$^{103m}_{45}$Rh$_{58}$

Evaluation of the decay data

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The initial evaluation was completed in May 2013 and then successively revised in January 2015, April 2021, April 2023 and June 2024. The present evaluation was carried out with a literature cut-off date of June 2024.

$^{\mathbf{103m}}_{45}\mathrm{Rh}_{58}$

1 Decay Scheme

^{103m}Rh undergoes 100% IT decay by means of a highly-converted 39,753-keV gamma transition.
Le ^{103m}Rh se désexcite par une transition gamma de 39,753 keV fortement convertie.

2 Nuclear Data

$T_{1/2}(^{103m}\mathrm{Rh})$	:	56,115	(16)	min
$Q^{IT}(^{103m}\mathrm{Rh})$	:	39,753	(6)	keV

2.1 Gamma Transitions and Internal Conversion Coefficients

	Energy (keV)	$P_{\gamma+ce}$ (%)	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{1,0}$(Rh)	39,753 (6)	100	E3+M4	142 (7)	1051 (30)	214 (6)	1440 (40)

3 Atomic Data

3.1 Rh

ω_K	:	0,809	(4)
$\bar{\omega}_L$	:	0,0494	(12)
n_{KL}	:	0,987	(4)

3.1.1 X Radiations

	Energy (keV)	Relative probability	
$X_{K_{tot}}$	20,073 - 23,173	183,7	
$K\alpha_2$	20,073	52,83	} $K\alpha$
$K\alpha_1$	20,215	100	
$K\beta_3$	22,699	8,50	} $K'\beta_1$
$K\beta_1$	22,725	16,55	
KN	23,167 - 23,173	4,97	
$X_{L_{tot}}$	2,378 - 3,067	96,8	
$X_{M_{tot}}$	0,189 - 0,546	2,685	

3.1.2 Auger Electrons

	Energy (keV)	Relative probability
Auger K_{tot}	16,281 - 22,838	143
KLL	16,281 - 17,083	100
KLX	19,133 - 20,146	39,2
KXY	21,922 - 22,838	3,69
Auger L_{tot}	0,004 - 3,133	6373
Auger M_{tot}	0,021 – 0,390	17540
Auger N_{tot}	0,001 – 0,064	19330

4 Electron Emissions

		Energy (keV)	Electrons (per 100 disint.)
$e_{AN_{tot}}$	(Rh)	0,001 - 0,064	259 (5)
$e_{AM_{tot}}$	(Rh)	0,021 - 0,390	235 (5)
$e_{AL_{tot}}$	(Rh)	0,004 - 3,133	85,4 (19)
$e_{AK_{tot}}$	(Rh)	16,281 - 22,838	1,92 (9)
	KLL	16,281 - 17,083	1,34 (6)
	KLX	19,133 - 20,146	0,525 (24)
	KXY	21,922 - 22,838	0,0495 (22)
$ec_{1,0\ T}$	(Rh)	16,533 - 39,751	99,9306 (15)
$ec_{1,0\ K}$	(Rh)	16,533 (6)	9,85 (45)
$ec_{1,0\ L}$	(Rh)	36,341 - 36,749	73 (3)
$ec_{1,0\ M}$	(Rh)	39,126 - 39,446	14,9 (5)
$ec_{1,0\ N}$	(Rh)	39,672 - 39,751	2,18 (8)

5 Photon Emissions

5.1 X-Ray Emissions

		Energy (keV)	Photons (per 100 disint.)	
XM_{tot}	(Rh)	0,189 - 0,546	0,1184 (23)	
XL_{tot}	(Rh)	2,378 - 3,067	4,27 (10)	
XK_{tot}	(Rh)	20,073 - 23,173	8,1 (4)	
$XK\alpha_2$	(Rh)	20,073	2,33 (10)	} $K\alpha$
$XK\alpha_1$	(Rh)	20,215	4,41 (20)	} $K\alpha$
$XK\beta_3$	(Rh)	22,699	0,375 (17)	} $K'\beta_1$
$XK\beta_1$	(Rh)	22,725	0,730 (33)	} $K'\beta_1$
XKN	(Rh)	23,167 - 23,173	0,219 (10)	

5.2 Gamma Emissions

	Energy (keV)	Photons (per 100 disint.)
$\gamma_{1,0}$(Rh)	39,753 (6)	0,0694 (15)

6 Main Production Modes

^{103}Pd EC decay
Possible impurities: ^{103}Pd, ^{109}Pd, ^{111}Pd, ^{111m}Pd

^{103}Ru β^- decay
Possible impurities: ^{97}Ru, ^{103}Ru, ^{105}Ru, ^{106}Ru

^{103}Rh(n,n′)^{103m}Rh
Possible impurity: ^{104m}Rh

^{103}Rh(d,d′)^{103m}Rh

^{103}Rh(α,α')^{103m}Rh

^{103}Rh(γ,γ')^{103m}Rh

7 References

- I. Backhurst. London Edinburgh Dublin Phil. Mag. J. Sci. 22 (1936) 737-752
  (K-shell fluorescence yield)
- R.J. Stephenson. Phys. Rev. 51 (1937) 637-642
  (K-shell fluorescence yield)
- A. Flammersfeld. Naturwissensch. 32 (1944) 36-37
  (Rh-103m half-life)
- M.L. Wiedenbeck. Phys. Rev. 67 (1945) 267-268
  (Rh-103m half-life)
- M.L. Wiedenbeck. Phys. Rev. 68 (1945) 237-239
  (Rh-103m half-life)
- A. Flammersfeld, O. Bruna. Z. Naturforsch. 2a (1947) 241-244
  (Rh-103m half-life)
- J.Y. Mei, C.M. Huddleston, A.C.G. Mitchell. Phys. Rev. 79 (1950) 429-432
  (Rh-103m half-life)
- E. Kondaiah. Phys. Rev. 79 (1950) 891-892
  (40-keV K/(L+M) ratio)
- J.M. Cork, J.M. LeBlanc, F.B. Stumpf, W.H. Nestor. Phys. Rev. 86 (1952) 575-576
  (K/L ratios)
- C.E. Roos. Phys. Rev. 93 (1954) 401-405
  (K-shell fluorescence yield)
- P. Avignon, A. Michalowicz, R. Bouchez. J. Phys. Radium 16 (1955) 404-410
  (Gamma-ray energy and emission probability, ICC(K), ICC(L), K/L ratio)
- G.M. Drabkin, V.I. Orlov, L.I. Rusinov. Izv. Akad. Nauk SSSR Ser. Fiz., Columbia Tech. Transl. 19 (1956) 294-304
  (ICC(K), K/L and L/M ratios)
- C.E. Roos. Phys. Rev. 105 (1957) 931-935
  (K-shell fluorescence yield)
- G.A. Jones, W.R. Phillips. Proc. Royal Soc. (London) 239A (1957) 487-493
  (Rh-103m half-life)

- A. Vuorinen. Proc. Symp. Standardization of Radionuclides, IAEA, Vienna, Austria (1967) 257-263
(Rh-103m half-life, K X-ray emission probabilities, K/(L+M+N) ratio)
- A.M. Bresesti, M. Bresesti, H. Neumann. J. Inorg. Nucl. Chem. 29 (1967) 15-20
(Ru-103 beta decay: 39.75-keV K X-ray emission probabilities, K/LMN ratio)
- J.C. Manthuruthil, H.J. Hennecke, C.R. Cothern. Phys. Rev. 165 (1968) 1363-1370
(ICC, multipolarity, mixing ratio)
- Y. Grunditz, S. Antman, H. Pettersson, M. Saraceno. Nucl. Phys. A133 (1969) 369-384
(Gamma-ray energy, ICC(K), subshell ratios, K X-ray emissio probabilities)
- Y. Kobayashi. JAERI report JAERI-1178 (1969) 21-22
(Rh-103m half-life)
- M.A. Lepri, W.S. Lyon. Int. J. Appl. Radiat. Isot. 20 (1969) 297-298
(39.75-keV K(alpha)/K(beta) ratio, ICC(K))
- H. Pettersson, S. Antman, Y. Grunditz. Erratum, Z. Phys. 235 (1970) 485
(Gamma-ray energy, L1/L2, L1/L3, L2/L3 ratios, ICC(K))
- H. Pettersson, S. Antman, Y. Grunditz. Z. Phys. 233 (1970) 260-274
(Gamma-ray energy, L1/L2, L1/L3, L2/L3 ratios, ICC(K))
- E.B. Nieschmidt, D.A. Pearson. IN-1317 (1970) 122-126
(Gamma-ray energy and emission probability, ICC(K), L subshell ratios)
- D.S. Brenner, M.L. Perlman. Nucl. Phys. A181 (1972) 207-216
(39.75-keV L1/L3, L2/L3 ratios)
- A. Pazsit, J. Csikai. Sov. J. Nucl. Phys. 35 (1972) 232-233
(Rh-103m half-life, 39.75-keV ICC(K))
- W. Bambynek, B. Crasemann, R.W. Fink, H.-U. Freund, H. Mark, C.D. Swift, R.E Price, P. Venugopala Rao. Rev. Mod. Phys. 44 (1972) 716-813
(K-shell fluorescence yield)
- E. Günther, K. Knauf, K.F. Walz. Int. J. Appl. Radiat. Isot. 24 (1973) 87-89
(Rh-103m half-life)
- H. Ing, W.G. Cross. Int. J. Appl. Radiat. Isot. 24 (1973) 437-450
(Ru-103 beta decay: K X-ray emission probabilities)
- K.H. Czock, N. Haselberger, F. Reichel. IAEA report IAEA/RL/26 (1974)
(ICC(total), ICC(K), K/(L+M+) ratio)
- D.C. Santry, J.P. Butler. Can. J. Phys. 52 (1974) 1421-1428
(Rh-103m half-life, 39.75-keC K X-ray emission probabilities)
- W. Bambynek, B. Crasemann, R.W. Fink, H.-U. Freund, H. Mark, C.D. Swift, R.E. Price, P. Venugopala Rao. Erratum, Rev. Mod. Phys. 46 (1974) 853
(K-shell fluorescence yield)
- K.H. Czock, N. Haselberger, F. Reichel. Int. J. Appl. Radiat. Isot. 26 (1975) 417-421
(ICC(total), ICC(K), 39.75-keV K X-ray emission probabilities)
- B. Martin, D. Merkert, J.L. Campbell. Z. Phys. A274 (1975) 15-21
(39.75-keV L1/L2, L1/L3, L2/L3, M, N, O ratios)
- E.S. Macias, M.E. Phelps, D.G. Sarantites, R.A. Meyer. Phys. Rev. C 14 (1976) 639-644
(Gamma-ray energy and emission probability, ICC(K), ICC(L), K X-ray emission probabilities)
- F.P. Larkins. At. Data Nucl. Data Tables 20 (1977) 311-387
(Auger-electron energies)
- F. Lagoutine, J. Legrand, C. Bac. Int. J. Appl. Radiat. Isot. 29 (1978) 269-272
(Rh-103m half-life)
- R. Vaninbroukx, G. Grosse, W. Zehner. NEA report NEANDC-202U Vol. III (1979) 28-30
(Preliminary Rh-103m half-life, Rh-103m K X-ray emission probability, ICC(total), ICC(K))
- R. Vaninbroukx, W. Zehner. Int. J. Appl. Radiat. Isot. 32 (1981) 850
(K X-ray emission probabilities)
- R. Vaninbroukx, G. Grosse, W. Zehner. Int. J. Appl. Radiat. Isot. 32 (1981) 589-591
(Rh-103m half-life)
- S. Singh, R. Rani, D. Mehta, N. Singh, P.C. Mangal, P.N. Trehan. X-ray Spectrom. 19 (1990) 155-158
(K-shell fluorescence yield)
- S.T. Perkins, D.E. Cullen, M.H. Chen, J.H. Hubbell, J. Rathkopf, J. Scofield. Lawrence Livermore National Laboratory report UCRL-50400 30 (1991)
(Atomic database)
- R.R. Garg, S. Puri, S. Singh, D. Mehta, J.S. Shahi, M.L. Garg, N. Singh, P.C. Mangal, P.N. Trehan. Nucl. Instrum. Methods Phys. Res. B72 (1992) 147-152
(K-shell fluorescence yield)

- D.E. Cullen, S.T. Perkins, S.M. Seltzer. Appl. Radiat. Isot. 44 (1993) 1343-1347
(Atomic database)
- U. Schötzig. Appl. Radiat. Isot. 45 (1994) 641-644
(K X-ray emission probability)
- J.H. Hubbell, P.N. Trehan, N. Singh, B. Chand, D. Mehta, M.L. Garg, R.R. Garg, S. Singh, S. Puri. J. Phys. Chem. Ref. Data 23 (1994) 339-364
(K-, L-, M-shell fluorescence yields)
- E. Schönfeld, H. Janssen. Nucl. Instrum. Methods Phys. Res. A369 (1996) 527-533
(K-, L-shell fluorescence yields, K(beta)/K(alpha), K(alpha2)/K(alpha1), KLX/KLL, KXY/KLL)
- E. Schönfeld, G. Rodloff. PTB report PTB-6.11-98-1 (1998)
(K Auger electrons)
- E. Schönfeld, G. Rodloff. PTB report PTB-6.11-1999-1 (1999)
(K X-ray energies and relative emission probabilities)
- M. Sainath, K. Venkatarananiah. Indian J. Pure Appl. Phys. 37 (1999) 87-91
(39.75-keV ICC(K), ICC(L), ICC(M))
- A. Kovalik, E.A. Yakushev, D.V. Filosofov, V.M. Gorozhankin, V.G. Kalinnikov. Proc. 50th Ann. Conf. Nucl. Spectrosc. Struct. At. Nuclei, St. Petersburg, Russia (2000) 175
(39.7537(21)-keV E3 gamma-ray energy)
- E. Schönfeld, H. Janssen. Appl. Radiat. Isot. 52 (2000) 595-600
(X-ray and Auger-electrom emission probabilities)
- S. Raman, C.W. Nestor Jr., A, Ichihara, M.B. Trzhaskovskaya. Phys. Rev. C 66 (2002) 044312
(Theoretical ICC)
- I.M. Band, M.B. Trzhaskovskaya, C.W. Nestor Jr., P.O. Tikkanen, S. Raman. At. Data Nucl. Data Tables 81 (2002) 1-334
(Theoretical ICC)
- J.H. Hubbell, P.N. Trehan, N. Singh, B. Chand, D. Mehta, M.L. Garg, R.R. Garg, S. Singh, S. Puri. Erratum, J. Phys. Chem. Ref. Data 33 (2004) 621
(K-, L-, M-shell fluorescence yields)
- T. Kibédi, T.W. Burrows, M.B. Trzhaskovskaya, P.M. Davidson, C.W. Nestor Jr. Nucl. Instrum. Methods Phys. Res. A589 (2008) 202-229
(Theoretical ICC)
- D. De Frenne. Nucl. Data Sheets 110 (2009) 2081-2256
(Nuclear levels)
- A. Kahoul, A. Abassi, B. Deghfel, M. Nekkab. Radiat. Phys. Chem. 80 (2011) 369-377
(K-shell fluorescence yield)
- B.Q. Lee, T. Kibédi, A.E. Stuchbery, K.A. Robertson, F.G. Kondev. Comput. Math. Methods Med. (2012) 651475
(Atomic radiation)
- B.Q. Lee, T. Kibédi, A.E. Stuchbery, K.A. Robinson, F.G. Kondev. Proc. Heavy Ion Accelerator Symp. (HIAS2013), EPJ Web of Conferences 63 (2013) 01002
(Auger electrons)
- B.Q. Lee, Hooshang Nikjoo, J. Ekman, P. Jonsson, A.E. Stuchbery, T. Kibédi. Int. J. Radiat. Biol. 92 (2016) 641-653
(Atomic radiation)
- J. Riffaud, M.-C. Lépy, Y. Ménesguen, A. Novikova. X-ray Spectrom. 46 (2017) 341-346
(K-shell fluorescence yield)
- N. Nica, J.C. Hardy, V.E. Iacob, V. Horvat, H.I. Park, T.A. Werke, K.J. Glennon, C.M. Folden III, V.I. Sabla J.B. Bryant, X.K. James, M.B. Trzhaskovskaya. Phys. Rev. C 98 (2018) 054321
(39.75-keV gamma ray: ICC(K), ICC(total), mixing ratio)
- J. Riffaud, P. Cassette, D. Lacour, V. Lourenco, I. Tartès, M.A. Kellett, M. Corbel, M.-C. Lépy, C. Domergue, C. Destouches, H. Carcreff, O. Vigneau. Appl. Radiat. Isot. 134 (2018) 399-405
(Absolute K X-ray emission probabilities, absolute gamma-ray emission probabilities)
- B.P.E. Tee, T. Kibédi, B.Q. Lee, M. Vos, R. du Rietz, A.E. Stuchbery. Proc. Heavy Ion Accelerator Symp. (HIAS2019), EPJ Web of Conferences 232 (2020) 01006
(Atomic radiation)
- J. Riffaud, M.-C. Lépy, P. Cassette, M. Corbel, M.A. Kellett, V. Lourenco. Appl. Radiat. Isot. 167 (2021) 109298
(absolute K X-ray emission probabilities, relative L X-ray emission probabilities, absolute gamma-ray emission probabilities)
- F.G. Kondev, Meng Wang, W.J. Huang, S. Naimi, G. Audi. Chin. Phys. C 45 (2021) 030001
(Rh-103m Q(IT))

- Meng Wang, W.J. Huang, F.G. Kondev, G. Audi, S. Naimi. Chin. Phys. C 45 (2021) 030003
  (Q-values)
- B.P.E. Tee, T. Kibédi, B.Q. Lee, A.E. Stuchbery. BrIccEmisDB database, in preparation for submission to At. Data Nucl. Data Tables (2023)
  (Atomic radiation)


γ Emission intensities
per 100 disintegrations
0,0694
1
7/2+ ; 39,753
56,115 min
1/2 - ; 0
Stable
0
103
Rh
45
58
Q^IT = 39,753 keV
% IT = 100

^{103m}Rh – Comments on evaluation of decay data

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^{103m}Rh IT decay separated from ^{103}Pd (100% EC decay)

Decay Scheme

^{103m}Rh undergoes 100% IT decay ($T_{½}$ = 56.115 minutes) to the ground state of ^{103}Rh (Q_{IT} = 39.753 (6) keV). A simple decay scheme can be proposed on the basis of the depopulation of the metastable state by means of the single 39.753-keV gamma ray to the ground state of ^{103}Rh.

Nuclear Data

There is a strong interest in the nuclear structure of ^{103}Rh and the IT decay of ^{103m}Rh because of the adoption of ^{103m}Rh as a neutron flux monitor.

Half-life of ^{103m}Rh

The measurements of 1967VuZZ, 1969KoZW, 1973Gu06, 1974Sa15, 1978La21 and 1981Va11 were adopted to give a weighted mean half-life of 56.115 (16) min based on LWM-NRM-Rajeval analyses (Avetools code, version 3.0, and V.AveLib 06-22 code, both ENSDF utility programs).

Reference	Half-life (min)	Selected detail, issues and uncertainties
1944Fl01	48 ± 5	^{103}Rh(n_f,n') reaction – outlier (Chauvenet criterion), and therefore not included in analytical procedures
1945Wi03/1945Wi12	45 ± 1	^{103}Rh(X,γ) reaction – outlier (Chauvenet criterion), and therefore not included in analytical procedures
1947Fl03	52 ± 2	^{103}Rh(d,d') reaction – outlier (Chauvenet criterion), and therefore not included in analytical procedures
1950Me26	56	separation of Pd target and ^{103m}Rh – uncertainty not specified, and therefore not included in analytical procedures
1957Jo19	57.5 ± 0.5	^{103}Rh(n,n') reaction – outlier (Chauvenet criterion), and therefore not included in analytical procedures
1967VuZZ	**56.6 ± 0.4**	^{103}Rh(n,n') reaction; 4π proportional counter and thin NaI crystal
1969KoZW	**56.6 ± 0.6**	^{102}Ru(n,γ)^{103}Ru($β^-$)^{103m}Rh; radiochemical separation, NaI(Tl) scintillation counter
1972Pa10	57.5	^{103}Rh($n_{14.7keV}$,n') reaction, Si(Li) detector – uncertainty not specified, and therefore not included in analytical procedures
1973Gu06	**56.116 ± 0.009**	^{nat}Pd(n,xn')^{103}Pd(EC)^{103m}Rh; three counting techniques: liquid scintillation counter, 2π-methane flow counter, and NaI(Tl) crystal – weighted mean of three sets of measurements is 56.116 (7), compared with a value of 56.116 (9) quoted by 1973Gu06; uncertainty adjusted to ± 0.016 to reduce weighting to ~ 0.50
1974Sa15	**56.3 ± 0.6**	^{103}Rh(n,n') reaction; decay curve followed over many half-lives, NaI(Tl) X-ray detector
1978La21	**56.112 ± 0.028**	ion exchange of ^{103m}Rh from ^{103}Pd solutions; decay curves involving 15 sources followed over three half-lives by means of an ill-defined photon spectrometer
1979VaZE	56.1 ± 0.1	preliminary measurement - replaced by half-life determined by 1981Va11
1981Va11	**56.114 ± 0.020**	ion exchange of ^{103m}Rh from ^{103}Pd solutions; decay curves followed over two and three half-lives, NaI(Tl) detector – weighted mean of two sets of measurements is 56.114 (12), compared with a value of 56.114 (20) quoted by 1981Va11
Recommended value	**56.115 ± 0.016**	recommended uncertainty adjusted from ± 0.011 to ± 0.016, to align with smallest uncertainty of the values used to calculate weighted-mean value

Limitation of relative statistical weight method (LWM), normalized residual method (NRM), Rajeval technique, expected value method (EVM), bootstrap method and Mandel-Paule approach were considered in the analysis of the data set.

Analytical method	Half-life (min)	χ^2/(N-1)	$\chi^2/(N-1)_{critical}$
UWM	56.31 ± 0.16	–	–
LWM	56.115 ± 0.011	0.45	2.21 for rejection at 95.0% confidence level
NRM	56.115 ± 0.011	0.45	2.21 for rejection at 95.0% confidence level
Rajeval	56.115 ± 0.011	0.45	2.21 for rejection at 95.0% confidence level
EVM	56.13 ± 0.08	–	97.0% confidence level
Bootstrap	56.22 ± 0.17	15.8	–
Mandel-Paule	56.115 ± 0.011	0.45	–

Half-life of (56.115 ± 0.016) minutes recommended for ^{103m}Rh, as quantified by LWM-NRM analytical procedures (1973Gu06 uncertainty increased to ± 0.016 in order to adjust weighting to ~ 0.50).

Q value

A Q_{IT} value for ^{103m}Rh of 39.753 (6) keV has been adopted (2021Ko07).

Gamma-ray energies and emission probabilities

Energies

The well-defined nuclear level energy for the first-excited metastable state was adopted from the Q_{IT} value, along with the recommended energy and associated uncertainty of the gamma-ray emission to the ground state of ^{103}Rh (2021Ko07).

Adopted energies, spins and parities for the relevant nuclear levels of ^{103}Rh (see also 2009De29, 2000KoZT).

Nuclear level number	Nuclear level energy (keV)	Spin and parity	Half-life	
0	0.0	1/2 –	stable	^{103}Rh
1	39.753 ± 0.006	7/2 +	56.115 (16) min	^{103m}Rh

Emission Probabilities

A simple decay scheme has been assembled for the IT decay of ^{103m}Rh. The 39.753-keV gamma transition depopulates the ^{103m}Rh nuclear level 100%, and is defined as (99.935%E3 + 0.065%M4) from spin and parity considerations ($7/2^+ \rightarrow 1/2^-$), internal conversion coefficients, and shell and subshell ratios (1950Ko10, 1952Co16, 1955Av11, 1955Dr43, 1967Br04, 1967VuZZ, 1968Ma08, 1969Gr13, 1969Le17, 1970NiZV, 1970Pe04, 1972Br02, 1972Pa10, 1974CzZY, 1975Cz03, 1975Ma32, 1976Ma37, 1979VaZE, 1999Sa78, 2018Ni14). Recommended internal conversion coefficients have been determined by means of the BrIcc code (frozen orbital approximation) of Kibédi *et al*. (2008Ki07), based on the theoretical model of Band *et al*. (2002Ba85, 2002Ra45).

Gamma-ray emission from 100% IT decay of ^{103m}Rh: multipolarity and theoretical internal-conversion coefficients (frozen orbital approximation).

E_γ (keV)	Multipolarity	α_K	α_L	α_{L1}	α_{L2}	α_{L3}	α_M	α_N	α_O	α_{total}
39.753 (6)	99.935%E3 + 0.065%M4 $\delta = 0.025^{+10}_{-15}$	142 (7)	1051 (30)	13 (5)	423 (6)	615 (18)	214 (6)	31.4 (9)	0.024 (11)	1440 (40)

Recommended gamma-ray energy, absolute emission probability, and transition probability from 100% IT decay of ^{103m}Rh.

	E_γ (keV)	P_γ^{abs} (%)	Transition probability (%)	Δ (TP − P_γ^{abs}) (%)
$\gamma_{1,0}$	39.753 (6)	0.0694 (15)	100.0	99.9306 (15)

Electron energies were determined from electron binding energies tabulated by Larkins (1977La19) and the evaluated gamma-ray energies. Absolute electron emission probabilities were calculated from the evaluated absolute gamma-ray emission probabilities and associated internal conversion coefficients.

Energies and emission probabilities of internal conversion electrons from 100% IT decay of ^{103m}Rh.

		Energy (keV)	Electrons per 100 disint.
$ec_{1,0\ T}$	(Rh)	16.533 – 39.751	99.9306 (15)
$ec_{1,0\ K}$	(Rh)	16.533 (6)	9.85 (+50-40) → 9.85 (45)
$ec_{1,0\ L}$	(Rh)	36.341 – 36.749	73 (3)
$ec_{1,0\ M}$	(Rh)	39.126 – 39.446	14.9 (5)
$ec_{1,0\ N+}$	(Rh)	39.672 – 39.751	2.18 (8)

Atomic Data

X-ray decay data and related parameters for ^{103m}Rh have been measured experimentally over many years (e.g., 1973In07, 1974Sa15, 1975Cz03, 1981Va22, 1994Sc43), and most recently by Riffaud *et al.* (2017Ri10, 2018Ri01, 2021Ri01). The ^{103}Rh(n,n')^{103m}Rh reaction is important for reactor dosimetry studies because of the generation of suitable data traceable to reactor operations. This radionuclide emits only X-rays for which emission probabilities can be determined by means of the single gamma-ray transition probability and fluorescence yields. While these ω_K, ω_L, etc. have been measured as well as calculated by means of semi-empirical and theoretical models, available experimental data are rather limited as implied in the following table (1936Ba01, 1937St02, 1954Ro45, 1957Ro58, 1990Si19, 1992Ga24, 2017Ri10). Both the X-ray and Auger-electron data have been subsequently calculated on the basis of the evaluated gamma-ray data, along with atomic data from 1996Sc06, 1998ScZM, 1999ScZX, 2000Sc47 (Rh: ω_K = 0.809 (4); ϖ_L = 0.0494 (12); n_{KL} = 0.987 (4)).

Fluorescence yields for Rh.

Reference	ω_K	ϖ_L	ϖ_M	Comments
1936Ba01	0.801[a]	–	–	experimental measurements
1937St02	0.77[a]	–	–	experimental measurements
1954Ro45	0.779[a]	–	–	experimental measurements
1957Ro58	0.786 ± 0.015[b]	–	–	experimental measurements
1990Si19/1994Hu23	0.829 ± 0.058	–	–	based upon 1990Si19 measurements of σ_K
1992Ga24/1994Hu23	–	0.051 ±0.005	–	based upon 1992Ga24 measurements of ϖ_L
2017Ri10	0.814 ± 0.041	–	–	experimental measurements
Mean or only value	0.803 ± 0.024	0.050 ± 0.002[c]	0.00135[d]	
1972Bb16	0.807 ± 0.031	–	–	assessment/evaluation of ω_K models
1994Hu23	0.792 0.8086	0.0499 0.0459	0.00135 0.00135	assessment/evaluation of ω_K, ϖ_L and ϖ_M models development of existing fitted functions
1996Sc06	0.809 ± 0.004	0.0494 ± 0.0012	–	assessment/evaluation of ω_K and ϖ_L models
2011Ka49	0.80205	–	–	assessment/evaluation of ω_K models

[a] Unspecified uncertainty – not included in weighted-mean analyses of experimental data set.
[b] Uncertainty adjusted from ± 0.015 to ± 0.034 to reduce weighting to no more than 0.50.
[c] Estimation, as guided by a single measurement (1992Ga24) and assessments/evaluations (1994Hu23, 1996Sc06).
[d] Estimation, as proposed by assessment/evaluation (1994Hu23).

Measured LX-ray decay data: ^{103m}Rh.

	Levels	Energy (keV)	Relative P_{LX}
2021Ri01	L3-M1	2.370	2.67 (14)
	L2-M1	2.513	1.73 (9)
	L3-M4,5	2.695	100 (5)
	L2-M4	2.891	48.5 (24)
	L1-M2	2.891	8.23 (41)
	L1-M3	2.915	–
	L3-N1	2.934	–
	L3-N4,5	3.012	8.00 (40)
	L1-M4,5	3.101	4.94 (25)
	L2-N4	3.154	0.841 (43)
	L1-N2,3	3.373	0.848 (44)

X-ray and Auger-electron spectra for the IT decay of ^{103m}Rh were determined by means of BrIccEmis calculations within the NS_RadList program, as described in 2012Le09, 2013LeZX, 2016Le19, 2020TeZY and 2023Texx. Transition energies within each propagation step were derived from the atomic binding energies determined by adopting the relativistic Dirac-Fock approach employed in the RAINE code (2002Ba85), along with the application of a semi-empirical correction procedure that aligns these energies more fully with known spectral data. Fixed transition rates were obtained from the EADL database (1991PeZY, 1993Cu08). Resulting X-ray and Auger-electron energies and emission probabilities are listed below for ^{103m}Rh probabilities (both sets of energies are listed as mean energies and ranges of energies at the 95% confidence level, with additional extensions of these energy ranges in italics for specific X-ray and Auger electron emissions). The number of simulated nuclear events is 10^6, and the intensity cut-offs for both the X-ray and Auger-electron listings are 0.01 per 100 decays. As defined by 1991PeZY, uncertainties in these theoretical X-ray emission probabilities are ~ 10% for the K and L shells and 30% for the outer shells, whereas uncertainties in the theoretical Auger-electron emission probabilities are < 15% for the K and L shells (except for Coster-Kronig and super Coster-Kronig transitions) and 30% for the outer shells.

X-ray energies and emission probabilities from IT decay of ^{103m}Rh (BrIccEmis/NS_RadList).

		Mean energy (keV)	Energy (keV) 95% confidence range/extension	Photons per 100 decays[a]
X_{tot}	(Rh)	14.255	2.378 – 22.725	12.5 (4)
XK_{tot}	(Rh)	20.599	20.073 –23.167/*23.173*	8.1 (4)
XKL2	(Rh)	20.073	20.073	2.33 (10)
XKL3	(Rh)	20.215	20.215	4.41 (20)
XKM	(Rh)	22.717	22.699 – 22.725	1.11 (5)
XKM2	(Rh)	22.699	22.699	0.375 (17)
XKM3	(Rh)	22.725	22.725	0.730 (33)
XKN	(Rh)	23.171	23.167 – 23.173	0.219 (10)
XKN2	(Rh)	23.167	23.167	0.0746 (34)
XKN3	(Rh)	23.173	23.173	0.144 (6)
XL_{tot}	(Rh)	2.743	2.378 – 3.067	4.27 (10)
XM_{tot}	(Rh)	0.321	0.189 – 0.546	0.1184 (23)

[a] Quoted uncertainties include direct contributions from only the internal-conversion electrons (2023Texx) – these data do not include significant uncertainties from the more complex but less well-defined atomic radiation probabilities as considered semi-quantitatively in EADL, whereby uncertainties in the theoretical X-ray radiative rates are ~ 10% for the K and L shells, and can be of the order of 30% for the outer shells (1991PeZY).

Auger-electron energies and emission probabilities from IT decay of ^{103m}Rh (BrIccEmis/NS_RadList).

		Mean Energy (keV)	Energy (keV) 95% confidence range/extension	Electrons per 100 decays[a]
Auger total	(Rh)	0.461	0.002 – 2.490	582 (12)
Auger K_{tot}	(Rh)	17.708	16.281 –21.922/*22.838*	1.92 (9)
Auger KLL	(Rh)	16.811	16.281 – 17.083	1.34 (6)
Auger KLX	(Rh)	19.574	19.133 – 20.146	0.525 (24)
Auger KXY	(Rh)	22.275	21.922 – 22.838	0.0495 (22)
Auger L_{tot}	(Rh)	2.139	*0.004*/0.064 –2.768/*3.133*	85.4 (19)
Auger Coster-Kronig LLM	(Rh)	0.038	0.004 – 0.051	0.94 (+22-17)
Auger Coster-Kronig LLX	(Rh)	0.098	0.031 – 0.313	5.36 (15)
Auger LMM	(Rh)	2.239	1.842 – 2.490	66.2 (15)
Auger LMX	(Rh)	2.600	2.383 – 2.824	12.25 (28)
Auger LXY	(Rh)	2.969	2.851 – 3.133	0.620 (14)
Auger M_{tot}	(Rh)	0.200	*0.021*/0.054 – 0.368/*0.390*	235 (5)
Auger Coster-Kronig MMX	(Rh)	0.103	0.021 – 0.178	69.0 (13)
Auger MXY	(Rh)	0.240	0.141 – 0.390	166.1 (34)
Auger N_{tot}	(Rh)	0.019	0.001 –0.034/*0.064*	259 (5)
Auger super Coster-Kronig NNN	(Rh)	0.019	0.001 – 0.034	249 (5)
Auger Coster-Kronig NNX	(Rh)	0.020	0.002 – 0.064	9.94 (21)

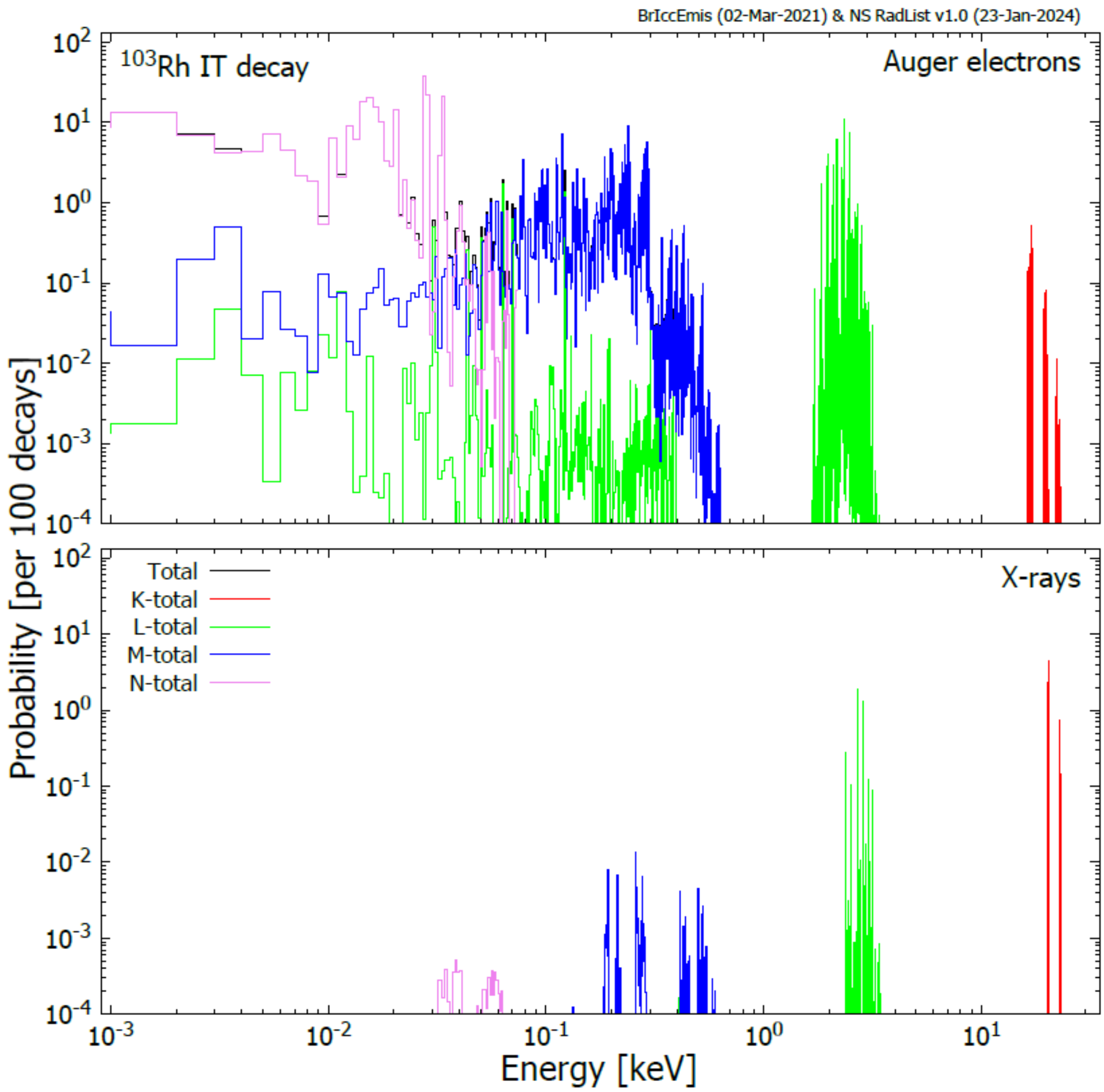
[a] Quoted uncertainties include direct contributions from only the internal-conversion electrons (2023Texx) – these data do not include significant uncertainties from the more complex but less well-defined atomic radiation probabilities as considered semi-quantitatively in EADL, whereby uncertainties in the theoretical Auger-electron radiative rates are < 15% for the K and L shells (except for Coster-Kronig and super Coster-Kronig transitions), and can be of the order of 30% or more for Coster-Kronig and super Coster-Kronig transitions and the outer shells (1991PeZY).

Total energy release per decay as determined from the BrIccEmis/NS_RadList studies:

Radiation	Total energy (keV per decay)	Total intensity (%)
Gamma rays	0.0276 (8)	0.0694 (19)
Conversion electrons	35.3 (12)	100.3 (35)
Auger electrons	2.67 (6)	582 (12)
X-rays	1.77 (6)	12.5 (4)
Summed total	39.8 (12)	
Q(IT)	39.753 (6)	

The final X-ray and Auger-electron spectra were effectively evaluated from one million simulated nuclear decay events. Both component spectra of the Auger-electron and X-ray emissions as calculated by the BrIccEmis code for the IT decay of ^{103m}Rh are shown in the following figure.

Auger-electron (upper panel) and X-ray (lower panel) spectra of ^{103m}Rh IT decay:



Main Production Modes for ^{103}Pd and ^{103m}Rh

^{103m}Rh: ^{103}Rh(n,n')^{103m}Rh, ^{103}Rh(d,d')^{103m}Rh, ^{103}Rh(α,α')^{103m}Rh, ^{103}Rh(γ,γ')^{103m}Rh
parent ^{103}Pd(EC)^{103m}Rh
parent ^{103}Ru(β⁻)^{103m}Rh: ^{102}Ru(n,γ)^{103}Ru, ^{102}Ru(d,p)^{103}Ru, ^{104}Ru(d,t)^{103}Ru, ^{100}Mo(α,n)^{103}Ru

Data Consistency

^{103m}Rh

A Q_{IT}-value of 39.753 (6) keV for the IT decay of ^{103m}Rh from NUBASE2020/AME2020 (2021Ko07, 2021Wa16) has been similarly compared with a calculated Q-value of 39.8 (6) keV to give a percentage deviation of – (0.1 ± 1.5)%, which supports the derivation of a consistent decay scheme with a modest variant.

References

1936Ba01 I. Backhurst, LVIII The X-ray K-fluorescence Yield, London Edinburgh Dublin Phil. Mag. J. Sci. **22** (1936) 737-752. [Rh ω_K]

1937St02 R.J. Stephenson, X-ray Fluorescence Yields, Phys. Rev. **51** (1937) 637-642. [Rh ω_K]

1944Fl01 A. Flammersfeld, Kernanregung durch Schnelle Neutronen bei Rhodium und Silber, Naturwissenschaften **32** (1944) 36-37. [^{103m}Rh half-life]

1945Wi03 M.L. Wiedenbeck, The Nuclear Excitation of Krypton and Rhodium, Phys. Rev. **68** (1945) 237-239. [^{103m}Rh half-life]

1945Wi12 M.L. Wiedenbeck, The Nuclear Excitation of Rhodium, Phys. Rev. **67** (1945) 267-268. [^{103m}Rh half-life]

1947Fl03 A. Flammersfeld, O. Bruna, Die Anregungsenergie der Isomeren Zustände des Rhodiums 103 und 104, Z. Naturforsch. **2a** (1947) 241-244. [^{103m}Rh half-life]

1950Ko10 E. Kondaiah, Disintegration of Ru^{103}, Phys. Rev. **79** (1950) 891-892. [K/(L+M) ratio (40 keV)]

1950Me26 J.Y. Mei, C.M. Huddleston, A.C.G. Mitchell, The Disintegration of Ruthenium-103 and Palladium-103, Phys. Rev. **79** (1950) 429-432. [^{103m}Rh half-life]

1952Co16 J.M. Cork, J.M. LeBlanc, F.B. Stumpf, W.H. Nestor, The Radioactive Decay of Ruthenium 103, Phys. Rev. **86** (1952) 575-576. [K/L ratios]

1954Ro45 C.E. Roos, A New Method for Measuring Auger Transitions, Phys. Rev. **93** (1954) 401-405. [Rh ω_K]

1955Av11 P. Avignon, A. Michalowicz, R. Bouchez, Étude de la Désintégration du ^{103}Pd, J. Phys. Radium **16** (1955) 404-410. [E_γ, P_γ, α_K, α_L, K/L ratio]

1955Dr43 G.M. Drabkin, V.I. Orlov, L.I. Rusinov, Investigation of the Nuclear Isomerism of Zn^{69}, Se^{79}, Se^{81}, Rh^{103} and Ba^{137}, Izvest. Akad. Nauk SSSR, Ser. Fiz., Columbia Tech. Transl. **19** (1956) 294-304. [α_K, K/L and L/M ratios]

1957Jo19 G.A. Jones, W.R. Phillips, Electrical Octupole Coulomb Excitation in Rhodium, Proc. Royal Soc. (London) **239A** (1957) 487-493. [^{103m}Rh half-life]

1957Ro58 C.E. Roos, K Fluorescence Yield of Several Metals, Phys. Rev. **105** (1957) 931-935. [Rh ω_K]

1967Br04 A.M. Bresesti, M. Bresesti, H. Neumann, Measurement of K X-ray Emission in the Decay of ^{103m}Rh, J. Inorg. Nucl. Chem. **29** (1967) 15-20. [^{103}Ru β^- decay: P_{KX}, K/(L+M+N) ratio of 39.75-keV gamma transition]

1967VuZZ A. Vuorinen, Calibration of ^{103m}Rh by the Coincidence Method, pp. 257-263, Proc. Symp. Standardization of Radionuclides, IAEA, Vienna, Austria (1967). [^{103m}Rh half-life, K/(K + L + M) ratio, P_{KX} of 39.75-keV gamma transition]

1968Ma08 J.C. Manthuruthil, H.J. Hennecke, C.R. Cothern, Internal-Conversion-Electron Study of the Decay of Ru^{103}, Phys. Rev. **165** (1968) 1363-1370. [ICC, multipolarities, mixing ratios]

1969Gr13 Y. Grunditz, S. Antman, H. Pettersson, M. Saraceno, Studies in the Decay of ^{103}Pd, Nucl. Phys. **A133** (1969) 369-384. [^{103}Pd half-life, E_γ, P_γ, α_K, subshell ratios, P_{KX} and P(357 keV)/P_{KX} ratio of ^{103}Pd-^{103m}Rh]

1969KoZW Y. Kobayashi, Half-lives of Rhodium-106, -105 and -103m, JAERI report JAERI-1178 (1969) 21-22. [^{103m}Rh half-life]

1969Le17 M.A. Lepri, W.S. Lyon, Decay of ^{103}Pd–^{103m}Rh, Int. J. Appl. Radiat. Isot. **20** (1969) 297-298. [K_α/K_β ^{103}Pd-^{103}Rh, 39.75-keV α_K]

1970NiZV E.B. Nieschmidt, D.A. Pearson, Nuclear Levels of ^{103}Rh, IN-1317 (1970) 122-126. [E_γ, P_γ, α_K, L subshell ratios]

1970Pe04 H. Pettersson, S. Antman, Y. Grunditz, Studies in the Decay of ^{103}Ru, Z. Phys. **233** (1970) 260-274; Erratum, Z. Phys. **235** (1970) 485. [E_γ, L_1/L_2, L_1/L_3, L_2/L_3 ratios, α_K]

1972Bb16 W. Bambynek, B. Crasemann, R.W. Fink, H.-U. Freund, H. Mark, C.D. Swift, R.E. Price, P. Venugopala Rao, X-Ray Fluorescence Yields, Auger, and Coster-Kronig Transition Probabilities, Rev. Mod. Phys. **44** (1972) 716-813; Erratum, Rev. Mod. Phys. **46** (1974) 853. [K-shell fluorescence yield]

1972Br02 D.S. Brenner, M.L. Perlman, Subshell Conversion-line Intensity Ratios for Some Pure Transitions, Nucl. Phys. **A181** (1972) 207-216. [39.75-keV L_1/L_3, L_2/L_3 ratios]

1972Pa10 A. Pazsit, J. Csikai, Cross Sections of the Reactions In^{113}(n,n')In^{113m} and Rh^{103}(n,n')Rh^{103m}, Sov. J. Nucl. Phys. **35** (1972) 232-233. [^{103m}Rh half-life, α_K(39.75 keV)]

1973Gu06 E. Günther, K. Knauf, K.F. Walz, The Half-life of ^{103m}Rh, Int. J. Appl. Radiat. Isot. **24** (1973) 87-89. [^{103m}Rh half-life]

1973In07 H. Ing, W.G. Cross, Absolute Counting of K X-rays from ^{103m}Rh in Thick Foils, Int. J. Appl. Radiat. Isot. **24** (1973) 437-450. [^{103}Ru β^- decay: P_{KX} of ^{103}Ru-^{103m}Rh]

1974CzZY K.H. Czock, N. Haselberger, F. Reichel, The Disintegration of ^{103m}Rh, IAEA report IAEA/RL/26 (1974). [α_{total}, α_K, K/(L + M + …..) ratio]

1974Sa15 D.C. Santry, J.P. Butler, Cross Section Measurements for the ^{103}Rh(n,n')^{103m}Rh Reaction from 0.122 to 14.74 MeV, Can. J. Phys. **52** (1974) 1421-1428. [^{103m}Rh half-life, P_{KX} of ^{103m}Rh]

1975Cz03 K.H. Czock, N. Haselberger, F. Reichel, The Disintegration of ^{103m}Rh, Int. J. Appl. Radiat. Isot. **26** (1975) 417-421. [α_{total}, α_K, P_{KX} of ^{103m}Rh]

1975Ma32 B. Martin, D. Merkert, J.L. Campbell, Intensity Ratios of L, M, N, O Subshell Conversion Electrons in M3 and E4 Transitions, Z. Phys. **A274** (1975) 15-21. [39.75-keV L_1/L_2, L_1/L_3, L_2/L_3, M, N, O ratios]

1976Ma37 E.S. Macias, M.E. Phelps, D.G. Sarantites, R.A. Meyer, Decay of 39-day ^{103}Ru and 17-day ^{103}Pd to the Levels of ^{103}Rh, Phys. Rev. **C14** (1976) 639-644. [E_γ, P_γ, α_K, α_L, P_{KX} and P(357 keV)/P_{KX} ratio of ^{103}Pd-^{103m}Rh]

1977La19 F.P. Larkins, Semiempirical Auger-electron Energies for Elements $10 \leq Z \leq 100$, At. Data Nucl. Data Tables **20** (1977) 311-387. [Auger-electron energies]

1978La21 F. Lagoutine, J. Legrand, C. Bac, Périodes de Quelques Radionucléides, Int. J. Appl. Radiat. Isot. **29** (1978) 269-272. [^{103m}Rh half-life]

1979VaZE R. Vaninbroukx, G. Grosse, W. Zehner, Studies of the Decay of ^{103m}Rh, NEA report NEANDC(E)-202U, Vol. III (1979) 28-30. [P_γ, P_{KX}, α_{total}, α_K of ^{103m}Rh]

1981Va11 R. Vaninbroukx, G. Grosse, W. Zehner, New Determinations of the Half-lives of ^{57}Co, ^{103}Ru, ^{103m}Rh, ^{103}Pd and ^{109}Cd, Int. J. Appl. Radiat. Isot. **32** (1981) 589-591. [^{103}Pd and ^{103m}Rh half-lives]

1981Va22 R. Vaninbroukx, W. Zehner, Determination of the K X-ray Emission Probability in the Decay of ^{103m}Rh, Int. J. Appl. Radiat. Isot. **32** (1981) 850. [^{103m}Rh P_{KX}]

1990Si19 S. Singh, R. Rani, D. Mehta, N. Singh, P.C. Mangal, P.N. Trehan, K X-ray Fluorescence Cross-section Measurements of Some Elements in the Energy Range 8-47 keV, X-ray Spectrom. **19** (1990) 155-158. [Rh ω_K]

1991PeZY S.T. Perkins, D.E. Cullen, M.H. Chen, J.H. Hubbell, J. Rathkopf, J. Scofield, Tables and Graphs of Atomic Subshell and Relaxation Data Derived from the LLNL Evaluated Atomic Data Library (EADL), Z = 1–100, Lawrence Livermore National Laboratory report UCRL-50400, **30** (1991). [atomic database]

1992Ga24 R.R. Garg, S. Puri, S. Singh, D. Mehta, J.S. Shahi, M.L. Garg, N. Singh, P.C. Mangal, P.N. Trehan, Measurements of L X-ray Fluorescence Cross Sections and Yields for Elements in the Atomic Range $41 \leq Z \leq 52$ at 5.96 keV, Nucl. Instrum. Methods Phys. Res. **B72** (1992) 147-152. [Rh ϖ_L]

1993Cu08 D.E. Cullen, S.T. Perkins, S.M. Seltzer, Photon and Electron Databases and Their Use in Radiation Transport Calculations, Appl. Radiat. Isot. **44** (1993) 1343-1347. [atomic database]

1994Hu23 J.H. Hubbell, P.N. Trehan, N. Singh, B. Chand, D. Mehta, M.L. Garg, R.R. Garg, S. Singh, S. Puri, J. Phys. Chem. Ref. Data **23** (1994) 339-364; Erratum, J. Phys. Chem. Ref. Data, **33** (2004) 621. [Rh ω_K, ϖ_L, ϖ_M]

1994Sc43 U. Schötzig, Photon Emission Probabilities in the Decay of ^{103}Ru/^{103m}Rh, Appl. Radiat. Isot. **45** (1994) 641-644. [^{103m}Rh P_{KX}]

1996Sc06 E. Schönfeld, H. Janβen, Evaluation of Atomic Shell Data, Nucl. Instrum. Methods Phys. Res. **A369** (1996) 527-533. [ω_K, ϖ_L, K_β/K_α, $K_{\alpha2}/K_{\alpha1}$, KLX/KLL, KXY/KLL]

1998ScZM E. Schönfeld, 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]

1999Sa78 M. Sainath, K. Venkataramaniah, Measurement of α_K, α_L, α_M of the Hindered E3 Transition in ^{103}Rh, Indian J. Pure Appl. Phys. **37** (1999) 87-91. [39.75-keV α_K, α_L, α_M]

1999ScZX E. Schönfeld, 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]

2000KoZT A. Kovalík, E.A. Yakushev, D.V. Filosofov, V.M. Gorozhankin, V.G. Kalinnikov, Energies of the 39.7 keV E3 Transition in ^{103}Rh, the 25.6 keV E1 Transition in ^{161}Dy, the 74.6 keV and 76.2 keV M1 Transitions in ^{161}Ho, and 67.2 keV E3 and 71.9 keV M1 + E2 Transitions in ^{158}Ho, Program and Thesis, Proc. 50th Ann. Conf. Nucl. Spectrosc. Struct. At. Nuclei, St. Petersburg, Russia (2000) 175. [39.7537(21)-keV γ-ray energy ^{103m}Rh]

2000Sc47 E. Schönfeld, H. Janβen, Calculation of Emission Probabilities of X-rays and Auger Electrons Emitted in Radioactive Disintegration Processes, Appl. Radiat. Isot. **52** (2000) 595-600. [P_X, P_{Ae}]

2002Ba85 I.M. Band, M.B. Trzhaskovskaya, C.W. Nestor, Jr., P.O. Tikkanen, S. Raman, Dirac–Fock Internal Conversion Coefficients, At. Data Nucl. Data Tables **81** (2002) 1-334. [Theoretical ICC]

2002Ra45 S. Raman, C.W. Nestor, Jr., A. Ichihara, M.B. Trzhaskovskaya, How Good are the Internal Conversion Coefficients Now? Phys. Rev. **C66** (2002) 044312, 1-23. [Theoretical ICC]

2008Ki07 T. Kibédi, T.W. Burrows, M.B. Trzhaskovskaya, P.M. Davidson, C.W. Nestor, Jr., Evaluation of Theoretical Conversion Coefficients using BrIcc, Nucl. Instrum. Methods Phys. Res. **A589** (2008) 202-229. [Theoretical ICC]

2009De29 D. De Frenne, Nuclear Data Sheets for A = 103, Nucl. Data Sheets **110** (2009) 2081-2256. [Nuclear levels]

2011Ka49 A. Kahoul, A. Abassi, B. Deghfel, M. Nekkab, K-shell Fluorescence Yields for Elements with $6 \leq Z \leq 99$, Radiat. Phys. Chem. **80** (2011) 369-377. [Rh ω_K]

2012Le09 B.Q. Lee, T. Kibédi, A.E. Stuchbery, K.A. Robertson, Atomic Radiations in the Decay of Medical Radioisotopes – A Physics Perspective, Comput. Math. Methods Med. Article ID 651475 (2012) 1-14, doi:10.1155/2012/651475. [Atomic radiation]

2013LeZX B.Q. Lee, T. Kibédi, A.E. Stuchbery, K.A. Robertson, F.G. Kondev, A Model to Realize the Potential of Auger Electrons for Radiotherapy, Proc. Heavy Ion Accelerator Symposium (HIAS2013), 8-12 April 2013, Canberra, Australia, EPJ Web of Conferences, **63** (2013) 01002, 1-5, editors: C. Simenel, M. Evers, T. Kibédi, D. Huy Luong, M. Reed, M. Srncik, A. Wallner; doi.org/10.1051/epjconf/20136301002. [Auger electrons]

2016Le19 B.Q. Lee, Hooshang Nikjoo, J. Ekman, P. Jönsson, A.E. Stuchbery, T. Kibédi, A Stochastic Cascade Model for Auger-electron Emitting Radionuclides, Int. J. Radiat. Biol. **92** (2016) 641-653; doi: 10.3109/09553002.2016.1153810. [Atomic radiation]

2017Ri10 J. Riffaud, M.-C. Lépy, Y. Ménesguen, A. Novikova, Measurement of K Fluorescence Yields of Niobium and Rhodium Using Monochromatic Radiation, X-ray Spectrom. **46** (2017) 341-346. [Rh ω_K]

2018Ni14 N. Nica, J.C. Hardy, V.E. Iacob, V. Horvat, H.I. Park, T.A. Werke, K.J. Glennon, C.M. Folden III, V.I. Sabla, J.B. Bryant, X.K. James, M.B. Trzhaskovskaya, Precise Measurement of α_K and α_T for the 39.8-keV E3 transition in ^{103}Rh: Test of Internal-conversion Theory, Phys. Rev. **C98** (2018) 054321, 1-11. [α_K, α_T, δ (39.75-keV γ-ray transition)]

2018Ri01 J. Riffaud, P. Cassette, D. Lacour, V. Lourenço, I. Tartès, M.A. Kellett, M. Corbel, M.-C. Lépy, C. Domergue, C. Destouches, H. Carcreff, O. Vigneau, Measurement of Absolute K X-ray Emission Intensities in the Decay of ^{103m}Rh, Appl. Radiat. Isot. **134** (2018) 399-405. [^{103m}Rh IT decay: absolute P_{KX}, absolute P_γ]

2020TeZY B.P.E. Tee, T. Kibédi, B.Q. Lee, M. Vos, R. du Rietz, A.E. Stuchbery, Development of a New Database for Auger-electron and X-ray Spectra, Proc. Heavy Ion Accelerator Symposium (HIAS2019), 9-13 September 2019, Canberra, Australia, EPJ Web of Conferences, **232** (2020) 01006, 1-4, editors: A.J. Mitchell, S. Pavetich, D. Koll; doi.org/10.1051/epjconf/202023201006. [Atomic radiation]

2021Ko07 F.G. Kondev, Meng Wang, W.J. Huang, S. Naimi, G. Audi, The NUBASE2020 Evaluation of Nuclear Physics Properties, Chin. Phys. **C45** (2021) 030001, 1-180; doi: 10.1088/1674-1137/abddae [Q_{IT}(^{103m}Rh)]

2021Ri01 J. Riffaud, M.-C. Lépy, P. Cassette, M. Corbel, M.A. Kellett, V. Lourenço, Measurement of the Absolute Gamma-ray Emission Intensities from the Decay of ^{103}Pd, Appl. Radiat. Isot. **167** (2021) 109298, 1-9. [^{103}Pd half-life, absolute P_{KX}, relative P_{LX}, absolute P_γ]

2021Wa16 Meng Wang, W.J. Huang, F.G. Kondev, G. Audi, S. Naimi, The AME2020 Atomic Mass Evaluation (II): Tables, Graphs and References, Chin. Phys. **C45** (2021) 030003, 1-512; doi: 10.1088/1674-1137/abddaf [Q-values]

2023Texx B.P.E. Tee, T. Kibédi, B.Q. Lee, A.E. Stuchbery, BrIccEmisDB Database and Computational Tool to Evaluate Atomic Relaxation Radiations, in preparation for submission to At. Data Nucl. Data Tables (2023-2024). [Atomic radiation]

65 references and three errata – 68 items

ENSDF Analysis Programs:
BrIcc, version 2.3b, 16 December 2014
BrIccEmis, 2 March 2021
NS_RadList, version 1.0, 7 December 2023
BrIccMixing, version 2.3d, 28 September 2019

ENSDF Utility Programs:
Avetools, version 3.0, 11 December 2014
V.AveLib, version 06-22, 19 March 2024
FMTCHK, version 10.4d, 29 November 2018

The above codes have undergone and will continue to undergo various forms of modification and improvement, which will be reflected in changes to the version number and date of issue into the public domain. Assistance from Tibor Kibédi (ANU, Australia – particularly BrIccEmis and NS_RadList) concerning improved operational features of some of the above codes is gratefully acknowledged by ALN.