4,7(2)·10^{-4}	4,19(9)·10^{-4}
Kβ_5	}	
K$\beta_{2,4}$	} 2,29·10^{-4}	2,24(6)·10^{-4}
KO$_{2,3}$	}	

6.2.Gamma emissions

The energies of gamma rays $\gamma_{2,0}$ and $\gamma_{2,1}$ have been adopted from 2000He14.

The energy of gamma ray $\gamma_{1,0}$ has been computed 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 energies of gamma rays $\gamma_{6,4}$, $\gamma_{8,6}$, $\gamma_{4,1}$, $\gamma_{3,0}$, $\gamma_{6,2}$, $\gamma_{4,0}$, $\gamma_{6,1}$, $\gamma_{29,22}$, $\gamma_{11,6}$, $\gamma_{8,3}$, $\gamma_{29,20}$, $\gamma_{9,4}$, $\gamma_{13,6}$, $\gamma_{18,8}$, $\gamma_{11,5}$, $\gamma_{25,11}$, $\gamma_{9,2}$, $\gamma_{13,4}$, $\gamma_{26,10}$, $\gamma_{26,9}$, $\gamma_{21,7}$, $\gamma_{13,2}$, $\gamma_{9,0}$, $\gamma_{20,6}$, $\gamma_{13,1}$, $\gamma_{16,3}$, $\gamma_{20,5}$, $\gamma_{21,5}$, $\gamma_{14,0}$, $\gamma_{16,1}$, $\gamma_{17,1}$, $\gamma_{20,3}$, $\gamma_{16,0}$, $\gamma_{17,0}$, $\gamma_{21,3}$, $\gamma_{22,3}$, $\gamma_{32,9}$, $\gamma_{30,7}$, $\gamma_{21,1}$, $\gamma_{22,1}$, $\gamma_{30,5}$, $\gamma_{27,1}$, $\gamma_{26,0}$, $\gamma_{36,8}$, $\gamma_{31,2}$, $\gamma_{28,0}$, $\gamma_{34,6}$, $\gamma_{33,4}$, $\gamma_{32,1}$, $\gamma_{36,6}$, $\gamma_{34,4}$, $\gamma_{33,2}$, $\gamma_{34,3}$, $\gamma_{33,1}$, γ709,42 keV, $\gamma_{33,0}$, $\gamma_{35,1}$, $\gamma_{34,0}$, $\gamma_{36,1}$, $\gamma_{35,0}$, $\gamma_{39,2}$ have been adopted from the evaluations of 1988ChZL. Those values were obtained as weighted averages based on the measurements of 1955Da02, 1964Wo03, 1966Ko06, 1976GuZN, 1978Ge06, 1959Sa10, 1968Je01, 1978Ge17, 1978Ov01, 1984Ov02, 1970Ne11, 1966Ya05, 1979Ar11.

The energy of gamma ray $\gamma_{8,4}$ has been obtained as the weighted average of measurement results of 1974HeYW, 1976GuZN, 1978Ge06 and 1998Ko61.

The gamma rays with energies of 128,05 keV, 129,2 keV,135,3 keV, 136,7keV and 138,5 keV were not observed by others and have been taken from 1979Ar11.

The remaining gamma ray energies have been taken from measurements 1978Ge06, 1978Ge17, and 1976GuZN and 1998Ab43.

The absolute emission probabilities of gamma rays $\gamma_{2,1}$, $\gamma_{1,0}$ and $\gamma_{2,0}$ have been adopted from the detailed Johnston's analysis (1996Jo28) that is based on experimental works of 1983De11, 1957Ma17, 1971Ge11, 1974Ca16, 1976GuZN, 1978Ge06, 1983Ah02, 19840v02, 1955Da02, 1975Le09, 1976Pl05, 1983Hu04, 1965Mc12.

The remaining gamma ray absolute emission probabilities have been taken from 1978Ge06, 1978Ge17, 1976GuZN and 1998Ab43.

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^{242}Pu – Comments on evaluation of decay data
by V. P. Chechev

This evaluation was completed in December 2003. The literature available by December 2003 was included.

1. DECAY SCHEME

The decay scheme can be basically considered completed though weak alpha transitions to some ^{238}U levels with energy more than 307 keV (see 2002Ak06) are possible. These alpha transitions to ^{238}U highly excited levels were not observed either. They are expected from data on level spins and Q(α) value. The above alpha transitions cannot influence the intensity balances for the four lower levels well established.

2. NUCLEAR DATA

Q(α) value is from 1995Au04.

The evaluated 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 the ^{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
1976Bulaynitsa	Bulaynitsa et al.	3,702(7) [c]		Specific activity, 4πα-X coincidences
1976Osborn	Osborn and Flotov	3,763(9)		Calorimetry
1978Meadows	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 1976Bulaynitsa 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, have 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 0,00724 to adjust weights according to the Limitation of Relative Statistical Weight method.

The LWEIGHT program has used the weighted average and expanded the uncertainty to 0,0284 so range includes the most precise values of 3,702(7) (1976Bulaynitsa).

The adopted value of the ^{242}Pu half-life is 3,73(3) 10^5 years.

The evaluated 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
1978Meadows	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 2p 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 χ^2/ν = 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 uncertainty.

2.1 Alpha Transitions

The energies of the alpha transitions have been calculated from the Q value and the level energies given in Table 3 from 2002Ch52.

Table 3. ^{238}U levels populated in the ^{242}Pu a-decay

Level number	Energy, keV	Spin and parity	Half-life	Probability of α-transition (x100)
0	0,0	0^+	4,468 10^9 yr	76,48(18)
1	44,915(13)	2^+	225 ps	23,49(18)
2	148,39(3)	4^+		0,0308(13)
3	307,19(8)	6^+		0,00085(6)

The probabilities of the most intense transitions $\alpha_{0,0}$ and $\alpha_{0,1}$ have been obtained by averaging experimental data taking into account the values calculated on the basis of gamma transition probability balances using the measured, in 1986Va33, gamma ray emission intensities and adopted total internal conversion coefficients. The probability of the $\alpha_{0,2}$-transition has been obtained by averaging the single experimental value of 1986Va33 and the value calculated from the gamma transition probability balance for the ^{238}U level of 148,39 keV.

It should be noted that in 1986Va33 the independent measurements were carried out for alpha intensities (with Si(Au) detector) and gamma intensities (with two Ge detectors). The correlation between these measurements can be only due to the same used sources 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 for the absolute gamma intensity measurements was made using absolute alpha particle counting under well-defined low solid angles, i.e. out of connection with the alpha intensity measurements.

The probability of the $\alpha_{0,3}$-transition has been evaluated from the P(γ+ce) balance for the ^{238}U level of 307,19 keV (Table 4).

Table 4. Experimental, calculated and evaluated values of α-transition probabilities (×100) in the decay of ^{242}Pu

	α-particle energy, keV	1953Asaro	1956Hu96	1976Baranov	1986Va33	Weighted average	Calculated [d]	Evaluated
$\alpha_{0,0}$	4902	80(6) [a]	74(4) [a]	79,7(20) [b]	76,45(17)	76,47(18) [c]	76,7(7)	76,48(18) [e]
$\alpha_{0,1}$	4858	20(6) [a]	26(4) [a]	20,2(20) [b]	23,52(17)	23,50(18) [c]	23,3(7)	23,49(18) [e]
$\alpha_{0,2}$	4756	-	-	-	0,0290(14)		0,0323(13)	0,0308(13) [f]
$\alpha_{0,3}$	4600	-	-	-	-		0,00085(6)	0,00085(6) [d]

[a] No uncertainties are quoted by the authors. The uncertainties adopted here are 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 are re-estimated by R. Vaninbroukx (1986LoZT).

[c] Weighted average of 4 experimental values, uncertainty is external.

[d] Calculated from P(γ+ce)-probability balances for corresponding levels.

[e] Weighted average of the mean of experimental values and calculated value.

[f] Weighted average of the experimental and calculated values, uncertainty is the smallest quoted uncertainty.

2.2. Gamma Transitions and Internal Conversion Coefficients

The gamma-ray transition probabilities have been deduced from their adopted gamma-ray emission probabilities and total internal conversion coefficients (ICC). The ICC are theoretical values from 1978Ro22 for the adopted energies and E2 multipolarities. The relative uncertainties of α_K, α_L, α_M, α_T 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 energies of U LX-rays have been taken from 1994Le37 where the fine structure of LX radiation was measured in the decay of ^{240}Pu.

The relative U LX-ray emission probabilities have been deduced from experimental data on α-decay of ^{240}Pu (1994Le37) and from data on α-decay of ^{238}Pu (1995Jo23). They agree for these even-even plutonium isotopes in limits better than 2%. The relative U LX-ray emission probabilities measured in 1990Po14 directly in the ^{242}Pu decay [5,6(9)-Ll; 71,6(72)-Lα; 100-L$\eta\beta$; 24,5(25)-Lγ] agree with the adopted values but much less accurate.

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 and from data on α-decay of ^{238}Pu.

3.3. Auger Electrons

The energies of Auger electrons are from 1977La19 and 1987Lagoutine.
The ratios P(KLX)/P(KLL), P(KXY)/P(KLL) are taken from 1996Sc06.

4. ALPHA EMISSIONS

The α-emission energies have been calculated from Q value and the level energies taking into account the recoil energies (2002Ch52). In Table 5 the calculated (evaluated) values of α-emission energies are compared with the experimental results obtained using alpha spectrometry and also with the recommended data by A. Rytz (1991Ry01).

Table 5. Experimental and evaluated a-emission energies in the decay of ^{242}Pu, keV

	Measured [a]				Recommended in 1991Ry01	Evaluated
	1953Asaro	1956Hu96	1956Ko67	1968Ba25		
$\alpha_{0,0}$	4904,6(20)	4903,7(30)	4907,2(30)	4900,4(12)	4902,3(14)	4902,2(9) [b]
$\alpha_{0,1}$	4860,6(20)	4859,7(30)	4863,2(30)	4856,1(12)	4858,1(15)	4858,1(9)
$\alpha_{0,2}$	-	-	-	-	-	4756,1(9)
$\alpha_{0,3}$	-	-	-	-	-	4600,0(9)

[a] Original values have been adjusted taking into account changes in calibration energies as suggested in 1991Ry01

5. ELECTRON EMISSIONS

The energies of the conversion electrons have been calculated from the gamma transition energies given in section 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 total emission probability of K Auger electrons have been computed using the evaluated total emission probability of K–conversion electrons P(ce$_K$) = 6,26(50) 10^{-5} % and the adopted ω_K = 0,970(4) from section 3.1.

The absolute total emission probability of L Auger electrons have been computed using the adopted total absolute emission probability of U LX–rays and the adopted ϖ_L = 0,500(19) from section 3.1.

6. PHOTON EMISSIONS

6.1. X-Ray Emissions

The absolute emission probability of U MX–rays ($\alpha\beta$) in the decay of ^{242}Pu has been calculated from the relative intensity P(XM$\alpha\beta$)/P(XL$\eta\beta$) = 0,41(4) measured in 1990Po14.

The total emission probability of U LX–rays P(XL) = 8,56(40) % has been calculated using the value ϖ_L = 0,500(19) from section 3.1 and the evaluated total emission probability of L conversion electrons P(ce$_L$) = 17,12(50)%.

The total KX –ray emission probability P(XK) = 6,07(50) 10^{-5} % has been computed using the value ω_K =0,970(4) from section 3.1 and the evaluated emission probability of K–conversion electrons P(ce$_K$) = 6,26(50) 10^{-5} %

6.2. Gamma Ray Emissions

The energies of gamma rays have been adopted from 1972Sc01.

The absolute emission intensities of the gamma rays $\gamma_{1,0}$ (44,915 keV) and $\gamma_{2,1}$ (103,50 keV) have been calculated from the evaluated P(α) values (Table 4) and the adopted total ICC on the basis of intensity balances for corresponding levels. The emission intensity of the gamma ray $\gamma_{3,2}$ (158,80 keV) has been adopted from the measurements of 1986Va33 (Table 6).

Table 6. Experimental, calculated and adopted emission probabilities of gamma rays (´100) in the ^{242}Pu decay

	Energy, keV	1972Sc01	1986Va33	Calculated	Adopted
$\gamma_{1,0}$	44,915	-	0,0372(7)	0,0376(8)	0,0376(8)
$\gamma_{2,1}$	103,50	0,0081(9) [a]	0,00263(9)	0,00251(11)	0,00251(11)
$\gamma_{3,2}$	158,80	0,005(2) [a]	0,000298(20)	-	0,000298(20)

[a] Not used in the evaluation as considered in 1986LoZT

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