DDEP EVALUATION OF ^{103}Pd/^{103}Rh^{m}: ELECTRON CAPTURE WITH PARENT-DAUGHTER EQUILIBRIUM

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Decay Data Evaluation Project – training workshop, 21-25 October 2024, CEA Saclay, Gif-sur-Yvette, France

timeline

1969-1972 Mössbauer spectroscopy, University of Leeds, UK
1972-1974 positronium annihilation, Virginia Tech, USA

1974-1977 Variable Energy Cyclotron - radioisotope production: ^{18}F, ^{52}Fe, ^{82}Sr-^{82}Rb, ^{127}I(p,5n)^{123}Xe(EC)^{123}I, and ^{201}Tl,
evaluate/assemble decay databases (UKPADD, UKHEDD), Harwell, UK

1977-1993 aerosol science, physical and chemical characterisation of severe reactor accident
aerosols, radioactive waste management,
evaluate/assemble decay databases (UKPADD, UKHEDD, JEF-2.2),
management functions, Winfrith, UK

1991-2001 evaluate/assemble decay databases (IAEA, JEF, JEFF),
management functions, Culham/Harwell, UK

2001-2009 Section Head, Nuclear Data Section, IAEA, Vienna, Austria,
evaluation of decay data (IAEA, DDEP, JEFF)

2009 → … more evaluations of decay data (IAEA, DDEP)

Words of agreement or argument, plus stating the obvious

Compilation: material/data assembled from other available sources;
Evaluation: derive data in the form of recommended values via personal assessment.

Prescriptive: imposition of a rule or custom via authoritative recommendation.

Error: mistake, wrong/incorrect measure of the estimated difference between an observed value and a true value of a quantity;
Uncertainty: data not definitive, quantification of the state of being unsure.

Uncertainty budget: detailed and comprehensive breakdown of the systematic and statistical uncertainties in a series of measurements – an emerging necessity in all experimental nuclear data studies as far as both referees and evaluators are concerned.

Words of agreement or argument, plus stating the obvious

Objective judgement: assessment not influenced by personal opinion or feelings of the assessor.

Subjective judgement: assessment that may require personal opinions in order to resolve an intractable problem/issue.
Frowned on in scientific study?

Evaluation of atomic and nuclear decay data

expressed at the 1σ confidence level

Half-life and uncertainty
Branching fractions (when more than one decay mode), and their uncertainties
Q-value(s) from AME2020 (Atomic Mass Evaluation (Atomic Mass Data Centre))
Spin, parity and energies of nuclear levels, and uncertainties of nuclear-level energies

E_γ (keV) and uncertainties, relative and absolute P_γ (%) and uncertainties
γ transitions: multipolarities and uncertainties, internal conversion coefficients (ICCs) and uncertainties, along with shell and subshell ratios and uncertainties
Conversion-electron energies (E_{ce} (keV)), relative and absolute P_{ce} (%) emission probabilities and uncertainties

E_α (keV) and uncertainties (recoil adjustment to quantify E_α (keV)), absolute P_α (%) emission probabilities, hindrance factor for α decay, and uncertainties
$E_{\beta-}$ (keV) and uncertainties, transition type, log*ft*, absolute $P_{\beta-}$ (%) emission probabilities and uncertainties
$E_{\beta+}$ (keV) and uncertainties, transition type, log*ft*, absolute $P_{\beta+}$ (%) emission probabilities and uncertainties
E_{EC} (keV) and uncertainties, transition type, log*ft*, absolute P_{EC} (%) transition probabilities and uncertainties, and relative P_K, P_L (P_{L1}, P_{L2}, P_{L3}), P_M, P_N, etc. probabilities, and uncertainties

X-ray energies and absolute emission probabilities, and their uncertainties
Auger-electron energies and emission probabilities, and their uncertainties
Spontaneous fission, nubar ($\underline{\nu}$), prompt neutron energy, prompt γ energy, fission-fragment energies, and their uncertainties
Beta-delayed neutron decay and their uncertainties

Nuclear structure and decay data

DDEP: **D**ecay **D**ata **E**valuation **P**roject – evaluation of decay-scheme data for individual radionuclides.

ENSDF: **E**valuated **N**uclear **S**tructure **D**ata **F**ile – full mass-chain and individual radionuclide evaluations of nuclear structure and decay data.

NSR: **N**uclear **S**cience **R**eferences – bibliographic file.

NDS: **N**uclear **D**ata **S**heets – journal devoted to nuclear data issues (notably ENSDF nuclear structure and decay data evaluations).

XUNDL: e**X**perimental **U**nevaluated **N**uclear **D**ata **L**ist prior to incorporation into ENSDF.

AME: **A**tomic **M**ass **E**valuation (re-evaluated within every ~ 4/5 years, AME2020).

Codes:

ALPHAD_RadD: hindrance factor of α transition,

DELTA: γ–γ correlation analyses to determine mixing ratios (δ),

BetaShape: average β^- energy, log*ft*; EC energy, log*ft* and fractional EC probabilities,

BrIcc: Band-Raman internal conversion coefficients (Hager and Seltzer, Rösel *et al*., Band and Raman),

BrIccMixing: multipole mixing ratios (δ),

Emission: X-ray and Auger-electron emission probabilities from atomic vacancies created by the nuclear processes,

GABS: absolute intensities and normalization factor of gamma rays,

GTOL: least-squares fit to gamma-ray energies → nuclear-level energies and net feedings to levels,

BrIccEmis/NS_RadList: X-rays, and conversion- and Auger-electron emissions,

and others.

^{103}Pd/^{103}Rh^{m} and ^{103}Rh^{m} – Evaluation of decay data

by Alan L. Nichols[1], Tibor Kibédi[2]

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Reviewer: Sylvain Leblond

Université Paris-Saclay, CEA, Laboratoire National Henri Becquerel (LNE-LNHB), 91120 Palaiseau, France

^{103}Pd/^{103}Rh^{m} evaluations: March/April 2021, September/October 2021, October 2023, June 2024
^{103}Pd: electron and X-ray emissions viewed as potentially suitable for palliative treatment and radiotherapeutic procedures (microdosimetry) – 90 references and three errata

pure ^{103}Rh^{m} evaluations: May 2013, January 2015, March/April 2021, April 2023, June 2024
^{103}Rh^{m}: adopted as a suitable neutron flux monitor in power reactors (^{103}Rh(n,n')^{103}Rh^{m}) – 65 references and three errata

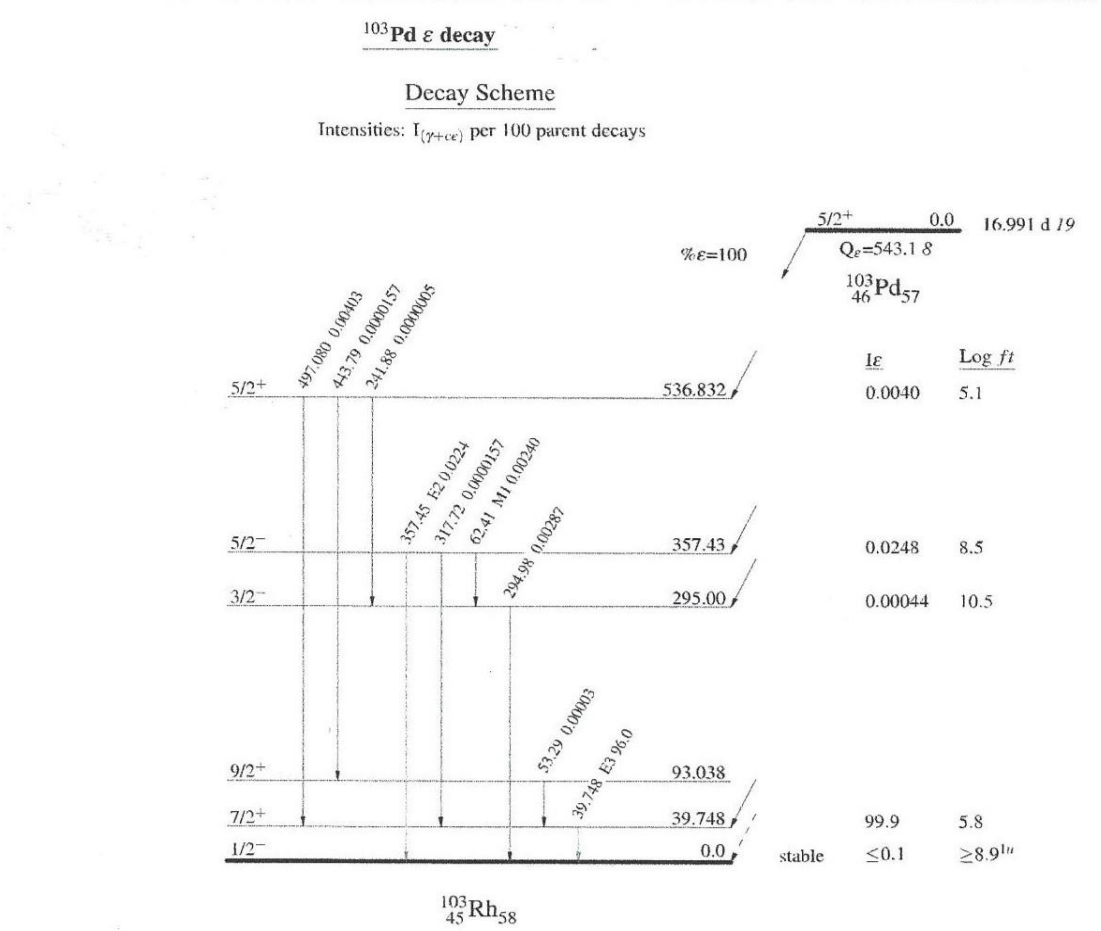
DDEP evaluation of ^{103}Pd/^{103}Rh^{m} – decay scheme

take a quick look at the degree of complexity

DDEP evaluation of ^{103}Pd/^{103}Rh^{m} – decay scheme

take a quick look at the degree of complexity

From ENSDF



EC decay of 99.9% to 39.75 keV nuclear level - while OK at first glance, γ-ray measurements are problematic. 39.753-keV γ ray is highly converted, and all other γ rays are low intensity as a consequence of the small EC transition probabilities

Half-life of ^{103}Pd

NSR identifier	Half-life (d)	Selected detail, issues and uncertainties
1947Ma32	17.0	**no uncertainty quoted** – not adopted in analytical procedures
1948Li03	17	**no uncertainty quoted** – not adopted in analytical procedures
1953Me24	**17.0 ± 0.4**	long-lived component after neutron irradiation of Pd target (Geiger-Muller tube: activity followed over 60 d)
1954Ri09	17.5 ± 0.5	X rays, total γ spectrum, 60- to 250-, 367- and 503-keV γ rays (NaI(Tl) crystal over 15 d (reference Fig. 2)); **outlier (Chauvenet criterion)** – not adopted in analytical procedures
1968Pa24	16.9 ± 0.1	**sparse information** - analysis of X-ray decay curves from proton-irradiated silver and indium targets (NaI(Tl) crystal over unspecified times) – not adopted in analytical procedures
1969Gr13	18.4 ± 0.5	conversion/Auger electrons, KX rays and γ rays (double-focussing β spectrometer and Ge(Li) detector over 70 d); **significant outlier (Chauvenet criterion)** – not adopted in analytical procedures
1975Cz05	**16.961 ± 0.016[a]**	conversion/Auger electrons (4π-proportional flow counter over 80 d) and 20-keV KX rays (NaI(Tl) crystal and Ge(Li) detector over 32 and 36 d, respectively) – focus on Ge(Li) data
1981Va11	**16.991 ± 0.019[b]**	decay of KX rays (Si(Li) detectors) and γ rays (NaI(Tl) crystal over 33 to 54 d); **detailed definition of systematic uncertainties**
2004Po24	16.8 ± 0.6	decay of 295-, 358- and 479-keV γ rays over ~ 100 d by means of HPGe detector; **outlier** – not adopted in final analytical procedure
2021Ri01	**17.049 ± 0.016**	regular determination of peak area of 357.4-keV γ ray over 50 d by means of HPGe detector; **well-defined uncertainties**
Recommended value	**17.00 ± 0.05**	**LWM, with uncertainty expanded from ± 0.03 to ± 0.05 d to cover 17.049 ± 0.016 d of 2021Ri01; χ^2/(N-1) of 5.18 and χ^2/(N-1)$_{critical}$ at 99% confidence level of 3.78 after a second pass;** **UWM of 17.000 ± 0.018**

[a] Weighted mean of three sets of measurements is 16.953 (7) d, compared with an adopted value of 16.961 (16) d quoted by 1975Cz05.
[b] Weighted mean of four sets of measurements is 16.992 (10) d, compared with an adopted value of 16.991 (19) d quoted by 1981Va11.

Avetools and V.AveLib 06-22 codes - analytical methods	Half-life (d)	χ^2/(N-1)	χ^2/(N-1)$_{critical}$
unweighted mean (UWM)	17.00 ± 0.10	–	–
limitation of relative statistical weights method (LWM)	17.00 ± 0.03	5.18	2.60 for rejection at 95% confidence level
normalised residual method (NRM)	16.984 ± 0.017	2.19	2.60 for rejection at 95% confidence level
Rajeval technique	16.990 ± 0.016	0.69	2.60 for rejection at 95% confidence level
expected value method (EVM)	17.00 ± 0.08	–	89.3% confidence level
bootstrap method	17.00 ± 0.06	5.19	–
Mandel-Paule	17.001 ± 0.033	5.18	–

10 half-life publications (1947-2021): outliers; ill-defined uncertainties; restricted statistical uncertainties; inadequate quantification of systematic uncertainties; superseded by further measurements by same laboratory/equipment

Half-life of $^{103}Rh^{m}$

NSR identifier	Half-life (min)	Selected detail, issues and uncertainties
1944Fl01	48 ± 5	$^{103}Rh(n_p,n')$ reaction – **outlier (Chauvenet criterion)**, and therefore not included in analytical procedures
1945Wi03/1945Wi12	45 ± 1	$^{103}Rh(X,\gamma)$ 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**	$^{102}Ru(n,\gamma)^{103}Ru(\beta^-)^{103m}Rh$; 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) min., compared with a value of 56.116 (9) min. quoted by 1973Gu06; uncertainty adjusted to ± 0.016 min. 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 - **superseded 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) min., compared with a value of 56.114 (20) min. quoted by 1981Va11
Recommended value	**56.115 ± 0.016**	recommended uncertainty adjusted from ± 0.011 to ± 0.016 min., to align with smallest uncertainty of the values used to calculate weighted-mean value

Avetools and V.AveLib 06-22 codes - analytical methods	Half-life (min)	$\chi^2/(N-1)$	$\chi^2/(N-1)_{critical}$
unweighted mean (UWM)	56.31 ± 0.16	–	–
limitation of relative statistical weights method (LWM)	56.115 ± 0.011	0.45	2.21 for rejection of 95.0% confidence level
normalised residual method (NRM)	56.115 ± 0.011	0.45	2.21 for rejection at 95.0% confidence level
Rajeval technique	56.115 ± 0.011	0.45	2.21 for rejection at 95.0% confidence level
expected value method (EVM)	56.13 ± 0.08	–	97.0% confidence level
bootstrap method	56.22 ± 0.16	15.8	–
Mandel-Paule	56.115 ± 0.011	0.45	–

13 half-life measurements (1944-1981): outliers; ill-defined uncertainties; restricted statistical uncertainties; inadequate quantification of systematic uncertainties; superseded by further measurements by same laboratory/equipment

DDEP evaluation of ^{103}Pd/^{103}Rh^{m} and ^{103}Rh^{m}: Q values

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

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

- ^{103}Pd EC decay – Q_{EC} value of 534.9 (24) keV to the excited metastable state of ^{103}Rh^{m}
- IT decay of ^{103}Rh^{m} to the stable ground state of ^{103}Rh → Q_{IT} value of 39.753 (6) keV
- Overall Q_{EC} value of 574.7 (24) keV for ^{103}Pd EC decay to the stable ground state of ^{103}Rh

DDEP evaluation of ^{103}Pd/^{103}Rh^{m}: γ-ray energies

Seven of eleven sets of γ-ray energies measured by 1954Ri09, 1955Av11, 1955Sa16, **1969Zo02**, **1969Gr13**, **1969Ra18**, **1970NiZV**, **1970Pe04**, **1976Ma37**, **2010Kr05** and 2018Ni14.
Weighted-mean values: Avetools, version 3.0, 11 December 2014 (ENSDF analysis code).

1969Zo02 ^{103}Ru(β$^-$) ^{103}Pd(EC)	1969Gr13 ^{103}Pd(EC)	1969Ra18 ^{103}Ru(β$^-$)	1970NiZV ^{103}Ru(β$^-$) ^{103}Pd(EC)	1970Pe04 ^{103}Ru(β$^-$)	1976Ma37 ^{103}Ru(β$^-$) ^{103}Pd(EC)	2010Kr05 ^{103}Ru(β$^-$)	2018Ni14 2009ENSDF	**Weighted mean (LWM)[a]**
39.78 (5)	**39.748 (8)**	**39.755 (12)**	**39.75 (7)**	**39.762 (16)**	**39.73 (2)**	–	–	**39.750 ± 0.006 → 39.753 ± 0.006[c,d]**
53.28 (5)	–	**53.275 (10)**	**53.3 (9)**	**53.271 (30)**	**53.29 (1)**	**53.286 (10)**	53.282 (7)	**53.283 ± 0.006**
62.3 (2)	**62.30 (12)**	–	**62.5 (1)**	–	**62.41 (3)**	–	–	**62.41 ± 0.03**
241.8 (1)	262?	–	–	**241.87 (25)**	**241.88 (5)**	**241.875 (10)**	–	**241.875 ± 0.010**
295.17 (10)	**294.70 (17)**	**294.72 (12)**	**295.0 (1)**	**294.82 (8)**	**294.98 (15)**	**294.964 (10)**	294.964 (10)[e]	**294.962 ± 0.015**
318.0 (3)	330?	–	**317.4 (3)**	–	**317.72 (5)**	–	–	**317.72 ± 0.05**
357.60 (10)	**356.98 (9)**	–	**357.5 (1)**	**357.21 (35)**	**357.45 (8)**	**357.382 (23)**	–	**357.38 ± 0.08**
444.11 (15)[b]	–	**443.77 (12)**	**443.9 (1)**	**443.63 (12)**	**443.79 (5)**	**443.810 (10)**	443.80 (2)	**443.809 ± 0.010**
497.23 (10)	496.74 (22)[b]	**497.080 (13)**	**497.1 (1)**	**496.92 (10)**	**497.08 (2)**	**497.085 (10)**	497.083 (6)	**497.083 ± 0.007**

[a] Weighted mean of selected γ-ray energy measurements – no adjustments made to weighting of input uncertainties.
[b] Chauvenet outlier – not included in analysis.
[c] Single γ transition of IT decay of ^{103}Rh^{m} daughter.
[d] Recommended Eγ 39.753 (6) keV in good agreement with Kovalik et al. (2000KoZT) and aligned with 2021Ko07 and 2021Wa16.
[e] A value of 295.964 (10) keV was erroneously listed in Table III of 2018Ni14 – corrected to 294.964 (10) keV.

DDEP evaluation of ^{103}Pd/^{103}Rh^{m}: nuclear levels of ^{103}Rh

Seven sets of γ-ray energies as measured by 1969Zo02, 1969Gr13, 1969Ra18, 1970NiZV, 1970Pe04, 1976Ma37 and 2010Kr05.

Weighted-mean values determined by GTOL, version 7.2h, 24-May-2013 (ENSDF analysis code).

Adopted energies, spins/parities for the nuclear levels of ^{103}Rh (GTOL v7.2h and 2009De29)

Nuclear level number	Nuclear level energy (keV)		Spin and parity	Half-life
	GTOL v7.2h	2009De29		
0	0.0	0.0	1/2 $^{-}$	stable
1	39.752 ± 0.006	**39.753 ± 0.006**	7/2 $^{+}$	(56.115 ± 0.016) min.
2	**93.034 ± 0.008**	93.036 ± 0.009	9/2 $^{+}$	(1.11 ± 0.03) ns[a]
3	**294.965 ± 0.010**	294.965 ± 0.008	3/2 $^{-}$	
4	**357.40 ± 0.03**	357.396 ± 0.017	5/2 $^{-}$	
5	**536.839 ± 0.008**	536.840 ± 0.007	5/2 $^{+}$	

[a]Weighted-mean of 0.114 (24) ns determined from measurements of 1.13 (3) ns by plastic scintillator and 1.13 (7) ns by beta spectrometer (1972Ja01), and 1.06 (5) ns by delayed coincidence with NaI(Tl) detector and plastic scintillator (1973Ba52); uncertainty increased from ± 0.024 to ± 0.03 ns in alignment with the smallest uncertainty of the values used to calculate the weighted mean.

DDEP evaluation of ^{103}Pd/^{103}Rh^{m}: published γ-ray emission probabilities

Five of ten sets of γ-ray emission probabilities measured by **1969Zo02**, 1969Gr13, 1970NiZV, **1976Ma37**, **2002Bf07**, **2004Po24** and **2021Ri01**.

Weighted-mean values: Avetools, version 3.0, 11 December 2014 (ENSDF analysis code).

E_γ (keV)	P_γ						
	1969Zo02[b]	1969Gr13[c]	1970NiZV[d]	**1976Ma37**[e]	**2002Bf07**[b]	**2004Po24**[b]	**2021Ri01**[c]
39.753 ± 0.006[a]	211 (10)	0.072 (6)	1100 (90)[f]	100	–	–	0.0647 (7)
53.283 ± 0.006	0.03 (1)	–	0.23	0.038 (30)	–	–	< 0.000008
62.41 ± 0.03	2.4 (2)	0.0042 (4)	20 (3)	1.52 (5)	–	–	0.001128 (16)
241.875 ± 0.010	–	< 0.0005[g]	–	0.0007 (7)[g]	–	–	–
294.962 ± 0.015	14.2 (14)	0.0108 (14)	72 (8)	4.1 (1)	14.08 (35)	12.3 (2)	0.00315 (7)
317.72 ± 0.05	0.04 (1)	< 0.0005[g]	0.41 (8)	0.022 (1)	–	–	0.0000137 (17)
357.38 ± 0.08	100.0	0.0610 (30)	531 (5)	32.3 (10)	100.0 (19)	100.0 (10)	0.02486 (17)
443.809 ± 0.010	0.075 (8)	–	0.23 (6)	0.022 (1)	–	–	0.000021 (8)
497.083 ± 0.007	17.5 (18)	0.0140 (14)	100 (10)	5.8 (2)	18.15 (36)	17.6 (3)	0.00439 (7)

[a] Single γ transition of ^{103}Rh^{m} (IT decay).
[b] Emission probabilities expressed relative to Pγ(357.38 keV) of 100.0.
[c] Expressed as absolute γ-ray emission probabilities per decay (1969Gr13) and per 100 decays (2012Ri01).
[d] Emission probabilities expressed relative to Pγ(497.81 keV) of 100 (10).
[e] Emission probabilities expressed relative to Pγ(39.753 keV) of 100.
[f] Statistical uncertainty only.
[g] Gamma emission not observed with confidence.

DDEP evaluation of ^{103}Pd/^{103}Rh^{m}: measured and recommended γ-ray emission probabilities relative to Pγ(357.38 keV) of 100.

Five of ten sets of γ-ray emission probabilities measured by 1954Ri09, 1955Av11, 1955Sa16, **1969Zo02**, 1969Gr13, 1970NiZV, **1976Ma37**, **2002Bf07**, **2004Po24** and **2021Ri01**.
Weighted-mean values: Avetools, version 3.0, 11 December 2014 (ENSDF analysis code).

E_γ (keV)	P_γ					
	1969Zo02	**1976Ma37[b]**	**2002Bf07**	**2004Po24**	**2021Ri01[b]**	**Recommended[c]**
39.753 ± 0.006[a]	211 (10)	310 (10)	–	–	**260 (3)**	**260 (3)[d]**
53.283 ± 0.006	0.03 (1)	0.12 (9)	–	–	< 0.032	**0.0231 (13)[e]**
62.41 ± 0.03	2.4 (2)	**4.71 (21)**	–	–	**4.54 (7)**	**4.56 (7)**
241.875 ± 0.010	–	0.0022 (22)	–	–	–	**0.0032 (3)[f]**
294.962 ± 0.015	14.2 (14)	**12.7 (5)**	14.08 (35)	**12.3 (2)**	**12.7 (3)**	**12.5 (2)[g]**
317.72 ± 0.05	0.04 (1)	**0.068 (4)**	–	–	**0.055 (7)**	**0.065 (6)**
357.38 ± 0.08	100.0	**100 (4)**	**100.0 (19)**	**100.0 (10)**	**100.0 (7)**	**100.0**
443.809 ± 0.010	**0.075 (8)**	**0.068 (4)**	–	–	**0.08 (3)**	**0.070 (4)**
497.083 ± 0.007	**17.5 (18)**	**18.0 (8)**	**18.15 (36) → 18.2 (4)**	**17.6 (3)**	**17.7 (3)**	**17.8 (3)[h]**

[a] Single γ transition of ^{103}Rh^{m} (IT decay).
[b] Emission probabilities adjusted in order to be expressed relative to Pγ(357.38 keV) of 100 and 100.0.
[c] Apart from the highly-converted 39.753-keV γ ray and low-intensity 53.283- and 241.875-keV γ rays, weighted-mean values of the measured relative emission probabilities were adopted with uncertainties that do not fall below the most precise measurements unless stated otherwise in the footnotes below.
[d] While the relative transition probability of the 39.753-keV γ ray is extremely important in defining the decay scheme with any degree of confidence, measurements of this parameter over many years have proved to be difficult and significantly disparate – a value of 260 (3) has been adopted on the basis of the recent well-defined measurement by 2021Ri01.
[e] A relative emission probability of 0.0231 (13) was adopted to achieve γ population-depopulation balance and a direct β^- population of zero for the 93.034-keV nuclear level of ^{103}Rh.
[f] Gamma emission not observed with confidence.
[g] LWM value of 12.45 (16) adjusted to 12.5 (2) to avoid the uncertainty falling below the most precise measurement.
[h] LWM value of 17.78 (18) adjusted to 17.8 (3) to avoid the uncertainty falling below the most precise measurement.

DDEP evaluation of ^{103}Pd/^{103}Rh^{m}: mixing ratio (δ)

Proposed mixing ratios of (M1 + E2) gamma transitions, BrIccMixing, version 2.3d, 28 September 2019.

E_γ (keV)	δ				
	1977Kr13 recommended	**1981Ha11 Measured**	**1981Mu18 measured**	**1983Kr01 re-determined**	**Recommended**
53.28	0.000 (55)	–	–	–	**0.00 (5)**
294.96	− 0.17 (1)[a]	–	–	–	**– 0.170 (13)**
497.08	− 0.125 (10)	**– 0.36 (8)**[a,b]	**– 0.42 (4)**[a]	**– 0.368 (11)**[a]	**– 0.371 (35)**

[a] *Used in BrIccMixing calculations to determine the recommend mixing ratio.*

[b] *Preferred δ value of – 0.36 (8) from gamma-ray angular distributions measurements of β⁻ decay of ^{103}Ru ground state (3/2⁺) at temperatures down to 2.8 mK, compared with δ value of – 0.34 (5) for β⁻ decay of ^{103}Ru ground state (5/2⁺).*

DDEP evaluation of ^{103}Pd/^{103}Rh^{m}: Parent-daughter in secular equilibrium

Parent ^{103}Pd (half-life of 17.00 (5) days) in secular equilibrium with daughter ^{103m}Rh (half-life of 56.115 (16) minutes)

^{103m}Rh($t_{1/2}$) < ^{103}Pd($t_{1/2}$) → ^{103}Pd concentration /^{103m}Rh concentration = $\frac{c_{103Pd}\,(\lambda_{103mRh} - \lambda_{103Pd})}{c_{103mRh} \cdot \lambda_{103mRh}}$

at equal detection coefficients $(c_{103Pd} = c_{103mRh})$, i.e., identical gamma-ray emission energies:

^{103}Pd activity/^{103m}Rh activity = $\frac{(\lambda_{103mRh} - \lambda_{103Pd})}{\lambda_{103mRh}} = \frac{103Pd(t_{1/2}) - 103mRh(t_{1/2})}{103Pd(t_{1/2})}$

^{103m}Rh activity/^{103}Pd activity = $\frac{103Pd(t_{1/2})}{103Pd(t_{1/2}) - 103mRh(t_{1/2})} = \frac{17.00(5)}{17.00(5) - 0.038969(11)} = 1.0023\ (29)$

– not exactly a big conversion factor

DDEP evaluation of ^{103}Pd/^{103}Rh^{m}: Normalisation factor (NF) for absolute γ-ray emission probabilities and EC-decay transition probabilities

Parent ^{103}Pd (half-life of 17.00 (5) days) in secular equilibrium with daughter ^{103m}Rh (half-life of 56.115 (16) minutes): normalisation factor (NF) for gamma rays and EC decay

Determined on the basis of direct γ population of the ground state of ^{103}Rh summing to 100%:

$$\sum(absolute\ \gamma\ transition\ probabilities\ direct\ to\ ^{103}Rh\ ground\ state) = 100$$

$$\Sigma[\{P^{rel}_{slow\gamma}(39.753\ keV)\ x\ (1+\alpha_{tot})\} + \{P^{rel}_{\gamma}(294.962\ keV)\ x\ (1+\alpha_{tot})\} + \{P^{rel}_{\gamma}(357.38\ keV)\ x\ (1+\ \alpha_{tot})\}]\ x\ NF = 100$$

$$[(374660\ (11263)/1.0023\ (29)) +\ 12.74\ (20)\ +\ \ 101.588\ (23)]\ x\ NF\ =\ \ 100$$

secular equilibrium of parent ^{103}Pd and daughter ^{103m}Rh recognised in terms of the delayed emission of the 39.753-keV γ ray (by a factor of 1.0023 (29))

$$373914\ (11290)\ \text{x}\ NF\ =\ 100$$

$$NF\ =\ 100\ /\ 373915\ (11290)\ =\ 0.000267 \pm 0.000008$$

(equivalent total EC summation calculation gives an identical value: NF = 0.000267 ± 0.000008)

Normalisation factor of (0.000267 ± 0.000008) → absolute emission probabilities of γ rays and absolute transition probabilities of EC decay from their relative probabilities.

DDEP evaluation of ^{103}Pd/^{103}Rh^{m}: intensity and uncertainty of 39.753-keV gamma ray

Transition and emission probabilities of 39.753-keV gamma ray derived from the recommended decay scheme.

EC and gamma population of the first excited state of ^{103}Rh:

$$TP_{\gamma}^{rel}(39.753\ keV) = \Sigma[\{P_{EC(0,1)}^{abs} \div NF\} + \{TP_{\gamma}^{rel}(53.28\ keV)\} + \{TP_{\gamma}^{rel}(317.72\ keV)\} + \{TP_{\gamma}^{rel}(497.98\ keV)\}]$$

$= \Sigma[\{99.9646\ (9) \div 0.000267\ (8)\} + 0.071\ (4) + 0.065\ (6) + 17.9\ (3)] = [374399\ (11218) + 18.0\ (3)]$

$= 374417\ (11218)$

$TP_{\gamma}^{abs}(39.753\ keV)$ = 374417 (11218) x 0.000267 (8) = 100 (4)% from above,

and 99.9695 (12)%, if overall accuracy is aligned with the determination of $P_{EC(0,1)}^{abs}(534.9\ keV)$;

also adjustments to $P_{\gamma}^{rel}(39.753\ keV)$ = 260 (11) → 260 (3) adopted from 2021Ri01

and $P_{\gamma}^{abs}(39.753\ keV)$ = 0.069375 (1926)% → 0.0694 (19)%.

DDEP evaluation of ^{103}Pd/^{103}Rh^{m}: recommended energies, and relative and absolute emission and transition probabilities of gammas

Evolution via evaluation, plus BrIcc and GABS, version 12, 20-June-2021 (ENSDF analysis code).

	E_γ (keV)	P_γ^{rel}	TP_γ^{rel}	P_γ^{abs} (%)	TP_γ^{abs} (%)
$\gamma_{1,0}$	39.753 (6)	260 (3)	374417 (11218)	0.069375 (1926) → 0.0694 (19)[a]	100 (4) → 99.9695 (12)[b]
$\gamma_{2,1}$	53.283 (6)	0.0231 (13)	0.071 (4)	0.0000062 (4)	0.0000190 (12)
$\gamma_{4,3}$	62.41 (3)	4.56 (7)	10.55 (18)	0.00122 (4)	0.00282 (10)
$\gamma_{5,3}$	241.875 (10)	0.0032 (3)	0.0032 (3)	0.00000085 (8)	0.00000086 (8)
$\gamma_{3,0}$	294.962 (15)	12.5 (2)	12.74 (20)	0.00334 (11)[a]	0.00340 (11)
$\gamma_{4,1}$	317.72 (5)	0.065 (6)	0.065 (6)	0.0000174 (17)	0.0000175 (17)
$\gamma_{4,0}$	357.38 (8)	100.0	101.588 (23)	0.0267 (8)[a]	0.0271 (8)
$\gamma_{5,2}$	443.809 (10)	0.070 (4)	0.071 (4)	0.0000187 (12)	0.0000189 (12)
$\gamma_{5,1}$	497.083 (7)	17.8 (3)	17.9 (3)	0.00475 (16)	0.00477 (16)

[a] Uncertainties of P_γ^{abs} for three γ emissions that populate the ground state directly and sum to 100% in terms of their transition probabilities were assessed by means of the GABS code, version 12, 20 June 2021 to avoid double accounting of uncertainties (39.753-, 294.96- and 357.38-keV) → P_γ^{abs}(39.753 keV) re-defined as 0.0694 (19)% rather than 0.069 (22)%, whereas there is no equivalent impact on the uncertainties of P_γ^{abs}(294.96- and 357.38-keV).

[b] TP_γ^{abs} adjusted from 100 (4) on the basis of the summed total TP_γ ground-state population of 100%, with contributions of 0.00340 (11)% and 0.0271 (8)% from the 294.96- and 357.38-keV γ transitions, respectively, to give a very precise TP_γ(39.753 keV) of 99.9695 (12)%.

DDEP evaluation of ^{103}Pd/^{103}Rh^{m}: recommended EC energies, absolute transition probabilities, logft and fractional EC probabilities P_K, P_L, P_M and P_N (BetaShape)

BetaShape, version 2.3.1, December 2023 (2015Mo10, 2019Mo35, 2023Mo21).

	E_{EC} (keV)[a]	P_{EC} (%)	^{103}Pd	^{103}Rh	transition type	log *ft*	P_K	P_L	P_{L1}	P_{L2}	P_M	P_N
$EC_{0,5}$	37.9 (24)	0.00480 (16)	5/2 +	5/2 +	allowed	7.33 (11)	0.55 (5)	0.35 (4)	0.34 (4)	0.0065 (7)	0.084 (11)	0.0186 (25)
$EC_{0,4}$	217.3 (24)	0.0300 (9)	5/2 +	5/2 −	1st forbidden non-unique	8.569 (18)	0.8459 (6)	0.1226 (4)	0.1204 (4)	0.002255 (8)	0.02590 (16)	0.00563 (6)
$EC_{0,3}$	279.7 (24)	0.00058 (7)	5/2 +	3/2 −	1st forbidden non-unique	10.52 (5)	0.8518 (5)	0.11804 (25)	0.11587 (25)	0.002171 (6)	0.02479 (13)	0.00538 (5)
$EC_{0,2}$	481.7 (24)	zero	5/2 +	9/2 +	[2nd forbidden non-unique]	–	–	–	–	–	–	–
$EC_{0,1}$	534.9 (24)	99.9646 (9)	5/2 +	7/2 +	allowed	5.880 (6)	0.86086 (30)	0.11104 (15)	0.10899 (15)	0.002047 (4)	0.02310 (11)	0.00501 (4)
$EC_{0,0}$	574.7 (24)	zero	5/2 +	1/2 −	[1st forbidden unique]	–	–	–	–	–	–	–
		Σ 100.0000(13)										

[a] *Determined from the recommended nuclear level energies and Q-value of 574.7 (24) keV (2021Wa16).*

DDEP evaluation of $^{103}Pd/^{103}Rh^{m}$: recommended Auger-electron energies and emission probabilities (BrIccEmis/NS_RadList)

BrIccEmis, 2 March 2021, and NS_RadList, version 1.0, December 2023 (2016Le19, 2020TeZY).
Intensity cut-off of the individual emissions listed below is 0.01 per 100 decays.

		Mean Energy (keV)	Electrons per 100 decays[a]
Auger total	(Rh)	0.650	1283 (12)
Auger K_{tot}	(Rh)	17.708	18.42 (9)
Auger KLL	(Rh)	16.811	12.90 (6)
Auger KLX	(Rh)	19.574	5.043 (24)
Auger KXY	(Rh)	22.275	0.4760 (23)
Auger L_{tot}	(Rh)	2.027	195.0 (20)
Auger Coster-Kronig LLM	(Rh)	0.040	10.41 (+22, -17)
Auger Coster-Kronig LLX	(Rh)	0.142	13.68 (15)
Auger LMM	(Rh)	2.236	143.1 (15)
Auger LMX	(Rh)	2.603	26.45 (28)
Auger LXY	(Rh)	2.977	1.339 (14)
Auger M_{tot}	(Rh)	0.198	514 (5)
Auger Coster-Kronig MMX	(Rh)	0.097	149.5 (13)
Auger MXY	(Rh)	0.239	364.6 (35)
Auger N_{tot}	(Rh)	0.019	555 (5)
Auger super Coster-Kronig NNN	(Rh)	0.019	525 (5)
Auger Coster-Kronig NNX	(Rh)	0.018	30.46 (21)

[a] *Quoted uncertainties include direct contributions from only electron capture and 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).*

DDEP evaluation of ^{103}Pd/^{103}Rh^{m}: recommended X-ray energies and emission probabilities (BrIccEmis/NS_RadList)

BrIccEmis, 2 March 2021, and NS_RadList, version 1.0, December 2023 (2016Le19, 2020TeZY).
Intensity cut-off of the individual emissions listed below is 0.01 per 100 decays.

		Mean Energy (keV)	Photons per 100 decays[a]
X_{tot}	(Rh)	18.640	87.0 (4)
XK_{tot}	(Rh)	20.599	77.5 (4)
XKL2	(Rh)	20.073	22.36 (11)
XKL3	(Rh)	20.215	42.39 (20)
XKM	(Rh)	22.717	10.68 (5)
XKM2	(Rh)	22.699	3.606 (17)
XKM3	(Rh)	22.725	7.021 (33)
XKN	(Rh)	23.171	2.104 (10)
XKN2	(Rh)	23.167	0.7169 (34)
XKN3	(Rh)	23.173	1.383 (7)
XL_{tot}	(Rh)	2.747	9.24 (10)
XM_{tot}	(Rh)	0.324	0.2595 (23)
XN_{tot}	(Rh)	0.048	0.02001 (14)

[a] Quoted uncertainties include direct contributions from only electron capture and 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).

DDEP evaluation of ^{103}Pd/^{103}Rh^{m}: data consistency check

Radiation	Total energy (keV per decay)	Total intensity (%)
Neutrinos	514.8 (21)	–
Gamma rays	0.157 (3)	0.1055 (33)
Conversion electrons	35.2 (+12, -11)	100 (+4, -3)
Auger electrons	8.32 (8)	1283 (12)
X-rays	16.21 (8)	87.1 (4)
Calculated component Q value	574.7 (25)	–
Total effective Q_{EC} value	574.7 (24)	–

^{103}Pd Q_{EC} value of 534.9 (24) keV to metastable excited state of ^{103}Rh^{m} (2021Wa16)
^{103}Rh^{m} Q_{IT} value of 39.753 (6) keV (NUBASE2020, 2021Ko07)

↓

Total effective Q_{EC} → 574.7 (24) keV when defined in terms of ^{103}Pd ground state to ^{103}Rh ground state

Percentage deviation of calculated component Q value = (0.0 ± 0.6)% → consistent decay scheme with a modest variant

DDEP evaluation of $^{103}Rh^{m}$

DDEP evaluation of $^{103}Rh^{m}$: nuclear levels and γ emission of ^{103}Rh

Adopted energies, spins and parities for the relevant nuclear levels of ^{103}Rh

Nuclear level number	Nuclear level energy (keV)	Spin and parity	Half-life
0	0.0	$1/2^-$	stable
1	39.753 ± 0.006	$7/2^+$	(56.115 ± 0.016) min.

Adopted γ-ray emission data: multipolarity and theoretical internal-conversion coefficients (frozen orbital approximation).

	E_γ (keV)[a]	Multipolarity	α_K	α_L	α_{L1}	α_{L2}	α_{L3}	α_M	α_N	α_O	α_{tot}
$\gamma_{1,0}$	39.753 (6)	99.935%E3 = 0.065%M4 δ = 0.025 (+10, -15)	142 (7)	1051 (30)	13 (5)	423 (6)	615 (18)	214 (6)	31.4 (9)	0.024 (11)	1440 (40)

DDEP evaluation of $^{103}Rh^{m}$: recommended energy, absolute emission and transition probabilities of the single γ ray and internal-conversion electrons

γ-ray evaluation includes BrIcc for ICCs

	E_γ (keV)	P_γ^{abs} (%)	$Transition\ probability$ (%)	$\Delta(TP - P_\gamma^{abs})$ (%)[a]
$\gamma_{1,0}$	39.753 (6)	0.0694 (15)	100.0	99.9306 (15)

Conversion electrons

		Energy (keV)	Electrons per 100 decays
$ec_{1,0\ T}$	(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)

DDEP evaluation of $^{103}Rh^{m}$: recommended Auger-electron energies and emission probabilities (BrIccEmis/NS_RadList)

BrIccEmis, 2 March 2021, and NS_RadList, version 1.0, December 2023 (2016Le19, 2020TeZY).
Intensity cut-off of the individual emissions listed below is 0.01 per 100 decays.

		Mean energy (keV)	Electrons per 100 decays[a]
Auger total	(Rh)	0.461	582 (12)
Auger K_{tot}	(Rh)	17.708	1.92 (9)
Auger KLL	(Rh)	16.811	1.34 (6)
Auger KLX	(Rh)	19.574	0.525 (24)
Auger KXY	(Rh)	22.275	0.0495 (22)
Auger L_{tot}	(Rh)	2.139	85.4 (19)
Auger Coster-Kronig LLM	(Rh)	0.038	0.94 (+22, -17)
Auger Coster-Kronig LLX	(Rh)	0.098	5.36 (15)
Auger LMM	(Rh)	2.239	66.2 (15)
Auger LMX	(Rh)	2.600	12.25 (28)
Auger LXY	(Rh)	2.969	0.620 (14)
Auger M_{tot}	(Rh)	0.200	235 (5)
Auger Coster-Kronig MMX	(Rh)	0.103	69.0 (13)
Auger MXY	(Rh)	0.240	166.1 (34)
Auger N_{tot}	(Rh)	0.019	259 (5)
Auger super Coster-Kronig NNN	(Rh)	0.019	249 (5)
Auger Coster-Kronig NNX	(Rh)	0.020	9.94 (21)

[a] Quoted uncertainties include direct contributions from only electron capture and 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).

DDEP evaluation of $^{103}Rh^{m}$: recommended X-ray energies and emission probabilities (BrIccEmis/NS_RadList)

BrIccEmis, 2 March 2021, and NS_RadList, version 1.0, December 2023 (2016Le19, 2020TeZY).
Intensity cut-off of the individual emissions listed below is 0.01 per 100 decays.

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

[a] Quoted uncertainties include direct contributions from only electron capture and 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).

DDEP evaluation of $^{103}Rh^{m}$: data consistency check

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)
Calculated component Q value	39.8 (12)	–
Effective Q_{IT} value	39.753 (6)	–

$^{103}Rh^{m}$ Q_{IT} value of 39.753 (6) keV (NUBASE2020, 2021Ko07)
Calculated component Q value of 39.8 (6) keV
↓
Percentage deviation of calculated Q value = – (0.1 ± 1.5)% → consistent decay scheme with a modest variant

Footnotes

ALPHAD_RadD: hindrance factor of α transition,

DELTA: γ–γ correlation analyses to determine mixing ratios (δ),

BetaShape: average β^- energy, log*ft*; EC energy, log*ft* and fractional EC probabilities,

BrIcc: Band-Raman internal conversion coefficients (Hager and Seltzer, Rösel *et al*., Band and Raman),

BrIccMixing: multipole mixing ratios (δ),

Emission: X-ray and Auger-electron emission probabilities from atomic vacancies created by the nuclear processes,

GABS: absolute intensities and normalization factor of gamma rays,

GTOL: least-squares fit to gamma-ray energies → nuclear-level energies and net feedings to levels,

BrIccEmis/NS_RadList: X-rays, and conversion- and Auger-electron emissions.

Decay-data measurements – why not use the above to assist in the determination of a consistent decay scheme with respect to your own studies and their uncertainty budgets? This is regularly carried out by some authors of papers published in Phys. Rev. C.

Half-lives, tropical year
1 year = 365.2422 days

"…… standing on the shoulders of giants" (in letter dated 1675 written by Isaac Newton)

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IAEA Research Coordination Meeting on "Gamma-ray standards for detector calibration", Rome, 11-13 June 1987
Back: Peter Christmas (NPL),
Dick Helmer (INEL), Nelcy Coursol (LMRI),
Klaus Debertin (PTB)
Front: Alan Nichols (UKAEA, Winfrith),
Walter Bambynek (CEC-JRC, Geel),
R. Jedlovsky (OMH), Frank Schima (NIST),
Y. Yoshizawa-san (Hiroshima University)
Alex Lorenz (IAEA, Nuclear Data Section)



IAEA Consultants' Meeting on "Gamma-ray standards for detector calibration", Grenoble, 30, 31 May 1985
Left to right:
Walter Bambynek (CEC-JRC, Geel),
Peter Christmas (NPL), Klaus Debertin (PTB),
Alan Nichols (UKAEA, Winfrith),
Alex Lorenz (IAEA, Nuclear Data Section),
Rene Vaninbroukx (CEC-JRC, Geel),
Alan Fudge (UKAEA, Harwell),
Dick Helmer (INEL)

elsewhere: T. Barta (OMH), Nelcy Coursol (LMRI), T. Yoshizawa-san (Hiroshima University, photographer)



Second IAEA Research Coordination Meeting on “Update of X- and gamma-ray decay data standards for detector calibration and other applications”, Braunschweig, 10-12 May 2000

Back row:

Alan Nichols (AEA Technology, Culham/Harwell, UK), Gabor Molnar (Institute of Isotope and Surface Chemistry, Budapest, Hungary), Stanislav Hlaváč (Slovak Academy of Sciences, Bratislava, Slovakia), Eckart Schönfeld (PTB, Braunschweig, Germany), Mike Herman, (IAEA-NDS, Vienna, Austria), José Maria Los Arcos (CIEMAT, Madrid, Spain)

Front row:

Andrzej Marcinkowski (Andrzej Soltan Institute for Nuclear Sciences, Warsaw, Poland), Otaviano Helene (Universidade de São Paulo, Brazil), Valery Chechev (V.G. Khlopin Radium Institute, St. Petersburg, Russia), Marie-Martine Bé (DAMRI/LNHB, Saclay, France), Dick Helmer (INEL, Idaho Falls, USA), Mike Woods (NPL, Teddington, UK)