ANNEX II:

COMMENTS ON EVALUATIONS

In the process of evaluating and recommending decay-data quantities, the CRP participants have made various decisions based on the availability and reliability of published data.

In carrying out these assessments, data may be deemed inappropriate to be kept in a data set and discarded; data may be renormalized based on the latest recommendations; or data uncertainties may be adjusted.

Each evaluator has documented this evaluation process and the reasons why certain data were rejected, adjusted or accepted.

This Annex collates all of these comments and should serve as a starting point for any future evaluation effort - as they form a high quality assessment of the currently available data. The comments for each radionuclide include the name of the evaluator and the date of the evaluation.

ANNEX II: COMMENTS ON EVALUATIONS

^{206}Hg - Comments on evaluation of decay data by F. G. Kondev

This evaluation was completed in May 2011 with a literature cut off by the same date. The Saisinuc software (2008DuZX) and associated supporting programs were used in assembling the data following the established protocol within the DDEP collaboration.

1 Decay Scheme

The nuclide ^{206}Hg disintegrates 100 % by β^- emissions. The strongest β^--decay branch of 62 (7) % populates the $J^\pi = 0^-$ ground state of the daughter nuclide ^{206}Tl. The level schemes of ^{206}Hg and ^{206}Tl are based on the ENSDF evaluations of Browne (1999Br39) and Kondev (2008Ko21).

2 Nuclear Data

$Q(\beta^-)$ value is taken from the evaluation of Audi et al (2003Au03).

The experimental half-life data for the ^{206}Hg ground state are presented in Table 1. These data were evaluated using different techniques (see for example 1992Ra08, 1994Ka08 and 2004Mb11 and references therein) and the results are presented in Table 2. The LRSW value of $T_{1/2}$ = 8.32 (7) min is recommended here with χ^2_ν = 3.22 ($\chi^2_\nu = \chi^2$/N-1) which is smaller than the critical value of $\chi^2_{\nu\ cryt}$ = 4.61 (99 % confidence level). The lifetimes assigned to the excited states of the daughter nuclide ^{206}Tl are taken from the ENSDF evaluation of Browne (1999Br39).

Table 1. Experimental data for the half-life of ^{206}Hg.

Author	**$T_{1/2}$ (min)**	**Used in the evaluation**
1961Nu01	7.5 (10)	No
1962Ka27	8.5 (1)	Yes
1964Wo05	8.1 (4)	Yes
1968Wo08	8.15 (10)	Yes

Table 2. Evaluated values for the half-life of ^{206}Hg.

Method/Author [a)]	**Evaluated $T_{1/2}$ (min)**	**χ^2/N-1**
UWM	8.25 (13)	3.70
WM	8.32 (7)	3.22
LRSW	8.32 (7)	3.22
NRM	8.27 (8)	2.30
RM	8.18 (9)	0.38
1999Br39	8.15 (10)	

[a)] UWM – Unweighted Mean; WM – Weighted Mean; LRSW – Limitation of Relative Statistical Weight; NRM – Normalized Residual; RM – Rajeval.

2.1 β- Transitions

Information of level and maximum β^--decay energies, $E_{\beta\ max}$, and β^--decay transition probabilities, P_β, and log *ft* values is presented in Table 3. The $E_{\beta\ max}$ values for the $\beta_{0,2}$ and $\beta_{0,3}$ transitions were determined from Q(β^-) (2003Au03) and the excitation energies for the 1^- states, deduced from the corresponding γ–ray transition energies (see section 2.2 and Table 4 for details). The $P_{\beta0,2}$ and $P_{\beta0,3}$ values were deduced from the decay scheme and the corresponding absolute γ–ray transition probabilities, as detailed in section 2.2 and Table 4. It was assumed that no direct β^--decay feeding takes places to the first excited state at 265.8 keV (J^π = 2-), since such a transition is a second-fold forbidden non-unique, and hence, the $\beta_{0,0}$ transition probability was determined as:

$$P_{\beta 0,0} = 100 - P_{\beta 0,2} - P_{\beta 0,3} \qquad (1)$$

The log *ft* values were calculated using the LOGFT program from the ENSDF evaluation package.

Table 3. Level energies, $E_{\beta\ max}$, P_β and log *ft* values in decay of ^{206}Hg.

	Level energy (keV)	**$E_{\beta-\ max}$ (keV)**	**P_β (%)**	**Nature**	**log *ft***
$\beta_{0,0}$	0.0	1308 (20)	62 (7)	First forbidden non-unique	5.67 (10)
$\beta_{0,2}$	304.896 (6)	1003 (20)	35 (7)	First forbidden non-unique	5.24 (10)
$\beta_{0,3}$	649.42 (5)	659 (20)	3.0 (4)	First forbidden non-unique	5.41 (6)

2.2 γ Transitions

The γ–ray transition energies, multipolarities, absolute transition probabilities and electron internal conversion coefficients are presented in Table 4.

Table 4. Energies, multipolarities, absolute transition probabilities and electron internal conversion coefficients for γ–ray transitions following β^-–decay of ^{206}Hg.

	Energy (keV)	Pγ+ce (%)	Multi-polarity	α_K	α_L	α_M	α_T
$\gamma_{1,0}$	265.832 (5)	0.014 (7)	E2	0.0855 (12)	0.0561 (8)	0.01440 (21)	0.1603 (23)
$\gamma_{2,0}$	304.896 (6)	36 (7)	M1	0.308 (5)	0.0519 (8)	0.01211 (17)	0.375 (6)
$\gamma_{3,0}$	649.42 (5)	2.3 (3)	M1	0.0412 (6)	0.00681 (10)	0.001585 (23)	0.0501 (7)
$\gamma_{3,2}$	344.52 (17)	0.70 (14)	M1	0.221 (4)	0.0371 (6)	0.00866 (13)	0.269 (4)
$\gamma_{3,1}$	383.59 (6)	0.014 (7)	M1(+E2)	0.10 (7)	0.021 (7)	0.0050 (15)	0.13 (8)

The γ–ray transition energies and multipolarities are taken from the ENSDF evaluation of Browne (1999Br39). The γ(3,1) energy is deduced from the adopted level energies difference. The electron internal conversion coefficients were calculated using a program supplied by the Saisinuc software (2008DuZX) which uses interpolated values of Band et al (2002Ba85) with the hole being taken into account. These are consistent with values given by the BrIcc program (2008Ki07). The $P_{\beta0,2}$ value was deduced from the reported in 1968Wo08 absolute γ–ray transition probabilities for the 304.9 keV transition of $P_{\gamma2,0+ce}$(304.9γ) = 36 (7) % and by taking into account a small feeding from the 1^- level at 649.4 keV via the 344.5 keV γ–ray transition. The $P_{\gamma+ce}$ values for the γ(1,0) and γ(2,1) transitions were determined from the absolute γ–ray emission probabilities, P_γ, shown in Table 5, and the total electron internal conversion coefficients as:

Table 5

	Relative Intensity				Abs. Total Int. (%)
E level (keV)	Eγ (keV)	1970As05	1969La18	1976TuZY	1968Wo08
265.832	265.832 (5)				
304.896	304.896 (6)	100 (1)			36 (7)
649.42	344.52 (17)	2.4 (1)	1.4	1.4	
	383.59 (6)			0.011	
	649.42 (5)	8.4 (17)	5.6	7.7	5 (2)

3 Atomic Data

The atomic data (fluorescence yields, X-ray energies and relative probabilities, and Auger electrons energies and relative probabilities) were provided by the Saisinuc software (2008DuZX). Details regarding the origin of these data can be found in 1996Sc06, 1998ScZM, 1999ScZX, 2000Sc47 and 2003De44.

4 Emissions

4.1 Photon emissions

The number of γ rays per 100 disintegrations was evaluated from the available experimental data, as described in section 2.2 (see also Table 5).

5 Electron emissions

The energies of the conversion electrons were calculated from the γ–ray transition energies presented in Table 4 and the corresponding electron shell binding energies (1977La19). The number of conversion electrons of type x=T,K and L where T stands for total, K and L for K- and L-shell electrons, per 100 disintegrations was calculated from the recommended in the present evaluation (see Table 5) numbers of photons per 100 disintegrations, $P_{\gamma1,0}$, and the corresponding electron internal conversion coefficients (see Table 4), $\alpha_{x1,0}$: $ec_{1,0x} = P_{\gamma1,0} \times \alpha_{x1,0}$.

The number of K and L Auger electrons per 100 disintegrations, $P(e_{AK(L)})$ was calculated from the number of vacancies in the K and L shells and the corresponding $P_{XK(L)}$ yield: $P(e_{AK}) = N_K - P_{XK}$ and $P(e_{AL}) = N_L - P_{XL}$.

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^{206}Tl - Comments on Decay Data Evaluation

by F.G. Kondev

This evaluation was completed in September 2006 with a literature cut off by the same date. The Saisinuc software (2002BeXX) and associated supporting programs were used in assembling the data following the established protocol within the DDEP collaboration.

1. Decay Scheme

The nuclide ^{206}Tl ($J^{\pi}=0^{-}$) disintegrates 100 % by β^{-} emissions. The strongest β^{-}-decay branch of 99.885 (14) % populates the $J^{\pi}=0^{+}$ ground state of the daughter nuclide ^{206}Pb. The level schemes of ^{206}Tl and ^{206}Pb are based on the ENSDF evaluation of Browne (1999Br39).

2. Nuclear Data

$Q(\beta^{-})$ value is taken from the evaluation of Audi *et al.* (2003Au03).

The experimental half-life data for the ^{206}Tl ground state are presented in Table 1. These data were evaluated using different techniques (see for example 1992Ra08, 1994Ka08 and 2004MaXX and references therein) and the results are presented in Table 2. The value of 1961Nu01 was excluded from the data analysis, since no uncertainty was quoted in the original publication. The LRSW value of $T_{1/2}$=4.202 (11) min is recommended here with χ^2_{ν} = 1.54 ($\chi^2_{\nu} = \chi^2$/N-1) which is smaller than the critical value of $\chi^2_{\nu\ crit}$ = 2.64 (99 % confidence level). The lifetimes of the excited states of the daughter nuclide ^{206}Pb are taken from the ENSDF evaluation of Browne (1999Br39).

Table 1. Experimental data for the half-life of ^{206}Tl

Author	$T_{1/2}$, min	Used in the evaluation
1941Fa04	4.23 (3)	Yes
1953Sa11	4.19 (2)	Yes
1959Po64	4.29 (5)	Yes
1961Nu01	4.2	No
1970Fl12	4.27 (5)	Yes
1971Pe03	4.183 (17)	Yes
1972CoYX	4.14 (5)	Yes
1972Gr01	4.2 (2)	Yes
1972Wi18	4.27 (5)	Yes

Table 2. Evaluated values for the half-life of ^{206}Tl

Method/Author [a)]	**Evaluated $T_{1/2}$, min**	c^2**/N-1**
UWM	4.222 (19)	2.02
WM	4.202 (11)	1.54
LRSW	4.202 (11)	1.54
NRM	4.202 (11)	1.54
RM	4.202 (11)	1.41
1999Br39	4.200 (17)	

[a)] UWM – Unweighted Mean; WM – Weighted Mean; LRSW – Limitation of Relative Statistical Weight; NRM – Normalized Residual; RM – Rajeval.

2.1. b^- **Transitions**

The experimental data for the maximum $\beta_{0,0}$ energy, $E_{\beta 0,0\ max}$, are presented in Table 3. The LRSW value of 1527 (3) keV (χ^2_ν = 1.48 is smaller than $\chi^2_{\nu\ crit}$ = 4.61 (99 % confidence level)) is comparable with Q(β^-) = 1532.4 (6) keV (2003Au03). The $E_{\beta\ max}$ values for the $\beta_{0,1}$ and $\beta_{0,2}$ transitions were determined from Q(β^-) (2003Au03) and the 2^+ and 0^+ level energies that were deduced from the corresponding transition energies (see section 2.2 and Table 4 for details). The $\beta_{0,1}$ and $\beta_{0,2}$ transition probabilities, P_β, were deduced from the decay scheme and the corresponding absolute γ–ray transition probabilities, $P_{\gamma+ce}$, as detailed in section 2.2 and Table 5. The P_β value for the $\beta_{0,1}$ transition is an upper limit, since the possible feeding from the 1166.4 keV level ($J^\pi=0^+$) via the yet unobserved 363.3 keV γ–ray transition ($\gamma_{2,1}$) was not taken into account. It should be noted that only a limit for $P_{\gamma 2,1}$ is reported in the literature (see section 2.2 for details). The $\beta_{0,0}$ transition probability was determined as: $P_{b\,0,0} = 100 - P_{b\,0,1} - P_{b\,0,2}$.

The lg *ft* values were calculated using the LOGFT program from the ENSDF evaluation package. The lg *f* values are based on the work of Gove and Martin (1971Go40). For the first forbidden $\beta_{0,0}$ transition (0^- ->0^+) the shape factor was measured by several authors, as shown in Table 3. The fit to the experimental data using the expression $S(W) = 1 + aW + b/W$, where W is the electron energy, yields the shape factor coefficients, *a* and *b*, which are also presented in Table 3. The value of $a = -$ 0.020 (2) (with *b* = 0.000) (1972Wi18) is recommended in the present evaluation. It should be noted that using this parameterization of the shape factor, a lg *f* value of 2.85 for the $\beta_{0,0}$ transition (0^- ->0^+) can be obtained. It is in a good agreement with lg *f* = 2.78, deduced using the LOGFT program (1971Go40).

Table 3. Measured $E_{\beta 0,0\ max}$ values and shape factor parameters *a* and *b* (S(W)=1+*a*W+*b*/W) for the first forbidden $0^- \rightarrow 0^+$ decay of ^{206}Tl

Author	***a***	***b***	**$E_{b0,0\ max}$, keV**	**Used in the evaluation**
1951Al14			1510 (10)	No
1961Ho17	-0.154	-0.484	1571 (10)	No
1970Fl12	-0.017 (5)	0.030 (9)	1523 (4)	Yes
1971Pe03	0.00 (1)	0.00	1534 (5)	Yes
1972Wi18	-0.020 (2)	0.000	1527 (4)	Yes
Adopted	**-0.020 (2)**	**0.000**	**1532.4 (6)**	

Table 4. Level energies, $E_{\beta\ max}$, P_β and log *ft* values in decay of ^{206}Tl

	Level energy, keV	**$E_{b-\ max}$, keV**	**P_b ´ 100**	**Nature**	**log *ft***
$\beta_{0,0}$	0.0	1532.4 (6)	99.885 (14)	First forbidden	5.1775 (13)
$\beta_{0,1}$	803.06 (3)	729.3 (6)	0.0051 (3)	First forbidden Unique	8.60^{1U} (3)
$\beta_{0,2}$	1166.4 (5)	366.0 (8)	0.110 (14)	First forbidden	5.99 (6)

2.2 Gamma Transitions and Electron Internal Conversion Coefficients

The γ–ray transition energies, multipolarities, absolute transition probabilities and electron internal conversion coefficients are presented in Table 5.

The γ–ray transition multipolarities are taken from the ENSDF evaluation of Browne (1999Br39). The recommended γ1,0 transition energy of 803.06 (3) keV is determined as the weighted mean of 803.10 (5) keV (1972Ma63) and 803.04 (3) keV (1996Ra16), the two most precise values reported in the literature. The γ2,0 transition between the excited 0^+ level and the 0^+ ground state is a pure E0, and hence, there is no γ–ray component associated with the decay of the former level. The transition energy is taken from the work of Draper *et al.* (1977Dr08) where the K-shell conversion electron energy was measured with a Si(Li) detector. The γ2,1 transition was not observed and its energy is inferred from the energy difference between the excited 0^+ and 2^+ levels. The electron internal conversion coefficients were calculated using a program supplied by the Saisinuc software (2002BeXX) which uses interpolated values of Band *et al.* (2002Ba85) with the hole being taken into account. The $P_{\gamma+ce}$ values for the γ1,0 and γ2,1 transitions were determined from the absolute γ–ray emission probabilities, P_γ, shown in Table 6, and the total electron internal conversion coefficients as: $P_{g+ce} = P_g \times (1 + a_T)$.

Experimental and evaluated P_γ values are shown in Table 6. The LRSW value of $P_{\gamma 1,0}$= 0.0050 (3) % (χ^2_ν = 2.40 is smaller than $\chi^2_{\nu\ cryt}$ = 4.61 (99 % confidence level)) is recommended for the γ1,0 transition. As stated above, the $\gamma_{2,1}$ transition was not observed experimentally and only a limit for its absolute emission probability was given in 1972CoYX and 1972Gr01. The value of $P_{\gamma2,1}$ < 0.00026 % (1972CoYX) is adopted in the present evaluation. The γ2,0 transition is a pure E0 ($0^+ \rightarrow 0^+$) and hence $P_{\gamma2,0}$ is zero. The recommended $P_{\gamma+ce}(\gamma_{2,0})$ value here is deduced from the measured absolute KX-ray yield, $P_{XK}(\gamma_{2,0})$, the corresponding fluorescence yield, ω_K, and the K/T conversion electrons ratio. The value of $P_{XK}(\gamma_{2,0})$ = 0.09 (1) %, deduced as a weighted mean of 0.08 (2) % (1972CoYX) and 0.10 (2) % (1972Gr01) (see Table 6), is adopted in the present work. It should be noted that an electron shake-off component of 0.02 % has been taken into account in these values. The K-shell to total conversion electrons ratio of K/T = 0.85 (6) was deduced from K/L = 5.7 (4), a weighted mean of the measured K/L = 5.61 (38) and 6 (1) in 1990Tr01 and 1977Dr08, respectively. This value is in very good agreement with that of K/T = 0.855, calculated using the electronic factors of Ω_K(E0) and Ω_L(E0) that are given by the BRICC program (2005KiZW). Using a K-fluorescence yield value of ω_K = 0.963 (4) (1996Sc06) one then obtains:

$$P_{g+ce}(g\,2{,}0) = P_{ce}(g\,2{,}0) = \left(P_{KX}(g\,2{,}0)/w_K\right)/(K/T) = 0.110\ (14)\ \%$$

Table 5. Energies, multipolarities, absolute transition probabilities and electron internal conversion coefficients for γ–ray transitions following β^-–decay of ^{206}Tl

	Energy, keV	$P_{\gamma+ce}$ × 100	Multi-polarity	α_K	α_L	α_M	α_N	α_T
$\gamma_{1,0}$	803.06 (3)	0.0051 (3)	E2	0.00801 (24)	0.00174 (5)	4.19 (13)10^{-4}	1.06 (3)10^{-4}	0.0103 (3)
$\gamma_{2,1}$	363.3 (5)	0.00015 (15)	(E2)	0.0414 (12)	0.0187 (6)	0.00476 (14)	0.00120 (4)	0.066 (2)
$\gamma_{2,0}$	1166.4 (5)	0.110 (14)	E0					

Table 6 Experimental and evaluated γ–ray emission probabilities.

Authors	**$P_{g1,0}$, %**	**$P_{XK}(g_{2,0})$ %** [a]	**$P_{g2,1}$, %**	**Comment** [b]
1968Zo02	0.0055 (5)			Not used
1970Zo02	0.0055 (4)			Expt.
1972CoYX	0.0041 (6)	0.08 (2)	<0.00026	Expt.
1972Gr01	0.004 (1)	0.10 (2)	<0.001	Expt.
Adopted	**0.0050 (3)**	**0.09 (1)**	**<0.00026**	**Evaluated**

[a] Absolute KX-ray yield
[b] Expt. – experimental value used in the present evaluation. The 1968Zo02 value is superseded by 1970Zo02

3. Atomic Data

The Atomic data (Fluorescence yields, X-Ray energies and Relative probabilities, and Auger electrons energies and Relative probabilities) were provided by the Saisinuc software (2002BeXX). Details regarding the origin of these data can be found in 1996Sc06, 1998ScZM, 1999ScZX, 2000ScXX and 2003DeXX.

4. Photon Emissions

4.1 X-Ray Emissions

The X-ray yield in β^- decay of ^{206}Tl is produced entirely in the decay of the 1166.4 keV (E0, $0^+ \rightarrow 0^+$) transition. Contributions from the much weaker 803.06 and 363.3 keV transitions can be neglected, since their X-ray yields are several orders of magnitude smaller than that of the 1166.4 keV transition.

For the 1166.4 keV E0 ($0^+ \rightarrow 0^+$) transition, the number of vacancies in the K-shell per 100 disintegrations was determined as:

$$N_K = P_{ceK} = P_{XK} / w_K = 0.090\,(10) / 0.963\,(4) = 0.093\,(11).$$

The corresponding number of vacancies in the L shell per 100 disintegrations was then determined as:

$$N_L = P_{ceL} + n_{KL} \times N_K = 0.0163\,(22) + 0.811\,(5) \times 0.093\,(11) = 0.092\,(11)\ \%$$

where $P_{ceL} = P_{ceK} / (K/L) = 0.0163\,(22)\ \%$ with K/L= 5.7 (4), a weighted mean of 5.61 (38) (1990Tr01) and 6 (1) (1977Dr08). The number of X-rays per 100 disintegrations was then calculated as:

$$P_{XK} = w_K \times N_K \text{ and } P_{XL} = \overline{w}_L \times N_L$$

4.2 Gamma Emissions

The number of γ rays per 100 disintegrations was evaluated from the available experimental data, as described in section 2.2 (see also Table 6).

5. Electron Emissions

The energies of the conversion electrons were calculated from the γ–ray transition energies presented in Table 5 and the corresponding electron shell binding energies (1977La19). For the γ1,0 transition, the number of conversion electrons of type x = T,L,M,N and O, where T stands for total, L for L-shell electrons, etc., per 100 disintegrations was calculated from the absolute photon intensity ($P_{\gamma 1,0}$ per 100 disintegrations) recommended in the present evaluation (see Table 6), and the corresponding electron internal conversion coefficients (see Table 5), $\alpha_{x1,0}$: $ec_{1,0x} = P_{\gamma 1,0} \times \alpha_{x1,0}$. For the γ2,0 transition, the number of K and L conversion electrons per 100 disintegrations was determined from the measured P_{XK} yield, w_K value and the K/L sub-shell ratio, as detailed in section 4.1.

The number of K and L Auger electrons per 100 disintegrations, $P(e_{AK(L)})$ was calculated from the number of vacancies in the K and L shells and the corresponding $P_{XK(L)}$ yield: $P(e_{AK}) = N_K - P_{XK}$ and $P(e_{AL}) = N_L - P_{XL}$.

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^{207}Tl - Comments on evaluation of decay data by F. G. Kondev

This evaluation was completed in September 2010, with a literature cut off by the same date, as a part of ANL commitment to the IAEA-CRP on "Updated Decay Data Library for Actinides".

1 Decay Scheme

The nuclide ^{207}Tl ($J^{\pi} = 1/2^{+}$) disintegrates 100 % by β^{-} emission. The strongest β^{-}-decay branch of 99.729 (10) % populates the $J^{\pi} = 1/2^{-}$ ground state of the daughter nuclide ^{207}Pb. The level schemes of ^{207}Tl and ^{207}Pb, including level energies and J^{π} values, are based on the ENSDF evaluation of Kondev and Lalkovski (2011Ko04).

2 Nuclear Data

Adopted $Q(\beta^{-})$ value of 1418 (5) keV is taken from the evaluation of Audi *et al.* (2003Au03).

The experimental half-life data for the ^{207}Tl ground state are listed in Table 1. The LRSW value of $T_{1/2}$ = 4.774 (12) min was adopted (χ^2_{ν} = 0.38, which is smaller than the critical value of $\chi^2_{\nu\ crit}$= 3.78 (99 % confidence level)).

Table 1. Experimental data for the half-life of ^{207}Tl.

Author	$T_{1/2}$ (min)	Used in evaluation
1931Cu01	4.76 (2)	Yes
1940Fa04	4.77 (5)	Yes
1953Sa11	4.79 (2)	Yes
1967Tr01	4.77 (3)	Yes

2.1 β- Transitions

The values for the maximum β^{-}-decay energies, $E_{\beta-,max}$, presented in Table 2, were deduced from $Q(\beta^{-})$ = 1418 (5) keV (2003Au03) and the adopted level energies of ENSDF (2011Ko04). The β^{-}-decay transition probabilities (P_{β}) were deduced from the decay scheme and the corresponding absolute γ transition probabilities. Comparisons with other measured values are given in Table 3. The log *ft* values were calculated using the LOGFT program from the ENSDF evaluation package, based on the work of Gove and Martin (1971Go40).

Table 2. Level energies, quantum numbers, $E_{\beta0,\iota\ max}$, P_{β} and log *ft* values in decay of ^{207}Tl.

	Level energy (keV)	J^{π}	$E_{\beta-\ max}$ (keV)	P_{β} (%)	Nature	log *ft*
$\beta_{0,2}$	897.698 (17)	3/2-	520 (5)	0.271 (10)	First forbidden non-unique	6.15
$\beta_{0,1}$	569.6982 (20)	5/2-	848 (5)	$< 8\times10^{-5}$	First forbidden unique	$> 10.8^{1U}$
$\beta_{0,0}$	0.0	1/2-	1418 (5)	99.729 (10)	First forbidden non-unique	5.11

Table 3. Beta-decay transition probabilities (P_β) in decay of ^{207}Tl.

	Present work (%)	1967Da10 (%)	1963Ch09 (%)	1988Hi14 (%)
$\beta_{0,2}$	0.271 (10)	0.24	0.155 (20)	
$\beta_{0,1}$	< 8×10^{-5}	< 1×10^{-2}		< 8×10^{-5}
$\beta_{0,0}$	99.729 (10)	99.76	99.845 (20)	

2.2 γ Transitions

The γ–ray energies, multipolarities, absolute transition probabilities and electron internal conversion coefficients are listed in Table 4. γ transition multipolarities are taken from the ENSDF evaluation of Kondev and Lalkovski (2011Ko04), while the electron conversion coefficients were calculated using the BrIcc code (2008Ki07).

The P_γ(897.77 γ) value of 0.263 (9) % was deduced from the intensity ratio of I_γ(898γ)/I_γ(351γ) = 0.0202 (7) (1988Hi14) and P_γ(351γ in ^{211}Bi α decay) = 13.02 (12) %. A P_γ(328.10γ) value of 0.00142 (14) % was deduced from the intensity ratio of I_γ(328.10γ)/I_γ(898γ) = 0.0054 (5) (1988Hi14) and P_γ(897.77γ) = 0.263 (9) %, as described above. The absolute emission probability for the 569.698 γ of 0.00185 (19) % was deduced from the intensity balance at the 569-keV level and by neglecting the small β^- decay feeding contribution of < 8x10^{-5} reported in 1988Hi14. The mixing ratio of + 0.091 (9) for the 569.698-keV transition was deduced as a weighted average of + 0.096 (11) (1970Kl03), + 0.075 (25) (1972Ha59), + 0.075 (25) (1976Av01), and + 0.11 (6) (1973Ba38).

Table 4. Energies, multipolarities, mixing ratios, absolute emission probabilities and electron internal conversion coefficients for γ transitions following the β^-–decay of ^{207}Tl.

	Energy (keV)	Multi-polarity	δ	P_γ (%)	α_K ×10^{-2}	α_L ×10^{-3}	α_M ×10^{-4}	α_{N+} ×10^{-4}	α_T
$\gamma_{2,0}$	897.77 (12)	M1+E2	+0.091 (9)	0.263 (9)	1.92 (3)	3.18 (5)	7.41 (11)	2.30 (4)	0.0233 (4)
$\gamma_{2,1}$	328.10 (12)	[M1]		0.00142 (14)	27.3 (4)	46.6 (7)	109.0 (16)	33.8 (5)	0.334 (5)
$\gamma_{1,0}$	569.698 (2)	E2		0.00185 (19)	1.584 (23)	4.39 (7)	10.81 (16)	3.30 (5)	0.0216 (3)

3 Atomic Data

The atomic data (fluorescence yields, X-ray energies and relative probabilities, and Auger electrons energies and relative probabilities) were provided by the SAISINUC software (2008DuZX). Details regarding the origin of these data can be found in 1996Sc06, 1998ScZM, 1999ScZX, 2000Sc47 and 2003De44.

4 Emissions

4.1 K x-rays

The X-ray data have been calculated using the evaluated gamma-ray data, and the atomic data from 1996Sc06, 1998ScZM and 1999ScZX. Both the X-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program. This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

5 Electron emissions

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

6 References

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^{208}Tl – Comments on evaluation of decay data by A. L. Nichols

Evaluated: July/August 2001
Re-evaluated: January 2004 and July 2010

Evaluation Procedures

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

Decay Scheme

The ground state of ^{208}Tl ($J^{\pi} = 5^{+}$) decays by beta minus emission to various excited levels of ^{208}Pb. A consistent decay scheme has been derived, assuming no direct beta decay to both the 2614.55-keV nuclear level and ground state of ^{208}Pb (based on spin-parity considerations). This decay scheme is primarily based on the gamma-ray measurements of 1960Em01, 1960Sc07, 1961Si11, 1969Au10, 1969La23, 1969Pa02, 1972DaZA/1973Da38, 1972Ja25, 1975Ko02, 1977Ge12, 1978Av01, 1982Sa36, 1983Sc13, 1983Va22, 1984Ge07, 1992Li05 and 1993El08.

Nuclear Data

^{228}Th decay chain is important in quantifying the environmental impact of the decay of naturally-occurring ^{232}Th. Specific radionuclides in this decay chain are noteworthy because of their decay characteristics (^{224}Ra alpha decay to ^{220}Rn; ^{212}Bi and ^{208}Tl gamma-ray emissions).

Half-life

The half-life is the weighted mean of the measurements of 1957Ba05, 1967La20, 1970Mu21 and 1971Ac02, with the uncertainty increased artificially to encompass the most precise study.

Reference	**Half-life (min)**
1957Ba05	3.100 (15)
1967La20	3.055 (6)
1970Mu21	3.17 (5)
1971Ac02	3.0527 (33)*
Recommended value	3.058 (6)#

* Uncertainty adjusted to ± 0.0055 to reduce weighting to no more than 0.50.
\# Weighted mean adopted, with uncertainty increased to include most precise value.

Gamma Rays

Energies

Both the 583.187 (2)- and 2614.511 (10)-keV gamma-ray energies were taken from 2000He14. All other gamma-ray transition energies were calculated from the structural details of the proposed decay scheme; the nuclear level energies of 2007Ma45 were adopted, and used to determine the energies and associated uncertainties of the gamma-ray transitions between the various populated-depopulated levels.

Adopted nuclear levels of ^{208}Pb: Energy, J^{π} and origins (2007Ma45).

Nuclear level	Nuclear level energy (keV)*	J^{π}	Origins
0	0.0	0 +	^{208}Bi EC decay, **^{208}Tl β^- decay**, ^{212}Po α decay, ^{206}Pb(t,x), ^{207}Pb(n,γ), ^{207}Pb(d,x), ^{208}Pb(γ, x), ^{208}Pb(e,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{210}Pb(p,x), ^{209}Bi(d,x), ^{209}Bi(t,x), Coulomb excitation, etc.
1	2614.552 ± 0.010	3 –	^{208}Bi EC decay, **^{208}Tl β^- decay**, ^{212}Po α decay, ^{206}Pb(t,x), ^{207}Pb(n,γ), ^{207}Pb(d,x), ^{208}Pb(e,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{210}Pb(p,x), ^{209}Bi(d,x), ^{209}Bi(t,x), Coulomb excitation, etc.
2	3197.711 ± 0.010	5 –	**^{208}Tl β^- decay**, ^{212}Po α decay, ^{206}Pb(t,x), ^{207}Pb(d,x), ^{208}Pb(e,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{210}Pb(p,x), ^{209}Bi(d,x), ^{209}Bi(t,x), Coulomb excitation, etc.
3	3475.078 ± 0.011	4 –	**^{208}Tl β^- decay**, ^{207}Pb(d,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{209}Bi(d,x), etc.
4	3708.451 ± 0.012	5 –	**^{208}Tl β^- decay**, ^{206}Pb(t,x), ^{207}Pb(d,x), ^{208}Pb(e,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{209}Bi(d,x), ^{209}Bi(t,x), etc.
5	3919.966 ± 0.013	6 –	**^{208}Tl β^- decay**, ^{207}Pb(d,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), etc.
6	3946.578 ± 0.014	4 –	**^{208}Tl β^- decay**, ^{207}Pb(d,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{209}Bi(d,x), etc.
7	3961.162 ± 0.013	5 –	**^{208}Tl β^- decay**, ^{206}Pb(t,x), ^{207}Pb(d,x), ^{208}Pb(e,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{210}Pb(p,x), ^{209}Bi(d,x), ^{209}Bi(t,x), etc.
8	3995.438 ± 0.013	4 –	**^{208}Tl β^- decay**, ^{207}Pb(n,γ), ^{207}Pb(d,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{209}Bi(d,x), etc.
9	4037.443 ± 0.014	7 –	^{206}Pb(t,x), ^{207}Pb(d,x), ^{208}Pb(e,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{210}Pb(p,x), etc.
10	4051.134 ± 0.013	3 –	^{207}Pb(n,γ), ^{207}Pb(d,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{209}Bi(d,x), etc.
11	4085.52 ± 0.04	2 +	^{206}Pb(t,x), ^{207}Pb(n,γ), ^{207}Pb(d,x), ^{208}Pb(γ, x), ^{208}Pb(e,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{210}Pb(p,x), ^{209}Bi(d,x), Coulomb excitation, etc.
12	4125.347 ± 0.012	5 –	**^{208}Tl β^- decay**, ^{207}Pb(d,x), ^{208}Pb(e,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{209}Bi(d,x), ^{209}Bi(t,x), etc.
13	4180.414 ± 0.014	5 –	**^{208}Tl β^- decay**, ^{206}Pb(t,x), ^{207}Pb(d,x), ^{208}Pb(e,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{210}Pb(p,x), ^{209}Bi(d,x), etc.
14	4206.277 ± 0.004	6 –	^{207}Pb(d,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{209}Bi(d,x), etc.
15	4229.590 ± 0.017	2 –	^{207}Pb(n,γ), ^{207}Pb(d,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x)
16	4254.795 ± 0.017	3 –	^{206}Pb(t,x), ^{207}Pb(n,γ), ^{207}Pb(d,x), ^{208}Pb(e,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{210}Pb(p,x), ^{209}Bi(d,x)
17	4261.871 ± 0.013	4 –	**^{208}Tl β^- decay**, ^{207}Pb(d,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{209}Bi(d,x), etc.
18	4296.560 ± 0.013	5 –	**^{208}Tl β^- decay**, ^{206}Pb(t,x), ^{207}Pb(d,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{210}Pb(p,x), ^{209}Bi(d,x), etc.
19	4323.946 ± 0.014	4 +	**^{208}Tl β^- decay**, ^{206}Pb(t,x), ^{207}Pb(d,x), ^{208}Pb(e,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{210}Pb(p,x), ^{209}Bi(d,x), etc.
20	4358.670 ± 0.013	4 –	**^{208}Tl β^- decay**, ^{207}Pb(d,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{209}Bi(d,x), etc.
21	4383.285 ± 0.017	6 –	**^{208}Tl β^- decay**, ^{207}Pb(d,x), ^{208}Pb(e,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{209}Bi(d,x), etc.
22	4423.647 ± 0.015	6 +	^{207}Pb(d,x), ^{208}Pb(e,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{210}Pb(p,x), ^{209}Bi(d,x), etc.
23	4480.746 ± 0.016	6 –	**^{208}Tl β^- decay**, ^{207}Pb(d,x), ^{208}Pb(e,x), ^{208}Pb(n,n′γ), ^{208}Pb(p,x), ^{208}Pb(d,x), ^{208}Pb(α,x), ^{209}Bi(d,x), etc.

* Nuclear levels at 4144 (5) and 4447 (5) keV not included, although proposed in studies of the ^{209}Bi(d,^{3}He) reaction.

Placements of gamma-ray transitions (2007Ma45).

	Adopted E_γ* (keV)	Proposed location in decay scheme (^{208}Pb nuclear levels)		Adopted E_γ* (keV)	Proposed location in decay scheme (^{208}Pb nuclear levels)
$\gamma_{5,4}$	211.52 (2)	3919.966 (13) – 3708.451 (12)	–	835.90 (11)	not placed in decay scheme
$\gamma_{4,3}$	233.37 (2)	3708.451 (12) – 3475.078 (11)	$\gamma_{3,1}$	860.53 (2)	3475.078 (11) – 2614.552 (10)
$\gamma_{7,4}$	252.71 (2)	3961.162 (13) – 3708.451 (12)	$\gamma_{20,3}$	883.59 (2)	4358.670 (13) – 3475.078 (11)
$\gamma_{3,2}$	277.37 (2)	3475.078 (11) – 3197.711 (10)	$\gamma_{12,2}$	927.64 (2)	4125.347 (12) – 3197.711 (10)
$\gamma_{7,3}$	486.08 (2)	3961.162 (13) – 3475.078 (11)	$\gamma_{13,2}$	982.70 (2)	4180.414 (14) – 3197.711 (10)
$\gamma_{4,2}$	510.74 (2)	3708.451 (12) – 3197.711 (10)	$\gamma_{4,1}$	1093.90 (2)	3708.451 (12) – 2614.552 (10)
$\gamma_{2,1}$	583.187 (2)	3197.711 (10) – 2614.552 (10)	$\gamma_{19,2}$	1126.24 (2)	4323.946 (14) – 3197.711 (10)
$\gamma_{18,4}$	588.11 (2)	4296.560 (13) – 3708.451 (12)	$\gamma_{20,2}$	1160.96 (2)	4358.670 (13) – 3197.711 (10)
$\gamma_{12,3}$	650.27 (2)	4125.347 (12) – 3475.078 (11)	$\gamma_{21,2}$	1185.57 (2)	4383.285 (17) – 3197.711 (10)
$\gamma_{13,3}$	705.34 (2)	4180.414 (14) – 3475.078 (11)	$\gamma_{23,2}$	1283.04 (2)	4480.746 (16) – 3197.711 (10)
$\gamma_{5,2}$	722.26 (2)	3919.966 (13) – 3197.711 (10)	$\gamma_{8,1}$	1380.89 (2)	3995.438 (13) – 2614.552 (10)
$\gamma_{6,2}$	748.87 (2)	3946.578 (14) – 3197.711 (10)	$\gamma_{17,1}$	1647.32 (2)	4261.871 (13) – 2614.552 (10)
$\gamma_{7,2}$	763.45 (2)	3961.162 (13) – 3197.711 (10)	$\gamma_{20,12}$	1744.12 (2)	4358.670 (13) – 2614.552 (10)
–	808.32 (13)	not placed in decay scheme	$\gamma_{1,0}$	2614.511 (10)	2614.552 (10) – 0
$\gamma_{18,3}$	821.48 (2)	4296.560 (13) – 3475.078 (11)			

* Values derived from the adopted energies of the ^{208}Pb nuclear levels as specified in columns 3 and 6, with the uncertainties rounded upwards on the basis of the recommended uncertainties of the nuclear level energies (2007Ma45).

Emission Probabilities

A consistent decay scheme has been constructed from the gamma-ray measurements of 1960Em01, 1960Sc07, 1961Si11, 1969Au10, 1969Pa02, 1969La23, 1972Ja25, 1972DaZA/1973Da38, 1975Ko02, 1977Ge12, 1978Av01, 1982Sa36, 1983Sc13, 1983Va22, 1984Ge07, 1992Li05 and 1993El08. The study of 1975Ko02 is particularly comprehensive, along with the gamma-ray measurements of 1993El08 below 1000 keV. Gamma-ray emission probabilities have been expressed relative to the 2614.511-keV transition, and specific sets of data were adjusted accordingly (some of the original measurements were quantified relative to the 583.187-keV gamma ray or as absolute emission probabilities, while minor modifications were made to the relevant emission probabilities for the partially resolved 277.37-, 510.74- and 583.187-keV gamma rays as reported by 1983Sc13). 1993El08 observed additional gamma rays (808.32 and 835.90 keV) that have not been successfully placed in the proposed decay scheme – all nuclear levels of ^{208}Pb below an energy of 4611 keV have been assessed in terms of shell-model calculations and particle-gamma coincidence measurements by 1997Sc21, arguing against the possible existence of additional nuclear levels below this energy that might accommodate either of these two gamma transitions.

Experimental studies have been made of weak crossover gamma transitions by Vasil'ev et al. (2006Va23) to provide upper limits for the emission probabilities of three such emissions:

E_γ (keV)	P_γ (%), expressed per 100 decays of ^{208}Tl
3197.7	≤ 0.0007
3475.0	≤ 0.0003
3708.5	≤ 0.0004

Other high-energy gamma emissions were identified as summation peaks. These crossover gamma transitions have not been included in the proposed decay scheme because of their somewhat ill-defined, low emission probabilities and tentative nature.

Published gamma-ray emission probabilities.

E_γ (keV)	P_γ						
	1960Em01	1960Sc07	1961Si11		1969Au10*	1969La23	1969Pa02
211.52 (2)	-	-	-	-	-	0.20 (5)	0.17 (8)
233.37 (2)	-	0.3	-	-	-	0.30 (5)	0.33 (17)
252.71 (2)	1.5 (7)	1.1	-	-		0.8 (1)	0.70 (11)
277.37 (2)	6.9 (8)	8.6	-	7.2 (7)	-	6.9 (5)	6.5 (4)
486.08 (2)	-	0.1 (1)	-	-	-	0.07 (4)	0.05 (2)
510.74 (2)	23 (2)	25.3 (12)	24 (3)	22.5 (25)	-	23 (1)	22.5 (12)
583.187 (2)	86.4 (56)	85.1 (40)	81 (5)	84 (5)	100	85 (4)	86 (4)
588.11 (2)	-	-	-	-	-	-	-
650.27 (2)	-	-	-	-	-	-	-
705.34 (2)	-	-	-	-	-	-	-
722.26 (2)	-	-	)	-	-	0.3 (1)	0.27 (8)
748.87 (2)	-	-	) 22.5 (20)	-	-	-	-
763.45 (2)	1.9 (5)	3.4 (2)	)	3.6 (7)	-	2.0 (2)	1.68 (8)
808.32 (13)	-	-	-	-	-	-	-
821.48 (2)	-	-	-	-	-	-	0.09 (4)
835.90 (11)	-	-	-	-	-	-	-
860.53 (2)	11.4 (12)	14.2 (6)	15.3 (20)	15.2 (15)	-	13 (1)	12.0 (8)
883.59 (2)	-	-	-	-	-	-	-
927.64 (2)	-	-	-	-	-	0.15 (5)	0.13 (3)
982.70 (2)	-	-	-	-	-	0.20 (5)	0.20 (3)
1004 (2)	-	-	-	-	-	-	~ 0.01
1093.90 (2)	-	0.7 (1)	~ 2	-	-	0.5 (1)	0.38 (5)
1126.24 (2)	-	-	-	-	-	-	-
1160.96 (2)	-	-	-	-	-	-	-
1185.57 (2)	-	-	-	-	-	-	-
1283.04 (2)	-	-	-	-	-	-	0.05 (2)
1380.89 (2)	-	-	-	-	-	-	0.02 (1)
1647.32 (2)	-	-	~ 3	-	-	-	~ 0.01
1744.12 (2)	-	-	-	-	-	-	-
2614.511 (10)	100	(100)	100	100	116.7 (24)	100	100

Published gamma-ray emission probabilities (cont.).

E_γ (keV)	**P_γ** (cont.)					
	1973Da38	**1972Ja25**	**1975Ko02**	**1977Ge12***	**1978Av01**	**1982Sa36†**
211.52 (2)	0.16 (4)	-	0.17 (2)	-	-	-
233.37 (2)	~ 0.2	-	0.31 (3)	-	-	-
252.71 (2)	0.8 (2)	-	0.80 (5)	-	0.62 (4)	0.28 (3)
277.37 (2)	6.6 (13)	6.2 (7)	6.8 (3)	-	6.1 (2)	2.4 (1)
486.08 (2)	0.04 (1)	-	0.050 (5)	-	-	-
510.74 (2)	22.9 (23)	21.9 (7)	21.6 (9)	-	22.8 (7)	7.8 (4)
583.187 (2)	85.0 (85)	86.0 (4)	86 (3)	100	85	30.0 (14)
588.11 (2)	~ 0.04	-	0.04 (2)	-	-	-
650.27 (2)	-	-	0.036 (5)	-	-	-
705.34 (2)	~ 0.02	-	0.022 (4)	-	-	-
722.26 (2)	0.21 (6)	-	0.203 (14)	-	0.27 (2)	-
748.87 (2)	0.05 (1)	-	0.043 (4)	-	-	-
763.45 (2)	1.7 (3)	-	1.64 (9)	-	1.82 (9)	0.7 (1)
808.32 (13)	-	-	-	-	-	-
821.48 (2)	0.04 (1)	-	0.040 (4)	-	-	-
835.90 (11)	-	-	-	-	-	-
860.53 (2)	11.8 (12)	11.5 (10)	12.0 (4)	14.79 (15)	13.9 (6)	4.2 (2)
883.59 (2)	~ 0.025	-	0.031 (3)	-	-	-
927.64 (2)	0.13 (4)	-	0.125 (11)	-	-	-
982.70 (2)	0.20 (6)	-	0.197 (15)	-	-	-
1004 (2)	-	-	< 0.005	-	-	-
1093.90 (2)	0.37 (7)	-	0.37 (4)	-	-	-
1126.24 (2)	-	-	0.005 (2)	-	-	-
1160.96 (2)	-	-	0.011 (3)	-	-	-
1185.57 (2)	-	-	0.017 (5)	-	-	-
1283.04 (2)	~ 0.05	-	0.052 (5)	-	-	-
1380.89 (2)	-	-	0.007 (3)	-	-	-
1647.32 (2)	-	-	0.002 (1)	-	-	-
1744.12 (2)	-	-	0.002 (1)	-	-	-
2614.511 (10)	100	(100)	100	118.5 (16)	(100)	-

Published gamma-ray emission probabilities (cont.).

E_γ (keV)	P_γ (cont.)				
	1983Sc13‡	1983Va22#	1984Ge07*	1992Li05	1993El08¶
211.52 (2)	-	-	0.228 (20)	-	0.18 (1)
233.37 (2)	-	-	0.31 (4)	-	0.30 (1)
252.71 (2)	-	-	0.955 (13)	-	0.77 (2)
277.37 (2)	2.33 (7)	2.29 (4)	7.55 (6)	2.54 (7)§	6.88 (12)
486.08 (2)	-	-	-	-	0.055 (11)
510.74 (2)	7.90 (23)	8.31 (14)	26.9 (9)	-	22 (1)
583.187 (2)	30.7 (8)	30.8 (6)	100.0 (6)	29.4 (7)§	86 (3)
588.11 (2)	-	-	-	-	0.07 (1)
650.27 (2)	-	-	-	-	0.065 (11)
705.34 (2)	-	-	-	-	-
722.26 (2)	-	-	0.31 (6)	-	0.27 (2)
748.87 (2)	-	-	-	-	0.054 (9)
763.45 (2)	0.73 (5)	-	2.15 (2)	0.651 (40)	1.72 (8)
808.32 (13)	-	-	-	-	0.029 (7)
821.48 (2)	-	-	-	-	0.041 (17)
835.90 (11)	-	-	-	-	0.075 (11)
860.53 (2)	4.55 (12)	-	14.78 (9)	4.32 (15)	12.6 (7)
883.59 (2)	-	-	-	-	-
927.64 (2)	-	-	-	-	0.13 (1)
982.70 (2)	-	-	-	-	0.21 (1)
1004 (2)	-	-	-	-	-
1093.90 (2)	-	-	0.525 (8)	-	0.47 (4)
1126.24 (2)	-	-	-	-	-
1160.96 (2)	-	-	-	-	-
1185.57 (2)	-	-	-	-	-
1283.04 (2)	-	-	-	-	0.049 (13)
1380.89 (2)	-	-	-	-	-
1647.32 (2)	-	-	-	-	-
1744.12 (2)	-	-	-	-	-
2614.511 (10)	35.6 (11)	-	119.1 (21)	-	98.1 (13)

* Emission probabilities relative to P_γ(583.187 keV) of 100.
† Emission probabilities relative to P_γ(583.187 keV) of 30.0.
‡ Emission probabilities relative to P_γ(583.187 keV) of 30.7.
# Emission probabilities relative to P_γ(583.187 keV) of 30.8.
¶ Absolute emission probabilities.
§ Unresolved overlap with another gamma-ray emission.

Equivalent measurements of specific emission probabilities deviate significantly between laboratories:

- 252.71-keV gamma ray: 1960Em01 and 1978Av01;
- 486.08-keV gamma ray: 1960Sc07;
- 510.74-keV gamma ray: 1960Sc07;
- 583.187-keV gamma ray: 1961Si11;
- 763.45-keV gamma ray: 1960Sc07 and 1961Si11;
- 860.53-keV gamma ray: 1960Sc07, 1961Si11 and 1978Av01;
- 927.64-keV gamma ray: 1969La23;
- 1093.90-keV gamma ray: 1960Sc07.

These particular values were judged to be outliers, and were not included in the weighted-mean analyses. Other gamma-ray emission probabilities were not reported with uncertainties within 1960Sc07, along with the 583.187-keV gamma-ray emission in 1978Av01; these data were also not included in the weighted-mean analyses. 1982Sa36, 1983Va22 and 1992Li05 reported measurements that did not include the main 2614.511-keV gamma-ray transition: the evaluated relative emission probability of the 583.187-keV gamma ray was adopted to create data sets comparable with the other studies, and therefore the assumed Pγ(583.187 keV) in these particular calculations were not included in the subsequent analysis.

While an uncertainty of 0.8 % can be derived for the relative emission probability of the 2614.511-keV gamma ray from the emission probabilities and uncertainties determined experimentally by 1969Au10, 1977Ge12, 1983Sc13, 1984Ge07 and 1993El08, the precise nature of this transition in such a well-defined area of the decay scheme permits the establishment of a recommended value of 100 % with no assigned uncertainty:

Reference	P_γ(2614.511 keV)
1969Au10	100 (2)
1977Ge12	100.0 (14)
1983Sc13	100 (3)
1984Ge07	100 (2)
1993El08	100.0 (13)
Weighted-mean value (LRSW)	100.0 (8) → 100 (1)
Recommended value	100

Gamma-ray emission probabilities: Relative to P_γ(2614.511 keV) of 100 %.

E_γ (keV)	P_γ^{rel}						
	1960Em01	**1960Sc07**	**1961Si11**		**1969Au10**	**1969La23**	**1969Pa02**
211.52 (2)	-	-	-	-	-	0.20 (5)	0.17 (8)
233.37 (2)	-	0.3§	-	-	-	0.30 (5)	0.33 (17)
252.71 (2)	1.5 (7)†	1.1§	-	-		0.8 (1)	0.70 (11)
277.37 (2)	6.9 (8)	8.6§	-	7.2 (7)	-	6.9 (5)	6.5 (4)
486.08 (2)	-	0.1 (1)†	-	-	-	0.07 (4)	0.05 (2)
510.74 (2)	23 (2)	25.3 (12)†	24 (3)	22.5 (25)	-	23 (1)	22.5 (12)
583.187 (2)	86.4 (56)	85.1 (40)	81 (5)†	84 (5)	85.7 (18)	85 (4)	86 (4)
588.11 (2)	-	-	-	-	-	-	-
650.27 (2)	-	-	-	-	-	-	-
705.34 (2)	-	-	-	-	-	-	-
722.26 (2)	-	-	)	-	-	0.3 (1)	0.27 (8)
748.87 (2)	-	-	) 22.5 (20)‡	-	-	-	-
763.45 (2)	1.9 (5)	3.4 (2)†	)	3.6 (7)†	-	2.0 (2)	1.68 (8)
808.32 (13)	-	-	-	-	-	-	-
821.48 (2)	-	-	-	-	-	-	0.09 (4)
835.90 (11)	-	-	-	-	-	-	-
860.53 (2)	11.4 (12)	14.2 (6)†	15.3 (20)†	15.2 (15)†	-	13 (1)	12.0 (8)
883.59 (2)	-	-	-	-	-	-	-
927.64 (2)	-	-	-	-	-	0.15 (5)†	0.13 (3)
982.70 (2)	-	-	-	-	-	0.20 (5)	0.20 (3)
1004 (2)	-	-	-	-	-	-	~ 0.01
1093.90 (2)	-	0.7 (1)†	~ 2	-	-	0.5 (1)	0.38 (5)
1126.24 (2)	-	-	-	-	-	-	-
1160.96 (2)	-	-	-	-	-	-	-
1185.57 (2)	-	-	-	-	-	-	-
1283.04 (2)	-	-	-	-	-	-	0.05 (2)
1380.89 (2)	-	-	-	-	-	-	0.02 (1)
1647.32 (2)	-	-	~ 3	-	-	-	~ 0.01
1744.12 (2)	-	-	-	-	-	-	-
2614.511 (10)	100	(100)	100	100	100 (2)	100	100

Gamma-ray emission probabilities: Relative to P_γ(2614.511 keV) of 100 % (cont.).

E_γ (keV)	**P_γ^{rel}** (cont.)					
	1973Da38	**1972Ja25**	**1975Ko02**	**1977Ge12**	**1978Av01**	**1982Sa36**
211.52 (2)	0.16 (4)	-	0.17 (2)	-	-	-
233.37 (2)	~ 0.2	-	0.31 (3)	-	-	-
252.71 (2)	0.8 (2)	-	0.80 (5)	-	0.62 (4)†	0.80 (9)
277.37 (2)	6.6 (13)	6.2 (7)	6.8 (3)	-	6.1 (2)	6.8 (3)
486.08 (2)	0.04 (1)	-	0.050 (5)	-	-	-
510.74 (2)	22.9 (23)	21.9 (7)	21.6 (9)	-	22.8 (7)	22.2 (11)
583.187 (2)	85.0 (85)	86.0 (4)	86 (3)	84.4 (11)	85§	[85.2 (3)]$^\#$
588.11 (2)	~ 0.04	-	0.04 (2)	-	-	-
650.27 (2)	-	-	0.036 (5)	-	-	-
705.34 (2)	~ 0.02	-	0.022 (4)	-	-	-
722.26 (2)	0.21 (6)	-	0.203 (14)	-	0.27 (2)	-
748.87 (2)	0.05 (1)	-	0.043 (4)	-	-	-
763.45 (2)	1.7 (3)	-	1.64 (9)	-	1.82 (9)	2.0 (3)
808.32 (13)	-	-	-	-	-	-
821.48 (2)	0.04 (1)	-	0.040 (4)	-	-	-
835.90 (11)	-	-	-	-	-	-
860.53 (2)	11.8 (12)	11.5 (10)	12.0 (4)	12.48 (13)	13.9 (6)†	11.9 (6)
883.59 (2)	~ 0.025	-	0.031 (3)	-	-	-
927.64 (2)	0.13 (4)	-	0.125 (11)	-	-	-
982.70 (2)	0.20 (6)	-	0.197 (15)	-	-	-
1004 (2)	-	-	< 0.005	-	-	-
1093.90 (2)	0.37 (7)	-	0.37 (4)	-	-	-
1126.24 (2)	-	-	0.005 (2)	-	-	-
1160.96 (2)	-	-	0.011 (3)	-	-	-
1185.57 (2)	-	-	0.017 (5)	-	-	-
1283.04 (2)	~ 0.05	-	0.052 (5)	-	-	-
1380.89 (2)	-	-	0.007 (3)	-	-	-
1647.32 (2)	-	-	0.002 (1)	-	-	-
1744.12 (2)	-	-	0.002 (1)	-	-	-
2614.511 (10)	100	(100)	100	100.0 (14)	(100)	-

Gamma-ray emission probabilities: Relative to P$_\gamma$(2614.511 keV) of 100 % (cont.).

E$_\gamma$ (keV)	**P$_\gamma^{rel}$** (cont.)					
	1983Sc13	**1983Va22**	**1984Ge07**	**1992Li05**	**1993El08**	**Recommended value***
211.52 (2)	-	-	0.19 (2)	-	0.18 (1)	0.18 (1)
233.37 (2)	-	-	0.26 (3)	-	0.31 (1)	0.31 (1)
252.71 (2)	-	-	0.80 (1)	-	0.78 (2)	0.78 (2)
277.37 (2)	6.5 (2)	6.3 (1)	6.34 (5)	7.36 (20)$^\Psi$	7.01 (12)	6.6 (3)
486.08 (2)	-	-	-	-	0.056 (11)	0.049 (4)
510.74 (2)	22.2 (6)	23.0 (4)	22.6 (8)	-	22 (1)	22.6 (2)
583.187 (2)	85.8 (22)	[85.2 (3)]#	84.0 (5)	[85.2 (3)]$^\Psi$	88 (3)	85.2 (3)
588.11 (2)	-	-	-	-	0.07 (1)	0.06 (1)
650.27 (2)	-	-	-	-	0.066 (11)	0.041 (5)
705.34 (2)	-	-	-	-	-	0.022 (4)
722.26 (2)	-	-	0.26 (5)	-	0.28 (2)	0.24 (4)
748.87 (2)	-	-	-	-	0.055 (9)	0.046 (3)
763.45 (2)	2.05 (14)	-	1.81 (2)	1.89 (12)	1.75 (8)	1.80 (2)
808.32 (13)	-	-	-	-	0.030 (7)	0.030 (7)
821.48 (2)	-	-	-	-	0.042 (17)	0.041 (4)
835.90 (11)	-	-	-	-	0.076 (11)	0.076 (11)
860.53 (2)	12.8 (3)	-	12.41 (8)	12.5 (4)	12.8 (7)	12.4 (1)
883.59 (2)	-	-	-	-	-	0.031 (3)
927.64 (2)	-	-	-	-	0.13 (1)	0.128 (7)
982.70 (2)	-	-	-	-	0.21 (1)	0.205 (8)
1004 (2)	-	-	-	-	-	-
1093.90 (2)	-	-	0.441 (7)	-	0.48 (4)	0.44 (1)
1126.24 (2)	-	-	-	-	-	0.005 (2)
1160.96 (2)	-	-	-	-	-	0.011 (3)
1185.57 (2)	-	-	-	-	-	0.017 (5)
1283.04 (2)	-	-	-	-	0.050 (13)	0.052 (5)
1380.89 (2)	-	-	-	-	-	0.007 (3)
1647.32 (2)	-	-	-	-	-	0.002 (1)
1744.12 (2)	-	-	-	-	-	0.002 (1)
2614.511 (10)	100 (3)	-	100 (2)	-	100.0 (13)	100

* Weighted mean values adopted when appropriate; remainder derived from proposed decay scheme; normalisation factor of 0.997 55 (4) calculated from total theoretical internal conversion coefficient of 2614.511-keV (0.002 46 (4)) gamma transition and transition probability of 100 % (1.00), with no direct β^- decay to the 2614.552-keV nuclear level and ground state of ^{208}Pb.

† Rejected as outlier, and not included in weighted-mean analysis.

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

‡ Unresolved data not included in the weighted-mean analysis.

Measurements did not include determination of the 2614.511-keV gamma ray; therefore, relative emission probability of 85.2 (3) for the 583.187-keV gamma ray was used to convert all other data in this study to comparable relative values – under these circumstances, P$_\gamma$(583.187 keV) was not included in the weighted-mean analysis.

$^\Psi$ unresolved overlap with another gamma-ray emission, and measurement did not include 2614.511-keV γ ray; therefore relative emission probability of 85.2 (3) was used for the 583.187-keV γ ray to convert other data in this study to comparable relative values – under these circumstances, P$_\gamma$(277.37 keV) and P$_\gamma$(583.187 keV) were not included in the weighted-mean analyses.

Multipolarities and Internal Conversion Coefficients

The major 583.187- and 2614.511-keV gamma rays were identified as E2 and E3 transitions, respectively. Many other gamma rays have mixed M1 + E2 multipolarities; these transitions were generally assumed to be 100 % M1, although estimated mixing ratios derived from the studies of 1954El07, 1957Kr56, 1957Vo22, 1963Da11, 1972Ja25, 1976Av03, 1978Av01 and 1990Go33 were used to determine specific multipolarities and theoretical internal conversion coefficients: ((97 % M1 + 3 % E2) for the 211.52-keV gamma transition, (67 % M1 + 33 % E2) for the 233.37-keV gamma transition, (86 % M1 + 14 % E2) for the 252.71-keV gamma transition, (99.96 % M1 + 0.04 % E2) for the 277.37-keV gamma transition, (99.75 % M1 + 0.25 % E2) for the 510.74-keV gamma transition, (91.2 % M1 + 8.8 % E2) for the 722.26-keV gamma transition, (99.0 % M1 + 1.0 % E2) for the 763.45-keV gamma transition, and (99.98 % M1 + 0.02 % E2) for the 860.53-keV gamma transition). The assigned multipolarity of the 860.53-keV gamma ray is particularly important in achieving the desired population-depopulation balance for the 2614.552-keV nuclear level. Recommended internal conversion coefficients have been determined from the frozen orbital approximation of Kibédi *et al.* (2008Ki07), based on the theoretical model of Band *et al.* (2002Ba85, 2002Ra45). Ion-pair formation coefficients were calculated by means of the methodology described by Kibédi *et al.* (2008Ki07). Uncertainties of ± 1.5 % were adopted for the E1 and E2 gamma transitions.

A normalisation factor (NF) of 0.997 55 (4) was calculated for the relative emission probabilities of the gamma rays, assuming no direct beta decay to the ground state of ^{208}Pb:

absolute transition probability of 2614.511-keV gamma ray = 100 %,
relative emission probability of 2614.511-keV gamma ray = 100 %, and
total theoretical internal conversion coefficient (2614.511-keV E3 transition) = 0.002 46 (4) (2002Ba85, 2002Ra45, 2008Ki07) →

$$P_\gamma^{abs} = P_\gamma^{rel} \; x \; NF = \frac{TP_\gamma^{abs}}{[1+\alpha_{total}]}$$

and, therefore:

$$NF = \frac{TP_\gamma^{abs}}{[1+\alpha_{total}] \; x \; P_\gamma^{rel}} = \frac{100}{[1+0.00246(4)] \; x \; 100}$$

$$NF = 0.99755(4)$$

Gamma-ray emissions: multipolarities, theoretical internal conversion coefficients (frozen orbital approximation) and ion-pair formation coefficients.

E_γ (keV)	Multipolarity	α_K	α_L	α_{M+}	α_{IPF}	α_{total}
211.52 (2)	97%M1 + 3%E2 δ = 0.18(2) 1957Kr56, 1957Vo22	0.890 (14)	0.1570 (22)	0.049	–	1.096 (17)
233.37 (2)	67%M1 + 33%E2 δ = 0.70(7) 1957Kr56, 1957Vo22	0.51 (3)	0.1136 (18)	0.0364	–	0.66 (3)
252.71 (2)	86%M1 + 14%E2 δ = -0.40(4) 1957Vo22, 1963Da11, 1978Av01	0.495 (14)	0.0926 (14)	0.0284	–	0.616 (15)
277.37 (2)	99.96%M1 + 0.04%E2 δ = 0.02(1) 1957Vo22, 1963Da11, 1976Av03, 1978Av01, 1990Go33	0.432 (6)	0.0739 (11)	0.0231	–	0.529 (8)
486.08 (2)	[M1] 1957Vo22	0.0954 (14)	0.01608 (23)	0.00492	–	0.1164 (17)
510.74 (2)	99.75%M1 + 0.25%E2 δ = -0.05(5) 1957Vo22, 1963Da11, 1976Av03, 1978Av01	0.0835 (13)	0.01406 (21)	0.00434	–	0.1019 (16)
583.187 (2)	E2 1954El07, 1957Kr56, 1963Da11, 1972Ja25, 1978Av01	0.01509 (22)	0.00410 (6)	0.00131	–	0.0205 (3)
588.11 (2)	[M1]	0.0577 (8)	0.00968 (14)	0.00302	–	0.0704 (10)
650.27 (2)	[M1]	0.0444 (7)	0.00742 (11)	0.00228	–	0.0541 (8)
705.34 (2)	[M1]	0.0360 (5)	0.00599 (9)	0.00181	–	0.0438 (7)
722.26 (2)	91.2%M1 + 8.8%E2 δ = 0.31(3) 1976Av03, 1978Av01	0.0317 (6)	0.00534 (10)	0.00166	–	0.0387 (7)
748.87 (2)	[M1]	0.0308 (5)	0.00512 (8)	0.00158	–	0.0375 (6)
763.45 (2)	99.0%M1 + 1.0%E2 δ = -0.10(1) 1957Vo22, 1963Da11, 1978Av01, 1990Go33	0.0291 (4)	0.00484 (7)	0.00146	–	0.0354 (5)
808.32 (13)	–	–	–	–	–	–
821.48 (2)	[M1]	0.0242 (4)	0.00402 (6)	0.00128	–	0.0295(5)
835.90 (11)	–	–	–	–	–	–
860.53 (2)	99.98%M1 + 0.02%E2 δ = 0.015 1957Vo22, 1963Da11, 1972Ja25, 1976Av03, 1978Av01, 1990Go33	0.0215 (3)	0.00356 (5)	0.00114	–	0.0262 (4)
883.59 (2)	[M1]	0.0201 (3)	0.00333 (5)	0.00097	–	0.0244 (4)
927.64 (2)	[M1]	0.01774 (25)	0.00293 (5)	0.00093	–	0.0216 (3)
982.70 (2)	[M1]	0.01530 (22)	0.00253 (4)	0.00077	–	0.0186 (3)
1093.90 (2)	E2	0.00449 (7)	0.000844 (12)	0.000266	–	0.00560 (8)
1126.24 (2)	E1	0.001691 (24)	0.000256 (4)	0.000081	0.00000206 (3)	0.00203 (3)
1160.96 (2)	[M1]	0.01000 (14)	0.001641 (23)	0.000496	0.00000259 (4)	0.01214 (17)
1185.57 (2)	[M1]	0.00947 (14)	0.001555 (22)	0.000480	0.00000501 (7)	0.01151 (17)
1283.04 (2)	[M1]	0.00775 (11)	0.001269 (18)	0.000388	0.0000232 (4)	0.00943 (14)
1380.89 (2)	[M1]	0.00643 (9)	0.001050 (15)	0.000315	0.0000546 (8)	0.00785 (11)
1647.32 (2)	[M1]	0.00411 (6)	0.000669 (10)	0.000207	0.000194 (3)	0.00518 (8)
1744.12 (2)	[M1]	0.00356 (5)	0.000578 (8)	0.000177	0.000255 (4)	0.00457 (7)
2614.511 (10)	E3	0.001708 (24)	0.000292 (4)	0.000089	0.000371 (6)	0.00246 (4)

Beta Particles

Energies

All beta-particle energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 2007Ma45 and the $Q_{\beta-}$ value of 4999.0 (17) keV adopted from 2003Au03 were used to determine the energies and uncertainties of the beta-particle transitions to the various levels.

Emission Probabilities

The beta-particle emission probabilities were calculated from gamma-ray probability balances, through the recommended gamma-ray emission intensities, and adopted multipolarities and theoretical internal conversion coefficients. A significant majority of the beta-particle transitions were defined as first forbidden non-unique.

Beta-particle emission probabilities per 100 disintegrations of ^{208}Tl.

	E_β(keV)	P_β				Transition type	log ft
		1960Em01	1960Sc07	1967Os01	Recommended value*		
$\beta_{0,23}$	518.3 (17)	–	–	–	0.052 (5)	1st forbidden non-unique	6.67
$\beta_{0,21}$	615.7 (17)	–	–	–	0.017 (5)	1st forbidden non-unique	7.41
$\beta_{0,20}$	640.3 (17)	–	–	4.15 (15)	0.045 (4)	1st forbidden non-unique	7.04
$\beta_{0,19}$	675.1 (17)	–	–	–	0.005 (2)	allowed	8.1
$\beta_{0,18}$	702.4 (17)	–	–	–	0.102 11)	1st forbidden non-unique	6.82
$\beta_{0,17}$	737.1(17)	–	–	–	0.002 (1)	1st forbidden non-unique	8.6
$\beta_{0,13}$	818.6 (17)	–	–	–	0.231 (9)	1st forbidden non-unique	6.70
$\beta_{0,12}$	873.7 (17)	–	–	–	0.174 (9)	1st forbidden non-unique	6.92
$\beta_{0,8}$	1003.6 (17)	–	–	–	0.007 (3)	1st forbidden non-unique	8.5
$\beta_{0,7}$	1037.8 (17)	3.6	4.6 (2)	< 0.6	3.17 (4)	1st forbidden non-unique	5.92
$\beta_{0,6}$	1052.4 (17)	–	–	–	0.048 (3)	1st forbidden non-unique	7.76
$\beta_{0,5}$	1079.0 (17)	–	–	–	0.63 (4)	1st forbidden non-unique	6.68
$\beta_{0,4}$	1290.5 (17)	24.3	23.9 (8)	21 (2)	24.1 (2)	1st forbidden non-unique	5.38
$\beta_{0,3}$	1523.9 (17)	20.6	22.7 (7)	22 (2)	22.1 (5)	1st forbidden non-unique	5.69
$\beta_{0,2}$	1801.3 (17)	51.3	48.8 (27)	52 (1)	49.2 (6)	1st forbidden non-unique	5.61
					Σ 99.9 (8)		

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

Atomic Data

The x-ray and Auger-electron data have been calculated using the evaluated gamma-ray data, and atomic data from 1996Sc06, 1998ScZM and 1999ScZX. Both the x-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.01, 28 January 2003). This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

K and L X-ray emission probabilities per 100 disintegrations of ^{208}Tl.

			Energy (keV)	Photons per 100 disint.
XL		(Pb)	9.184 – 15.216	2.75 (12)
	XL_l	(Pb)	9.184	0.0671 (19)
	XL_α	(Pb)	10.450 – 10.551	1.27 (4)
	XL_η	(Pb)	11.349	0.0209 (7)
	XL_β	(Pb)	12.142 – 13.015	1.155 (25)
	XL_γ	(Pb)	14.765 – 15.216	0.220 (5)
XK_α	$XK_{\alpha2}$	(Pb)	72.8049 (8)	2.03 (5)
	$XK_{\alpha1}$	(Pb)	74.9700 (9)	3.42 (7)
$XK'_{\beta1}$	$XK_{\beta3}$	(Pb)	84.451	}
	$XK_{\beta1}$	(Pb)	84.937	} 1.17 (3)
	$XK''_{\beta5}$	(Pb)	85.470	}
$XK'_{\beta2}$	$XK_{\beta2}$	(Pb)	87.238	}
	$XK_{\beta4}$	(Pb)	87.580	} 0.353 (11)
	$XKO_{2,3}$	(Pb)	87.911	}

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

Data Consistency

A Q_β-value of 4999.0 (17) keV has been adopted from the atomic mass evaluation of Audi *et al.* (2003Au03) while in the course of formulating the decay scheme of ^{208}Tl. This value has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{208}Tl beta-decay process (i.e. β^-, conversion electrons, γ, etc.):

$$\text{calculated Q-value} \quad = \quad \sum (E_i \times P_i) \quad = \quad 4989\ (14)\ \text{keV}$$

Percentage deviation from the Q-value of Audi *et al.* is (0.2 ± 0.3) %, which supports the derivation of a highly consistent decay scheme.

Acknowledgement

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^{209}Tl- Comments on Evaluation of Decay Data

By F.G. Kondev

This evaluation was completed in May 2011, with a literature cut off by the same date, as a part of ANL commitment to the IAEA-CRP on "Updated Decay Data Library for Actinides".

1. Decay Scheme

The nuclide ^{209}Tl ($J^{\pi}=1/2^{+}$) disintegrates 100 % by β^{-} emissions. The strongest β^{-}-decay branch of 97.70 (15) % populates the $J^{\pi}=1/2^{-}$ excited state at 2149.29 keV of the daughter nuclide ^{209}Pb. The decay scheme of ^{209}Tl was constructed by the evaluator, based on the work of Gromov (2000Gr35) and Ardisson (1998Ar03). The ENSDF evaluation of Martin (1991Ma16) was consulted for J^{π} and mutipolarity assignments to levels in ^{209}Pb.

2. Nuclear Data

Adopted Q(β^{-}) value of 3976 (8) keV is taken from the evaluation of Audi *et al.* (2003Au03).

The experimental data for the half-life of the ^{209}Pb ground state are very scarce. The value of 2.161 (7) min (1998Ar03) is adopted in the present evaluation. It is in agreement with the other known, but less precise, value of 2.20 (17) min (1950Ha64).

2.1. β^{-} Transitions

The values for the maximum β^{-}-decay energies, $E_{\beta-,max}$, presented in Table 1, were deduced from Q(β^{-}) = 3976 (8) keV (2003Au03) and the level energies deduced in the present evaluation, as detailed in section 2.2. The β^{-}-decay transition probabilities, P_{β}, were deduced from the decay scheme and the corresponding absolute γ–ray transition probabilities. The sum of the β- intensities to levels above 2149 keV is 2.30 (15) %. Then the β- feeding to the 2149-keV level is (100 - 2.30 (15)) % = 97.70 (15) %. The log *ft* values were calculated using the LOGFT program from the ENSDF evaluation package. The log *f* values are based on the work of Gove and Martin (1971Go40).

2.2. Gamma Transitions and Electron Internal Conversion Coefficients

The γ–ray transition energy data are presented in Table 2. Statistical analysis using the LWEIGHT program has been performed and the corresponding gamma-ray energies were deduced (the last column of Table 2). With those energies, the level scheme was fitted using the *gtol* program from the ENSDF analysis package and new level energies (shown in Table 1) were obtained.

The γ–ray transition multipolarities were taken from the ENSDF evaluation of Martin (1991Ma16) and the recent work of Gromov (2000Gr35) and Ardisson (1998Ar03). The electron conversion coefficients were calculated using the BrIcc code (2008Ki07).

Table 1. Level energies, quantum numbers, $E_{\beta0,ı\ max}$, P_{β} and log *ft* values in decay of ^{209}Tl ($J^{\pi}=1/2^{+}$)

Level energy (keV)	J^{π}	$E_{\beta-\ max}$, keV	P_{β} (%)	Nature	log *ft*
2524.14 (25)	(1/2,3/2)	587 (8)	0.420 (22)		
3361.36 (17)	(1/2,3/2)	615 (8)	0.10 (3)		
3069.72 (13)	3/2-	906 (8)	0.645 (16)	first forbidden	6.3
2905.14 (25)	3/2-	1071 (8)	0.70 (9)	first forbidden	6.5
2524.14 (25)	(1/2,3/2)+	1451 (8)	0.070 (15)	allowed	8.0
2460.8 (3)	(5/2)-	1515 (8)	0.031 (16)	first forbidden unique	9.2

2315.68 (13)	(3/2)-	1660 (8)	0.32 (11)	first forbidden	7.5
2149.29 (6)	1/2-	1827 (8)	97.70 (15)	first forbidden	5.2
2032.07 (6)	1/2+	1944 (8)	<0.1	allowed	> 8.3
1566.94 (5)	5/2+				
0.0	9/2+				

The gamma-ray emission probability data are presented in Table 3. The unplaced gamma rays and their emission probabilities are presented in Table 4. Future work is merited to obtain a more complete decay scheme of ^{209}Tl.

3. Atomic Data

The Atomic data (Fluorescence yields, X-Ray energies and Relative probabilities, and Auger electrons energies and Relative probabilities) were provided by the Saisinuc software (2008DuZX). Details regarding the origin of these data can be found in 1996Sc06, 1998ScZM, 1999ScZX, 2000Sc47 and 2003De44.

Table 2. Measured, deduced and adopted gamma-ray energies in β^-–decay of ^{209}Tl

2003ChZV	2000Gr35	1999GrZT	1998Ar03	1993El08	1989Ko26	1986He06	1981Di14	1977Vy02	adopted
	117.18 (10)	117.1 (3)	117.24 (5)	117.24 (1)	117.21 (1)		117.25 (5)	117.211 (21)	117.224 (7)
			284.04 (23)	284.04 (25)					284.04 (23)
			311.5 (3)	311.5 (3)					311.5 (3)
			375.5 (2)	375.5 (2)					375.5 (2)
465.2	465.21 (4)	465.0 (4)	465.10 (5)	465.10 (1)	465.14 (1)	465.4 (1)	465.1 (2)	465.065 (25)	465.128 (24)
582.4	582.4 (2)								582.4 (2)
	748.5 (3)		748.0 (3)	748.0 (3)					748.3 (2)
	755.6 (3)								755.6(3)
	873.5 (4)								873.5 (4)
920.2	920.8 (1)	919.9 (3)	920.34 (9)	920.34 (7)	920.2 (3)				920.43 (11)
1239.8	1239.7 (2)	1239.2 (3)	1239.76 (15)	1239.76 (15)					1239.66 (11)
1329.2	1329.3 (3)	1329.6 (3)	1329.3 (3)	1329.3 (3)	1239.5 (5)				1329.29 (16)
1566.9	1566.9 (3)	1566.7 (3)	1566.96 (5)	1566.96 (1)	1567.11 (2)		1566.9 (2)	1566.95 (6)	1566.93 (5)
	2149.0 (10)								2149.0 (10)
2315.9	2315.9 (3)	2315.7 (3)							2315.80 (21)

Table 3. Measured, deduced and adopted γ–ray emission probabilities for γ–ray transitions in β^-–decay of ^{209}Tl

Eg, keV	2003ChZV	2000Gr35	1999GrZT	1998Ar03	1993El08	1989Ko26	1981Di14	1977Vy02	adopted
117.24 (1)		78 (4)	74 (2)	73 (4)	73 (1)	85 (4) *	85.6 (59) *	84 (2) *	77.22 (27) [a)]
284.04 (25)				0.14 (7)	0.14 (7)				0.14 (7)
311.5 (3)				0.028 (14)	0.028 (14)				0.028 (14)
375.5 (2)				0.070 (15)	0.070 (15)				0.070 (15)
465.10 (1)	80.4 (21) *	97 (5)	93.2 (16) *	95 (5)	95 (5)	96 (4)	99.1 (64)	100 (3) *	96.62 (5) [a)]
582.4	0.33 (3)	0.28 (4)							0.312 (24)
748.5 (3)		0.07 (3)		0.09 (3)	0.086 (30)				0.080 (21)
755.6(3)		0.11 (2)							0.11 (2)
873.5 (4)		0.59 (8)							0.59 (8)
920.8 (1)	0.62 (3)	0.63 (5)	0.63 (2)	0.70 (7)	0.70 (7)	0.63 (6)			0.631 (15)
1239.8	0.45 (4)	0.42 (7)	0.41 (3)	0.31 (12)	0.31 (12)				0.420 (22)
1329.2	0.14	0.10 (3)	0.21 (3)	0.026 (5)	0.026 (5)	0.42 (4)			0.10 (3)
1566.9	100 (1)	100 (5)	100.0 (8)	100 (5)	100 (5)	100 (4)	100.6 (64)	93 (3) *	99.707 (5) [a)]
2149.0 (10)	<0.0006	0.015 (5)							0.015 (5)
2315.9 (3)	0.0284 (24)	0.03 (1)	0.030 (5)						0.0288 (21)

* not included in the statistical analysis

[a)] deduced from $100/(1+\alpha_T)$ due to cascading.

Table 4. Gamma-ray energies and emission probabilities for transitions in β^-–decay of ^{209}Tl, which were not placed in the decay scheme

2003ChZV		2000Gr35		1999GrZT		1998Ar03	
		469.9	0.12 (3)			469.7 (3)	0.03 (2)
		860.5 (3)	0.26 (4)				
		890.0 (4)	0.12 (3)				
		902.8 (4)	0.10 (2)				
970.3	0.054 (15)						
		1661.1 (5)	0.10 (2)				
		1673.2 (4)	0.48 (4)				
		1781.7 (5)	0.04 (2)				
				2005.3 (2)	0.020 (5)		
2032.1	<0.019	2032.1 (5)	0.001				
2548.2	0.015 (6)						

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^{210}Tl - Comments on evaluation of decay data
by V. Chisté and M. M. Bé

This evaluation was completed in 2007. Literature available by August 2007 has been included.

1 Decay Scheme

^{210}Tl disintegrates by beta minus emission to excited levels of ^{210}Pb. A weak delayed neutron emission was reported (1961St20 and 1957Ko42). Level energies, spins and parities are from the mass-chain evaluation of E. Browne (2003Br13) and B. Harmatz (1981Ha54).

This decay scheme is mainly based on the measurements of P. Weinzierl (1964We06). Several inconsistencies appeared :

- β branching to levels : 3879-, 3458-, and 3069-keV were deduced from γ-ray transition intensity imbalance. β^- feedings to the 1096- and 1192-keV levels are uncertain. There is no experimental evidence for β^- transitions with energy > 3 MeV to these levels. β^- feedings the 1869-, 2208- and 2412-keV levels, suggested by γ-ray transition intensity imbalances (< 10 %, < 9 % and < 12 % , respectively), are uncertain.

- An 83-keV γ-ray is not placed in the present decay scheme as suggested by B. Harmatz (1981Ha54) (transition between 1275-keV level and 1192-keV level), because there is no experimental evidence that the 1275-keV level in ^{210}Pb was populated in the β^- decay of ^{210}Tl.

These discrepancies cannot be resolved without new experimental results. New measurements are strongly suggested.

Some agreement was found between the adopted Q(β^-) value of Audi and the effective Q(β^-) value of 5470 (1000) keV calculated from decay scheme data, which indicates a consistency and correctness of the decay scheme.

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).

Experimental ^{210}Tl half-life values (in minutes) are given in Table 1:

Table 1: Experimental values of ^{210}Tl half-life.

Reference	Experimental value (min)	Comments
M. Curie (1931Cu01)	1.32	Not used. No uncertainty.
A.V. Kogan (1957Ko42)	1.50 (25)	
P. Weinzierl (1964We06)	1.30 (3)	
Recommended value	**1.30 (3)**	χ^2 = 0.63

A weighted average has been calculated using Lweight computer program (version 3). The largest contribution to the weighted average comes from P. Weinzierl (1964We06), amounting to a statistical weight of 98 %.

The recommended value of ^{210}Tl half-life is the weighted average of 1.30 minutes with an internal uncertainty of 0.03 minutes. The reduced-χ^2 value is 0.63.

2.1 b$^-$ Transitions and Emissions.

The end-point energies of the β$^-$ transitions in the decay of $^{210}Tl \rightarrow ^{210}Pb$ have been obtained from the Q(β$^-$) value (2003Au03) and the level energies given by E. Browne (2003Br13).

The adopted β$^-$ transition probabilities were deduced from the P(γ + ce) balance at each level of the decay scheme. Table 2 shows the adopted β$^-$ transition probabilities compared with the only three β$^-$ transitions reported by P. Weinzierl (1964We06). No β$^-$ transitions with $E_{\beta-}$ > 3MeV were observed by these authors.

Table 2: Experimental and recommended (calculated) values of β$^-$ transition probabilities.

Level	Energy (keV)	P. Weinzierl (1964We06)	Adopted values
11	1380 (12)	25 %	2 %
10	1603 (12)		7 %
9	1860 (12)	56 %	24 %
8	2024 (12)		10 %
7	2413 (12)	19 %	10 %
3	4290 (12)		31 %
2	4386 (12)		13 %

The sum of the adopted β$^-$ transition probabilities is equal to 97 %. The 3 % missing cannot be placed in the decay scheme without more information about the β$^-$ decay of ^{210}Tl.

The values of lg ft and the average β$^-$ energies have been calculated using the computer program LOGFT for β$^-$ transitions.

2.2 g Transitions.

The transition probabilities were deduced from the absolute γ-ray emission intensities and the relevant internal conversion coefficients. (see **5.2** g **Emissions**).

Multipolarities of the γ-ray transitions were deduced from conversion electron measurements and K/L ratios of 1964We06:

83-keV γ-ray: [E2] 97-keV γ-ray: M1 + E2 296-keV γ-ray: E2
356-keV γ-ray: [M1] 356-keV γ-ray: [M1] 799-keV γ-ray: E2
1070-keV γ-ray: [E1]

The internal conversion coefficients (ICC's) for these γ-ray transitions were calculated using the BrIcc computer program (calculation for 'frozen orbital approximation'), which interpolates from theoretical values of I. M. Band *et al.* (2002Ba85).
Due to the large uncertainty on the 83- and 97-keV transition energy, only estimated ICC values are given.

3 Atomic Data.

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

4 Electron Emissions.

The conversion electrons emission probabilities have been deduced using the γ-ray emission intensities and ICC's.

5 Photon Emissions.

5.1 X-ray Emissions.

The X-ray absolute intensities have been calculated from γ-ray data and ICC using the EMISSION computer program. The KX-ray intensity is compared in Table 3 to the measured value of P. Weinzierl (1964We06).

Table 3: Experimental and recommended (calculated) values of X-ray absolute intensities.

	P. Weinzierl (1964We04)	Recommended value
K x-ray	20 (4) %	23 (11) %

5.2 g Emissions.

The energies of the γ-ray emissions given in Section 5 are from E. Browne (2003Br13).

The experimental relative γ-ray emission intensities measured by P. Weinzierl (1964We06) (single experimental data set found in the literature) given in Table 4 are relative to that of the 799-keV γ-ray. Only one set of measured data (1964We06) is available.

Table 4: The experimental data set of the relative γ-ray emission intensities.

Energy (keV)	Relative γ-ray Emission intensity (%) (1964We06)
83 [(a)]	2.0
97	4 (2)
296	80 (10)
356 [(a)]	4 (2)
382 [(a)]	3 (2)
480	2 (1)
670 [(a)]	2 (1)
799	100
860	7 (2)
910 [(a)]	3 (2)
1070	12 (5)
1110	7 (2)
1210	17 (4)
1316	21 (5)
1410	5 (2)
1490 [(a)]	2 (1)
1540 [(a)]	2 (1)
1590	2 (1)
1650 [(a)]	2 (1)
2010	7 (2)
2090 [(a)]	5 (2)
2270	3 (2)
2360	8 (3)
2430	9 (3)

(a) γ-ray not placed in level scheme as explained in Weinzierl (1964We06).

The normalization factor of **98.969 (30)** to convert the relative γ–ray emission intensities to absolute intensities was obtained using the formula of :

$$N = \left(\frac{100}{(1 + \alpha_T) P_{rel}(799\gamma)} \right)$$

The uncertainties were calculated through their propagation on the above formula.

The evaluated relative and absolute γ-ray emission intensities are given in Table 5.

Table 5: Evaluated relative and absolute γ-ray emission intensities.

Energy (keV)	Relative γ-ray Emission intensity (%)	Absolute γ-ray emission intensity (%)
83 (a)	2.0	1.98 (40)
97	4 (2)	4 (2)
296	80 (10)	79 (10)
356 (a)	4 (2)	4 (2)
382 (a)	3 (2)	3 (2)
480	2 (1)	2 (1)
670 (a)	2 (1)	2 (1)
799	100	98.969 (30)
860	7 (2)	6.9 (20)
910 (a)	3 (2)	3 (2)
1070	12 (5)	11.9 (49)
1110	7 (2)	6.9 (20)
1210	17 (4)	16.8 (40)
1316	21 (5)	20.8 (50)
1410	5 (2)	4.9 (20)
1490 (a)	2 (1)	2 (1)
1540 (a)	2 (1)	2 (1)
1590	2 (1)	2 (1)
1650 (a)	2 (1)	2 (1)
2010	7 (2)	6.9 (20)
2090 (a)	5 (2)	4.9 (20)
2270	3 (2)	3 (2)
2360	8 (3)	7.9 (30)
2430	9 (3)	8.9 (30)

(a) γ-ray not placed in level scheme as explained in Weinzierl (1964We06).

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^{209}Pb - Comments on evaluation of decay data by F. G. Kondev

This evaluation was completed in February 2011, with the same literature cut off date, as a part of ANL commitment to the IAEA-CRP on "Updated Decay Data Library for Actinides".

1 Decay Scheme

The nuclide ^{209}Pb ($J^{\pi} = 9/2^{+}$) disintegrates 100 % by β^{-} emissions with a single β^{-}-decay branch to the ground state ($J^{\pi} = 9/2^{-}$) of the daughter nuclide ^{209}Bi. The level schemes of ^{209}Pb and ^{209}Bi, including level energies and J^{π} values, are based on the ENSDF evaluation of Martin (1991Ma16).

2 Nuclear Data

Adopted Q(β^{-}) value of 644.0 (12) keV is taken from the evaluation of Audi *et al.* (2003Au03).

The experimental half-life data for the ^{209}Pb ground state are listed in Table 1. The LRSW value of $T_{1/2}$ = 3.277 (15) h was adopted (χ^2_{ν} =1.87, which is smaller than the critical value of $\chi^2_{\nu\ cryt}$ = 3.32 (99 % confidence level)).

Table 1. Experimental data for the half-life of ^{209}Pb.

Author	$T_{1/2}$ (h)	Used in evaluation
1972Be44	3.253 (14)	Yes
1971Pe03	3.31 (3)	Yes
1959Po64	3.31 (3)	Yes
1942Ma03	3.3 (1)	Yes
1941Fa04	3.32(3)	Yes
1940Kr08	2.75 (5)	No

2.1 β- Transitions

The decay of ^{209}Pb proceeds with a single β^{-} transition directly to the ^{209}Bi ground state. The maximum β^{-}-decay energy recommended in Table 2 was deduced from Q(β^{-}) = 644.0 (12) keV (2003Au03). The log *ft* value was calculated using the LOGFT program from the ENSDF evaluation package, which is based on the work of Gove and Martin (1971Go40).

Table 2. Level energy, quantum number, $E_{\beta 0,\iota\ max}$, P_{β} and log *ft* value in decay of ^{209}Pb.

	Level energy (keV)	J^{π}	$E_{\beta-\ max}$ (keV)	P_{β} (%)	Nature	log *ft*
$\beta_{0,0}$	0.0	9/2-	644.0 (12)	100	First forbidden non-unique	5.536 (4)

3 References

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^{210}Pb - Comments on evaluation of decay data by V. Chisté and M. M. Bé

This evaluation was completed in 2007. Literature available by October 2007 has been included.

1 Decay Scheme

^{210}Pb disintegrates by beta minus emission to an excited level and to the ground state level of ^{210}Bi. A weak alpha transition to the ^{206}Hg ground state has been observed (1.9 (4) 10^{-6} %). Spins and parities are from the ENSDF mass-chain evaluations by E. Browne (2003Br13 for A = 210) and R. G. Helmer (1990He18 for A = 206).

The good agreement found between the adopted Q(β^-) value of Audi and the effective Q(β^-) value of 63.9 (11) keV calculated from decay scheme data indicates the completeness and correctness of the decay scheme.

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).

Experimental ^{210}Pb half-life values (in years) are given in Table 1:

Table 1: Experimental values of ^{210}Pb half-life.

Reference	Experimental value (a)	Comments
G. N. Antonoff (1910An**)	16.5	Not used. No uncertainty. ZnS counting.
I. Curie (1929Cu**)	23	Not used. No uncertainty. α counting.
M. Curie (1931Cu01)	19.5	Not used. No uncertainty.
F. Wagner (1950Wa**)	25.4 (15)	Ion Chamber.
R. J. Tobailem (1955To14)	19.40 (35)	Ion Chamber.
W. F. Merritt (1957Me47)	22.4 (4)	4π proportional counter.
G. Harbottle (1959Ha20)	20.4 (3)	Ion Chamber.
B. D. Pate (1959Pa03)	23.3 (5)	4π proportional counter.
W. R. Eckelmann (1960Ec01)	21.4 (5)	Geological.
L. Imre (1963Im02)	22.85 (70)	β counting.
H. Ramthun (1964Ra12)	21.96 (51)	Calorimetry.
H. R. von Gunten (1967Vo04)	22.2 (10)	Proportional counter.
A. Höndorf (1969Ho06)	22.26 (11)	α spectrometry.
G. A. Rech (2002Re18)	21.8 (3)	γ spectrometry.
Adopted value	**22.23 (12)**	χ^2 = 1.53

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

The evaluators have chosen to take into account the eleven experimental values with reported uncertainties found in the literature and given in Table 1. The values of Wagner (1950Wa**), Tobailem (1955To14) and Harbottle (1959Ha20) are rejected by the LWEIGHT program, because they are outliers, based on the Chauvenet's criterion. The largest contribution (71 %) to the weighted average comes from the value of Höndorf (1969Ho06).

The adopted value of ^{210}Pb half-life is a weighted average of **22.23 a** and the external uncertainty of **0.12 a**. The reduced-χ^2 value is 1.53.

2.1 α Transitions and Emissions

The transition energy of the α-particles group to the ground of ^{206}Hg given in Section 2.1 is from Q_{α} (2003Au03).

For the probability of the α transition to the ground state of ^{206}Hg, the available published data are given in Table 2.

Table 2: Experimental and adopted values of the α transition probability to the ground state of ^{206}Hg.

Reference	Experimental value (10^{-6} %)	Comments
M. Nurmia (1961Nu01)	1.8 (5)	Superseded by 1962Ka27
P. Kauranen (1962Ka27)	1.7 (3)	
G. K. Wolf (1964Wo05)	2.7 (6)	
Adopted value	**1.9 (4)**	χ^2 = 2.22

The adopted value of α transition to the ground state of ^{206}Hg is the weighted average, calculated using LWEIGHT computer program, of **1.9 10^{-6} %** with the external uncertainty of **0.4 10^{-6} %**. The reduced-χ^2 value is 2.22.

2.2 β⁻ Transitions and Emissions

The end-point energies of the β^- transitions in the decay of ^{210}Pb → ^{210}Bi have been obtained from the $Q_{\beta-}$ (2003Au03) value and the level energies of R. G. Helmer (1990He18), given in Table 3.

Table 3: ^{210}Bi level populated in the decay of ^{210}Pb.

Level Number	Level energy, (keV)	Spin and parity.
0	0	1^-
1	46.539 (1)	0^-

For these two levels, the adopted β^- transition probabilities and the associated uncertainties were deduced from the γ transition probability balance at each level of the decay scheme, taking into account, also, the α transition probability to the ground state of ^{206}Hg. In the table 4, our adopted values of β^- transitions probabilities are compared with the experimental results found in the literature: C. S. Wu (1953Wu28), J. Tousset (1957To16 and 1958To10), W. Stanners (1956St99) and I. M. Rogachev (1963Ro31). Except to C. S. Wu (1953Wu28), a fair agreement has been found, within the uncertainty limits, between the experimental results and the recommended values for the 17-keV and 63.5-keV β^- transitions.

Table 4: Adopted and experimental values of β^- transition probabilities.

	17-keV β^- transition	63.5-keV β^- transition
C. S. Wu (1953Wu28)	92 (5) %	8 (5) %
J. Tousset (1957To16)		19 (4) %
J. Tousset (1958To10)	81 (14) %	19 (4) %
W. Stanners (1956St99)	84.5 (35) %	15.5 (35) %
I. M. Rogachev (1963Ro31)		≤ 19 (2) %
Adopted value	80.2 (13) %	19.8 (13) %

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

2.3 γ Transitions

The 46.5-keV γ-ray transition probability was calculated using the γ-ray emission intensity (see **5.2 γ Emissions**) and the relevant internal conversion coefficient. Multipolarity of this γ-ray transition is M1 (from E. Browne (2003Br13)).

The internal conversion coefficients (ICC) and their associated uncertainties for 46.5-keV γ-ray transition have been calculated using the BrIcc computer program (calculation for 'hole'), which interpolated from theoretical values of I. M. Band (2002Ba85). The α_T value is then 17.86 (25) compared to the previous value of 19.0 (6) from Rösel tables.

3 Atomic Data

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

4 Electron Emissions

The conversion electrons emission probabilities have been deduced using the γ-ray emission intensities and ICC's. The calculated total conversion electrons intensity of 75.2 (10) % is in fair agreement with the measured value of 81 (4) % from W. Stanners (1956St99).

5 Photon Emissions

5.1 X-ray Emissions

The X-ray absolute intensities have been calculated from γ-ray data and ICC using the EMISSION computer program and compared in Table 5 with the measured values found in the literature. For L_l, L_α and L_η x-rays, a good agreement was found between the experimental results given by 1987Me17 and 1990Sc08 and the recommended values deduced from decay scheme balance.

Table 5: Experimental and recommended (calculated) values of L X-ray absolute intensities.

	R. W. Fink (1957Fi06)	R. J. Gehrke (1971Ge11)	D. Metha (1987Me17)[a]	U. Schötzig (1990Sc08)	Recommended Values
L_l			0.584 (18)	0.55 (3)	0.552 (17)
L_α			10.27 (32)	9.48 (17)	10.3 (3)
L_η			0.074 (4)	0.075 (4)	0.075 (2)
L_β			11.6 (4)	10.9 (4)	9.05 (13)
L_γ			2.64 (8)	2.36 (5)	1.97 (3)
L total	23.8 (20)	22.8 (15)	25.2 (3)	23.4 (4)	22.0 (5)

[a] Normalized with I_γ (46.5-keV) = 4.252 (40) % (see **5.2** γ Emissions.)

5.2 γ Emissions

The energy of the γ-ray emission given in Section 5 is from R. G. Helmer (1981He15 and 2000He14).
For the 46.5-keV γ-ray from ^{210}Bi, the experimental data set of absolute γ-ray emission intensity and adopted value in this evaluation are given in Table 6.

Table 6: The experimental data set of the relative γ-ray emission intensity.

Reference	Experimental values (%)	Comments
D. K. Butt (1951Bu37)	3.5 (4)	Not used by the evaluators.
C. S. Wu (1953Wu28)	2.8 (6)	Not used by the evaluators.
P. E. Damon (1954Da23)	3.8 (6)	Not used by the evaluators.
R. W. Fink (1957Fi06)	4.5 (4)	
I. Y. Krause (1958Kr71)	4.05 (8)	Not used by the evaluators.
K. Ya. Gromov (1969Gr33)	4.8 (6)	
K. Debertin (1983De11)	4.18 (9)	Superseded by 1990Sc08.
Y. Hino (1990Hi03)	4.26 (7)	
U. Schötzig (1990Sc08)	4.24 (5)	
Adopted value	4.252 (40)	χ^2 = 0.42

The sets of values from D. K. Butt (1951Bu37), C. S. Wu (1953Wu28) and P. E. Damon (1954Da23) were omitted from analysis due to discrepancy with the other data and a lack of information in the articles about experimental measurements carried out and, therefore on the results.

The original uncertainty given by I. Y. Krause (1958Kr71) (= 0.08) seems under-estimated for the measurement method (NaI spectrometry) then it was decided to omit this value from the analysis.

The adopted value for 46.5-keV γ-ray emission intensity is the weighted average, calculated using LWEIGHT computer program, of **4.252 %** with the internal uncertainty of **0.040 %**. The reduced-χ^2 value is 0.42.

The evaluated absolute 46.5-keV γ-ray emission and transition probabilities are given in Table 7.

Table 7: Recommended absolute 46.5-keV γ-ray emission and transition probabilities.

Energy (keV)	Absolute γ-ray emission probability (%)	Absolute γ-ray transition probability (%)
46.539 (1)	4.252 (40)	80.2 (13)

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^{211}Pb - Comments on evaluation of Decay Data

By F.G. Kondev

This evaluation was completed in March 2011, with a literature cut off by the same date, as a part of ANL commitment to the IAEA-CRP on "Updated Decay Data Library for Actinides".

1. Decay Scheme

The nuclide ^{211}Pb (J^{π}=9/2^{+}) disintegrates 100 % by β^{-} emissions. The strongest β^{-}-decay branch of 91.28 (12) % populates the J^{π}=9/2^{-} ground state of the daughter nuclide ^{211}Bi. The level schemes of ^{211}Pb and ^{211}Bi, including J^{π} values, are based on the ENSDF evaluation of Browne (2004Br45).

2. Nuclear Data

Adopted Q(β^{-}) value of 1367 (6) keV is taken from the evaluation of Audi *et al.* (2003Au03).

The experimental data for the half-life of the ^{211}Pb ground state are very scarce. The value of 36.1 (2) min that is included in ENSDF (2004Br45) originates from the work of Sargent (1939Sa11) and Nurmia (1965Nu03). This value is adopted in the present evaluation, but new measurements are certainly required to confirm this value.

2.1. β^{-} Transitions

The values for the maximum β^{-}-decay energies ($E_{\beta-,max,}$ presented in Table 1) were derived from Q(β^{-}) = 1367 (6) keV (2003Au03) and the level energies deduced in the present evaluation, as detailed in section 2.2. The β^{-}-decay transition probabilities (P_{β}) were deduced from the decay scheme and the corresponding absolute γ–ray transition probabilities. Log *ft* values were calculated using the *LOGFT* program from the ENSDF evaluation package, based on the work of Gove and Martin (1971Go40).

2.2. Gamma Transitions and Electron Internal Conversion Coefficients

The γ–ray transition energy data are presented in Table 2. Statistical analysis using the *LWEIGHT* program has been performed, and the resulting gamma-ray energies are listed in column 13 of Table 2. With those energies, the level scheme was fitted using the *GTOL* program from the ENSDF analysis package, and new level energies were obtained (shown in Table 1). Then adopted gamma-ray energies were determined from the corresponding level energies.

The γ–ray transition multipolarities and mixing ratios were taken from the ENSDF evaluation of Browne (2004Br45). The electron conversion coefficients were calculated using the *BrIcc* code (2008Ki07).

Table 1. Level energies, quantum numbers, $E_{\beta0,i\ max}$, P_{β} and log *ft* values in the β^{-} decay of ^{211}Pb (J^{π}=9/2^{+}).

Level energy (keV)	J^{π}	$E_{\beta-\ max}$ (keV)	P_{β} (%)	Nature	log *ft*
1270.75 (6)	(7/2,9/2,11/2)-	96 (6)	0.0172 (15)	first forbidden non-unique	5.93
1234.3 (4)		133 (6)	0.0009 (3)	-	-
1196.33 (5)		171 (6)	0.019 (4)	-	-
1109.509 (23)	9/2-	257 (6)	1.06 (4)	first forbidden non-unique	5.58
1103.52 (20)		263 (6)	0.0047 (7)	-	-
1080.64 (4)		286 (6)	0.0570 (24)	-	-
1014.38 (4)	(7/2,9/2,11/2)-	-	-	-	-
831.984 (12)	9/2-	535 (6)	6.32 (9)	first forbidden non-unique	5.73

Level energy (keV)	**J$^{\pi}$**	**E$_{\beta- max}$ (keV)**	**P$_{\beta}$ (%)**	**Nature**	**log *ft***
766.680 (13)	(9/2,11/2)-	600 (6)	< 0.09	first forbidden non-unique	> 7.7
404.834 (9)	7/2-	962 (6)	1.57 (9)	first forbidden non-unique	7.21
0.0	9/2-	1367 (6)	91.28 (12)	first forbidden non-unique	5.99

The gamma-ray emission probability data are presented in Table 3. The reported values were determined relative to $I_\gamma(351.07_\gamma) = 100$ %, where the 351.07 keV transition depopulates the first $3/2^+$ level of the ^{207}Tl nuclide fed in the α decay of ^{211}Bi. The statistical analysis using the *LWEIGHT* program has been performed and *deduced* intensities were obtained (column 14 of Table 3). Using the absolute emission probability of $I_\gamma(351.07_\gamma) = 13.06$ (12) % (2011Ko04) and %α (^{211}Bi) = 99.724 (4) % (2004Br45), a normalization factor of 0.1302 (12) was obtained. This value was used to determine the *adopted* gamma-ray emission probabilities, which are shown in the last column of Table 3.

A number of weak transitions, summarized in Table 4, have been assigned to the β^- decay of ^{211}Pb by 1988Hi14 (five gamma rays), 1971Da34 (nine gamma rays), 1968Ha21 (three gamma rays) and 1968Br17 (one gamma ray). However, the experimental information presented in those articles is insufficient to assign these gamma rays unambiguously to the decay of ^{211}Pb, and hence they were not placed in the proposed decay scheme. None of the above publications reported the same unplaced gamma rays, which facilitated the conclusion made in this evaluation to exclude them from the proposed decay scheme. Further work, including gamma-ray coincidence studies, is merited to obtain a more complete decay scheme for ^{211}Pb.

3. Atomic Data

The atomic data (fluorescence yields, X-ray energies and relative probabilities, and Auger electrons energies and relative probabilities) were provided by the SAISINUC software (2008DuZX). Details regarding the origin of these data can be found in 1996Sc06, 1998ScZM, 1999ScZX, 2000Sc47 and 2003De44.

4. Data Consistency

The adopted Q_β-value of 1367 (6) keV (2003Au03) has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{211}Pb beta-decay process (i.e. β^-, conversion electrons, γ, etc.):

$$Q_{\beta-}(\text{calc}) \quad = \quad \sum (E_i \times P_i) \quad = \quad 1368\ (6)\ \text{keV}$$

Percentage deviation from the Q-value of Audi *et al.* is 0.0731 (5) %, which supports the derivation of a highly consistent decay scheme.

Table 2. Measured, deduced and adopted gamma-ray energies in β^-–decay of ^{211}Pb.

1988Hi14	1976Bl13	1971Da34	1968Br17	1968Go15	1968Ha21	1967Da20	1967Da10	1965Co06	1965Me07	1963Va05	1962Gi03	deduced, keV	adopted, keV
	65.420 (14)		65.5 (2)	65.4 (2)		65.7 (10)	65.5 (5)		65.502 (8) g)			65.420 (14)	65.304 (18)
		95.0 (2)		95.0 (6)		94.5 (5)						95.0 (2)	95.13 (5)
313.64 (12)	313.58 (9)	313.8 (2)	313.6 (3)	313.6 (5)		313.5 (10)	313 (1)	290 (10)	310 (3)			313.59 (9)	313.96 (4)
342.02 (12)	342.90 (4)*	342.7 (2)		342.7 (3)			342.5 (10)		340 (3)			342.91 (4)	342.829 (26)
	362.062 (17)*		362.9 (5) ?									362.072 (17)	361.846 (16)
404.89 (12)	404.843 (10)	404.84 (4)	404.8 (1)	404.8 (1)	405	404.8 (5)	404.7 (3)	400 (7)	404.84 (4) g)	404	405 (5)	404.853 (10)	404.834 (9)
427.14 (12)	427.078 (10)	426.99 (4)	427.0 (1)	426.9 (1)	427	427.1 (5)	427.0 (3)	430 (7)	426.99 (4) g)	426	425 (5)	427.088 (10)	427.150 (15)
				429.1 (5)								429.1 (5)	429.65 (6)
504.12 (12)		503.3 (4)		503.6 (7)								504.12 (12)	504.07 (6)
	609.33 (4)*	609.5 (2)	609.1 (2)	609.3 (5)		610 (2)			612 (5) f)		615 (5)	609.38 (4)	609.55 (4)
	676.65 (7)*		676.6 (3)	675.2 (3)				650 (10)				676.69 (7)	675.81 (4)
704.66 (12)	704.59 (3)	704.5 (1)	704.5 (2)	704.3 (2)	702	703.3 (8)	703.8 (3)	706 (7)	702 (3)	700	700 (5)	704.64 (3)	704.675 (25)
766.45 (12)	766.47 (3)	766.34 (7)	766.3 (2)	766.4 (1)	766	766.2 (8)	766.2 (3)	758 (7)	766.34 (7) g)		755 (10)	766.51 (3)	766.680 (13)
832.02 (12)	831.96 (3)	831.83 (4)	831.8 (1)	831.8 (1)	832	831.8 (5)	831.7 (5)	830 (7)	831.83 (4) g)	830	830 (2)	832.01 (3)	831.984 (12)
865.87 (24)	865.88 (14)	865.6 (3)	865.5 (3)	865.2 (2)		866 (2)	864 (1)		860 (10)			865.93 (14)	865.92 (6)
1014.71 (12)	1014.59 (5)	1014.7 (2)	1014.4 (3)	1014.1 (5)		1014.8 (10)	1014 (1)		1020 (3)		1020 (10)	1014.64 (5)	1014.38 (4)
1080.10 (13)	1080.11 (6)	1080.2 (1)	1080.0 (3)	1080.0 (5)	1076	1080.9 (10)	1079 (1)	1060 (15)	1076 (3)			1080.16 (6)	1080.64 (4)
1103.52 (20)	1103.7 (8)	1103.4 (4)	1103.0 (6) ?									1103.52 (20)	1103.52 (20)
1109.48 (13)	1109.43 (5)	1109.5 (2)	1109.8 (3)	1109.1 (1)	1106	1109.6 (8)	1108.5 (10)	1100 (15)	1104 (2)	1104	1100 (5)	1109.48 (5)	1109.509 (23)
1196.15 (14)	1196.28 (5)	1196.6 (2)	1196.1 (3)	1195.5 (5)		1196.6 (10)	1194 (1)		1188 (2)			1196.33 (5)	1196.33 (5)
		1234.3 (4)	1234.6 (10)									1234.3 (4)	1234.3 (4)
1270.79 (18)	1270.66 (8)	1270.8 (2)	1270.3 (3)	1270.0 (5)	1265	1271.2 (10)	1269 (1)		1265 (2)			1270.71 (8)	1270.75 (6)

*) value omitted from the statistical data analysis.
g) value reported in 1965Me07, but measured by A. Green, PhD thesis, University of California at Davis with Ge detector (unpublished).

Table 3. Measured, deduced and adopted gamma-ray emissions probabilities for gamma-transitions in β^-–decay of ^{211}Pb.

Eg, keV	1988Hi14	1976Bl13	1971Da34	1968Br17	1968Go15	1968Ha21	1967Da20	1967Da10	1965Co06	1965Me07	1963Va05	1962Gi03	deduced, rel	adopted, %
65		0.57 (6)	0.60 (4)	0.58 (11)			0.10 (5) *	~0.35 *		0.5 (2)			0.59 (3)	0.077 (4)
95			0.14 (2)					~0.10					0.14 (2)	0.018 (3)
314		0.20 (3)	0.24 (3)	0.19 (4)	0.10 (5)		0.26 (5)	0.21 (7)	0.90 (21) *	~0.2 *			0.206 (16)	0.0268 (21)
343		1.63 (13) *	0.27 (4)		0.15 (5)					~0.3 *			0.22 (3)	0.029 (4)
362		0.326 (24)		0.30 (8)									0.324 (23)	0.042 (3)
405	29.3 (9)	30.2 (14)	30.0 (9)	30.8 (15)	29.6 (20)	28.6 (11)	28.0 (28)	29.9 (35)	30.6 (28)	27.4 (12)	26 (5)	34(4)	29.4 (4)	3.83 (6)
427	13.9 (4)	14.2 (7)	13.5 (6)	14.3 (8)	13.7 (10)	11.6 (7)	14.0 (14)	13.9 (17)	21.5 (21) *	14.5 (14)	12.5 (25)	22 (3) *	13.9 (3)	1.81 (4)
429					0.065 (25)								0.065 (25)	0.008 (3)
504	0.045 (6)		0.12 (2) *		~ 0.006 *								0.045 (6)	0.0059 (8)
610		0.407 (24) *	0.18 (3)	0.38 (4)	0.25 (5)		0.30 (6)	0.21 (7)		0.9 (2) *		0.76 (13) *	0.25 (7)	0.033 (9)
676		0.130 (8)		0.173 (15)	0.10 (5)				1.3 (3) *				0.139 (7)	0.0181 (9)
705	3.6 (1)	3.6 (3)	3.77 (19)	3.68 (23)	3.7 (3)	2.9 (1) *	3.0 (3)	3.3 (4)	5.3 (6) *	3.7 (2)	3.8 (11)	5.5 (4) *	3.61 (7)	0.47 (1)
767	4.94 (16)	5.1 (4)	5.55 (28)	5.04 (30)	4.9 (3)	4.5 (1)	4.0 (4)	5.1 (6)	6.3 (6)	5.2 (2)		6.1 (4)	4.8 (3)	0.62 (4)
832	26.7 (8)	25.4 (20)	29.8 (7) *	25.6 (23)	24.1 (17)	27.4 (4)	23.0 (23)	26.4 (35)	26.4 (28)	27.4 (12)	24.8 (25)	34.2 (13) *	26.9 (3)	3.50 (5)
866	0.042 (6)	0.033 (4)	0.050 (8)	0.053 (15)	0.07 (2)		0.03 (1)	0.0347 (14)		0.04 (2)			0.0354 (13)	0.0046 (2)
1014	0.129 (8)	0.122 (8)	0.14 (1)	0.128 (15)	0.15 (1)		0.13 (2)	0.125 (21)		0.14 (2)		0.38 (19) *	0.133 (4)	0.0173 (5)
1081	0.095 (6)	0.090 (7)	0.120 (12)	0.083 (10)	0.08 (1)	0.0025 (1) *	0.08 (2)	0.104 (14)	0.49 (7) *	0.13 (12) *			0.093 (4)	0.0121 (5)
1104	0.033 (4)	0.049 (5)	0.040 (6)	0.023 (5)									0.036 (5)	0.0047 (7)
1110	0.90 (3)	0.82 (6)	1.15 (8)	0.79 (8)	0.81 (6)	0.0105 (7) *	0.70 (15)	0.87 (10)	0.83 (14)	1.03 (10)	1.07 (16)	1.46 (19) *	0.891 (21)	0.116 (3)
1196	0.072 (5)	0.081 (6)	0.10 (1)	0.079 (15)	0.08 (1)		0.08 (2)	0.076 (14)		0.11 (3)			0.079 (3)	0.0103 (4)
1234			0.010 (2)	0.0053 (15)									0.0070 (23)	0.0009 (3)
1271	0.043 (4)	0.057 (5)	0.070 (7)	0.048 (8)	0.08 (1)	0.0006 (1) *	0.05 (1)	0.042 (7)		0.06 (2)			0.052 (9)	0.0068 (12)

*) value omitted in the statistical data analysis.

Table 4. Gamma-ray energies and emission probabilities (relative to $I_{\gamma}(351.07\gamma) = 100$) for transitions that were not placed in the proposed decay scheme of ^{211}Pb.

Eγ, keV	1988Hi14	1971Da34	1968Ha21	1968Br17
81.0 (2)		0.35 (9)		
83.8 (1)		0.45 (7)		
88.2 (2)		0.13 (3)		
94.3 (3)		0.09 (2)		
97.3 (2)		0.09 (1)		
244			0.003 (1)	
275			0.004 (1)	
478.0 (4)		0.10 (2)		
479.6 (2)	0.04 (1)			
481.1 (4)		0.20 (4)		
481.92 (12)	0.08 (1)			
491.82 (12)	0.032 (6)			
494.2 (3)	0.013 (5)			
500.4 (5)		0.09 (2)		
502.0 (2)	0.028 (6)			
951			0.0017 (1)	
1090.5 (5)		0.020 (5)		
1120 (1)				0.0019 (11)

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^{212}Pb – Comments on evaluation of decay data by A. L. Nichols

Evaluated: July/August 2001
Re-evaluated: January 2004 and May 2010

Evaluation Procedures

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

Decay Scheme

A reasonably simple and consistent decay scheme has been constructed from the gamma-ray measurements of 1960Ro16, 1961Gi02, 1972DaZA (1973Da38), 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 123.449 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)

Beta Particles

Energies

All beta-particle energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 2005Br03 and Q-value of 569.9 keV (2003Au03) were used to determine the energies and uncertainties of the beta-particle transitions to the various levels.

Emission Probabilities
The beta-particle emission probabilities were calculated from gamma-ray energy balances, using the recommended internal conversion coefficients determined from the frozen orbital approximation of Kibédi *et al.* (2008Ki07) based on the theoretical model of Band *et al.* (2002Ba85, 2002Ra45):

415.272 keV nuclear level:
[Σ $P_{\gamma i}$ (1 + α_i) depopulating 415.272-keV level]·NF was calculated to be 11.44 (45)·NF; since NF = 0.004 36 (3), populating beta-particle emission probability is calculated to be 4.99 (21) % (0.0499 (21));

238.632 keV nuclear level:
{[Σ $P_{\gamma i}$ (1 + α_i) depopulating 238.63-keV level] - P_γ(176.640 keV)(1 + α(176.640 keV))}·NF was calculated to be 187.3 (23)·NF; since NF = 0.004 36 (3), populating beta-particle emission probability is calculated to be 81.7 (11) % (0.817 (11));

115.183 keV nuclear level:
spin and parity considerations support no direct beta decay to this level;
population and depopulation by gamma transitions requires balance of the form
Σ $P_{\gamma i}$ (1 + α_i) populating 115.183-keV level should equal P_γ(115.183 keV)(1 + α(115.183 keV)); hence TP_γ(123.449 keV) = 0.46 (4)·NF, and P_γ(123.449 keV) = 0.12 (1)·NF;

ground state (0.0 keV):
(i) through population of ground state: [Σ $P_{\gamma i}$ (1 + α_i) populating ground state]·NF + $P_{\beta_{0,0}}$ = 100 and NF = 0.004 36 (3) to give $P_{\beta_{0,0}}$ = 13.3 (11) % (0.133 (11))
(ii) through summation of beta decay and NF = 0.004 36 (3)

$$P_{\beta_{0,0}} = 13.3\ (11)\ \%\ (0.133\ (11)).$$

Beta-particle emission probabilities per 100 disintegrations of ^{212}Pb, transition type and log *ft*.

E_β(keV)	P_β		transition type	log *ft*
	1948Ma30	Recommended value*		
154.6 (19)	-	4.99 (21)	(1st forbidden non-unique)	5.35
331.3 (19)	-	81.7 (11)	(1st forbidden non-unique)	5.18
569.9 (19)	12 (2)	13.3 (11)	(1st forbidden non-unique)	6.74

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

Gamma Rays

Energies
All gamma-ray transition energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 2005Br03 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-, 176.640-, 238.632- and 300.089-keV gamma rays, using the relevant data from the measurements of 1960Ro16, 1961Gi02, 1972DaZA (1973Da38), 1978Av01, 1982Sa36, 1983Sc13, 1983Va22,

1984Ge07 and 1992Li05. The relative emission probability of the 415.272-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 123.449 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_γ(238.632 keV) of 100.

E_γ (keV)	P_γ^{rel}				
	1960Ro16	1961Gi02	1972DaZA	1978Av01	1982Sa36
115.183 (5)	[observed]	1.4 (3)	1.3 (3)	1.4 (1)	1.65 (12)
123.449 (5)	-	-	-	-	-
176.640 (11)	~ 0.5	0.50 (10)	0.10 (3)	-	-
238.632 (2)	100	100	100	100 (3)	100 (5)
300.089 (12)	7.7 4)	6.9 (4)	7.7 (15)	6.3 (2)	6.7 (5)
415.272 (11)	~ 0.3	0.33 (5)	-	-	-

E_γ (keV)	P_γ^{rel} (cont.)				
	1983Sc13	1983Va22	1984Ge07	1992Li05	Recommended value*
115.183 (5)	-	-	1.37 (2)	-	1.43 (5)
123.449 (5)	-	-	-	-	0.12 (1)‡
176.640 (11)	-	-	0.12 (1)	-	0.12 (1)
238.632 (2)	100 (3)	100 (1)	100 (1)	100 (2)	100 (1)
300.089 (12)	7.5 (2)	7.3 (1)	7.6 (1)	7.6 (3)	7.3 (3)
415.272 (11)	-	-	-	-	0.33 (5)

* Weighted mean values adopted when appropriate using LWEIGHT.

‡ Derived from proposed decay scheme – balance of gamma transitions that populate-depopulate 115.183-keV nuclear level.

A weighted mean normalisation factor of 0.004 36 (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_γ (keV)	P_γ^{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 2005Br03 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 300.089-keV gamma rays (1957Ni11, 1957Kr49, 1959Se59, 1960Ro16, 1963Da11, 1969Kr06 and 1978Av01); the 176.640- and 415.272-keV gamma rays were also assigned 100 % M1 multipolarity, while the 123.45-keV gamma transition was defined as E2. Recommended internal conversion coefficients have been determined from the frozen orbital approximation of Kibédi *et al*. (2008Ki07), based on the theoretical model of Band *et al*. (2002Ba85, 2002Ra45).

Multipolarity assignments.

Reference	E_γ (keV)	Multipolarity
1957Ni11	115.183 (5)	M1 [K/L = 5 (1)]
1957Kr49	115.183 (5)	M1
	176.640 (11)	E0 [K/L = 1 : 0.18 (2)]
	238.632 (2)	M1
	300.089 (12)	M1
1959Se59	115.183 (5)	M1
		[L_I:L_{II}:L_{III} → 100 : 10.4 (3) : 0.88 (10)]
	238.632 (2)	M1
		[L_I:L_{II}:L_{III} → 100 : 10.4 (2) : 0.74 (5)]
1960Ro16	115.183 (5)	M1 [α_K = 5.8 (9)]
	238.632 (2)	M1 [α_K = 0.74 (7)]
1963Da11	238.632 (2)	M1
	415.272 (11)	M1 [α_K ~ 0.35]
1969Kr06	238.632 (2)	M1
1978Av01	115.183 (5)	E2
	238.632 (2)	M1 (+ E2)
	300.089 (12)	M1 + E2

Gamma-ray emissions: multipolarities and theoretical internal conversion coefficients (frozen orbital approximation).

E_γ (keV)	Multipolarity	α_K	α_L	α_{M+}	α_{total}
115.183 (5)	(M1)	5.53 (8)	0.972 (14)	0.298 (5)	6.80 (10)
123.449 (5)	(E2)	0.421 (6)	1.766 (25)	0.613 (9)	2.80 (4)
176.640 (11)	(M1)	1.646 (23)	0.287 (4)	0.087 (1)	2.02 (3)
238.632 (2)	(M1)	0.710 (10)	0.1232 (18)	0.0388 (5)	0.872 (13)
300.089 (12)	(M1)	0.378 (6)	0.0653 (10)	0.0207 (3)	0.464 (7)
415.272 (11)	(M1)	0.1571 (22)	0.0269 (4)	0.0080 (1)	0.192 (3)

Atomic Data

The x-ray data have been calculated using the evaluated gamma-ray data, and the atomic data from 1996Sc06, 1998ScZM and 1999ScZX. Both the x-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.01, 28 January 2003). This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

K and L X-ray emission probabilities per 100 disintegrations of ^{212}**Pb.**

			Energy (keV)	Photons per 100 disint.
XL		(Bi)	9.420 – 15.709	13.8 (6)
	XL_l	(Bi)	9.420	0.340 (9)
	XL_α	(Bi)	10.731 – 10.839	6.36 (16)
	XL_η	(Bi)	11.712	0.103 (3)
	XL_β	(Bi)	12.480 – 13.393	5.76 (12)
	XL_γ	(Bi)	15.248 – 15.709	1.111 (23)
XK_α	$XK_{\alpha2}$	(Bi)	74.8157	10.07 (18)
	$XK_{\alpha1}$	(Bi)	77.1088	16.8 (3)

$XK'_{\beta1}$	$XK_{\beta3}$	(Bi)	86.835 }	
	$XK_{\beta1}$	(Bi)	87.344 }	5.77 (13)
	$XK''_{\beta5}$	(Bi)	87.862 }	
$XK'_{\beta2}$	$XK_{\beta2}$	(Bi)	89.732 }	
	$XK_{\beta4}$	(Bi)	90.074 }	1.77 (5)
	$XKO_{2,3}$	(Bi)	90.421 }	

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

Data Consistency

A Q_β-value of 569.9 (19) keV has been adopted from the atomic mass evaluation of Audi *et al.* (2003Au03) while in the course of formulating the decay scheme of ^{212}Pb. This value has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{212}Pb beta-decay process (i.e. β^-, conversion electrons, γ, etc.):

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 569\ (7)\ \text{keV}$$

Percentage deviation from the Q-value of Audi *et al.* is (0.158 ± 0.013) %, which supports the derivation of a highly consistent decay scheme.

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^{214}Pb - Comments on evaluation of decay data by V. Chisté and M. M. Bé

This evaluation was completed in 2010. Literature available by Dec. 2010 was included, and the half-life value was updated in Dec. 2010 to include new publication.

1 Decay Scheme

^{214}Pb disintegrates by beta minus emission to the excited levels and to the ground state of ^{214}Bi. Spins and parities are from the mass-chain evaluation of Y. A. Akovali (1988Ak01 and 1995El07 for A = 214).
A good agreement was found between the recommended Q value of Audi and the effective Q value (1024 (11) keV) calculated from the decay scheme data.

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).

Experimental ^{214}Pb half-life values (in minutes) are given in Table 1:

Table 1: Experimental values of ^{214}Pb half-life

Reference	Experimental value (min)	Comments.
M. Curie (1931Cu01)	26.8 (9)	
D. E. Martz (1991Ma**)	26.89 (3)	Uncertainty increased to take into account systematic uncertainty.
M. Voltaggio (2011Vo**)	27.06 (7)	To be published in Appl. Rad. Isotop.
Recommended value	**26.916 (44)**	$\chi^2 = 2.5$

The original uncertainty value given by D. E. Martz (1991Ma**) was multiplied by 2, in order to take into account the systematic uncertainties which were not considered by 1991Ma**. With the 3 values presented in Table 1, a weighted average was calculated using LWEIGHT computer code (version 3). The largest contribution to weighted average comes from the value of Martz (1991Ma**), amounting to 84 %.

The recommended value of ^{214}Pb half-life is the weighted average of 26.916 minutes with an external uncertainty of 0.044 minute. The reduced-χ^2 value is 2.5.

2.1 β^- Transitions and Emissions

The maximum energies of the β^- transitions in the decay of ^{214}Pb $\rightarrow$ ^{214}Bi were obtained from the Q^- value and the level energies given in Table 2 from Y. A. Akovali (1995El07).

Table 2: ^{214}Bi levels populated in the decay of ^{214}Pb.

Level number	Level energy, (keV)	Spin and parity	Half-life
0	0.0	1^-	19.9 (4) min
4	295.224 (2)	1^-	≤ 0.05 ns
5	351.932 (2)	0^-, 1^-	≤ 0.10 ns
7	533.67 (2)	(1^-)	
8	797.24 (9)		
9	839.00 (4)	1^+	

The adopted β⁻ transition probabilities were deduced from the P(γ + ce) balance at each level of the decay scheme. In the Table 3, the recommended values of β⁻ transition probabilities are compared with the experimental results found in the literature: E. E. Berlovich (1952Be78) and S. Kageyama (1953Ka40) observed only two β⁻ transitions 672-keV and 729-keV and H. Daniel (1956Da28) and K. O. Nielsen (1957Ni11) observed the1024-keV β⁻ transition. A fair agreement has been found between the results given by S. Kageyama and the recommended value for the 729-keV β⁻ transition.

Table 3: Recommended and experimental values of β⁻ transition probabilities

	672-keV β⁻ transition	729-keV β⁻ transition	1024-keV β⁻ transition
E. E. Berlovich (1952Be78)	25 %	75 %	
S. Kageyama (1953Ka40)	56 %	44 %	
H. Daniel (1956Da28)			6.3 (20) %
K. O. Nielsen (1957Ni11)			< 10 %
Recommended	**46.52 (37) %**	**41.09 (39) %**	**9.2 (7) %**

The values of lg *ft* and average β⁻ energies have been calculated with the program LOGFT for the β⁻ transitions.

2.2 γ Transitions

The γ-ray transition probabilities were deduced using the γ-ray emission intensities and the relevant internal conversion coefficients.

Multipolarities and δ (recommended by 1995El07) of these γ-ray transitions and the internal conversion coefficients (ICC's) are shown in Table 4.The internal conversion coefficients have been obtained using:

A - Icc99v3a computer program (GETICC dialog) which is based on the new tables of Band *et al.* (2002Ba85) (calculation for 'no hole') and Rösel (1978Ro22).
B - BrIcc computer program ("Frozen orbital approximation") which interpolated from theoretical values of Band *et al.* (2002Ba85).

Table 4: Multipolarities of γ-ray transitions

E_γ (keV)	Multipolarity	α_T (Band)[a]	α_T (Rösel)[a]	α_T (BrIcc)[b]
53.2275 (21)	M1 + E2, δ = 0.030 (10)	1.212 (36) E+01	1.288 (39) E+01	1.214 (19) E+01
241.997 (3)	M1 (+E2), δ = 0.00 (15)	8.37 (25) E-01	8.88 (27) E-01	8.38 (18) E-01
258.87 (3)	M1	6.95 (21) E-01	7.37 (22) E-01	6.96 (10) E-01
274.80 (5)	M1 + E2, δ = 1.0	3.73 (11) E-01	3.92 (12) E-01	3.74 (6) E-01
295.224 (2)	M1 + E2, δ = 0.30 (13)	4.54 (14) E-01	4.82 (14) E-01	4.6 (3) E-01
305.26 (3)	[E1]	2.91 (9) E-02	2.95 (9) E-02	2.92 (4) E-02
351.932 (2)	M1 (+ E2), δ = 0.00 (35)	3.00 (9) E-01	3.19 (10) E-01	3.00 (25) E-01
480.43 (2)	M1 (+E2), δ = 0.0 (10)	1.302 (39) E-01	1.384 (42) E-01	1.3 (5) E-03
487.09 (7)	(E1)	1.046 (31) E-02	1.058 (32) E-02	1.047 (15) E-03
533.66 (2)	[M1,E2]	6.24 (19) E-02	6.57 (20) E-02	6 (4) E-02
543.81 (7)	[E1]	8.34 (25) E-03	8.43 (25) E-03	8.34 (12) E-03
580.13 (3)	(E1)	7.32 (22) E-03	7.40 (22) E-03	7.32 (11) E-03
785.96 (9)	E1	4.07 (12) E-03	4.10 (12) E-03	4.06 (6) E-03
839.00 (4)	(E1)	3.60 (11) E-03	3.63 (11) E-03	3.59 (5) E-03

a: A fractional uncertainty of 3 % was adopted for all conversion coefficients.
b: Associated uncertainties are calculated by BrIcc.

The evaluators have adopted the internal conversion coefficients interpolated from the Rösel's tables, because these ICCs lead to a better decay scheme, where the sum of all the β transition probabilities is equal to 100.6 %. The others two ICC's set of values, Band and BrIcc, lead to an inconsistent decay scheme, where the sum of all β transitions probabilities would be of the order of 102 – 103 %. Moreover, the effective Q value, of 1024 (11) keV, calculated from the decay scheme data with Rösel's Icc, is closer to the recommended value of 1019 (11) keV than the 1029 (15) keV with the "No hole" approximation.

3 Atomic Data

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

4 Electron Emissions

The conversion electron emission probabilities have been calculated from γ-ray transition data.

5 Photon Emissions

5.1 X-ray Emissions

The X-ray absolute intensities were calculated from γ-ray data and Rösel's ICC using the EMISSION computer program and compared in Table 5 with the measured values of U. Schötzig (1983Sc13) and E. W. A. Lingeman (1969Li11). A good agreement was found between the experimental results given by 1969Li11 and 1983Sc13 and the recommended values deduced from the decay scheme balance. For the Kβ x-ray, a fair agreement was found between 1969Li11 and the recommended one.

Table 5: Experimental and recommended (calculated) values of X-ray

	U. Schötzig (1983Sc13)	E. W. A. Lingeman (1969Li10)	Recommended values
Kα x-ray (74.82 + 77.11 keV)	16.3 (4) %	17.3 (20) %	16.73 (23) %
Kβ x-ray		4.3 (8) %	4.69 (10) %

5.2 γ Emissions

The γ-ray energy emissions given are from Y. A. Akovali (1995El07).

The experimental relative γ emission intensities in ^{214}Bi are based on all available relative and absolute measurements of γ-rays for the ^{226}Ra decay chain. The normalization factor to convert the relative emission intensities to absolute intensities is the weighted average of the measured absolute γ-ray emission intensities (Table 6) of the most intense line in ^{226}Ra decay chain, presents in the ^{214}Bi disintegration namely the 609.3 keV line.

Table 6: The experimental absolute 609.3 keV gamma-ray emission intensity

References	Experimental values (%)	Comments
E. W. A. Lingeman (1969Li10)	42.8 (40)	
D. G. Olson (1983Ol01)	45.0 (7)	
U. Schötzig (1983Sc13)	44.6 (5)	
W. –J. Lin (1991Li11)	46.1 (5)	
J. Morel (1998Mo14)	44.8 (6)	Omitted (superseded in 2004Mo07)
J. Morel (2004Mo07)	45.57 (18)	
Recommended value	**45.49 (19)**	χ^2 = 1.45

The recommended normalization factor is the weighted average of the five experimental values: 45.49 with an external uncertainty of 0.19.

The experimental relative γ emission intensities given in Table 7 are relative to the ^{214}Bi 609-keV γ-ray.

Table 7: The experimental data set of the relative γ emission intensities (see next page)

Reference	53-keV γ-ray	107-keV γ-ray	137-keV γ-ray	141-keV γ-ray	170-keV γ-ray	196-keV γ-ray	205-keV γ-ray	216-keV γ-ray	241-keV γ-ray
1964Ew04									16.0 (16)
1969Li10									17.1 (18)[b]
1969Wa27									19.33 (30)[a]
1969Gr33	3.15 (34)[a]								16.2 (17)[a]
1970Mo28									16.10(21)
1975Ha31						0.16 (7)[a]			17.5 (17)[a]
1977Zo01									16.06 (19)[a]
1982Ak03						0.14 (2)[a]			16.1 (24)[a]
1982Fa10					0.020 (8)[a]				16.53 (31)[a]
1983Ol01									16.49 (29)
1983Sc13	2.44 (11)								15.65 (25)
1990Mouze		0.015 (3)			0.032 (6)	0.15 (2)	0.025 (6)	0.022 (5)	16.23 (10)
1991Li11									16.33 (25)
2000Sa32						0.16 (8)	0.026 (12)		16.1 (10)
2002De03	2.329 (23)		0.10 (4)	0.06 (3)					15.896 (48)
2002MoZP	2.329 (23)								15.98 (6)
2004Mo07	2.329 (23)[a]								15.880 (48)[a]
Recommended	2.331 (16)	0.015 (3)			0.032 (6)	0.151 (9)	0.025 (5)	0.022 (5)	15.977 (48)
χ^2	0.5					0.015	0.005		2.0

Reference	258-keV γ-ray	274-keV γ-ray	295-keV γ-ray	305-keV γ-ray	314-keV γ-ray	323-keV γ-ray	351-keV γ-ray	462-keV γ-ray	480-keV γ-ray
1964Ew04			40.46 (40)				77 (8)		
1969Li10	1.32 (22)	1.10 (22)[b]	42.6 (44)[b]		0.220 (44)	0.066 (22)	80 (9)	0.46 (11)	0.66 (15)
1969Wa27			47.87 (91)[a]				87.2 (19)[a]		
1969Gr33	1.16 (7)[a]	1.01 (10)[a]	40.2 (40)[a]		0.137 (23)[a]		79 (7)[a]	0.444 (46)[a]	
1970Mo28			41.45 (56)[b]				79.7 (11)		
1975Ha31	1.24 (12)[a]	0.71 (7)[a]	40.2 (40)[a]	0.050 (25)[a]	0.198 (50)[a]	0.062 (25)[a]	86 (9)[a]	0.446 (50)[a]	0.73 (7)[a]
1977Zo01			42.01 (53)[a]				80.42 (81)[a]		
1982Ak03	1.17 (15)[a]	0.86 (16)[a]	42.2 (54)[a]	0.075 (16)[a]	0.185 (28)[a]	0.072 (40)[a]	82 (11)[a]	0.44 (7)[a]	0.75 (10)[a]
1982Fa10	1.72 (4)[a]		42.52 (59)[a]				81.3 (8)[a]		0.68 (2)[a]
1983Ol01			40.8 (6)				78.7 (11)		
1983Sc13			40.0 (7)				77.2 (9)		
1990Mouze	1.23 (6)	0.84 (6)	41.85 (26)[a]	0.068 (10)	0.17 (2)	0.06 (1)	81.48 (48)[a]	0.40 (4)	0.71 (5)
1991Li11	1.152 (25)	1.042 (25)[b]	42.43 (47)[a]				82.7 (9)[a]	0.486 (20)	0.703 (24)
2000Sa32	1.15 (4)	0.83 (8)	40.8 (12)	0.080 (15)	0.158 (20)	0.084 (20)	78.5 (24)	0.470 (14)	0.74 (3)
2002De03	1.171(9)	0.787 (23)	40.36 (12)				78.16 (23)		0.749 (10)
2002MoZP			40.61 (13)				78.34 (23)		
2004Mo07	1.171(9)[a]	0.760(27)[a]	40.32 (12)[a]				78.10 (23)[a]		0.75 (1)[a]
Recommended	1.169 (8)	0.796 (21)	40.48 (31)	0.0692 (47)	0.169 (13)	0.063 (7)	78.26 (16)	0.469 (12)	0.741 (9)
χ^2	0.56	0.43	0.57	0.56	0.82	0.65	0.52	1.24	0.95

Reference	487-keV γ-ray	533-keV γ-ray	538-keV γ-ray	543-keV γ-ray	580-keV γ-ray	765-keV γ-ray	785-keV γ-ray	839-keV γ-ray
1964Ew04								
1969Li10	0.77 (18)	0.37 (9)			0.70 (13)		2.31 (33)	1.30 (18)
1969Wa27								
1969Gr33	0.91 (23)[a]	0.501 (46)[a]			0.89 (9)[a]		2.41 (23)[a]	1.41 (14)[a]
1970Mo28								
1975Ha31	0.88 (10)[a]	0.408 (50)[a]		0.050 (16)[a]	0.80 (7)[a]		2.48 (25)[a]	1.42 (14)[a]
1977Zo01								
1982Ak03	0.88 (11)[a]	0.42 (5)[a]		0.14 (2)[a]	0.79 (11)[a]		2.32 (32)[a]	1.33 (19)[a]
1982Fa10	0.83 (3)[a]							1.30 (3)[a]
1983Ol01								
1983Sc13							2.286 (45)	
1990Mouze	0.83 (7)	0.39 (3)	0.044 (6)	0.15 (2)	0.76 (6)	0.17 (3)	2.33 (17)	1.29 (10)
1991Li11	0.928 (35)	0.409 (20)			0.774 (31)		2.396 (45)	1.290 (20)
2000Sa32	0.90 (5)	0.39 (3)	0.037 (20)	0.100 (10)	0.74 (4)	0.11 (1)	2.33 (7)	1.29 (4)
2002De03	0.961 (12)				0.823 (11)			
2002MoZP								
2004Mo07	0.961 (12)[a]				0.824 (10)[a]			
Recommended	0.951 (14)	0.399 (14)	0.043 (6)	0.11 (2)	0.811 (13)	0.116 (18)	2.339 (28)	1.290(18)
χ^2	1.54	0.18	0.11	5	1.80	3.6	0.75	0.001

a: Not used by the evaluators (see below).
b: the experimental value has been shown to be outlier value by the Lweight program.

There were omitted from analysis:

a) four sets of values, A. Hachem (1975Ha31), G. Mouze (1981Mo28), H. Akcay (1982Ak03), G. Mouze (1990Mo08) and O. Diallo (1993Di09), because these values comes from the same laboratory of G. Mouze (1990Mo**).

b) the sets of values from K. Ya. Gromov (1969Gr33), G. Wallace (1969Wa27) and M. A. Farouk (1982Fa10), because a lack of information in the articles describing their experimental measurements.

c) the set of values from V. Zobel (1977Zo01), because these values changed the consistency of the data set when introduced in the preliminary calculation with Lweight program, and produced inconsistent set of data for gamma emission intensities. Therefore, in the case of 295-keV and 351-keV γ-rays, the values of G. Mouze (1990Mouze) and W.-J. Lin (1991Li11), consistent with Zobel values, were not used by the evaluators for the weighted mean calculations.

d) the relative γ emission intensity values given by 2004Mo07, because they are those measured by J. U. Delgado (2002De03). In 2004Mo07 article, the author measured the 609.3 keV absolute emission probability (Table 2) and normalized the 2002De03 data set with this value of 45.57 (18).

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

The evaluated relative and absolute γ-ray emission intensities are given in Table 8.

Table 8: Evaluated relative and absolute γ-ray emission intensities

Energy (keV)	Relative emission intensity	Absolute emission intensity (%)
53.2275 (21)	2.331 (16)	1.060 (9)
107.22 (9)	0.015 (3)	0.0068 (14)
137.45 (30)	0.10 (4)	0.045 (18)
141.3 (6)	0.06 (3)	0.027 (14)
170.07 (6)	0.032 (6)	0.0146 (27)
196.20 (5)	0.151 (9)	0.069 (9)
205.68 (9)	0.025 (5)	0.0114 (23)
216.47 (7)	0.022 (5)	0.0100 (23)
241.997 (3)	15.977 (48)	7.268 (22)
258.87 (3)	1.169 (8)	0.5318 (43)
274.80 (5)	0.796 (21)	0.362 (10)
295.224 (2)	40.48 (8)	18.414 (36)
305.26 (3)	0.0692 (47)	0.0315 (21)

Energy (keV)	Relative emission intensity	Absolute emission intensity (%)
314.32 (7)	0.169 (13)	0.077 (6)
323.83 (4)	0.063 (7)	0.0287 (32)
351.932 (2)	78.26 (16)	35.60 (7)
462.00 (7)	0.469 (12)	0.213 (6)
480.43 (2)	0.741 (9)	0.3371 (43)
487.09 (7)	0.951 (14)	0.433 (7)
533.66 (2)	0.399 (14)	0.182 (6)
538.41 (8)	0.043 (6)	0.0196 (27)
543.81 (7)	0.11 (2)	0.050 (9)
580.13 (3)	0.811 (13)	0.369 (6)
765.96 (9)	0.116 (18)	0.053(8)
785.96 (9)	2.339 (28)	1.064 (13)
839.04 (9)	1.290 (18)	0.587 (8)

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^{210}Bi - Comments on evaluation of decay data
by V. Chisté and M. M. Bé

This evaluation was completed in 2008. Literature available by January 2008 was included.

1 Decay Scheme

^{210}Bi disintegrates by beta minus emission to the ground state level of ^{210}Po. Weak alpha transitions to excited levels of ^{206}Tl have been observed (1.40 (15) 10^{-4} %). Spins and parities are from the ENSDF mass-chain evaluations E. Browne (2003Br13 for A = 210). For ^{206}Tl, spins and parities are from L. I. Rusinov measurements (1961Ru02).

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).

Experimental ^{210}Bi half-life values (in days) are given in Table 1:

Table 1: Experimental values of ^{210}Bi half-life.

Reference	Experimental value (d)	Comments
A. Pompéi (1935Po01)	5.02 (1)	Ionization chamber.
N. Hole (1944Ho**)	5.15 (10)	GM counter.
F. Begemann (1952Be22)	5.02 (2)	GM counter.
E. E. Lockett (1953Lo09)	4.989 (13)	Ionization chamber.
J. Robert (1956Ro18)	5.013 (5)	Ionization chamber.Superseded by 1959Ro51
J. Robert (1959Ro51)	5.013 (5)	Ionization chamber.
Recommended value	**5.012 (5)**	χ^2 = 1.32

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

The evaluators have chosen to use just five experimental values with uncertainties given in Table 1. The value of Hole (1944Ho**) has been rejected by the LWEIGHT program because it is an outlier, based on the Chauvenet's criterion. With this data set, the largest contribution to the weighted average comes from the value of Robert (1959Ro51) amounting to 68 % of the total statistical weight.

The recommended value of ^{210}Bi half-life is the weighted average of **5.012 d** with an external uncertainty of **0.005 d**. The reduced-χ^2 value is 1.32.

2.1 α Transitions and Emissions

The recommended values of emission energies of the α-particles are given by A. Rytz (1991Ry01).

Table 2: Experimental values of emission energies of the α-particles.

Reference	$\alpha_{0,1}$ (keV)	$\alpha_{0,2}$ (keV)	Comments
R. J. Walen (1960Wa14)	4686 (2)	4649 (2)	Uncertainty given by Rytz.
P. Kauranen (1962Ka27)	4700	4660	Not used: no uncertainty.
R. C. Lange (1969La18)	4697 (5)	4660 (5)	Uncertainty given by Rytz.
Recommended value (1991Ry01)	**4687 (4)**	**4650 (4)**	χ^2 = 4.2. External uncertainty.

Several experimental values of the α branching to ^{206}Tl are given in Table 3.

Table 3: Experimental and recommended values of total α branching for $^{210}Bi \rightarrow {}^{206}Tl$.

Reference	Experimental value (10^{-4} %)	Comments
E. Broda (1947Br36)	0.5	Not used: no uncertainty.
R. J. Walen(1959Wa05)	1.25	Not used: no uncertainty.
R. W. Fink (1956Fi09)	1.7 (2)	
M. Nurmia (1961Nu01)	1.9 (4)	Superseded by 1962Ka27
P. Kauranen (1962Ka27)	1.32 (10)	
Recommended value	**1.40 (15)**	χ^2 = 2.9

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

The value given by M. Nurmia (1961Nu01) is from the same laboratory as 1962Ka27, thus, it was not included in the averaging procedure. Then, the recommended alpha transition branching is the average of the values given by R. W. Fink (1956Fi09) and P. Kauranen (1962Ka27).

The recommended value of α transitions to the excited levels of ^{206}Tl is the weighted average of **1.40 10^{-4} %** with an external uncertainty of **0.15 10^{-4} %**. The reduced-χ^2 value is 2.9.

The individual α particle probabilities to the 265-keV and 304-keV levels are (1959Wa05, 1960Wa14) 0.56 (6) 10^{-4} % and 0.84 (9) 10^{-4} %, respectively.

2.2 b$^-$ Transitions and Emissions

The end-point energy of the β^- transition in the decay of $^{210}Bi \rightarrow {}^{210}Po$ is from the $Q_{\beta-}$(2003Au03). The recommended and experimental values are shown in Table 4.

Table 4: Experimental and recommended values of the end-point energy of the β^- transition.

Reference	$E_{\beta-}$ (keV)
A. Flammersfeld (1939Fl02)	1170
G. J. Neary (1940Ne04)	1170
E. A. Plassmann (1954Pl30)	1155 (5)
H. Daniel (1962Da03)	1160.5 (5)
S. T. Hsue(1967Hs01)	1161.5 (15)
D. Flothmann (1969Fl02)	1153
Recommended value (2003Au03)	**1162.1 (8)**

For the $\beta_{0,0}$ transition probability and associated uncertainty, the following relation was applied:
$P_{\beta0,0}$ = 100 % - P_α,
where P_α = 1.40 (15) 10^{-4} % (see 2.2 α Transitions and Emissions). Then: $P_{\beta0,0}$ = 99.99986 (2) %.

The lg ft value and the average β^- energy have been calculated with the program LOGFT for a 1st forbidden transition.

2.3 g Transitions and Emissions

Multipolarity of γ-ray transitions are from L. I. Rusinov (1961Ru02):
265-keV γ-ray: E2
304-keV γ-ray: M1

The γ-ray transition probabilities following the α-decay of $^{210}Bi \rightarrow {}^{206}Tl$ were deduced from the decay-scheme balance using the recommended α-particle intensity values given in section 2.1 α Transitions and Emissions, shown in Table 5.

Table 5: Adopted values of α transition and γ-ray emission probabilities.

γ-ray energy (keV)*	α probability (%)	γ-ray absolute transition probability (%)	γ-ray absolute emission probability (%)
265.832 (5)	0.000 056 (6)	0.000 056 (6)	0.000 048 (5)
304.896 (6)	0.000 084 (9)	0.000 084 (9)	0.000 061 (7)

*From 1999Br39

The γ-ray emission intensities were obtained using the γ-ray transition probabilities (given in Table 6) and the relevant internal conversion coefficients, calculated using the BrIcc computer code (calculation for 'hole'), which interpolated from theoretical values of I. M. Band (2002Ba85) .

3 Atomic Data

Atomic values, ω_K, ϖ_L and n_{KL} are from Schönfeld and Janβen (1996Sc06).

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^{211}Bi – Comments on Evaluation of Decay Data by A. Luca

This evaluation was completed in July 2009. The literature available by December 31st, 2008 was included.

1. Evaluation Procedures

The Limitation of Relative Statistical Weight (LWM) method was applied for averaging numbers throughout this evaluation; this method was implemented by using the computer code LWEIGHT, ver. 4 (designed for Excel, MS Office). The uncertainty assigned to an average value in this evaluation is never lower than the lowest uncertainty of any of the experimental input values.

2. Decay Scheme

^{211}Bi decays 99.724 (4) % by alpha particle emissions, populating the ^{207}Tl ground state (83.56 (23) %) and the 351.03 keV excited state (16.16 (23) %). ^{211}Bi has also a weak beta minus decay branch (0.276 (4) %) to the ground state of ^{211}Po; although these β^- particles were not observed experimentally (the low intensity beta-particle emission is obscured by the intense β^- particles emission from the ^{211}Pb sources used for measurements), the existence of the beta minus decay and the adopted value of the corresponding branching ratio are based on the alpha-particle spectrometry measurements of the emission probabilities ratio, $I\alpha(^{211}Po)/(I\alpha(^{211}Po)+I\alpha(^{211}Bi))$, performed by several scientists (see references from Table 1). The adopted value represents the weighted mean of the experimental results published in the literature (see also Table 1, below); an earlier value, 0.32 % (without a quoted uncertainty), determined by Rutherford et al. (1931), was not taken into account. Another important study of the ^{211}Bi decay scheme is presented in the reference 1966Go13. The most recent evaluations of the ^{211}Bi nuclear structure, alpha and beta minus decay data, published in Nuclear Data Sheets, were made by M. J. Martin (1993) and E. Browne (2004). In the present evaluation, the spin and parity of the levels have been adopted from the above mentioned A = 207 and A = 211 ENSDF mass-chain evaluations (1993Ma73 and 2004Br45, respectively).

Table 1: Beta minus branching ratio for the ^{211}Bi decay

Beta minus branching ratio (experimental), %	Reference
0.274 (4)	1967Da10
0.274 (10)	1965Nu03
0.29 (1)	1962Gi04
Recommended value: 0.276 (4) %	

3. Nuclear Data

The adopted alpha decay energy value Q(α) = 6750.33 (46) keV, is from 2003Au03. This value is in very good agreement with the effective Q(α) value of 6750.63 keV (with an uncertainty of 0.21 keV), calculated from the decay scheme data, by using the SAISINUC software, version 2008 April. The adopted beta minus decay energy value Q(β) = 574 (5) keV is also from 2003Au03.

3.1. Half-life

In the literature, four measured ^{211}Bi half-life ($T_{1/2}$) values are reported. All these measurements are old (the most recent is from 1970), so new half-life measurements are needed to improve the quality of the evaluation. The half-life values and their uncertainties are presented in Table 2.

The value recommended by Curie et al. (1931), with an estimated uncertainty added by the evaluator, was included, too. The uncertainty of other two results (1954Sp32 and 1965Nu03) was also estimated by the evaluator. The set of data is consistent and the recommended value, 2.15 minutes, with an uncertainty of 0.02 minutes, is the weighted average (LWM, χ^2_ν=3.7) of the four input values.

Table 2 : ^{211}Bi Half-life values

$T_{1/2}$ (minutes)	Uncertainty of $T_{1/2}$ (minutes)	Reference
2.16	0.08	1931Cu01
2.15	0.02	1954Sp32
2.13	0.03	1965Nu03
2.22	0.06	1970Mu21

3.2. Alpha and Beta transitions and emissions

In the literature, the most important reference that studies measurements of alpha-particle energies and emission intensities for ^{211}Bi alpha transitions is 1991Ry01.

For this evaluation, the two adopted alpha-particle emission energies were calculated as weighted means of the experimental values presented in Table 3 (both data sets are consistent):

Table 3: Energy of the alpha-particles emitted in the ^{211}Bi decay

Alpha-particle group	Energy of the alpha particles (experimental), keV	Reference
$\alpha_{0,1}$	6300 (10)	1989It01
	6278.2 (7)	1991Ry01
	6279 (1)	1992Sc26
	Recommended energy value: 6278.5 (9) keV	
$\alpha_{0,0}$	6622.9 (6)	1971Gr17 and 1991Ry01
	6620 (10)	1989It01
	6621.33 (69)	1991Ry01
	6623 (1)	1992Sc26
	Recommended energy value: 6622.4 (6) keV	

The ratio of the 6278.5 keV to the sum of 6278.5 keV and 6622.4 keV alpha-particle emission probabilities was determined in a similar way, as the weighted mean of four experimental values reported in the literature and presented below, in Table 4. This data set is discrepant and, consequently, the uncertainty was expanded to include in its range the most precise relative value (16.43 (4) from 1967Da10); the adopted value is 16.20 (23). Considering both the experimental results and the normalization condition (modified to take into account the beta minus decay, see section 2), i.e. the sum of the two absolute alpha-particle emission probabilities must be 100 % - 0.276 (4) % = 99.724 (4) %, the computed absolute emission probability of the 6278.5 keV alpha-particles is 16.16 (23) %. The 6622.4 keV alpha-particles absolute emission probability is then 83.56 (23) %.

The beta minus transition is of the first order forbidden type (non-unique) and populates the ground state of ^{211}Po. The beta particles must have a maximum energy of 574 keV (corresponding to the Q(β) value) and an absolute emission probability of 0.276 (4) %. The adopted values of the average beta minus energy (172.9 (18) keV) and log ft (5.99) were obtained by using the LOGFT computer program.

Table 4: Experimental values of the relative alpha-particles emission probability ratio (6278.5 keV) / (6278.5 keV + 6622.4 keV)

Alpha-particle emission probability ratio (6278.5 keV) / (6278.5 keV + 6622.4 keV) x 100	Reference
15.8 (1)	1962Gi04
15.9 (3)	1962Wa18
16.02 (5)	1966Go13
16.43 (4)	1967Da10

3.3. γ- transitions: γ rays and internal conversion electrons

There is a single gamma-ray transition following the ^{211}Bi decay. Both its energy and emission probability were studied by many scientists. Table 5 summarizes the experimental results published in the literature. The adopted energy of this gamma-ray transition is the weighted mean of the 6 values from Table 5 (consistent data set): 351.03 (4) keV.

The absolute emission probability of this gamma-ray was determined from the alpha feeding of 16.16 (23) % to the ^{207}Tl excited state: 16.16 (23) / 1.243 (4) = 13.00 (19) %, where 0.243 (4) is the total internal conversion coefficient (total ICC), which is in good agreement with the experimental values reported in references 1976Bl13 and 1982Mo30 (see Table 5).

All the internal conversion coefficients (ICCs) adopted in this evaluation were computed with the program BrIcc, version 2.2 /2008, using the “Frozen Orbitals” approximation (2008Ki07). The energy range of the internal conversion electrons corresponding to the gamma-ray transition is from 265.5 keV to 351.02 keV, whereas the total number of conversion electrons emitted per 100 disintegrations is 3.17 (7) (i.e.3.17 (7) %)

Table 5: ^{211}Bi γ-ray Energy and Absolute Emission Probability (experimental values)

E_γ (keV)	Uncertainty E_γ (keV)	Absolute Emission Probability (%)	Uncertainty of absolute emission probability (%)	Reference
351.0	0.1	10.70	0.30	1968Br17
351.0	0.3			1973UrZX
351.01	0.04			1975VaYT
351.07	0.05	12.27	1.4	1976Bl13
351.89	0.20	13.3	1.3	1982Mo30
351.06	0.12			1988Hi14

4. Atomic data

The K-shell fluorescence yield (ω_K), the mean L-shell fluorescence yield (ϖ_L) and the mean number of vacancies in the L-shell produced by one vacancy in the K-shell (η_{KL}) were determined using the computer program EMISSION v.3.10, 28-Jan-2003: 0.963 (4), 0.367 (15) and 0.812 (5) respectively.

4.1. Auger electrons and X-rays

The relative probability values of the K Auger electron emissions (KLL, KLX, KXY) normalized to the KLL value, were computed using the same EMISSION computer program. The total numbers of K and L Auger electrons emitted per disintegration were also calculated (in %): 0.096 (11) and 1.620 (21), respectively. The energy ranges for K and L Auger electrons were filled-in by the SAISINUC program, version 2008 April.

The relative probability (normalized to $K_{\alpha 1}$ X-rays emission) and the absolute emission probability values of the different groups of K and L X-rays were determined using the same EMISSION program. The adopted values (in %) of the total absolute emission probability of the KX-rays and LX-rays were 2.50 (6) and 0.931 (19), respectively. The energy range values of the K and L X-rays are from the tables linked to SAISINUC.

Only one reference reporting the measurement of the ^{207}Tl KX-rays energies and emission probabilities was found in the literature (1976Bl13). A comparison between these experimental values and the results of this evaluation is presented in Table 6.

For the two K_α X-rays the results are in very good agreement for energy and unsatisfactory for the absolute emission probability values. The Tl-Kα2 and Tl-Kα1 x-ray absolute emission probabilities reported in 1976Bl13 are about 30 % lower than expected (See Table 6). The cause of this serious disagreement is unknown.

For the two K_β X-rays, the energy values are in good agreement, whereas the absolute emission probabilities values again are in clear disagreement. There are at least two possible causes of this disagreement:

- the evaluated values refer to a sum of three components, not only to $K\beta_1$, respectively $K\beta_2$ (see the Note below Table 6);
- the measurements reported in the article 1976Bl13 include also the Rn $K\alpha_1$ X-rays with an energy of 83.788 keV, situated just between the two components of interest; the presence of this additional peak makes the spectral analysis of this region more difficult, considering the software tools available in 1976 (a higher uncertainty than reported for the experimental results is possible).

This second assumption is supported by the very good agreement between the sum of Tl-$K\beta_1$ and Tl-$K\beta_2$ absolute emission probabilities (in %), according to Table 6: 0.542 (12) (evaluated) and 0.55 (6) (experimental).

Neither measurements of ^{207}Tl LX-rays energies nor of emission probabilities were found in the literature, in order to compare them with the results of this evaluation.

Table 6: Comparison of the evaluated Tl KX-rays energy and absolute emission probability values with experimental results from 1976Bl13

X-rays identification	Evaluated energy (keV)	Evaluated Absolute Emission Probability (in %)	Experimental energy (keV)	Experimental absolute emission probability (in %) (1976Bl13)
Tl-Kα_2	70.832	0.726 (16)	70.839 (13)	0.51 (8)
Tl-Kα_1	72.872	1.225 (27)	72.857 (10)	0.82 (12)
Tl-Kβ_1	82.577	0.417 (11) *	83.019 (80)	0.24 (4)
Tl-Kβ_2	84.838	0.124 (4) *	84.720 (50)	0.31 (4)

* Note: the evaluated absolute emission probabilities of the two K_β X-rays include not only the contributions of the Kβ_1 and Kβ_2 components, but also Kβ_3, K''β_5, Kβ_4 and KO$_{2,3}$.

5. Main production mode

The main production mode of ^{211}Bi is by beta minus decay of the ^{211}Pb nuclei (both nuclides are members of the Actinium-Uranium natural radioactive series). ^{211}Bi can be produced also by the alpha decay of ^{215}At (a process of very low probability in the above mentioned radioactive series, because ^{215}At is produced by the weak beta minus decay branch of ^{215}Po, which is about $2.3 \cdot 10^{-4}$ %).

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^{212}Bi – Comments on evaluation of decay data by A. L. Nichols

Evaluated: July/August 2001
Re-evaluated: January 2004 and May 2010

Evaluation Procedures

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

Decay Scheme

^{212}Bi undergoes beta decay to ^{212}Po (beta branch of 64.07 (7) %), and alpha decay to ^{208}Tl (alpha branch of 35.93 (7) %). The alpha branch 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	α-decay branch (%)
1960Sc07	35.96 (6)
1962Be09	35.81 (4)
1962Fl03	36 (1)
1965Wa09	36.00 (3)*
Recommended value	35.93 (7)

* Uncertainty increased to ± 0.033 so that weighting does not exceed 50 %.

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, 1966KlZZ, 1967Be19, 1968Yt02, 1972DaZA (1973Da38), 1978Av01, 1982Be09, 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)

* Uncertainty increased to ± 0.052 so that weighting does not exceed 50 %.

There is no evidence of any change in the half-life of ^{212}Bi on extreme cooling of alpha-active ^{224}Ra samples and decay products within a metallic environment (2007St23). Sources were held at temperatures at and below 1 kelvin for periods of several days, and exhibited an upper limit of change in the alpha-decay half-lives of the order of 1 %.

Alpha Particles

Energies

All alpha-particle energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies specified by 2007Ma45 and Q-values of 2003Au03 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 below) and theoretical internal conversion coefficients, combined with an alpha branch of 35.93 (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. A value of 1.50 (2) was adopted for the radius parameter $r_0(^{208}Tl)$ as specified by Martin to calculate the hindrance factors (2007Ma45).

Alpha-particle energies, measured relative and recommended absolute emission probabilities, and hindrance factors.

E_α(keV)	P_α^{rel}				P_α^{abs}	HF
	1951Ry17	1960Wa14	1962Be09		Recommended value*	
5302 (2)	0.016	0.000 11 (1)	-	-	0.000 040 (4)‡	20 300
5344 (2)	0.147	0.001	-	-	0.000 36 (3)‡	3 770
5481.4 (3)	-	0.014	~ 0.04	~ 0.02	0.005 0 (4)‡	1 380
5606.60 (5)	1.08	1.19	)	)	0.43 (3)‡	67
			) 1.35 (6)	) 1.22 (2)		
5625.7 (4)	-	0.162 5	)	)	0.060 (3)	595
5768.29 (6)	1.67	1.78	1.63 (11)	1.67 (2)	0.61 (3)	279
6051.04 (3)	69.86#	69.7	70.2 (3)	70.2 (2)	25.1 (1)	126
6090.14 (3)	27.16#	27.1	27.0 (5)	26.8 (2)	9.7 (1)	481
9498.78 (11)†	-	-	-	-	0.002 4 (2)	-
10432.94 (11)†	-	-	-	-	0.001 0 (1)	-
10552.1 (2)†	-	-	-	-	0.010 6 (7)	-

* Recommended emission probabilities derived from evaluated gamma-ray emission probabilities, theoretical internal conversion coefficients and alpha branch of 35.93 (7) %, unless stated otherwise (expressed per 100 disintegrations of ^{212}Bi).

‡ Data reported by 1960Wa14 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.

Long-range 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 727.330 keV emit high-energy, long-range alpha particles (energies of 10552.1, 10432.94 and 9498.78 keV, respectively). All measurements were expressed relative to 10^6 emission probability for the 8785.17-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 ($\beta^-\alpha$ decay).

E_α (keV)	P_α^{rel}			
	1951Ry17	1962Be09	1965Le08	Mean value
[8 785.17 (11)]*	10^6	10^6	10^6	10^6
9 498.78 (11)	35	45	34	38
10 432.94 (11)	20	17	10	16
10 552.1 (2)	170	167	160	166
total α (of $\beta^-\alpha$)	225	229	204	219 (15)

* ^{212}Po alpha decay directly to the ground state of ^{208}Pb as $\alpha_{0,0}$.

Total α emissions from $\beta^-\alpha$ decay have an estimated mean value of 219 relative to 10^6 for the emission probability of the 8785.17-keV alpha particle of ^{212}Po, with an uncertainty of ± 15 to cover the range of measured data. Therefore, a mean value of 0.014 % was estimated for the $\beta^-\alpha$ branch, combined with an uncertainty of approximately 7 % (($\beta^-\alpha$) branch of 0.014 (1) %):

$$\beta^-\alpha \text{ branch} = [219 (15) \times 64.07 (7)] / 10^6 = 0.014 (1) \%$$

Absolute alpha-particle emission probabilities for this small branch were calculated from the mean values and ($\beta^-\alpha$) branch.

Beta Particles

Energies
All beta-particle energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 2005Br03 and Q-value of 2252.1 (17) keV from 2003Au03 were used to determine the energies and uncertainties of the beta-particle transitions to the various levels.

Emission Probabilities
The beta-particle emission probabilities were calculated from gamma-ray transition intensity balances, using the recommended gamma-ray emission probabilities and the theoretical internal conversion coefficients determined from the frozen orbital approximation of Kibédi *et al.* (2008Ki07) and based on the theoretical model of Band *et al.* (2002Ba85, 2002Ra45).

Beta-particle energies, emission probabilities, transition types and log *ft* values.

E_β(keV)	P_β		transition type	log *ft*
	1957Bu34	Recommended value*		
446.1 (17)	8.5	0.68 (4)	(1st forbidden non-unique)	6.67
451.2 (17)	-	0.032 (4)	(1st forbidden non-unique)	8.03
572.7 (17)	-	0.21 (4)	(1st forbidden non-unique)	7.55
631.4 (17)	6	1.90 (3)	(1st forbidden non-unique)	6.740
739.4 (17)	-	1.44 (1)	(1st forbidden non-unique)	7.094
1524.8 (17)	10	4.50 (6)	(1st forbidden non-unique)	7.718
2252.1 (17)	63	55.31 (9)	(1st forbidden non-unique)	7.267

* Recommended emission probabilities derived from evaluated gamma-ray emission probabilities, theoretical internal conversion coefficients, beta branch of 64.06 (7) % and beta-alpha branch of 0.014 (1) % (expressed per 100 disintegrations of ^{212}Bi).

Gamma Rays

Energies
All gamma-ray transition energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 2005Br03 and 2007Ma45 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/1973Da38, 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 (i.e., 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 transition probabilities were estimated for the 180.2- and 1800.9-keV gamma rays in the beta-decay mode, and the 164.80-, 433.5-, 492.84-, 580.5- and 620.4-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-particle emission probability).

Published gamma-ray emission probabilities.

E_γ (keV)		P_γ						
		1960Sc07[*]	**1962Be09**	**1962Fl03**[‡]	**1967Be19**[#]	**1968Yt02**[$]	**1972DaZA**[$]	**1978Av01**[Δ]
39.858 (4)	(Tl)	-	-	-	-	-	-	-
43 (3)	(Tl)	-	-	-	-	-	-	-
143 (3)	(Tl)	-	-	-	-	-	-	-
144 (2)	(Tl)	-	-	-	-	-	-	-
164.80 (6)	(Tl)	-	-	-	-	-	-	-
180.2 (2)	(Po)	-	-	-	-	-	-	-
267 (2)	(Tl)	-	-	-	-	-	-	-
287 (2)	(Tl)	-	-	-	-	-	-	-
288.18 (5)	(Tl)	-	0.775 (40)[#]	-	0.82 (2)	-	0.9 (2)	0.97 (5)
289 (2)	(Tl)	-	-	-	-	-	-	-
310 (2)	(Tl)	-	-	-	-	-	-	-
328.04 (5)	(Tl)	-	0.299 (23)[#]	-	0.33 (1)	-	0.36 (7)	-
433.5 (4)	(Tl)	-		-	0.04 (1)	-	~ 0.025	-
452.98 (4)	(Tl)	-	) 1.18 (5)[#]	-	0.84 (2)	-	0.88 (17)	1.10 (6)
473.4 (4)	(Tl)	-	)	-	0.122 (8)	-	0.10 (3)	-
492.84 (4)	(Tl)	-	-	-	< 0.008	-	-	-
580.5 (3)	(Tl)	-	-	-	-	-	-	-
620.4 (3)	(Tl)	-	-	-	-	-	-	-
727.330 (9)	(Po)	11.1 (7)	) 100[†]	11.8 (24)	-	-	17.6 (17)	21.0 (8)
785.37 (9)	(Po)	1.70 (26)	)	-	-	-	2.8 (6)	3.26 (16)
893.408 (14)	(Po)	0.66 (7)	4.9 (3)[†]	0.5 (1)	-	-	0.94 (19)	-
952.12 (2)	(Po)	0.16 (4)	-	-	-	-	0.46 (9)	-
1073.6 (2)	(Po)	) 0.99 (8)	) 10.1 (4)[†]	-	-	-	~ 0.03	-
1078.63 (10)	(Po)	)	)	0.7 (1)	-	-	1.4 (2)	-
1512.70 (8)	(Po)	0.49 (5)	3.4 (3)[†]	-	-	0.99 (15)	0.8 (1)	-
1620.738 (10)	(Po)	2.81 (20)	20.0 (6)[†]	3.0 (6)	-	4.85 (50)	3.9 (4)	-
1679.450 (14)	(Po)	-	-	-	-	0.230 (7)	0.16 (3)	-
1800.9 (2)	(Po)	-	-	-	-	-	-	-
1805.96 (10)	(Po)	0.17 (3)	1.4 (2)[†]	0.5 (1)	-	0.41 (10)	0.25 (5)	-

Published gamma-ray emission probabilities (cont.).

$E_γ$ (keV)		$P_γ$ (cont.)				
		1982Sa36¶	1983Sc13Ψ	1983Va22Ψ	1984Ge07Δ	1992Li05Ψ
39.858 (4)	(Tl)	0.9 (1)	-	-	3.49 (28)	-
43 (3)	(Tl)	-	-	-	-	-
143 (3)	(Tl)	-	-	-	-	-
144 (2)	(Tl)	-	-	-	-	-
164.80 (6)	(Tl)	-	-	-	-	-
180.2 (2)	(Po)	-	-	-	-	-
267 (2)	(Tl)	-	-	-	-	-
287 (2)	(Tl)	-	-	-	-	-
288.18 (5)	(Tl)	0.32 (3)	0.274 (23)	-	1.106 (10)	0.389 (57)
289 (2)	(Tl)	-	-	-	-	-
310 (2)	(Tl)	-	-	-	-	-
328.04 (5)	(Tl)	-	0.120 (4)	-	0.423 (20)	3.23 (12)
433.5 (4)	(Tl)	-	-	-	-	-
452.98 (4)	(Tl)	0.42 (5)	0.256 (23)	-	1.191 (11)	0.370 (49)
473.4 (4)	(Tl)	-	-	-	-	-
492.84 (4)	(Tl)	-	-	-	-	-
580.5 (3)	(Tl)	-	-	-	-	-
620.4 (3)	(Tl)	-	-	-	-	-
727.330 (9)	(Po)	6.9 (4)	6.56 (15)	7.00 (18)	21.63 (13)	6.93 (18)
785.37 (9)	(Po)	1.01 (7)	1.07 (5)	-	3.62 (4)	1.05 (5)
893.408 (14)	(Po)	0.49 (8)	0.352 (36)	-	1.25 (6)	-
952.12 (2)	(Po)	-	-	-	-	-
1073.6 (2)	(Po)	-	-	-	-	-
1078.63 (10)	(Po)	-	0.58 (4)	-	1.85 (6)	0.555 (41)
1512.70 (8)	(Po)	-	0.276 (42)	-	-	-
1620.738 (10)	(Po)	-	1.38 (8)	-	4.88 (10)	1.44 (9)
1679.450 (14)	(Po)	-	-	-	-	-
1800.9 (2)	(Po)	-	-	-	-	-
1805.96(10)	(Po)	-	-	-	-	-

* 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 0.436 (4).
Ψ Absolute emission probabilities.

Absolute gamma-ray emission probabilities per 100 disintegrations of ^{212}Bi.

E_γ (keV)		P_γ^{abs}						
		1960Sc07	1962Be09	1962Fl03	1967Be19	1968Yt02	1972DaZA	1978Av01
39.858 (4)	(Tl)	-	-	-	-	-	-	-
43 (3)	(Tl)	-	-	-	-	-	-	-
143 (3)	(Tl)	-	-	-	-	-	-	-
144 (2)	(Tl)	-	-	-	-	-	-	-
164.80 (6)	(Tl)	-	-	-	-	-	-	-
180.2 (2)	(Po)	-	-	-	-	-	-	-
267 (2)	(Tl)	-	-	-	-	-	-	-
287 (2)	(Tl)	-	-	-	-	-	-	-
288.18 (5)	(Tl)	-	0.278 (14)	-	0.29 (1)	-	0.3 (1)	0.35 (2)
289 (2)	(Tl)	-	-	-	-	-	-	-
310 (2)	(Tl)	-	-	-	-	-	-	-
328.04 (5)	(Tl)	-	0.107 (8)	-	0.12 (1)	-	0.13 (3)	-
433.5 (4)	(Tl)	-		-	0.014 (4)	-	~ 0.009	-
452.98 (4)	(Tl)	-	) 0.424 (18)	-	0.30 (1)	-	0.32 (6)	0.40 (2)
473.4 (4)	(Tl)	-	)	-	0.044 (3)	-	0.04 (1)	-
492.84 (4)	(Tl)	-	-	-	< 0.003	-	-	-
580.5 (3)	(Tl)	-	-	-	-	-	-	-
620.4 (3)	(Tl)	-	-	-	-	-	-	-
727.330 (9)	(Po)	7.11 (45)	) [7.85]	7.6 (15)	-	-	6.3 (6)	7.6 (3)
785.37 (9)	(Po)	1.09 (17)	)	-	-	-	1.0 (2)	1.17 (6)
893.408 (14)	(Po)	0.42 (4)	0.38 (2)	0.32 (6)	-	-	0.34 (7)	-
952.12 (2)	(Po)	0.10 (3)	-	-	-	-	0.17 (3)	-
1073.6 (2)	(Po)	) 0.63 (5)	) 0.79 (3)	-	-	-	~ 0.01	
1078.63 (10)	(Po)	)	)	0.45 (6)	-	-	0.50 (7)	-
1512.70 (8)	(Po)	0.31(3)	0.27 (2)	-	-	0.36 (5)	0.29 (4)	-
1620.738 (10)	(Po)	1.80 (13)	1.57 (5)	1.9 (4)	-	1.74 (18)	1.4 (1)	-
1679.450 (14)	(Po)	-	-	-	-	0.083 (3)¶	0.06 (1)	-
1800.9 (2)	(Po)	-	-	-	-	-	-	-
1805.96 (10)	(Po)	0.11 (2)	0.11 (2)	0.32 (6)	-	0.15 (4)	0.09 (2)¶	-

Absolute gamma-ray emission probabilities per 100 disintegrations of ^{212}Bi (cont.).

E_γ (keV)		P_γ^{abs} (cont.)					
		1982Sa36	1983Sc13	1983Va22	1984Ge07	1992Li05	Recommended value*
39.858 (4)	(Tl)	0.9 (1)	-	-	1.07 (9)	-	1.07 (1)†
43 (3)	(Tl)	-	-	-	-	-	-**
143 (3)	(Tl)	-	-	-	-	-	-**
144 (2)	(Tl)	-	-	-	-	-	-**
164.80 (6)	(Tl)	-	-	-	-	-	0.0055 (6)‡
180.2 (2)	(Po)	-	-	-	-	-	0.0031 (12)
267 (2)	(Tl)	-	-	-	-	-	-**
287 (2)	(Tl)	-	-	-	-	-	-**
288.18 (5)	(Tl)	0.32 (3)	0.274 (23)	-	0.339 (3)¶	0.389 (57)	0.32 (2)
289 (2)	(Tl)	-	-	-	-	-	-**
310 (2)	(Tl)	-	-	-	-	-	-**
328.04 (5)	(Tl)	-	0.120 (4)¶	-	0.129 (6)	3.23 (12)Ψ	0.121 (3)
433.5 (4)	(Tl)	-	-	-	-	-	0.011 (1)‡
452.98 (4)	(Tl)	0.43 (5)	0.256 (23)	-	0.365 (3)¶	0.370 (49)	0.34 (3)
473.4 (4)	(Tl)	-	-	-	-	-	0.044 (3)
492.84 (4)	(Tl)	-	-	-	-	-	0.039 (10)‡
580.5 (3)	(Tl)	-	-	-	-	-	0.0011 (2)‡
620.4 (3)	(Tl)	-	-	-	-	-	0.0038 (4)‡
727.330 (9)	(Po)	7.0 (4)	6.56 (15)	7.00 (18)	6.62 (4)¶	6.93 (18)Ψ	6.65 (4)
785.37 (9)	(Po)	1.02 (7)	1.07 (5)	-	1.11 (1)	1.05 (5)	1.11 (1)
893.408 (14)	(Po)	0.50 (8)§	0.352 (36)	-	0.383 (18)	-	0.38 (1)
952.12 (2)	(Po)	-	-	-	-	-	0.14 (4)
1073.6 (2)	(Po)	-	-	-	-	-	0.0154 (6)#
1078.63 (10)	(Po)	-	0.58 (4)	-	0.566 (18)¶	0.555 (41)	0.55 (2)
1512.70 (8)	(Po)	-	0.276 (42)	-	-	-	0.29 (1)
1620.738 (10)	(Po)	-	1.38 (8)	-	1.49 (3)¶	1.44 (9)	1.51 (3)
1679.450 (14)	(Po)	-	-	-	-	-	0.07 (1)
1800.9 (2)	(Po)	-	-	-	-	-	-
1805.96 (10)	(Po)	-	-	-	-	-	0.12 (3)

* Weighted mean values adopted when appropriate; remainder derived from proposed decay scheme (see other footnotes).

** Gamma rays with emission probabilities denoted by a dash (–) are believed to be relevant to the α branch of the decay scheme, but could not be quantified in terms of absolute P_γ, and are omitted from the final recommendations.

† 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 1982Be09 measurement of Pγ(1078.63 keV) / Pγ(1073.6 keV) = 35.7 (35) to give Pγ(1073.6 keV) of 0.55 (2) / 35.7 (35) = 0.0154 (6) , which was used to define the Pγ of the 180.2-keV gamma emission and the TPγ of the 1800.9-keV gamma transition.

¶ 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.

Placements of gamma-ray transitions.

Adopted Eγ (keV)	Proposed location in decay scheme of β^- branch (^{212}Po nuclear levels)	Adopted Eγ (keV)	Proposed location in decay scheme of α branch (^{208}Tl nuclear levels)
180.2 (2)	1800.9 (2) – 1620.738 (10)	39.858 (4)	39.858 (4) – 0
727.330 (9)	727.330 (9) – 0	43 (3)	803 (2) – 760 (2)
785.37 (9)	1512.70 (8) – 727.330 (9)	143 (3)	760 (2) – 617 (2)
893.408 (14)	1620.738 (10) – 727.330 (9)	144 (2)	617 (2) – 473.4 (4)
952.12 (2)	1679.450 (14) – 727.330 (9)	164.80 (6)	492.84 (4) – 328.04 (5)
1073.6 (2)	1800.9 (2) – 727.330 (9)	267 (2)	760 (2) – 492.84 (4)
1078.63 (10)	1805.96 (10) – 727.330 (9)	287 (2)	760 (2) – 473.4 (4)
1512.70 (8)	1512.70 (8) – 0	288.18 (5)	328.04 (5) – 39.858 (4)
1620.738 (10)	1620.738 (10) – 0	289 (2)	617 (2) – 328.04 (5)
1679.450 (14)	1679.450 (14) – 0	310 (2)	803 (2) – 492.84 (4)
1800.9 (2)	1800.9 (2) – 0	328.04 (5)	328.04 (5) – 0
1805.96 (10)	1805.96 (10) – 0	433.5 (4)	473.4 (4) – 39.858 (4)
		452.98 (4)	492.84 (4) – 39.858 (4)
		473.4 (4)	473.4 (4) – 0
		492.84 (4)	492.84 (4) – 0
		580.5 (3)	620.4 (3) – 39.858 (4)
		620.4 (3)	620.4 (3) – 0

A number of the gamma transitions required to create a reasonably comprehensive decay scheme cannot be quantified in terms of absolute P_γ because measured data are lacking – these particular gamma rays are denoted by a dash (–) in the “Recommended value” column of the table entitled “Absolute gamma-ray emission probabilities per 100 disintegrations of ^{212}Bi” (see above).

<u>Multipolarities and Internal Conversion Coefficients</u>

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; both the 473.4- and 620.4-keV gamma transitions were arbitrarily defined as 50 % M1 + 50 % E2. Although some contradictions did occur, other mixing ratios were adopted from the studies of 1966KlZZ, 1978Av01 and 1982Be09:

99.36 % M1 + 0.64 % E2 for 288.08-keV,
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 gamma rays.

Multipolarity assignments

Reference	E_γ (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

Recommended internal conversion coefficients have been determined from the frozen orbital approximation of Kibédi *et al.* (2008Ki07), based on the theoretical model of Band *et al.* (2002Ba85, 2002Ra45). Ion-pair formation coefficients were calculated by means of the methodology described by Kibedi *et al.* (2008Ki07).

Gamma-ray emissions: multipolarities, theoretical internal conversion coefficients (frozen orbital approximation) and ion-pair formation coefficients.

E_γ (keV)		Multipolarity	α_K	α_L	α_{M+}	α_{IPF}	α_{total}
39.858 (4)	(Tl)	(M1)	–	17.81 (25)	5.49 (6)	–	23.3 (4)
43 (3)	(Tl)	–	–	–	–	–	–
143 (3)	(Tl)	–	–	–	–	–	–
144 (2)	(Tl)	–	–	–	–	–	–
164.80 (6)	(Tl)	(E2)	0.263 (4)	0.413 (6)	0.140 (2)	–	0.816 (12)
267 (2)	(Tl)	–	–	–	–	–	–
287 (2)	(Tl)	–	–	–	–	–	–
288.18 (5)	(Tl)	99.36 % M1 + 0.64 % E2 δ = 0.080	0.357 (5)	0.060 5 (9)	0.0185 (2)	–	0.436 (7)
289 (2)	(Tl)	–	–	–	–	–	–
310 (2)	(Tl)	–	–	–	–	–	–
328.04 (5)	(Tl)	(M1)	0.252 (4)	0.042 5 (6)	0.013 5 (2)	–	0.308 (5)
433.5 (4)	(Tl)	(M1)	0.119 3 (17)	0.019 9 (3)	0.006 1 (1)	–	0.145 3 (21)
452.98 (4)	(Tl)	(M1)	0.106 1 (15)	0.017 72 (25)	0.005 48 (6)	–	0.129 3 (18)
473.4 (4)	(Tl)	50 % M1 + 50 % E2 δ = 1.0 (2)	0.059 (8)	0.011 5 (10)	0.003 5 (2)	–	0.074 (10)
492.84 (4)	(Tl)	E2	0.020 7 (3)	0.006 33 (9)	0.002 07 (3)	–	0.029 1 (4)
580.5 (3)	(Tl)	E2	0.014 70 (21)	0.003 88 (6)	0.001 22 (2)	–	0.019 8 (3)
620.4 (3)	(Tl)	50 % M1 + 50 % E2 δ = 1.0 (2)	0.030 (4)	0.005 4 (5)	0.001 6 (2)	–	0.037 (5)
180.2 (2)	(Po)	(M1)	1.692 (25)	0.298 (5)	0.090 0 (10)	–	2.08 (3)
727.330 (9)	(Po)	E2	0.010 54 (15)	0.002 57 (4)	0.000 82 (1)	–	0.013 93 (20)
785.37 (9)	(Po)	99.2 % M1 + 0.8 % E2 δ = 0.090	0.031 6 (5)	0.005 39 (8)	0.001 71 (2)	–	0.038 7 (6)
893.408 (14)	(Po)	99.8 % M1 + 0.2 % E2 δ = 0.045	0.022 7 (4)	0.003 86 (6)	0.001 24 (2)	–	0.027 8 (4)
952.12 (2)	(Po)	70 % M1 + 30 % E2 δ = 0.65	0.015 48 (22)	0.002 69 (4)	0.000 83 (1)	–	0.019 0 (3)
1073.6 (2)	(Po)	E2	0.005 10 (8)	0.001 002 (14)	0.000 318 (4)	–	0.006 42 (9)
1078.63 (10)	(Po)	98.2 % M1 + 1.8 % E2 δ = 0.135	0.013 86 (20)	0.002 34 (4)	0.000 72 (1)	–	0.016 92 (24)
1512.70 (8)	(Po)	E2	0.002 74 (4)	0.000 483 (7)	0.000 150 7 (16)	0.000 066 3 (10)	0.003 44 (5)
1620.738 (10)	(Po)	(M1)	0.004 94 (7)	0.000 824 (12)	0.000 251 (3)	0.000 185 (3)	0.006 20 (9)
1679.450 (14)	(Po)	E2	0.002 27 (4)	0.000 391 (6)	0.000 123 8 (14)	0.000 125 2 (18)	0.002 91 (4)
1800.9 (2)	(Po)	E0	–	–	–	–	–
1805.96 (10)	(Po)	E2	0.002 00 (3)	0.000 338 (5)	0.000 096 2 (12)	0.000 175 8 (25)	0.002 61 (4)

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 1.07 (1) % (0.0107 (1)) was adopted on the basis of the relevant alpha-particle emission probability, gamma-ray transition probability and a total internal conversion coefficient of 23.3 (4).

Atomic Data

The x-ray data have been calculated using the evaluated gamma-ray data, and the atomic data from 1996Sc06, 1998ScZM and 1999ScZX. Both the x-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.01, 28 January 2003). This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

K and L X-ray emission probabilities per 100 disintegrations of ^{212}Bi.

			Energy (keV)	Photons per 100 disint.
XL		(Tl)	8.953 – 14.738	7.1 (3)
	XL_l	(Tl)	8.953	0.171 (6)
	XL_α	(Tl)	10.172 – 10.268	3.30 (10)
	XL_η	(Tl)	10.994	0.023 0 (7)
	XL_β	(Tl)	11.812 – 12.643	2.76 (5)
	XL_γ	(Tl)	14.291 – 14.738	0.579 (9)
XK_α	$XK_{\alpha2}$	(Tl)	70.8325 (8)	0.052 5 (23)
	$XK_{\alpha1}$	(Tl)	72.8725 (8)	0.089 (4)
$XK'_{\beta1}$	$XK_{\beta3}$	(Tl)	82.118 }	
	$XK_{\beta1}$	(Tl)	82.577 }	0.030 1 (14)
	$XK''_{\beta5}$	(Tl)	83.115 }	
$XK'_{\beta2}$	$XK_{\beta2}$	(Tl)	84.838 }	
	$XK_{\beta4}$	(Tl)	85.134 }	0.008 9 (5)
	$XKO_{2,3}$	(Tl)	85.444 }	
XL		(Po)	9.658 – 16.213	0.056 3 (24)
	XL_l	(Po)	9.658	0.001 38 (4)
	XL_α	(Po)	11.016 – 11.130	0.025 3 (7)
	XL_η	(Po)	12.085	0.000 440 (13)
	XL_β	(Po)	12.823 – 13.778	0.024 1 (6)
	XL_γ	(Po)	15.742 – 16.213	0.004 77 (11)
XK_α	$XK_{\alpha2}$	(Po)	76.864 (4)	0.038 8 (8)
	$XK_{\alpha1}$	(Po)	79.293 (5)	0.064 7 (13)
$XK'_{\beta1}$	$XK_{\beta3}$	(Po)	89.256 }	
	$XK_{\beta1}$	(Po)	89.807 }	0.022 3 (6)
	$XK''_{\beta5}$	(Po)	90.363 }	
$XK'_{\beta2}$	$XK_{\beta2}$	(Po)	92.263 }	
	$XK_{\beta4}$	(Po)	92.618 }	0.006 93 (20)
	$XKO_{2,3}$	(Po)	92.983 }	

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

Data Consistency

An effective Q-value of 3674.4 (11) keV has been adopted from the atomic mass evaluation of Audi *et al*. (2003Au03) while in the course of formulating the decay scheme of ^{212}Bi. This value has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{212}Bi alpha- and beta-decay processes (i.e. α, β^-, conversion electrons, γ, etc.):

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 3670\ (9)\ \text{keV}$$

Percentage deviation from the effective Q-value of Audi *et al.* is (0.12 ± 0.24) %, which supports the derivation of a highly consistent decay scheme.

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^{213}Bi - Comments on evaluation of the decay data

by Huang Xiaolong, Wang Baosong

This evaluation was completed in 2006. Literature available by January 2006 was included.

1. Decay Scheme

^{213}Bi disintegrates 97.91 (3) % by β^- emission to the levels in ^{213}Po and 2.09 (3) % through α decay to ^{209}Tl. ^{213}Bi ground state has $J^\pi = 9/2^-$ (1992Ak01).

The ^{213}Bi β^- decay scheme was built from the γ-γ coincidence measurements of 1998Ar03 and 2000Gr35. The ^{213}Bi α decay scheme was built from the α–γ coincidence measurements of 1964Gr11, the singles α- particle measurements of 1997Ch53 and γ-γ coincidence measurements of 1998Ar03.

The decay branching ratios have been deduced by the evaluator using the absolute photon intensity (96.58 (10), 1991Ma16) adopted for the 465 keV γ-ray from ^{209}Tl β^- decay and measured absolute intensity (2.022 (26), 1986He06) of the same γ-ray following the ^{213}Bi α decay. Our recommended α decay branching ratio is I_α = 2.09 (3) %, thus $I_{\beta-}$ = 97.91 (3) %.

The three values of the ^{213}Bi α decay branching ratio found in the literature are presented in Table 1. The corresponding β^- branching ratios are: I_{β}- = 97.84 (11) %, (deduced by 1964Gr11); $I_{\beta-}$ = 97.91 (3) %, (deduced from the measurements of 1986He06); I_{β}- = 97.80 (3) %, measured in equilibrium with ^{213}Po by 1997Ch53.

Table 1: Measured and recommended branching ratio for ^{213}Bi α decay.

I_α (%)	References	Comments
2.16 (11)	1964Gr11	Deduced from measured I_α
2.09 (3)	1986He06	Deduced from the P_γ(465 keV) from ^{209}Tl following ^{213}Bi α decay and measured value by 1986He06
2.20 (3)	1997Ch53	Measured in equilibrium with ^{213}Po
2.15 (4)		LWM
2.09 (3)		Recommended

The recommended Q(α) value of 5983 (6) keV and Q(β^-) values of 1423 (5) keV in Audi(2003Au03) agrees with the Q(α) value of 5979 (2) keV and Q(β^-) values of 1422 (6) keV, calculated by the evaluator (using program RADLST) from average radiation energies. This agreement supports the completeness and correctness of the decay scheme.

2. Nuclear Data

The Q values are from the 2003Au03 evaluation.
Level energies have been obtained from a least-squares fit to γ-ray energies (GTOL computer code). Spin and parities are from 1992Ak01, 1998Ar03 and 2000Gr35.
The measured and recommended ^{213}Bi half-life values are listed in Table 2.

Table 2: Measured half-life values of ^{213}Bi and recommended value

$T_{1/2}$ (min)	References	Measurement method
46	1947En03	
47 (1)	1950Ha52	Alpha pulse analyzer, 9 $T_{1/2}$
46 (1)	1964Gr11	
45.59 (6)	1973Po16	ZnS(Ag), weighted average of 2 sources,8 $T_{1/2}$
46.2 (4)		Unweighted mean(except 1947En03)
45.60 (6)		LWM(except 1947En03),χ^2 = 1.07
45.59 (6)	Recommended value	From 1973Po16

The half-life weighted average has been calculated by LWM program. The recommended value is taken from the measurement of 1973Po16.

2.1 β^- transitions

The maximum energies of the β^- transitions in the decay of ^{213}Bi have been deduced from the Q value (2003Au03) and the level energies.

The adopted β^- transition probabilities and the associated uncertainties were deduced from the γ-ray transition probability balance at each level of the decay scheme. Measured and adopted β^- transition probabilities are given in table 3.

Table 3: Measured and adopted probabilities (%) of β^- transitions

Level energy (keV)	1955Ma61	1968Va17	**Adopted value**
0		65 (3)	**66.2 (4)**
292.8			**0.21 (9)**
440.4	32	35 (3)	**30.8 (4)**
600.8			**0.002 5 (19)**
868			**0.012 9 (6)**
1003.6			**0.064 8 (23)**
1045.6			**0.020 (4)**
1100.2			**0.595 (17)**
1119.4			**0.060 8 (20)**
1328.2			**0.000 39 (13)**

The values of *lg ft* and average β^- energies have been calculated with the program LOGFT.

2.2 γ-ray Transitions

The γ-ray transition probabilities were calculated using the γ-ray emission intensities and the relevant internal conversion coefficients.

Multipolarities and mixing ratios of γ-ray transitions are from 2000Gr35, 1977Vy02 and 1969DzZZ.

The internal conversion coefficients (ICC) and their associated uncertainties for γ-ray transitions have been obtained using the BrIcc computer program, which uses the "Frozen Orbital" approximation (2002Ba85). Experimental and theoretical conversion coefficients are compared in Table 4.

Table 4: Comparison of the calculated and measured conversion coefficients

E_γ (keV)	Multipolarity	Mixing ratio	α(theory)	α(exp.) 2000Gr35
147.7	E2		$\alpha_T = 1.453$, $\alpha_K = 0.31$, $\alpha_L = 0.85$	$\alpha_K = 0.33$ (14)
292.8	M1+E2	1.2 (+11 -8)	$\alpha_T = 0.3$, $\alpha_K = 0.22$, $\alpha_L = 0.06$	$\alpha_K = 0.20$ (5)
323.7	E2+M1	1.26 (16)	$\alpha_T = 0.178$, $\alpha_K = 0.134$, $\alpha_L = 0.03$	$\alpha_K = 0.131$ (15)
440.44	M1		$\alpha_T = 0.179$, $\alpha_K = 0.146$	$\alpha_K = 0.13$ (2)

2.3 α Transitions

1997Ch53 measured the upper limit for intensity of the E_α(868 keV level) = 5018 keV, and the value is < 10^{-4}. But this measurement did not support the assumption that the 868 keV level is excited in ^{209}TI by the ^{213}Bi α decay. Thus the 868 keV level is not considered here.

Measured energies of alpha particles are listed in table 5. The measured values are in good agreement with the calculated results from Q_α(2003Au03) and the level energies. Our recommended values are from 1964Gr11.

Table 5: Measured and recommended values of α-particle energies (in keV) from ^{213}Bi α decay

1947En02	1964Gr11	1967Dz02	Deduced	Recommended
	5549 (10)		5553 (6)	5549 (10)
5860 (30)	5869 (10)	5870 (6)	5871 (6)	5869 (10)

Experimental and recommended α-particle relative intensities to 100 % α decay are listed in Table 6. Our recommended α-particle relative intensities are deduced from the calculated results of the γ transition probability balance. These calculated results are in good agreement with the measured relative intensities of 1964Gr11 and 1997Ch53.

Table 6: Experimental, recommended α-particle relative intensities to 100% α decay

E_α(keV)	I_α(%)		
	1964Gr11	1997Ch53	Recommended
5549 (10)	7.4 (14)	6.8 (1)	8.9 (2)
5869 (10)	92.6 (14)	93.2 (14)	91.1 (14)

The recommended α-particle emission intensities are the relative intensities values recommended in table 6 multiplied by 0.0209 (3).

3. Atomic data

Atomic fluorescence yields (ω_K,ϖ_L, ϖ_M, η_{KL} and η_{LM}) are from Schönfeld (1996Sc06).

The X-ray and Auger electron emission intensities have been deduced from γ-ray and conversion electron data by using the computer code RADLST. Measured and calculated X-ray emission intensities are compared in Table 7.

Table 7: Comparison of the calculated and measured X-ray emission intensities

	1972Dz14	Adopted (deduced)
$K_{\alpha1}$	1.6 (2)	1.6 (3)
$K_{\alpha2}$	0.93 (12)	0.99 (15)

The deduced KX-ray emission intensities agree with the measured value of 1972Dz14, thus confirming the completeness of the decay scheme.

4. Electron Emissions.

The conversion electron emission probabilities have been deduced from γ-ray transition data.

5. Photon Emissions

5.1 γ-ray energy values

The measurements of the γ- ray energy value of ^{213}Bi are listed in Table 8 associated with their LWM average value. The recommended values are taken from the LWM of the measurements of 1977Vy02, 1981Di14, 1989Ko26, 1998Ar03 and 2000Gr35, or from 1998Ar03 in the case of only one energy measurement (402.8 keV, 884.6 keV, 886.66 keV, 897.0 keV and 1328.2 keV).

Table 8: Measured and recommended values of γ-ray energy (in keV) for ^{213}Bi

1977Vy02	**1981Di14**	**1989Ko26**	**1998Ar03**	**2000Gr35**	**Recommended**
		147.63 (8)	147.66 (5)	147.7 (1)	147.70 (4)
292.86 (10)	292.85 (2)	292.80 (1)	292.76 (5)	292.81 (1)	292.80 (1)
323.81 (5)	323.7 (2)	323.71 (3)	323.69 (5)	323.80 (4)	323.70 (2)
			402.8 (3)		402.8 (3)
440.42 (2)	440.4 (2)	440.46 (1)	440.43 (5)	440.44 (1)	440.44 (1)
			574.8 (3)	575.2 (5)	574.9 (3)
			600.7 (3)	601.0 (2)	600.9 (2)
			604.9 (3)	604.94 (21)	604.93 (17)
			646.03 (9)	646.0 (1)	646.0 (1)
659.81 (10)	659.7 (2)	659.8 (1)	659.77 (5)	659.74 (2)	659.75 (2)
		710.8 (1)	710.81 (21)	710.82 (3)	710.82 (3)
807.36 (4)	807.3 (2)	807.36 (1)	807.38 (5)	807.37 (1)	807.37 (1)
		826.8 (2)	826.47 (6)	826.59 (5)	826.55 (4)

1977Vy02	1981Di14	1989Ko26	1998Ar03	2000Gr35	Recommended
		868.0 (2)	867.98 (3)	867.93 (3)	867.96 (2)
			880.2 (3)	880.91 (1)	880.91 (1)
			884.6 (3)		884.6 (3)
			886.66 (14)		886.66 (14)
			897.0 (3)		897.0 (3)
		1003.57 (3)	1003.55 (5)	1003.59 (3)	1003.58 (2)
			1045.70 (9)	1045.10 (40)	1045.67 (8)
1100.14 (6)	1100.1 (2)	1100.16 (2)	1100.12 (5)	1100.18 (2)	1100.16 (1)
1119.60 (14)		1119.4 (1)	1119.29 (5)	1119.50 (4)	1119.42 (8)
			1328.2 (3)		1328.2 (3)

5.2 Relative values of the γ-ray intensities

The measurements of the relative γ-ray intensities of ^{213}Bi α decay and β^- decay are listed in table 9 and table 10, respectively.

For α decay, the recommended values are taken from the LWM average of the measurements of 1989Ko26, 1998Ar03 and 2000Gr35. For β^- decay, the recommended values are taken from the LWM average of the measurements of 1986He06, 1989Ko26, 1998Ar03 and 2000Gr35 (according to the availability of the reported data).

Table 9: Measured and recommended relative γ-ray intensities for ^{213}Bi α decay (the intensity of the 440.44 keV γ-ray is considered 100)

E_γ (keV)	I_γ						
	1969ArZV	1977Vy02	1981Di14	1989Ko26	1998Ar03	2000Gr35	Recommended
323.70(2)	0.67 (10)	1.12 (8)	0.660 (15)	0.619 (37)	0.567 (46)	0.618 (32)	0.607 (2)

Table 10: Measured and recommended relative γ-ray intensities for ^{213}Bi γ- decay

E (keV)	I γ							
	1969ArZV	1977Vy02	1981Di14	1986He06	1989Ko26	1998Ar03	2000Gr35	Recommended
147.70 (4)					0.0429 (43)	0.0567 (46)	0.087 (32)	0.049 (3)
292.80 (1)	1.81 (14)	2.65 (38)	1.555 (87)	1.644 (27)	1.571 (63)	1.594 (88)	1.58 (4)	1.613 (20)
402.8 (3)						0.00038 (12)		0.00038 (12)
440.44 (1)	100	100	100	100	100	100	100	100
574.9 (3)						0.00241 (65)	0.0099 (39)	0.0026 (6)
600.9 (2)						0.00268 (84)	0.0165 (32)	0.010 (7)
604.93 (17)						0.00192 (69)	0.0091 (24)	0.0055 (17)
646.0 (1)$^{\times}$						0.00885 (84)	0.0095 (39)	0.0089 (8)
659.75 (2)	0.19 (10)	0.53 (5)	0.185 (6)		0.1476 (89)	0.1383 (77)	0.173 (12)	0.165 (20)
710.82 (3)					0.0429 (43)	0.0391 (42)	0.0469 (39)	0.043 (2)
807.37 (1)	1.14 (14)	1.59 (5)	1.152 (26)	1.119 (46)	1.048 (42)	0.923 (57)	1.114 (71)	1.10 (5)
826.55 (4)					0.0271 (16)	0.0218 (19)	0.0303 (51)	0.0249 (14)
867.96 (2)					0.0476 (29)	0.0425 (42)	0.0484 (43)	0.0467 (21)
880.91 (1)$^{\times}$						0.0111 (38)	0.0165 (16)	0.015 (2)
884.6 (3)$^{\times}$						0.00111 (38)		0.0011 (4)
886.66 (14)						0.00391 (73)		0.0039 (7)
897.0 (3)$^{\times}$						0.00119 (35)		0.0012 (4)
1003.58 (2)					0.205 (12)	0.192 (19)	0.209 (12)	0.205 (8)
1045.67 (8)						0.069 (12)	0.134 (75)	0.071 (12)
1100.16 (1)	1.05 (14)	1.71 (8)	1.000 (24)		1.095 (44)	0.992 (61)	0.988 (67)	1.016 (19)
1119.42 (8)		0.214 (25)			0.238 (14)	0.192 (12)	0.201 (12)	0.208 (7)
1328.2 (3)						0.0015 (5)		0.0015 (5)

$^{\times}$: not placed in level scheme.

5.3 Absolute values of the γ-ray emission probabilities

There is only one measurement of the absolute γ-ray emission probability of the 440.44 keV from ^{213}Bi β^- decay which was measured in equilibrium with ^{229}Th by 1986He06 in 1986. This measurement can be adopted as the normalization factor N, that is, N = 0.261 (3).

The evaluated absolute γ-ray emission probabilities are the relative values evaluated in table 9 and table 10 multiplied by 0.261 (3).

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^{214}Bi - Comments on evaluation of decay data by V. Chisté and M. M. Bé

This evaluation was completed in 2007. Literature available by December 2007 was included. The half-life value was re-evaluated in Dec. 2010 in order to include the Martz's result.

1 Decay Scheme

^{214}Bi disintegrates by beta minus emissions to the excited levels and to the ground state of ^{214}Po (99.979 (13) %) and by alpha emission to the excited levels of ^{210}Tl (0.021 (13) % (1960Wa14)). Spins and parities are from the mass-chain evaluation of Y. A. Akovali (1988Ak01 and 1995El07 for A = 214) and E. Browne (2003Br13 for A = 210).

A good agreement was found between the adopted Q(β^-) value of Audi and the effective Q(β^-) value of 3261 (10) keV calculated from decay scheme data.

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).

Experimental ^{214}Bi half-life values (in minutes) are given in Table 1:

Table 1: Experimental values of ^{214}Bi half-life

Reference	Experimental value (min)	Comments
H. Daniel (1956Da06)	19.9 (4)	
D. E. Martz (1991Ma**)	19.71 (2)	Uncertainty increased to take into account systematic uncertainty.
Recommended value	**19.8 (1)**	χ^2 = 0.25

The original uncertainty value given by D. E. Martz (1991Ma**) was multiplied by 2, in order to take into account the systematic uncertainties which were not considered by 1991Ma**. With the 2 values presented in Table 1, an average was calculated using LWEIGHT computer code (version 3). The reduced-χ^2 value is 0.25.

Due the difficulty in estimating a realistic uncertainty to the Martz value, the evaluators have decided to recommend for the half-life the unweighted average of 19.8 minutes with an uncertainty of 0.1 minute, covering both experimental values.

2.1 β^- Transitions and Emissions

The maximum energies of the β^- transitions in the decay of ^{214}Bi → ^{214}Po have been obtained from the Q^- value (2003Au03) and the level energies given in Table 2 from Y. A. Akovali (1995El07).

Table 2: ^{214}Po levels populated in the decay of ^{214}Bi.

Level Number	Level energy, (keV)	Spin and parity	Level Number	Level energy, (keV)	Spin and parity
0	0	0^+	**37**	2662.29 (12)	(2^+)
1	609.316 (7)	2^+	**38**	2694.6 (2)	$1^{(-)}, 2^+$
4	1377.675 (12)	2^+	**39**	2698.8 (3)	$1^{(-)}, 2^+$
5	1415.489 (19)	0^+	**40**	2699.2 (2)	$1^{(-)}, 2^+$
6	1543.375 (14)	2^+	**41**	2719.22 (9)	$1^-, 1^+, 2^+$
7	1661.28 (3)	2^+	**42**	2728.59 (4)	$(1,2)^+$

Level Number	Level energy, (keV)	Spin and parity	Level Number	Level energy, (keV)	Spin and parity
8	1712.93 (20)	$(3)^+$	**43**	2769.9 (2)	$1^-, 1^+, 2^+$
9	1729.611 (13)	2^+	**44**	2785.9 (2)	$1^-, 1^+, 2^+$
10	1742.98 (3)	0^+	**47**	2827.0 (2)	$1^-, 1^+, 2^+$
11	1764.498 (14)	1^+	**48**	2861.1 (3)	$1^-, 1^+, 2^+$
12	1847.431 (14)	2^+	**49**	2869.6 (2)	
13	1890.287 (21)	2^+	**50**	2880.3 (2)	$1^-, 1^+, 2^+$
14	1994.63 (3)	$(2)^-$	**51**	2893.6 (2)	$1^-, 1^+, 2^+$
15	2010.81 (4)	2^+	**52**	2897.0 (3)	
16	2017.3 (5)	0^+	**53**	2919.5 (3)	
17	2088.41 (12)	$1^-, 1^+, 2^+$	**54**	2921.8 (4)	$1^-, 1^+, 2^+$
18	2118.552 (17)	1^+	**55**	2928.6 (3)	$1^-, 1^+, 2^+$
19	2147.78 (6)	$1^{(-)}, 2^+$	**56**	2934.5 (3)	$1^-, 1^+, 2^+$
20	2192.56 (4)	2^+	**57**	2940.6 (2)	$1^{(-)}, 2^-, 2^+$
21	2204.13 (9)	1^+	**58**	2962.8 (7)	
23	2266.39 (18)	$1^{(-)}, 2^+$	**60**	2978.8 (2)	$1^-, 1^+, 2^+$
24	2293.34 (5)	$1^{(+)}, 2^+$	**61**	2986.2 (2)	$(1^-), 2^-, 2^+$
25	2348.3 (9)	$1^-, 1^+, 2^+$	**62**	3000.0 (2)	$1^{(-)}, 2^+$
26	2360.8 (4)	$1^-, 1^+, 2^+$	**65**	3014.1 (3)	$1^-, 1^+, 2^+$
27	2423.19 (15)	$1^+, 2^-, 2^+$	**69**	3053.9 (2)	$1^-, 1^+, 2^+$
28	2447.70 (6)	1^-	**70**	3068.3 (8)	
29	2482.46 (4)	$(2)^+$	**72**	3081.7 (3)	$1^-, 1^+, 2^+$
30	2505.21 (15)	$1^{(-)}, 2^+$	**73**	3094.0 (4)	$(1^-, 2^+)$
31	2508.2 (2)		**75**	3142.6 (4)	$1^-, 1^+, 2^+$
32	2544.9 (3)		**76**	3149.2 (5)	$1^-, 1^+, 2^+$
34	2562.4 (3)		**77**	3160.4 (6)	$1^-, 1^+, 2^+$
35	2604.66 (14)	$(2)^+$	**79**	3173.3 (6)	
36	2630.85 (17)	$1^-, 1^+, 2^+$	**80**	3183.6 (4)	$1^-, 1^+, 2^+$

The adopted β^- transition probabilities and the associated uncertainties were deduced from the γ transition probability balance at each level of the decay scheme.

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

2.2 γ Transitions

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

Multipolarities of γ-ray transitions are from Y. A. Akovali (1995El07 for A = 214) and E. Browne (2003Br13 for A = 210) and shown in Table 3.

Table 3: Multipolarities of γ-ray transitions

	Multipolarity	E_γ (keV)
^{210}Tl	(M1)	62.5 (10)
^{214}Po	[M1,E2]	221 (1), 386.823 (18), 452.92 (10), 469.756 (18), 474.52 (5), 543.0 (2), 595.32 (7), 633.14 (10), 634.72 (21), 649.19 (7), 661.1 (2), 697.88 (20), 740.73 (18), 752.84 (3), 814.885 (10), 878.03 (12), 915.74 (15), 939.6 (5), 991.49 (19), 1051.964 (31), 1103.61 (20), 1104.79 (19)

	[M1]	252.80 (6), 349.009 (24), 388.941 (50), 461.15 (20), 703.11 (4), 788.6 (5), 1594.81 (8)
	[E1]	268.614 (26), 333.35 (6), 454.850 (26), 487.95 (13), 572.76 (7), 615.53 (10), 617.0 (2), 683.22 (6), 704.9 (3), 786.1 (4), 904.29 (10), 917.8 (3), 1032.37 (8), 1069.96 (8), 1207.70 (3), 1385.314 (31)
	[E2]	405.74 (4), 528 (1),639.62 (10), 832.38 (11), 1133.664 (31), 1172.98 (10), 1543.375 (14)
	(E2)	1407.98 (4)
	(M1 + E2)	1401.494 (41) δ = 1.6 (5)
	E2	609.316 (7), 719.869 (37), 806.173 (20), 1377.675 (12), 1661.28 (6), 1729.611 (13),
	E1	665.445 (23), 2447.86 (10)
	M1 + E2	768.359 (14) δ = 2.8 (7)
		934.059 (16) δ = -0.3 (1)
		1120.295 (15) δ = 0.18 (2)
		1155.182 (16) δ = 0.33 (6)
		1238.115 (12) δ = -0.03 (3)
		1509.236 (15) δ = -0.053 (35)
		1583.244 (40) δ = -0.20 (10)
	M1	821.18 (3), 826.46 (20), 1280.97 (2), 1764.498 (14), 2118.552 (30), 2204.21 (4)

The internal conversion coefficients (ICC) and the associated uncertainties for these γ-ray transitions have been obtained using the BrIcc computer program (calculation for 'hole'), which interpolated the new values from theoretical values of I. M. Band (2002Ba85).

2.3 α Transitions and Emissions

The energies of the α-particle transitions given in Section 2.3 have been obtained from Q_α (2003Au03) and the level energies given by E. Browne (2003Br13) .

The adopted $\alpha_{0,0}$, $\alpha_{0,2}$ and $\alpha_{0,3}$ emission energies are the recommended values of A. Rytz (1991Ry01) and the other α emission energies are from E. Browne (2003Br13).

The recommended α emission probabilities come from the measured values of R. J. Walen (1960Wa14).

For the α of long range, the energy and emission probabilities are from the measurements of C.-F. Leang (1965Le08).

3 Atomic Data

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

4 Electron Emissions

The conversion electron emission probabilities have been deduced from γ-ray transition data.

5 Photon Emissions

5.1 X-ray Emissions

The X-ray absolute intensities have been calculated from γ-ray data and ICC using the EMISSION computer program and compared in Table 4 with the measured values of U. Schötzig (1983Sc13).

Table 4: Experimental and recommended (calculated) values of X-ray absolute intensities

	U. Schötzig (1983Sc13)	Recommended values
Kα x-ray	1.77 (5) %	1.135 (25) %
Kβ x-ray		0.320 (9) %

5.2 γ Emissions

The γ-ray energies are from Y. A. Akovali (1995El07 for A = 214) and E. Browne (2003Br13 for A = 210).

For the ^{210}Tl γ-rays, the absolute γ-ray emission intensities have been deduced from the α emission intensities measured by R. J. Walen (1960Wa14).

The experimental relative γ-ray emission intensities in ^{214}Po are based on all available relative and absolute measurements of γ-rays for the ^{226}Ra decay chain. The normalization factor to convert the relative γ-ray emission intensities to absolute intensities is the weighted average of the measured values of the 609.3-keV γ-ray absolute intensity (Table 5).

Table 5: The experimental values of 609.3-keV γ-ray absolute intensity

References	Experimental values (%)	Comments
E. W. A. Lingeman (1969Li10)	42.8 (40)	
D. G. Olson (1983Ol01)	45.0 (7)	
U. Schötzig (1983Sc13)	44.6 (5)	
W. –J. Lin (1991Li11)	46.1 (5)	
J. Morel (1998Mo14)	44.8 (6)	Omitted : superseded by 2004Mo07
J. Morel (2004Mo07)	45.57 (18)	
Recommended value	**45.49 (19)**	$\chi^2 = 1.45$

Evaluators' recommended normalization factor is the weighted average of the five experimental values: 45.49 with an external uncertainty of 0.19.

The experimental relative γ-ray emission intensities are given in Table 6 relatively to the ^{214}Bi 609-keV γ-ray intensity.

Table 6: The experimental data set of the relative γ-ray emission intensities (next page).

Energy (keV)	1969Li10	1696Wa27*	1969Gr33*	1975Ha31*	1977Zo01	1982Ak03*	1982Fa10*	1983Ol01	1983Sc13	1990Mouze	1991Li11	2000Sa32	2002De03	2002MoZP	2004Mo07*	Evaluated	χ2
221						0.012 (7)						0.130 (13)				0.130 (13)	
230												0.0063 (21)				0.0063 (21)	
252						0.033 (7)				0.028 (4)		0.019 (7)				0.0258 (39)	1.3
268						0.031 (8)				0.035 (4)		0.059 (28)				0.0355 (40)	0.72
273	0.18 (9)			0.384 (50)		0.25 (5)				0.27 (3)		0.29 (10)	0.265 (23)		0.278 (17)	0.264 (18)	0.33
280	0.132 (22)			0.136 (50)		0.13 (2)				0.13 (2)		0.17 (4)				0.136 (14)	0.42
304	0.18 (9)			0.074 (25)		0.069 (15)				0.055 (5)		0.065 (20)				0.056 (5)	1.1
333			0.148 (23)	0.15 (7)		0.16 (3)				0.14 (1)		0.13 (3)				0.139 (9)	0.1
334	0.132 (44)			0.074 (37)		0.072 (14)				0.066 (8)		0.090 (17)				0.072 (10)	1.8
348										0.34 (5)		0.20 (5)				0.27 (7)	3.9
386	0.68 (26)		1.41 (18)	0.64 (7)		0.64 (10)				0.63 (5)		0.70 (15)	0.651 (12)		0.647 (11)	0.650 (12)	0.10
388	0.81 (26)			0.83 (7)		0.87 (12)				0.85 (1)	0.92 (6)	0.86 (4)	0.888 (14)		0.89 (13)	0.864 (10)	1.5
394				0.019 (9)		0.033 (4)				0.032 (3)		0.024 (3)				0.0280 (40)	3.6
396				0.050 (25)		0.060 (9)				0.059 (7)		0.053 (10)				0.057 (4)	0.24
405	0.33 (9)		0.341 (34)	0.40 (7)		0.38 (5)				0.37 (2)		0.39 (3)				0.375 (16)	0.28
452						0.068 (11)				0.067 (8)						0.067 (8)	
454	0.62 (11)		0.64 (7)	0.64 (7)		0.67 (8)	0.63 (2)			0.64 (3)		0.59 (3)	0.640 (12)		0.642 (12)	0.634 (10)	0.82
461						0.078 (13)				0.14 (2)		0.10 (3)				0.128 (18)	1.2
469						0.30 (5)				0.27 (2)		0.34 (3)				0.292 (32)	3.8
474	0.15 (7)			0.24 (7)		0.23 (4)				0.22 (2)		0.190 (20)				0.203 (14)	0.86
485						0.052 (11)				0.048 (9)		0.035 (20)				0.046 (8)	0.35
487										0.061 (20)						0.061 (20)	
494						0.031 (5)				0.031 (4)		0.019 (3)				0.023 (6)	5.8
496						0.015 (4)				0.015 (4)						0.015 (4)	
501				0.038 (7)		0.041 (7)				0.040 (5)		0.035 (19)				0.0397 (48)	0.06
519				0.0124 (50)		0.035 (6)				0.036 (4)		0.039 (11)				0.0364 (38)	0.07
524				0.033 (12)		0.038 (6)				0.037 (4)		0.039 (13)				0.0372 (38)	0.02
528						0.025 (5)				0.024 (3)		0.022 (11)				0.0239 (29)	0.03
536				0.124 (50)		0.14 (2)				0.14 (2)		0.12 (3)				0.134 (17)	0.31
543	0.22 (7)		0.296 (34)	0.20 (7)		0.14 (2)				0.13 (2)		0.27 (4)				0.194 (46)	3.4
547	0.066 (22)			0.071 (14)		0.08 (1)				0.08 (1)		0.074 (7)				0.075 (6)	0.22
551										0.012 (3)						0.012 (3)	
572	0.132 (44)		0.159 (23)	0.161 (25)		0.17 (2)				0.16 (2)		0.16 (4)				0.156 (17)	0.17
595						0.035 (7)				0.038 (4)		0.039 (6)				0.0383 (33)	0.02
600										0.018 (8)						0.018 (8)	

Energy (keV)	1969Li10	1696Wa27*	1969Gr33*	1975Ha31*	1977Zo01	1982Ak03*	1982Fa10*	1983Ol01	1983Sc13	1990Mouze	1991Li11	2000Sa32	2002De03	2002MoZP	2004Mo07*	Evaluated	χ2
609	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
615	0.20 (7)			0.099 (25)		0.13 (5)				0.12 (2)		0.11 (3)				0.121 (16)	0.71
617				0.074 (25)		0.066 (44)				0.053 (6)		0.077 (11)				0.059 (10)	3.7
626						0.036 (6)						0.009 (3)				0.009 (3)	
630			0.228 (34)	0.037 (12)		0.039 (6)				0.035 (4)		0.039 (5)				0.0366 (31)	0.39
633	0.110 (44)			0.124 (12)		0.12 (2)				0.11 (1)		0.130 (10)				0.120 (7)	1,0
634						0.014 (5)				0.014 (5)						0.014 (5)	
639				0.074 (25)		0.061 (11)				0.065 (10)		0.085 (10)				0.075 (10)	2,0
649	0.110 (44)			0.124 (12)		0.114 (15)				0.13 (2)		0.10 (3)				0.119 (16)	0.37
658						0.037 (8)				0.046 (8)		0.030 (8)				0.038 (8)	2,0
661				0.094 (37)		0.077 (13)				0.11 (2)		0.120 (10)				0.118 (9)	0.2
665	3.08 (44)		3.49 (30)	3.59 (37)		3.36 (37)	2.87 (6)			3.51 (20)	3.21 (7)	3.33 (10)	3.359 (17)	3.386 (21)	3.364 (17)	3.364 (15)	1.4
677						0.012 (5)				0.012 (5)						0.012 (5)	
683	0.176 (44)		0.296 (46)	0.186 (25)		0.18 (3)				0.18 (2)		0.190 (20)				0.184 (13)	0.08
687				0.012 (6)		0.016 (5)				0.015 (4)		0.014 (5)				0.0146 (31)	0.02
693				0.012 (6)		0.012 (5)				0.015 (6)		0.012 (4)				0.0129 (33)	0.17
697	0.154 (44)		0.501 (46)	0.100 (50)		0.14 (2)				0.14 (2)		0.150 (10)				0.148 (9)	0.11
699						0.044 (9)				0.035 (10)						0.035 (10)	
703	1.03 (13)		1.55 (16)	1.14 (12)		1.08 (15)	0.82 (3)			1.11 (7)	1.038 (27)	1.12 (8)				1.053(24)	0.57
704										0.11 (3)		0.113 (29)				0.112 (21)	0.006
708						0.031 (9)				0.042 (11)		0.025 (3)				0.0262 (43)	2.2
710	0.13 (7)		0.364 (34)	0.161 (50)		0.16 (2)				0.16 (2)		0.170 (9)				0.168 (8)	0.25
719	0.84 (11)		1.22 (13)	0.94 (12)		0.90 (13)				0.91 (8)	0.833 (24)	0.91 (3)				0.865 (22)	1.5
722				0.099 (50)		0.075 (11)				0.073 (9)		0.107 (15)				0.082 (15)	3.8
733	0.066 (22)			0.087 (25)		0.086 (12)				0.085 (8)		0.092 (17)				0.084 (7)	0.45
740						0.11 (2)				0.088 (13)		0.095 (5)				0.0941 (47)	0.25
752	0.24 (7)			0.31 (7)		0.30 (4)				0.28 (2)		0.28 (4)				0.278 (17)	0.15
768		9.90 (21)	10.6 (10)	11.4 (12)	10.90 (15)	11.9 (17)	10.64 (20)		10.46 (16)	10.91 (8)	10.86 (14)	10.39 (31)	10.66 (5)	10.77 (3)	10.68 (5)	10.755 (36)	2.3
786	0.64 (18)											0.70 (10)				0.69 (10)	0.09
788										0.041 (8)		0.020 (10)				0.033 (10)	2.7
806	2.42 (44)µ		2.68 (25)	2.97 (37)		2.92 (43)	2.49 (6)			2.90 (22)	2.682 (45)	2.76 (11)	2.788 (22)	2.777 (14)	2.791 (20)	2.774 (13)	1.2
815	0.088 (44)			0.050 (25)		0.087 (13)				0.081 (8)		0.110 (20)				0.085 (7)	0.91
821	0.35 (9)			0.40 (7)		0.37 (6)				0.36 (3)		0.37 (3)				0.364 (21)	0.04
826	0.29 (13)			0.21 (7)		0.29 (4)				0.28 (3)		0.29 (4)				0.284 (24)	0.02
832	0.066 (22)			0.062 (25)		0.064 (10)				0.062 (6)		0.080 (3)				0.076 (5)	3.7

Energy (keV)	1969Li10	1696Wa27*	1969Gr33*	1975Ha31*	1977Zo01	1982Ak03*	1982Fa10*	1983Ol01	1983Sc13	1990Mouze	1991Li11	2000Sa32	2002De03	2002MoZP	2004Mo07*	Evaluated	χ2
847				0.037 (12)		0.052 (12)				0.057 (7)		0.053 (15)				0.035 (13)	0.06
873						0.032 (10)				0.042 (9)		0.040 (10)				0.041 (7)	0.02
878						0.022 (7)				0.026 (6)						0.026 (6)	
904	0.15 (7)			0.198 (50)		0.15 (2)				0.14 (2)		0.16 (4)				0.144 (17)	0.1
915				0.050 (12)		0.070 (14)				0.065 (8)		0.043 (6)				0.051 (11)	4.8
917						0.010 (7)				0.010 (7)						0.010 (7)	
930						0.058 (13)				0.10 (2)		0.08 (3)				0.094 (17)	0.31
934	6.8 (7)	6.26 (18)	7.0 (7)	7.3 (7)	6.93 (10)	7.0 (9)	6.54 (13)		6.75 (9)	6.88 (5)	6.66 (9)	6.70 (20)	6.783 (34)	6.83 (4)	6.788 (34)	6.814 (22)	1.05
939						0.030 (8)				0.028 (8)		0.045 (9)				0.036 (8)	2,0
943			0.205 (34)	0.037 (12)		0.034 (8)				0.037 (6)		0.050 (26)				0.038 (6)	0.24
949						0.009 (6)				0.012 (5)						0.012 (5)	
952										0.013 (5)						0.013 (5)	
961						0.046 (12)				0.03 (2)		0.022 (3)				0.0222 (30)	0.16
964	0.81 (11)		0.78 (8)	0.85 (9)		0.82 (10)				0.80 (5)	0.796 (38)	0.80 (7)				0.799 (27)	0.01
976				0.050 (25)		0.029 (8)				0.033 (5)		0.035 (13)				0.0333 (47)	0.02
991				0.0031 (15)		0.009 (6)				0.022 (5)		0.050 (22)				0.023 (6)	1.5
1013				0.022 (11)						0.018 (3)		0.034 (11)				0.0191 (41)	1.9
1021				0.025 (12)						0.034 (6)		0.036 (15)				0.034 (6)	0.02
1032	0.154 (44)			0.161 (50)						0.13 (1)		0.17 (3)				0.135 (9)	0.9
1038				0.025 (12)						0.018 (3)		0.030 (10)				0.0190 (33)	1.3
1045				0.062 (12)						0.051 (6)		0.037 (20)				0.050 (6)	0.45
1051	0.73 (9)		0.71 (7)	0.68 (7)			0.76 (3)			0.66 (5)	0.692 (24)	0.72 (4)				0.713 (17)	1.1
1067				0.062 (25)						0.055 (20)		0.051 (24)				0.053 (15)	0.02
1069	0.57 (9)		0.73 (14)	0.62 (7)						0.56 (4)	0.605 (33)	0.65 (6)				0.595 (23)	0.59
1103	0.35 (7)			0.21 (10)						0.21 (3)		0.24 (7)				0.233 (33)	1.7
1104			0.250 (34)	0.17 (7)						0.16 (3)						0.16 (3)	
1118										0.015 (8)		0.034 (11)				0.022 (9)	1.9
1120	33.0 (33)	31.90 (73)	29.4 (28)	34.0 (35)	32.72 (39)		33.52 (42)	32.73 (48)	32.31 (46)	33.13 (22)	33.19 (46)	32.3 (10)	32.71 (10)	32.77 (12)	32.74 (10)	32.77 (7)	0.64
1130				0.099 (25)						0.078 (9)		0.080 (11)				0.079 (7)	0.02
1133	0.55 (11)		0.478 (46)	0.62 (6)						0.56 (3)	0.545 (29)	0.57 (3)				0.558 (17)	0.12
1155	3.74 (44)		3.72 (34)	3.96 (50)			3.65 (7)			3.5 (4)	3.583 (46)	3.4 (7)	3.594 (36)	3.595 (17)	3.597 (32)	3.594 (15)	0.06
1167				0.021 (17)						0.027 (4)		0.028 (10)				0.0271 (37)	0.01
1172	0.066 (22)µ			0.113 (41)						0.098 (12)		0.132 (9)				0.120 (16)	5.1
1207	1.03 (13)		0.89 (9)	1.10 (11)						0.98 (6)	0.991 (35)	1.04 (7)				0.998 (27)	0.18
1226				0.058 (19)						0.028 (11)		0.074 (20)				0.039 (18)	4.1

Energy (keV)	1969Li10	1696Wa27*	1969Gr33*	1975Ha31*	1977Zo01	1982Ak03*	1982Fa10*	1983Ol01	1983Sc13	1990Mouze	1991Li11	2000Sa32	2002De03	2002MoZP	2004Mo07*	Evaluated	χ2
1230										0.015 (6)		0.08 (4)				0.016 (10)	2.6
1238	13.4 (13)µ	12.77 (12)	12.8 (11)	14.9 (15)	12.94 (17)		13.25 (22)	13.01 (18)	12.71 (16)	12.87 (9)	12.73 (18)	12.7 (4)	12.83 (6)	12.80 (4)	12.85 (5)	12.819 (29)	0.43
1280	3.30 (44)µ		2.92 (28)	3.59 (50)			3.22 (6)			3.17 (17)	3.144 (46)	3.15 (11)	3.147 (28)	3.159 (16)	3.151 (28)	3.155 (13)	0.05
1284										0.052 (12)		0.020 (7)				0.028 (14)	5.3
1303	0.24 (7)		0.284 (34)	0.25 (6)						0.21 (2)	0.246 (15)	0.20 (5)				0.231 (12)	0.83
1316	0.154 (44)			0.198 (50)						0.16 (2)		0.20 (3)				0.170 (16)	0.69
1330				0.024 (11)						0.026 (3)		0.039 (17)				0.0264 (30)	0.57
1341				0.050 (25)						0.046 (6)		0.059 (29)				0.047 (6)	0.19
1351			0.205 (34)							0.008 (2)		0.014 (4)				0.0092 (24)	1.8
1353				0.0099 (25)						0.008 (2)						0.008 (2)	
1377	9.5 (11)µ	8.70 (48)	9.0 (9)	9.9 (11)	8.87 (15)		8.66 (16)			8.82 (12)	8.79 (14)	8.52 (25)µ	8.689 (19)	8.79 (3)	8.720 (44)	8.722 (25)	2.5
1385	1.76 (33)	1.29 (30)	1.66 (17)	2.04 (20)						1.81 (8)µ	1.664 (40)µ	1.76 (5)	1.744 (17)	1.755 (16)	1.750 (19)	1.750 (11)	1.8
1392				0.041 (19)						0.018 (4)		0.035 (15)				0.0191 (42)	1.2
1401	3.30 (44)µ		3.03 (28)	3.47 (37)						2.91 (16)	2.792 (45)	3.0 (4)	2.924 (20)	2.934 (13)	2.927 (20)	2.923 (16)	2.3
1407	5.7 (7)		5.9 (6)	6.2 (7)						5.37 (6)	4.73 (13)µ	5.5 (5)	5.233 (26)	5.250 (19)	5.245 (42)	5.252 (17)	1.3
1419				0.0111 (25)						0.011 (3)		0.013 (3)				0.0120 (21)	0.22
1470										0.020 (3)		0.035 (15)				0.0206 (29)	0.96
1479	0.110 (44)			0.124 (50)						0.11 (1)		0.14 (3)				0.113 (9)	0.45
1509	4.84 (44)		4.77 (46)	5.45 (50)	4.78 (9)		4.77 (9)		4.57 (11)	4.76 (5)	4.64 (9)	4,63 (15)	4.61 (6)	4.67 (3)	4.64 (6)	4.679 (21)	0.95
1515										0.015 (2)		0.039 (10)				0.0159 (46)	5.5
1538	1.17 (13)µ		0.72 (7)	1.14 (12)						0.95 (6)	0.827 (31)	0.98 (5)				0.882 (49)	4.1
1543	0.75 (18)			0.74 (7)						0.68 (4)	0.44 (11)	0.67 (3)				0.664 (29)	1.5
1583	1.60 (15)		1.47 (5)	1.86 (19)			1.57 (3)			1.58 (8)	1.517 (34)	1.64 (17)		1.556 (13)		1.555 (11)	0.39
1594	0.66 (20)		0.51 (6)	0.69 (6)						0.61 (4)	0.55 (8)	0.63 (10)				0.603 (33)	0.21
1599	0.75 (20)		0.66 (7)	0.85 (11)						0.72 (4)	0.51 (12)	0.73 (7)				0.707 (33)	0.98
1636				0.040 (12)						0.024 (3)		0.06 (3)				0.0244 (36)	1.4
1657				0.16 (7)						0.10 (1)		0.14 (3)				0.104 (12)	1.6
1661	2.55 (26)		2.49 (20)	2.72 (25)			2.55 (5)			2.33 (12)	2.53 (7)	2.37 (22)	2.271 (34)	2.299 (14)	2.284 (34)	2.304(20)	2.5
1665										0.018 (3)		0.046 (9)				0.032 (14)	4.8
1683	0.53 (9)		0.52 (6)	0.56 (6)						0.49 (3)	0.475 (13)	0.43 (4)		0.481 (9)		0.478 (7)	0.52
1711												0.050 (10)				0.050 (10)	
1729	7.03 (9)µ	6.94 (20)	6.6 (6)	7.5 (7)	6.29 (10)		6.56 (12)			6.60 (4)µ	6.42 (9)	6.33 (15)	6.226 (31)	6.25 (3)	6.229 (31)	6.251 (22)	1.2
1751										0.002 (1)						0.002 (1)	
1764	36.7 (35)µ	35.34 (10)	34.4 (34)	40.0 (40)	34.23 (44)		34.91 (41)		33.2(7)	34.48 (25)	33.85 (46)	33.3 (10)	33.54 (10)	33.63 (9)	33.56 (10)	33.66 (10)	2.5
1813				0.026 (10)						0.024 (2)		0.020 (10)				0.0238 (20)	0.15

Energy (keV)	1969Li10	1696Wa27*	1969Gr33*	1975Ha31*	1977Zo01	1982Ak03*	1982Fa10*	1983Ol01	1983Sc13	1990Mouze	1991Li11	2000Sa32	2002De03	2002MoZP	2004Mo07*	Evaluated	χ2
1838	0.81 (11)		0.88 (8)	0.89 (10)						0.74 (3)		0.77 (4)				0.753(23)	0.32
1847	5.1 (7)µ		4.76 (46)	5.32 (50)	4.52 (9)		4.59 (9)			4.57 (6)		4.35 (13)	4.448 (36)	4.42 (3)	4.457 (31)	4.451 (26)	1.6
1873	0.48 (11)		0.478 (46)	0.557 (50)						0.46 (2)		0.51 (5)				0.467 (18)	0.44
1890	0.22 (7)		0.205 (46)	0.21 (7)						0.17 (1)		0.17 (3)				0.171 (9)	0.25
1895	0.40 (9)		0.432 (46)	0.37 (6)						0.31 (2)		0.35 (4)				0.321 (18)	0.8
1898				0.136 (50)						0.11 (2)		0.10 (3)				0.107 (17)	0.08
1935			0.432 (46)	0.111 (50)						0.067 (7)		0.16 (4)				0.070 (16)	5.2
1994										0.005 (1)		0.010 (5)				0.0052 (10)	0.96
2010	0.081 (13)			0.111 (12)						0.100 (5)		0.093 (5)				0.0954 (37)	1.1
2021				0.074 (12)						0.045 (5)		0.057 (11)				0.0471 (46)	0.99
2052	0.154 (44)		0.250 (34)	0.173 (25)						0.15 (1)		0.16 (3)				0.151 (9)	0.52
2085	0.022 (7)			0.0198 (50)						0.018 (1)						0.0181 (10)	0.32
2089	0.110 (22)		0.137 (46)	0.124 (12)						0.096 (5)		0.12 (3)				0.0973 (48)	0.49
2109	0.220 (44)		0.20 (6)	0.235 (50)					0.180 (9)	0.19 (1)		0.17 (3)				0.185 (6)	0.48
2118	2.86 (33)µ	2.76 (13)	2.61 (23)	3.03 (31)	2.53 (5)		2.51 (5)		2.57 (7)	2.56 (3)		2.65 (25)µ	2.536 (20)	2.548 (21)	2.537 (20)	2.545 (12)	0.17
2147	0.026 (7)			0.036 (10)						0.029 (2)		0.050 (10)				0.0295 (28)	2.3
2160										0.004 (1)		0.026 (1)				0.015 (11)	
2176										0.007 (1)		0.015 (6)				0.0072 (13)	1.7
2192	0.154 (44)			0.161 (50)					0.070 (13)	0.073 (6)		0.093 (5)				0.084 (7)	3.4
2204	11.7 (11)µ	11.22 (47)	11.37 (24)	12.38 (27)	10.77 (20)		10.66 (20)		10.95 (70)	11.02 (9)		11.1 (3)	10.74 (5)	10.75 (9)	10.76 (5)	10.80 (5)	1.8
2251				0.015 (7)						0.012 (1)						0.012 (1)	
2260			0.057 (23)	0.0149 (50)						0.019 (1)		0.020 (3)				0.0191 (9)	0.1
2266	0.033 (7)			0.045 (12)						0.037 (2)		0.034 (4)				0.0362 (17)	0.34
2270				0.0111 (50)						0.0029 (5)		0.010 (5)				0.0030 (7)	2,0
2284										0.011 (1)		0.011 (3)				0.0110 (9)	
2287										0.010 (1)						0.010 (1)	
2293	0.73 (9)		0.67 (7)	0.83 (9)			0.67 (2)		0.662 (20)	0.67 (3)		0.72 (6)	0.665 (17)	0.677 (10)	0.665 (17)	0.673 (8)	0.57
2310										0.003 (2)						0.003 (2)	
2312	0.020 (7)			0.0235 (50)						0.019 (2)		0.018 (5)				0.0189 (18)	0.029
2319										0.0009 (3)		0.0050 (10)				0.0030 (20)	8.4
2325				0.0040 (20)						0.0037 (4)		0.009 (3)				0.0038 (7)	3.1
2331	0.046 (9)		0.034 (11)	0.0557 (50)						0.048 (3)		0.076 (7)				0.056 (9)	5.7
2348										0.0003 (2)						0.0003 (2)	
2353										0.0008 (3)						0.0008 (3)	
2361				0.0040 (12)						0,0033 (3)		0.0060 (10)				0.0046 (14)	3.6

Energy (keV)	1969Li10	1696Wa27*	1969Gr33*	1975Ha31*	1977Zo01	1982Ak03*	1982Fa10*	1983Ol01	1983Sc13	1990Mouze	1991Li11	2000Sa32	2002De03	2002MoZP	2004Mo07*	Evaluated	χ2
2369										0.006 (1)		0.008 (3)				0.0062 (9)	0.4
2376	0.0132 (44)		0.057 (23)	0.022 (7)						0.019 (1)		0.034 (7)				0.0190 (17)	3.2
2390				0.0042 (10)						0.0034 (3)		0.006 (3)				0.00343 (30)	0.74
2405										0.0009 (3)		0.0040 (10)				0.0024 (16)	4.8
2423	0.0132 (44)			0.0115 (40)						0.010 (1)		0.018 (4)				0.0106 (14)	2.1
2444										0,018 (9)						0.018 (9)	
2447	3.63 (40)μ	3.32 (6)	3.79 (28)	3.96 (37)	3.32 (8)		3.28 (6)			3.42 (3)		3.30 (10)	3.402 (24)	3.41 (4)	3.408 (24)	3.403 (16)	0.50
2459										0.0031 (5)						0.0031 (5)	
2482				0.0046 (19)						0.0021 (4)						0.0021 (4)	6.1
2505	0.0154 (44)			0.0149 (37)						0.012 (1)		0.025 (7)				0.0124 (13)	1.9
2550										0.0007 (2)						0.0007 (2)	
2562										0.0004 (3)						0.0004 (3)	
2564										0.0003(2)						0.0003(2)	
2604				0.00099 (25)						0.0008 (2)						0.0008 (2)	
2630				0.0020 (10)						0.0018 (3)		0.0050 (17)				0.0019 (5)	3.4
2662										0.0006 (2)		0.0004 (1)				0.00044 (9)	0.8
2694	0.068 (9)		0.072 (34)	0.079 (7)			0.078 (2)			0.066 (3)		0.062 (4)				0.072 (6)	4.5
2699	0.0110 (44)			0.0050 (19)						0.0061 (5)						0.0062 (5)	1.2
2719	0.0033 (11)			0.0040 (12)						0.0038 (4)						0.00374 (38)	0.18
2769	0.057 (9)		0.057 (23)	0.062 (7)			0.047 (2)			0.053 (3)		0.048 (15)				0.0494 (17)	1.2
2785	0.0110 (22)			0.0149 (25)						0.012 (1)		0.030 (11)				0.0120 (11)	1.4
2826	0.0046 (11)			0.0062 (12)						0.0048 (4)		0.011 (6)				0.00480 (38)	0.55
2861				0.00074 (37)						0.0009 (2)		0.008 (5)				0.00091 (28)	2.01
2880	0.0176 (33)		0.019 (6)	0.024 (7)						0.020 (2)		0.030 (3)				0.0222 (35)	4.8
2893	0.0132 (33)		0.016 (7)	0.0149 (37)						0.012 (1)		0.017 (3)				0.0126 (10)	1.3
2921	0.035 (7)		0.032 (11)	0.037 (6)						0.029 (1)		0.035 (4)				0.0295 (11)	1.4
2928				0.0026 (10)						0.0024 (2)						0.0024 (2)	
2934				0.00124 (50)						0.0010 (2)		0.005 (3)				0.00102 (27)	1.8
2978	0.031 (7)		0.038 (23)	0.037 (6)			0.029 (2)			0.030 (1)		0.034 (7)				0.0302 (9)	0.85
2999	0.0220 (44)		0.015 (7)	0.024 (6)						0.019 (1)		0.030 (5)				0.0195 (15)	2.5
3053	0.046 (7)		0.046 (23)	0.053 (7)						0.041 (2)		0.057 (3)				0.048 (7)	1.8
3081	0.0110 (44)			0.0124 (37)						0.011 (1)		0.020 (4)				0.0115 (15)	2.4
3093				0.00111 (37)						0.0008 (1)		0.0010 (3)				0.00082 (9)	0.4
3142	0.0022 (9)			0.0035 (12)						0.0026 (2)		0.0060 (28)				0.00260 (19)	0.84
3149										0.00019						0.00019	

Energy (keV)	1969Li10	1696Wa27*	1969Gr33*	1975Ha31*	1977Zo01	1982Ak03*	1982Fa10*	1983Ol01	1983Sc13	1990Mouze	1991Li11	2000Sa32	2002De03	2002MoZP	2004Mo07*	Evaluated	χ2
3160	0.00110 (44)			0.00111 (50)						0.0010 (2)		0.0030 (17)				0.00104 (18)	0.7
3183	0.00110 (44)			0.0032 (10)						0.0028 (2)		0.0060 (10)				0.0023 (10)	1.3

*: Not used by the evaluators (see below).
µ: the experimental value has been shown to be outlier value by the Lweight program.

There were omitted from analysis:

a) four sets of values, A. Hachem (1975Ha31), G. Mouze (1981Mo28), H. Akcay (1982Ak03), G. Mouze (1990Mo08) and O. Diallo (1993Di09), because these values come from the same laboratory of G. Mouze (1990Mo**).

b) the sets of values from K. Ya. Gromov (1969Gr33), G. Wallace (1969Wa27) and M. A. Farouk (1982Fa10), because of a lack of information in the articles about the experimental measurements carried out and, therefore on the results.

c) the relative γ-ray intensity values given in 2004Mo07, because they are those measured by J. U. Delgado (2002De03). In 2004Mo07, the author measured the absolute 609.3-keV γ-ray emission probability (Table 5) and normalized the 2002De03 data set with their value of 45.57 (18).

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

The evaluated relative and absolute γ-ray intensities are given in Table 7.

Table 7: Evaluated relative and absolute γ-ray intensities

Energy (keV)	Relative γ-ray intensity (%)	Absolute γ-ray intensity (%)	Energy (keV)	Relative γ-ray intensity (%)	Absolute γ-ray intensity (%)	Energy (keV)	Relative γ-ray intensity (%)	Absolute γ-ray intensity (%)	Energy (keV)	Relative emission intensity (%)	Absolute γ-ray intensity (%)
221	0.130 (13)	0.059 (6)	**703**	1.053(24)	0.479 (11)	**1238**	12.819 (29)	5.831 (13)	**2204**	10.80 (5)	4.913 (23)
230	0.0063 (21)	0.0029 (10)	**704**	0.112 (21)	0.051 (10)	**1280**	3.155 (13)	1.435 (6)	**2251**	0.012 (1)	0.0055 (5)
252	0.0258 (39)	0.0117 (18)	**708**	0.0262 (43)	0.0119 (20)	**1284**	0.028 (14)	0.013 (6)	**2260**	0.0191 (9)	0.0087 (4)
268	0.0355 (40)	0.0161 (18)	**710**	0.168 (8)	0.076 (4)	**1303**	0.231 (12)	0.105 (5)	**2266**	0.0362 (17)	0.0165 (8)
273	0.264 (18)	0.120 (8)	**719**	0.865 (22)	0.393 (10)	**1316**	0.170 (16)	0.077 (7)	**2270**	0.0030 (7)	0.0014 (3)
280	0.136 (14)	0.062 (6)	**722**	0.082 (15)	0.037 (7)	**1330**	0.0264 (30)	0.0120 (14)	**2284**	0.0110 (9)	0.0050(4)
304	0.056 (5)	0.0255 (23)	**733**	0.084 (7)	0.038 (3)	**1341**	0.047 (6)	0.0214 (27)	**2287**	0.010 (1)	0.0046 (5)
333	0.139 (9)	0.063 (4)	**740**	0.0941 (47)	0.0428 (21)	**1351**	0.0092 (24)	0.0042 (11)	**2293**	0.673 (8)	0.306 (4)
334	0.072 (10)	0.033 (5)	**752**	0.278 (17)	0.126 (8)	**1353**	0.008 (2)	0.0036 (9)	**2310**	0.003 (2)	0.0014 (9)
348	0.27 (7)	0.123 (32)	**768**	10.755 (36)	4.892 (16)	**1377**	8.722 (25)	3.968 (11)	**2312**	0.0189 (18)	0.0086 (8)

Energy (keV)	Relative γ-ray intensity (%)	Absolute γ-ray intensity (%)	Energy (keV)	Relative γ-ray intensity (%)	Absolute γ-ray intensity (%)	Energy (keV)	Relative γ-ray intensity (%)	Absolute γ-ray intensity (%)	Energy (keV)	Relative γ-ray intensity (%)	Absolute γ-ray intensity (%)
386	0.650 (12)	0.296 (5)	**786**	0.69 (10)	0.31 (5)	**1385**	1.750 (11)	0.796 (5)	**2319**	0.0030 (20)	0.0014 (9)
388	0.864 (10)	0.394 (5)	**788**	0.033 (10)	0.015 (5)	**1392**	0.0191 (42)	0.0087 (19)	**2325**	0.0038 (7)	0.0017 (3)
394	0.0280 (40)	0.0127 (18)	**806**	2.774 (13)	1.262 (6)	**1401**	2.923 (16)	1.330 (7)	**2331**	0.056 (9)	0.026 (4)
396	0.057 (4)	0.0259 (18)	**815**	0.085 (7)	0.039 (3)	**1407**	5.252 (17)	2.389 (8)	**2348**	0.003 (2)	0.0014 (9)
405	0.375 (16)	0.171 (7)	**821**	0.364 (21)	0.166 (10)	**1419**	0.0120 (21)	0.0055 (10)	**2353**	0.0008 (3)	0.00036 (14)
452	0.067 (8)	0.031 (4)	**826**	0.284 (24)	0.129 (11)	**1470**	0.0206 (29)	0.0094 (13)	**2361**	0.0046 (14)	0.0021 (6)
454	0.634 (10)	0.288 (5)	**832**	0.076 (5)	0.035 (2)	**1479**	0.113 (9)	0.051 (4)	**2369**	0.0062 (9)	0.0028 (4)
461	0.128 (18)	0.058 (8)	**847**	0.035 (13)	0.016 (6)	**1509**	4.679 (21)	2.128 (10)	**2376**	0.0190 (17)	0.0086 (8)
469	0.292 (32)	0.133 (15)	**873**	0.041 (7)	0.019 (3)	**1515**	0.0159 (46)	0.0072 (21)	**2390**	0.00343 (30)	0.00156 (14)
474	0.203 (14)	0.092 (6)	**878**	0.026 (6)	0.0118 (27)	**1538**	0.882 (49)	0.401 (22)	**2405**	0.0024 (16)	0.0011 (7)
485	0.046 (8)	0.021 (4)	**904**	0.144 (17)	0.066 (8)	**1543**	0.664 (29)	0.302 (13)	**2423**	0.0106 (14)	0.0048 (6)
487	0.061 (20)	0.028 (9)	**915**	0.051 (11)	0.023 (5)	**1583**	1.555 (11)	0.707 (5)	**2444**	0.018 (9)	0.008 (4)
494	0.023 (6)	0.011 (3)	**917**	0.010 (7)	0.005 (3)	**1594**	0.603 (33)	0.274 (15)	**2447**	3.403 (16)	1.548 (7)
496	0.015 (4)	0.0068 (18)	**930**	0.094 (17)	0.043 (8)	**1599**	0.707 (33)	0.322 (15)	**2459**	0.0031 (5)	0.00141 (23)
501	0.0397 (48)	0.0181 (22)	**934**	6.814 (22)	3.100 (10)	**1636**	0.0244 (36)	0.0111 (16)	**2482**	0.0021 (4)	0.00096 (18)
519	0.0364 (38)	0.0166 (17)	**939**	0.036 (8)	0.016 (4)	**1657**	0.104 (12)	0.047 (5)	**2505**	0.0124 (13)	0.0056 (6)
524	0.0372 (38)	0.0169 (17)	**943**	0.038 (6)	0.017 (3)	**1661**	2.304(20)	1.048 (9)	**2550**	0.0007 (2)	0.00032 (9)
528	0.0239 (29)	0.0109 (13)	**949**	0.012 (5)	0.0055 (23)	**1665**	0.032 (14)	0.015 (6)	**2562**	0.0004 (2)	0.00018 (9)
536	0.134 (17)	0.061 (8)	**952**	0.013 (5)	0.0059 (23)	**1683**	0.478 (7)	0.217 (3)	**2564**	0.0003(2)	0.00014 (9)
543	0.194 (46)	0.088 (21)	**961**	0.0222 (30)	0.0101 (14)	**1711**	0.050 (10)	0.023 (5)	**2604**	0.0008 (2)	0,00036 (9)
547	0.075 (6)	0.034 (3)	**964**	0.799 (27)	0.363 (12)	**1729**	6.251 (22)	2.844 (10)	**2630**	0.0019 (5)	0,00086 (23)
551	0.012 (3)	0.0055 (14)	**976**	0.0333 (47)	0.0151 (21)	**1751**	0.002 (1)	0.0009 (5)	**2662**	0.00044 (9)	0,00020 (4)
572	0.156 (17)	0.071 (8)	**991**	0.023 (6)	0.011 (3)	**1764**	33.66 (10)	15.31 (5)	**2694**	0.072 (6)	0.033 (3)
595	0.0383 (33)	0.0174 (15)	**1013**	0.0191 (41)	0.0087 (19)	**1813**	0.0238 (20)	0.0108 (9)	**2699**	0.0062 (5)	0.00282 (23)
600	0.018 (8)	0.008 (4)	**1021**	0.034 (6)	0.016 (3)	**1838**	0.753(23)	0.343 (10)	**2719**	0.00374 (38)	0.00170 (17)
609	100	45.49 (19)	**1032**	0.135 (9)	0.061 (4)	**1847**	4.451 (26)	2.025 (12)	**2769**	0.0494 (17)	0.0225 (8)
615	0.121 (16)	0.055 (7)	**1038**	0.0190 (33)	0.0086 (15)	**1873**	0.467 (18)	0.212 (8)	**2785**	0.0120 (11)	0.0055 (5)

617	0.059 (10)	0.027 (5)	**1045**	0.050 (6)	0.023(3)	**1890**	0.171 (9)	0.078 (4)	**2826**	0.00480 (38)	0.00218 (17)
Energy (keV)	Relative γ-ray intensity (%)	Absolute γ-ray intensity (%)	**Energy (keV)**	Relative γ-ray intensity (%)	Absolute γ-ray intensity (%)	**Energy (keV)**	Relative γ-ray intensity (%)	Absolute γ-ray intensity (%)	**Energy (keV)**	Relative γ-ray intensity (%)	Absolute γ-ray intensity (%)
626	0.009 (3)	0.0041 (14)	**1051**	0.713 (17)	0.324 (8)	**1895**	0.321 (18)	0.146 (8)	**2861**	0.00091 (28)	0.00041 (13)
630	0.0366 (31)	0.0166 (14)	**1067**	0.053 (15)	0.024 (7)	**1898**	0.107 (17)	0.049 (8)	**2880**	0.0222 (35)	0.0101 (16)
633	0.120 (7)	0.055 (3)	**1069**	0.595 (23)	0.271 (10)	**1935**	0.070 (16)	0.032 (7)	**2893**	0.0126 (10)	0.0057 (5)
634	0.014 (5)	0.0064 (23)	**1103**	0.233 (33)	0.106 (15)	**1994**	0.0052 (10)	0.0024 (5)	**2921**	0.0295 (11)	0.0134 (5)
639	0.075 (10)	0.034 (5)	**1104**	0.16 (3)	0.073 (14)	**2010**	0.0954 (37)	0.0434 (17)	**2928**	0.0024 (2)	0.00109 (9)
649	0.119 (16)	0.054 (7)	**1118**	0.022 (9)	0.010 (4)	**2021**	0.0471 (46)	0.0214 (21)	**2934**	0.00102 (27)	0.00046 (12)
658	0.038 (8)	0.017 (4)	**1120**	32.77 (7)	14.91 (3)	**2052**	0.151 (9)	0.069 (4)	**2978**	0.0302 (9)	0.0137 (4)
661	0.118 (9)	0.054 (4)	**1130**	0.079 (7)	0.036 (3)	**2085**	0.0181 (10)	0.0082 (5)	**2999**	0.0195 (15)	0.0089 (7)
665	3.364 (15)	1.530 (7)	**1133**	0.558 (17)	0.254 (8)	**2089**	0.0973 (48)	0.0443 (22)	**3053**	0.048 (7)	0.022 (3)
677	0.012 (5)	0.0055 (23)	**1155**	3.594 (15)	1.635 (7)	**2109**	0.185 (6)	0.084 (3)	**3081**	0.0115 (15)	0.0052 (7)
683	0.184 (13)	0.084 (6)	**1167**	0.0271 (37)	0.0123 (17)	**2118**	2.545 (12)	1.158 (5)	**3093**	0.00082 (9)	0.00037 (4)
687	0.0146 (31)	0.0066 (14)	**1172**	0.120 (16)	0.055 (7)	**2147**	0.0295 (28)	0.0134 (13)	**3142**	0.00260 (19)	0,00118 (9)
693	0.0129 (33)	0.0059 (15)	**1207**	0.998 (27)	0.454 (12)	**2160**	0.015 (11)	0.007 (5)	**3149**	0.00019	0.00019
697	0.148 (9)	0.067 (4)	**1226**	0.039 (18)	0.018 (8)	**2176**	0.0072 (13)	0.0033 (6)	**3160**	0.00104 (18)	0.00047 (8)
699	0.035 (10)	0.016(5)	**1230**	0.016 (10)	0.007 (5)	**2192**	0.084 (7)	0.038 (3)	**3183**	0.0023 (10)	0.0011 (5)

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^{215}Bi – Comments on evaluation of decay data by A. L. Nichols and F. G. Kondev

Evaluated: June 2011

Evaluation Procedure

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

Decay Scheme

The ^{215}Bi ground state (J^{π} = (9/2^{-})) decays 100 % by β^{-} emission to various excited levels and the ground state of ^{215}Po. A reasonably complex but inadequate decay scheme has been constructed primarily from the gamma-ray measurements of Kurpeta *et al.* (2003Ku26) in which 19 distinct gamma-ray emissions were identified with the β^{-} decay of ^{215}Bi. Although these authors assessed that there is no direct beta decay to the ground state of ^{215}Po, their reported absolute emission probabilities for the gamma rays populating the ground state are in conflict with this proposal.

Direct β^{-} feeding to the ground state of daughter ^{215}Po has not been satisfactorily determined. Therefore, the evaluators resorted to comparisons with the β^{-} decay of other odd-even Bi radionuclides (^{213}Bi) and β^{-}-decay theory in order to define the β^{-} and γ emission probabilities in absolute terms. Further studies are required to clarify and define more clearly the ^{215}Bi decay scheme, particularly with respect to the absolute gamma-ray emission probabilities and quantification of direct β^{-} feeding to the ground state of daughter ^{215}Po.

Nuclear Data

^{215}Bi is part of the (4n + 3) naturally-occurring decay chain, and of relevance in quantifying the environmental impact of ^{235}U and decay-chain products. Specific radionuclides in this decay chain are noteworthy because of their decay characteristics (^{215}Po, ^{211}Bi and ^{211}Po alpha decay).

Half-life

^{215}Bi was first observed by 1953Hy83, and assigned a half-life of (8 ± 2) min. However, the recommended half-life is the weighted mean of three more recent measurements (1965Nu03, 1989Bu09 and 1990Ru02).

Reference	Half-life (min)
1965Nu03	7.4 (6)
1989Bu09	7.5 (4)
1990Ru02	7.7 (2)
Recommended value	7.6 (2)

^{215}Po half-life of 1.781 (4) millisecond was adopted from the evaluation of Browne (2001Br31).

Q value

Q^{-} of 2189 (15) keV was adopted from the evaluated tabulations of Audi *et al.* (2003Au03).

Beta particles

Energies

All beta-particle energies were calculated from the structural details of the proposed decay scheme. A combination of nuclear level energies recommended by 2001Br31 and derived from 2003Ku26, and a Q-value of 2189 (15) keV (2003Au03) were used to determine the energies and uncertainties of the beta-particle emissions to the various levels.

Adopted nuclear levels of ^{215}Po: Energy, J^{π} and origins (2001Br31, 2003Ku26).

Nuclear level	Nuclear level energy (keV)	J^{π}	Origins
0	0.0	9/2 +	**^{215}Bi β^- decay**, ^{219}Rn α decay
1	271.228 ± 0.010	7/2 +	**^{215}Bi β^- decay**, ^{219}Rn α decay
2	293.56 ± 0.04	11/2 +	**^{215}Bi β^- decay**, ^{219}Rn α decay
3	401.812 ± 0.010	5/2 +	**^{215}Bi β^- decay**, ^{219}Rn α decay
4	517.60 ± 0.06	7/2 +, 9/2 +	**^{215}Bi β^- decay**, ^{219}Rn α decay
5	608.30 ± 0.07	(11/2 +, 13/2 +)	**^{215}Bi β^- decay**, ^{219}Rn α decay
6	676.66 ± 0.07		**^{215}Bi β^- decay**, ^{219}Rn α decay
7	708.1 ± 0.5		^{219}Rn α decay
8	732.7 ± 0.4		^{219}Rn α decay
9	835.32 ± 0.22		**^{215}Bi β^- decay**, ^{219}Rn α decay
10	877.2 ± 0.6		^{219}Rn α decay
11	891.1 ± 0.3		^{219}Rn α decay
12	930 ± 1		^{219}Rn α decay
13	1073.7 ± 0.4	(5/2 +)	^{219}Rn α decay
14	1077.6 ± 2.0*		**^{215}Bi β^- decay**
15	1094.2 ± 1.0		^{219}Rn α decay
16	1176.2 ± 2.0*		**^{215}Bi β^- decay**
17	1294.5 ± 0.1*		**^{215}Bi β^- decay**
18	1398.8 ± 0.4*		**^{215}Bi β^- decay**

* Calculated from the energies of the depopulating gamma rays (2003Ku26), and the lower-energy nuclear levels that they populate.

Emission Probabilities

Direct beta-particle feeding to the ground state of ^{215}Po has not been unambiguously defined from the various γ-ray measurements. Under these circumstances, a systematic assessment of the appropriate properties of odd-even Bi nuclides in the vicinity of ^{215}Bi has been undertaken to explore whether a reasonable approximation can be made of beta decay directly to the ground state of ^{215}Po (1991Ma16, 2001Br31, 2003Ak06, 2004Br45, 2007Ba19).

(a) Spin and parity of ^{215}Bi

Nuclide	^{209}Bi	^{211}Bi	^{213}Bi	^{215}Bi	^{217}Bi
β^- decay	stable	0.28 %	97.91 %	100 %	100 %
Direct β^- decay to ground state	–	0.28 %	65.9 %	?	?
α decay	stable	99.72 %	2.09 %	–	–
Spin and parity	$9/2^-$	$9/2^-$	$9/2^-$	$(9/2^-)$	?
Spin and parity of Po ground state	$1/2^-$	$9/2^+$	$9/2^+$	$9/2^+$	$(11/2^+)$

Spins and parities of $9/2^-$ are well defined for ^{209,211,213}Bi, and can be similarly assigned with reasonable confidence as $(9/2^-)$ for ^{215}Bi.

(b) Direct beta-particle feeding of ^{215}Bi to the ground state of ^{215}Po

Population-depopulation balances have been calculated on the basis of the relative emission probabilities of the gamma rays (see below) in order to derive relative beta-particle emission probabilities to all of the excited nuclear levels of ^{215}Po.

The β^- decay of ^{215}Bi was assumed to occur primarily via first forbidden non-unique transitions to the ground state ($9/2^+$) and 293.56-keV nuclear level ($11/2^+$) of ^{215}Po. The preparation of recommended decay-data files for DDEP necessitates the formulation of decay schemes that are based on absolute emission and transition probabilities that frequently encompass well-defined normalization factors in conjunction with accurate relative emission probabilities and various other nuclear parameters (e.g. internal conversion coefficients). This ideal situation cannot be achieved for ^{215}Bi because of existing inadequacies in the measured data. Therefore, the main β^- branches populate the 293.56-keV nuclear level and ground state of ^{215}Po, and their important emission probabilities have been derived somewhat unusually through application of the fifth-power law of β^- decay (1933Sa01, 1955Ev23, 1963KaZZ).

A general approximation has been formulated for the ratio of allowed beta-particle emission probabilities, based on the observation that the mean life (τ) for partial β^- decay is inversely proportional to the fifth power of the β^- end-point energy (1955Ev23, 1963KaZZ):

$$\frac{1}{\tau_\beta} \propto [(M(Z) - M(Z \pm 1)c^2)]^5$$

where

$$\tau_\beta = \frac{\tau_{exp}}{P_\beta} \quad \text{and} \quad \tau_{exp} \text{ is the lifetime of the parent nuclide.}$$

Therefore

$$\frac{1}{\tau_\beta} \sim (E_\beta)^5$$

This approximation has been applied to the major first-forbidden non-unique beta-particle emissions of ^{215}Bi directly to the ground state of ^{215}Po ($(9/2^-) \rightarrow 9/2^+$)

$$\frac{1}{\tau_{0,0}} \sim (E_{\beta_{0,0}})^5 \qquad (1)$$

and to the 293.56-keV nuclear level of ^{215}Po ($(9/2^-) \rightarrow 11/2^+$)

$$\frac{1}{\tau_{0,2}} \sim (E_{\beta_{0,2}})^5 \qquad (2)$$

Combining equations (1) and (2):

$$\frac{\tau_{0,2}}{\tau_{0,0}} = \frac{P_{\beta_{0,0}}}{P_{\beta_{0,2}}} \sim \left(\frac{E_{\beta_{0,0}}}{E_{\beta_{0,2}}}\right)^5 = \left[\frac{2189(15)}{1895(15)}\right]^5 = 1.155^5 \sim 2.055$$

where $P_{\beta_{0,0}}$ and $P_{\beta_{0,2}}$ are the β-particle emission probabilities to the ground state and 293.56-keV nuclear level, respectively.

The proposed decay scheme, recommended relative emission probabilities of the gamma rays and α_{total} have been used to determine a $P^{rel}_{\beta_{0,2}}$ value of 125 (7) by the appropriate summation of the measured gamma population/depopulation of the 293.56-keV nuclear level. Therefore:

$$P^{rel}_{\beta_{0,0}} \sim 2.055 \times 125\,(7) = 257\,(14)$$

with an uncertainty assigned in a somewhat arbitrary manner on the basis of the uncertainty derived for $P^{rel}_{\beta_{0,2}}$.

The normalization factor (*NF*) for the relative emission probabilities of both the β^- particles and γ rays has been determined from the total βγ transitions populating the ground state of ^{215}Po directly:

$$P^{rel}_{\beta_{0,0}} \times NF + \sum P^{rel}_{\gamma}(1 + \alpha_{total}) \times NF = 100$$

$$257\,(14) \times NF + [164\,(7) \times NF] = 100$$

$$NF = 100/421\,(16) = 0.238\,(9)$$

Both P^{abs}_{β} to the ground state and 293.56-keV nuclear level of ^{215}Po were simply calculated from their P^{rel}_{β} values and *NF*, and are coupled together on the basis of crude estimates of their uncertainties (i.e. arbitrary uncertainty of 20 % assigned to the value of $P_{\beta^-_{0,2}}$):

$P^{abs}_{\beta_{0,2}}$ of 30 (6) %

and $P^{abs}_{\beta_{0,0}}$ of 61 (6) %.

These data should be treated with a high degree of caution. Their derivation also impacts significantly on the quantification of the other beta-particle emission probabilities.

Apart from the beta-particle emission directly to the ground state of ^{215}Po, the relative emission probabilities of all of the other beta-particle decays were calculated from population-depopulation balances of the relative gamma transition probabilities, as derived from the relative gamma-ray emission probabilities and internal conversion coefficients determined from the frozen orbital approximation of Kibédi *et al*. (2008Ki07) based on the theoretical model of Band *et al*. (2002Ba85, 2002Ra45). Direct beta population of the 271.228-keV nuclear level of ^{215}Po was calculated to be zero from the calculation of the known gamma transition probabilities populating and depopulating this particular excited state ((9/2$^-$) to 7/2$^+$ (1st forbidden non-unique)).

Beta-particle emission probabilities per 100 disintegrations of ^{215}Bi, transition type and log *ft*.

E_β(keV)	P_β Recommended value	transition type‡	log *ft*#
790 (15)	2.8 (1)*	[1st forbidden non-unique]	6.00
895 (15)	2.0 (2)*	[1st forbidden non-unique]	6.34
1013 (15)	0.2 (1)*	[1st forbidden non-unique]	7.5
1111 (15)	0.7 (1)*	[1st forbidden non-unique]	7.1
1354 (15)	1.5 (1)*	[1st forbidden non-unique]	7.10
1512 (15)	0.5 (1)*	[1st forbidden non-unique]	7.8
1581 (15)	0.7 (1)*	(1st forbidden non-unique)	7.7
1671 (15)	0.3 (2)*	(1st forbidden non-unique)	8.1
1787 (15)	0.5 (1)*	(1st forbidden unique)	9.0
1895 (15)	30 (6) *†	(1st forbidden non-unique)	6.35
1918 (15)	–	(1st forbidden non-unique)	–
2189 (15)	61 (6)†	(1st forbidden non-unique)	6.28
	Σ 100 (8)		

* Recommended absolute β^- emission probabilities derived from the relative gamma-ray emission probabilities, normalization factor of 0.238 (9), and theoretical internal conversion coefficients.

† Absolute emission probabilities calculated from fifth-power relationship of β^- end-point energies, with an arbitrary estimated uncertainty of 20 % assigned to the 1895-keV β^- emission probability.

‡ Transition types within square brackets [] are not based on any spin-parity assignments – they have been assumed to be first forbidden non-unique as observed for the majority of the higher-energy β^- transitions.

\# Log *ft* values calculated on the assumption of first forbidden non-unique transitions, apart from the 1787-keV beta emission (defined as most likely to be first forbidden unique).

The observed systematics of the two principle emissions in β^- decay for odd-even nuclides has been used in a quantitative manner to derive beta-particle emission probabilities in absolute terms. This approach is both approximate and of highly questionable merit – under these unsatisfactory circumstances, further experimental studies are required to determine direct β^- feeding to the ground state of daughter ^{215}Po with good accuracy.

Gamma rays

Energies

All gamma-ray transition energies were calculated from the structural details of the proposed decay scheme derived from 2001Br01 and 2003Ku26. The lower-energy nuclear level energies of 2001Br31 were adopted, along with higher-energy nuclear levels calculated from the gamma-ray studies of 2003Ku26. These data were subsequently used to re-determine the energies and associated uncertainties of the gamma-ray transitions between the various populated-depopulated levels.

Emission Probabilities

The only known experimental studies of relevance in defining the decay scheme of ^{215}Bi are the measurements by Ruchowska *et al.* (1990Ru02) in which the emission probabilities of seven gamma-ray transitions were quantified in terms of Pγ(293.56 keV) of 1000 (redefined as 100 %), and the more extensive studies of Kurpeta *et al.* (2003Ku26) in which the emission probabilities of 19 gamma-ray transitions were quantified.

Table 3 and Fig. 6 of 2003Ku26 contain highly questionable absolute β-particle and γ-ray emission probabilities. While the resulting γ-ray transition probabilities populating the ^{215}Po ground state directly sum to only 57.6 %, no direct β^- decay is advocated to achieve a correct summation of 100 %. Private communications between Kurpeta (Institute of Experimental Physics, Warsaw University) and Kondev (ANL), April 2011, have clarified the caption of Table 3: γ intensities listed in this table are relative and not absolute (defined erroneously as %

per decay). Therefore, these γ-ray emission probabilities have been re-defined as relative to Pγ(293.56 keV) of 100 %.

A number of unobserved low-intensity gamma rays have also been introduced by considering the equivalent gamma-ray studies of the α decay of ^{219}Rn – this process results in the introduction of the 130.58-, 224.04- and 405.43-keV gamma transitions, each with relative emission probabilities of less than 0.15 %.

Gamma-ray emission probabilities: as published, and relative to P_γ(293.56 keV) of 100 %.

E_γ (keV)	P_γ^{rel}			
	1990Ru02	2003Ku26† as published	adjusted	Recommended value*
130.58 (1)	–	–	–	0.039(4)‡
224.04 (7)	–	–	–	0.14 (2)‡
271.228 (10)	5.5 (5)	2.9 (1)	8.2 (3)	8.2 (3)
293.56 (4)	100 (7)	35.2 (11)	100 (3)	100 (3)
383.10 (8)	–	0.2 (1)	0.6 (3)	0.6 (3)
401.81 (1)	1.0 (4)	0.7 (1)	2.0 (3)	2.0 (3)
405.43 (7)	–	–	–	0.024 (4)‡
517.60 (6)	1.9 (3)	1.5 (1)	4.3 (3)	4.3 (3)
541.76 (22)	–	0.3 (1)	0.9 (3)	0.9 (3)
564.09 (22)	1.3 (3)	1.0 (1)	2.8 (3)	2.8 (3)
608.30 (7)	–	1.0 (1)	2.8 (3)	2.8 (3)
676.66 (7)	0.6 (2)	0.6 (1)	1.7 (3)	1.7 (3)
776.9 (1)	–	1.2 (2)	3.4 (6)	3.4 (6)
784 (2)	–	0.5 (1)	1.4 (3)	1.4 (3)
806.4 (20)	–	0.6 (1)	1.7 (3)	1.7 (3)
835.32 (22)	1.4 (3)	0.9 (1)	2.6 (3)	2.6 (3)
905 (2)	–	0.3 (1)	0.9 (3)	0.9 (3)
1023.3 (1)	–	0.9 (1)	2.6 (3)	2.6 (3)
1105.2 (4)	–	2.2 (1)	6.3 (3)	6.3 (3)
1127.6 (4)	–	0.7 (1)	2.0 (3)	2.0 (3)
1294.5 (1)	–	0.9 (1)	2.6 (3)	2.6 (3)
1398.8 (4)	–	1.2 (1)	3.4 (3)	3.4 (3)

† Published as absolute emission probabilities of doubtful overall pedigree (transition probabilities directly populating the ^{215}Po ground state only sum to 57.6 %, while direct β^- decay of zero is advocated); J. Kurpeta (Institute of Experimental Physics, Warsaw University), private communication to F.G. Kondev (ANL), 27 April 2011, concerning caption of Table 3 (2003Ku26): γ intensities are relative and not % per decay – therefore, emission probabilities have been adjusted to be relative to Pγ(293.56 keV) of 100 %.

* Recommended data biased completely towards the more extensive measurements of 2003Ku26.

‡ Derived from equivalent γ-ray measurements of ^{219}Rn α decay.

Major disagreements are observed between the emission probability measurements of 1990Ru02 and 2003Ku26 that negate the merit of any form of weighted-mean analysis. Under these circumstances, the more comprehensive data of 2003Ku26 have been adopted relative to Pγ(293.56 keV) of 100 %.

Multipolarities and Internal Conversion Coefficients

The decay scheme specified by 2001Br31 has been used to define the multipolarity of specific gamma transitions on the basis of the known spins and parities of the nuclear levels. Thus, the 224.04- and 401.81-keV gamma-ray emissions are adjudged to be E2 transitions. Multipolarity mixing ratios for the 130.58- and 271.228-keV gamma transitions of 0.60 (6) and 4.0 (4), respectively, were derived from the K/L and L sub-shell conversion-electron ratios determined by Davidson and Connor (1970Da09), while the 293.56- and 517.60-keV gamma-ray emissions were arbitrarily assigned mixing ratios of 1.0 (2) (i.e. 50 % M1 + 50 % E2). Recommended internal conversion coefficients have been determined from the frozen orbital approximation of Kibédi *et al*. (2008Ki07), based on the theoretical model of Band *et al*. (2002Ba85, 2002Ra45).

Gamma-ray emissions: multipolarities and theoretical internal conversion coefficients (frozen orbital approximation).

E_γ (keV)	Multipolarity	α_K	α_L	α_{M+}	α_{total}
130.58 (1)	73.5%M1 + 26.5%E2 δ = 0.60(6)	3.19 (16)	0.94 (4)	0.31	4.44 (13)
224.04 (7)	(E2)	0.1296 (19)	0.1407 (20)	0.0487	0.319 (5)
271.228 (10)	6%M1 + 94%E2 δ = 4.0(4)	0.111 (6)	0.0668 (11)	0.0232	0.201 (7)
293.56 (4)	(50%M1 + 50%E2) δ = 1.0(2)	0.25 (4)	0.062 (4)	0.028	0.34 (5)
383.10 (8)	–	–	–	–	–
401.81 (1)	E2	0.0351 (5)	0.01528 (22)	0.00512	0.0555 (8)
405.43 (7)	–	–	–	–	–
517.60 (6)	50%M1 + 50%E2 δ = 1.0(2)	0.058 (9)	0.0115 (11)	0.0035	0.073 (10)
541.76 (22)	–	–	–	–	–
564.09 (22)	–	–	–	–	–
608.30 (7)	(M1 + E2)	–	–	–	–
676.66 (7)	–	–	–	–	–
776.9 (1)	–	–	–	–	–
784 (2)	–	–	–	–	–
806.4 (20)	–	–	–	–	–
835.32 (22)	–	–	–	–	–
905 (2)	–	–	–	–	–
1023.3 (1)	–	–	–	–	–
1105.2 (4)	–	–	–	–	–
1127.6 (4)	–	–	–	–	–
1294.5 (1)	–	–	–	–	–
1398.8 (4)	–	–	–	–	–

While a decay scheme has been formulated from the gamma-ray emission probability measurements of Kurpeta *et al.* (2003Ku26), further studies are required to determine the absolute and relative gamma-ray emission probabilities and also quantify any direct β^- feeding to the ground state of daughter ^{215}Po with much greater confidence. Such work would assist greatly to remove the severe doubts associated with the proposed decay scheme.

Atomic Data

The x-ray data have been calculated using the evaluated gamma-ray data, and the atomic data from 1996Sc06, 1998ScZM and 1999ScZX. Both the x-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.01, 28 January 2003). This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

K and L X-ray emission probabilities per 100 disintegrations of ^{215}Bi.

			Energy (keV)	Photons per 100 disint.
XL		(Po)	9.658 – 16.213	2.7 (3)
	XL_l	(Po)	9.658	0.065 (8)
	XL_α	(Po)	11.016 – 11.130	1.20 (13)
	XL_η	(Po)	12.085	0.022 (3)
	XL_β	(Po)	12.823 – 13.778	1.18 (11)
	XL_γ	(Po)	15.742 – 16.213	0.24 (2)
XK_α	$XK_{\alpha 2}$	(Po)	76.864 (4)	1.8 (3)
	$XK_{\alpha 1}$	(Po)	79.293 (5)	3.0 (5)
$XK'_{\beta 1}$	$XK_{\beta 3}$	(Po)	89.256	}
	$XK_{\beta 1}$	(Po)	89.807	} 1.02 (16)
	$XK''_{\beta 5}$	(Po)	90.363	}
$XK'_{\beta 2}$	$XK_{\beta 2}$	(Po)	92.263	}
	$XK_{\beta 4}$	(Po)	92.618	} 0.32 (5)
	$XKO_{2,3}$	(Po)	92.983	}

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

Data Consistency

A Q_β-value of 2189 (15) keV has been adopted from the atomic mass evaluation of Audi *et al*. (2003Au03) while in the course of formulating the decay scheme of ^{215}Bi. This value has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{215}Bi beta-decay process (i.e. β^-, conversion electrons, γ, etc.):

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 2190\ (170)\ \text{keV}$$

Percentage deviation from the Q-value of Audi *et al*. is (0 ± 8) %, which supports the derivation of a highly consistent decay scheme with a large variant.

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^{210}Po - Comments on evaluation of decay data by V. Chisté and M. M. Bé

This evaluation was completed in 2008. Literature available by February 2008 was included.

1 Decay Scheme

^{210}Po disintegrates by alpha emission to the 803-keV excited level and ground state level of ^{206}Pb. Energy levels, spins and parities are from the ENSDF mass-chain evaluations R.G. Helmer (1990He18) and E. Browne (1999Br39).

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).

Experimental ^{210}Po half-life values (in days) are given in Table 1:

Table 1: Experimental values of ^{210}Po half-life.

Reference	Experimental value (d)	Comments
E. V. Schweidler (1912Sc**)	136.5	Not used: no uncertainty.
M. Curie (1920Cu**)	140.0	Not used: no uncertainty.
A. Dorabialska (1931Do**)	137.6 (6)	Calorimetry.
A. S. Sanielevici (1936Sa**)	139.6 (14)	Calorimetry.
W. H. Beamer (1949Be54)	138.30 (14)	Calorimetry.
D. C. Ginnings (1953Gi10)	138.39 (14)	Calorimetry.
M. L. Curtis (1953Cu46)	138.374 (32)	α counting.
J. F. Eichelberger (1954Ei20)	138.400 (6)	Calorimetry. Not used. Superseded by 1964EiZZ.
J. F. Eichelberger (1964EiZZ)	138.3763 (17)	Calorimetry
Recommended value	**138.3763 (17)**	χ^2 = 0.10

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

The evaluators have chosen to use six experimental values with uncertainty found in the literature and given in Table 1. The values of A. Dorabialska (1931Do**) and A. S. Sanielevici (1936Sa**) have been rejected by the LWEIGHT program, they are statistical outliers, based on the Chauvenet's criterion. With this data set, the largest contribution (99 %) to weighted average comes from the value of J. F. Eichelberger (1964EiZZ).

The recommended value of ^{210}Po half-life is the weighted average of **138.3763 d** with an internal uncertainty of **0.0017 d**. The reduced-χ^2 value is 0.10.

2.1 a Transitions and Emissions

The recommended value of $\alpha_{0,0}$ emission energy is given by A. Rytz (1991Ry01), based on a measurement by D. J. Gorman (1973Go39). The experimental and recommended values of $\alpha_{0,0}$ emission energy are shown in Table 2.

Table 2: Experimental and recommended (calculated) values of $\alpha_{0,0}$ emission energy.

Reference	$\alpha_{0,0}$ emission energy (keV)	Comments
S. Rosenblum (1933Ro03)	5298 (6)	
W. B. Lewis (1934Le01)	5298 (21)	
E. R. Collins (1953Co64)	5304.3 (29)	
G. H. Briggs (1954Br07)	5300.6 (26)	Evaluated value reported by author.
I. I. Agapkin (1957Ag15)	5297.8 (15)	
F. A. White (1958Wh09)	5305.4 (10)	
C. P. Browne (1960Br20)	5308.6 (30)	
E. H. Beckner (1961Be13)	5302.5 (15)	
A. Rytz (1961Ry05)	5304.9 (6)	
D. J. Gorman (1973Go39)	5304.51 (7)	
Recommended value (1991Ry01)	**5304.33 (7)**	

For $\alpha_{0,1}$, the emission energy has been obtained from Q_α(2003Au03) = 5407.46 (7) keV and the level energy given in Table 3 from R. G. Helmer (1990He18).

Table 3: ^{206}Pb excited level populated in the decay of ^{210}Po.

Level Number	Level energy, (keV)	Spin and parity.
1	803.10 (5)	2^+

The emission intensities of the α-particles have been deduced from the P(γ + ce) decay scheme balance at each level and shown in Table 4.

Table 4: Emission intensities of the α-particles.

α emission energy (keV)	Emission Intensities (%)
4516.66 (9)	0.00124 (4)
5304.33 (7)	99.99876 (4)

The ratio Iα(4516)/ Iα(5304), with the recommended values (Table 4), is 1.24 (4) 10^{-5}, which can be compared with the measured value of 1.07 (2) 10^{-5} (1958Ba45).

2.2 g Transitions

The transition probability was calculated using the experimental 803-keV γ-ray emission intensity and the relevant internal conversion coefficient (see **4.2** g **Emissions**).

Multipolarity of the 803-keV γ-ray transition (E2) is given by S. de Benedetti (1952De08).

The internal conversion coefficient (ICC) for the the 803-keV γ-ray transition has been interpolated from theoretical values of I. M. Band (2002Ba85) using the BRICC computer program (calculation for 'hole').

3 Atomic Data

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

4 Photon Emissions

4.1 X-rays

The X-ray absolute intensities have been calculated from γ-ray data and ICC using the EMISSION computer program.

4.2 g Emissions

The energies of the γ-ray emission given in section 5.2 is from R. G. Helmer (1990He18).

For the 803-keV γ-ray, the experimental data set of γ-ray emission intensity is given in Table 5.

Table 5: The experimental data set of the γ-ray emission intensity.

Reference	Experimental values (10^{-3} %)	Comments
M. A. Grace (1951Gr15)	1.80 (14)	
M. Riou (1952Ri04)	1.6 (2)	
W. C. Barber (1952Ba20)	1.5 (4)	
O. Rojo (1955Ro30)	1.20 (12)	
R. W. Hayward (1955Ha09)	1.21 (6)	
A. Ascoli (1956As46)	1.21 (8)	
N. S. Shimanskaia (1956Sh24)	1.2 (2)	
V. V. Ovechkin (1957Ov09)	1.22 (9)	
Recommended value	**1.23 (4)**	χ^2 = 0.69

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

The evaluators have used the eight experimental values given with uncertainties in the literature and shown in Table 5. The value of M.A. Grace (1951Gr15) has been rejected by the LWEIGHT program, as statistical outlier, based on the Chauvenet's criterion. In the data set of seven values, the largest contribution (41 %) to the weighted average comes from the value of R.W. Hayward (1955Ha09).

The recommended value of the relative γ-ray emission intensity is the weighted average of **1.23 10^{-3} %** with the internal uncertainty of **0.04 10^{-3} %**, and a reduced-χ^2 value of 0.69.

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^{211}Po – Comments on Evaluation of Decay Data by A. Luca

This evaluation was completed in August 2009. The literature available by December 31st, 2008 was included.

1. Evaluation Procedures

The Limitation of Relative Statistical Weight (LWM) method was applied for averaging numbers throughout this evaluation; this method was implemented by using the computer code LWEIGHT, ver. 4 (designed for Excel, MS Office). The uncertainty assigned to an average value in this evaluation is never lower than the lowest uncertainty of any of the experimental input values.

2. Decay Scheme

^{211}Po decays 100 % by alpha particle emissions, mainly to the ground state of ^{207}Pb. The most recent evaluations of the ^{211}Po nuclear structure and decay data, published in Nuclear Data Sheets, were done by E. Browne (2004) and M.J. Martin (1993). In the present evaluation, the spin, parity and energy of the levels, together with the multipolarities and mixing ratios of the γ-ray transitions, have been adopted from the A=207 ENSDF mass-chain evaluation 1993Ma73.This data evaluation refers only to the decay of the ^{211}Po ground state, and not to the decay of the ^{211}Po metastable state at 1462 keV (with a half-life of 25.2 s).

3. Nuclear Data

The adopted alpha decay energy value Q(α)=7594.48 (51) keV, is from 2003Au03. This value is in very good agreement with the effective Q(α) value of 7594.2 (20) keV, deduced from average radiation energies from the decay scheme data, by using the SAISINUC software, version 2008 April.

3.1. Half-life

In the literature, five measured ^{211}Po half-life ($T_{1/2}$) values are reported. The value from 1931Cu01 is unrealistically low (in strong disagreement with all the other values), and was excluded from the data set, according to the Chauvenet's criterion implemented by the LWEIGHT computer code. The half-life values and their uncertainties are presented in Table 1. The value recommended by Curie et al. (1931), with an estimated uncertainty added by the evaluator, has been also included. The set of data, excluding the value given in 1931Cu01 is consistent and the recommended half-life value, 0.516 (3) s, is the weighted average (LWM, χ^2_ν=3.7) of the four input values. The reference *Nuclear Science References* (NSR) keynumbers are:

Table 1 : ^{211}Po Half-life values

$T_{1/2}$ (seconds)	Uncertainty of $T_{1/2}$ (seconds)	Reference
0.005	0.005	1931Cu01
0.52	0.02	1954Sp32
0.5	0.1	1954Wi26
0.56	0.04	1958To25
0.516	0.003	1974Ba29

3.2. Alpha transitions and emissions

The most important reference in the literature that studies measurements of alpha-particle energies and emission intensities for ^{211}Po alpha transitions is 1991Ry01.

For this evaluation, three adopted alpha-particle energies were deduced as weighted means of the experimental values presented in Table 2; the complete data set of the main alpha-particle group (7450.2 keV) is consistent, while from the other two data sets, the values from 1953AsZZ were rejected from the weighted mean computations, according to Chauvenet's criterion. The hindrance factors were determined by using the ALPHAD version 2.0a (2006) computer program (developed at BNL/NNDC, USA).

Table 2: Energy of the alpha-particles emitted in the ^{211}Po decay

Alpha-particle group	Energy of the alpha particles (experimental), keV	Reference
$\alpha_{0,2}$	6570 (10)	Leininger et al. (1951)
	6570 (40)	1951Ne02
	6560 (10)	1953AsZZ
	6569 (20)	1953Ho49
	6571 (4)	1968GuZX
	6570.0 (25)	1969Go23
	6568 (1)	1978Ya04
	Recommended energy value: 6568.4 (10) keV	
$\alpha_{0,1}$	6900 (10)	Leininger et al. (1951)
	6900 (40)	1951Ne02
	6880 (10)	1953AsZZ
	6895 (20)	1953Ho49
	6890.7 (25)	1962Wa18
	6891 (4)	1968GuZX
	6892.5 (25)	1969Go23
	6891 (1)	1978Ya04
	Recommended energy value: 6891.2 (10) keV	
$\alpha_{0,0}$	7430 (40)	1951Ne02
	7430 (20)	1953Ho49
	7442 (15)	1954Br07
	7450.3 (2)	1962Wa18, updated in 1991Ry01
	7440 (30)	1963Jo09
	7448 (4)	1968GuZX
	7449.8 (30)	1969Go23, updated in 1991Ry01
	7460 (20)	1969Ha32
	7448 (10)	1970Va13
	7443.3 (20)	1982Bo04, updated in 1991Ry01
	7456.2 (30)	1985La17, updated in 1991Ry01
	Recommended energy value: 7450.2 (3) keV	

The reference 1951Ne02 is the only one that reports the detection of another group of alpha particles emitted in the decay of ^{211}Po, with an energy of 6340 (60) keV and an emission probability of $7 \cdot 10^{-4}$. In the report UCRL-2325 (1953), R.W. Hoff doesn't confirm the detection of this alpha-particle decay branch, but establishes that there are no alpha-particle groups with emission probabilities higher than $2 \cdot 10^{-4}$, in the energy range from 6.26 MeV to 6.57 MeV. In a similar study presented in 1969Go23, a maximum limit of $2 \cdot 10^{-5}$ is given for the emission probability of any alpha-particle group in the energy range (5.88 to 6.43) MeV. As there is no other experimental data to confirm the existence of this branch, the evaluator adopted a decay scheme with only the three alpha particle groups given in Table 2.

The recommended emission probabilities of the alpha-particle emissions of 6568.4 keV and 6891.2 keV are the weighted means of the published experimental values, presented in

Table 3. From the first data set in this table, the values of 1978Ya04 (0.58 (1) %) and 1951Ne02 (0.48 (5) %) were rejected by the Chauvenet's criterion. A similar procedure, applied to the second data set from Table 3, lead to the rejection of the value published in the reference 1962Wa18 (0.70 (14) %).

The adopted emission probability of the main alpha-particle emission, 7450.2 keV, was computed from the normalization condition (the sum of the three alpha-particle emission probabilities is 100 %): 98.936 (19) %.

Table 3: Emission probabilities of the alpha-particles emitted in the ^{211}Po decay

Alpha-particles energy (keV)	Experimental emission probability (%)	Reference
6568.4	0.5 (1)	Leininger et al. (1951)
	0.48 (5)	1951Ne02
	0.53 (1)	1953AsZZ
	0.53 (5)	1953Ho49
	0.53 (3)	1968GuZX
	0.537 (19)	1975Ja04
	0.58 (1)	1978Ya04
	0.513 (9)	1985La17
	Recommended emission probability: 0.523 (9) %; HF=17.9	
6891.2	0.6 (1)	Leininger et al. (1951)
	0.57 (5)	1951Ne02
	0.50 (1)	1953AsZZ
	0.50 (5)	1953Ho49
	0.70 (14)	1962Wa18
	0.57 (3)	1968GuZX
	0.546 (19)	1975Ja04
	0.60 (1)	1978Ya04
	0.524 (9)	1985La17
	Recommended emission probability: 0.541 (17) %; HF=272	
7450.2	**Recommended emission probability: 98.936 (19) %; HF=112**	

3.3. γ- transitions: γ rays and internal conversion electrons

There are only few papers that report measurements of the γ-ray energies and emission probabilities following the ^{211}Po decay: 1954Mi70 and 1975Ja04 (energy values), 1968Br17 and 1985La17 (absolute emission probabilities), respectively. 1975Ja04 and 1972As11 report relative emission probabilities.

The adopted gamma-ray energy values are the weighted means of the experimental values published in 1954Mi70 and 1975Ja04, as presented below in Table 4 (for the 328 keV photons just one measurement was made, and published in 1975Ja04):

Table 4: Gamma-rays energy values in the decay of ^{211}Po

Experimental energy values (keV)	Reference
562 (5)	1954Mi70
569.65 (10)	1975Ja04
Recommended energy value: 569.65 (15) keV	
880 (8)	1954Mi70
897.8 (1)	1975Ja04
Recommended energy value: 897.8 (2) keV	
328.2 (2)	1975Ja04
Recommended energy value: 328.2 (2) keV	

Using the measured 328.2 keV gamma-ray relative photon intensity of 0.6 (2) (the intensity of the 569.65 keV photons is considered as 100, see reference 1975Ja04), the internal conversion coefficients and the intensity balance for each of the two excited states of ^{207}Pb, the corresponding absolute gamma-ray emission probabilities and their uncertainties were computed for all the three γ rays; these data are given below in Table 5. A comparison between the evaluated data and the experimental values (included in the same table, with the corresponding references) shows a good agreement, with the exception of the relative emission probability of 897.8 keV reported by 1985La17.

The internal conversion coefficients were computed with the program BrIcc, version 2.2b/20-Jan-2009, using the “Frozen Orbitals” approximation. In the article of L.J. Jardine (1975), an experimental value of 0.016 (3) was determined for the K-conversion coefficient associated to both gamma-ray transitions of 569.65 keV and 897.8 keV; this value is in good agreement with the theoretical ICC’s, computed with BrIcc: 0.01583 (23), respectively 0.0192 (3).

Table 5: γ-rays absolute and relative emission probabilities in the decay of ^{211}Po

E_γ (keV)	Recommended Absolute Emission Probability (%)	Experimental Absolute Emission Probability (%)	Evaluated relative emission probabilities	Experimental relative emission probabilities	Total ICC (α_T)
328.2	0.0032 (11)		0.6 (2)*	0.6 (2)[c]	0.334 (5)
569.65	0.534 (17)	0.534 (19)[a] 0.512 (36)[b]	100	100.0 (14)[b] 100[c,d]	0.0216 (3) E2
897.8	0.507 (9)	0.535 (40)[b]	94.9 (35)	104.4 (20)[b] 97 (5)[c] 83 (11)[d]	0.0233 (4) M1

Note: a – reference 1968Br17; b – reference 1985La17; c – reference 1975Ja04;
d – reference 1972As11 (renormalized); * - value adopted from reference 1975Ja04.

4. Atomic data

The K-shell fluorescence yield (ω_K), the mean L-shell fluorescence yield (ϖ_L) and the mean number of vacancies in the L-shell produced by one vacancy in the K-shell (η_{KL}) were determined using the computer program EMISSION v.3.10, 28-Jan-2003: 0.963 (4), 0.379 (15) and 0.811 (5) respectively.

4.1. Auger electrons and X-rays

The relative probability values of the K Auger electron emissions (KLL, KLX, KXY) normalized to the KLL value, were computed using the EMISSION computer program. The total numbers of K and L Auger electrons emitted per 100 disintegrations were also calculated as 0.00071 (8) and 0.01216 (17), respectively. The energy ranges for K and L Auger electrons were filled-in by the SAISINUC program, version 2008 April.

The relative probability (normalized to $K_{\alpha 1}$ X-rays emission) and the absolute emission probability values of the different groups of K and L X-rays were deduced using the EMISSION program. The adopted values of the total absolute emission probability of the KX-rays and LX-rays were 0.0184 (5) % and 0.00740 (16) %, respectively. The energy range values of the K and L X-rays are from the tables linked to SAISINUC.

Neither measurement of ^{207}Pb KX-rays and LX-rays energies nor of emission probabilities was found in the literature in order to compare it with the results of this evaluation.

5. Main production mode

The main production mode of ^{211}Po is by β^- decay of the ^{211}Bi nuclei (in the Actinium-Uranium natural radioactive series).

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^{212}Po – Comments on evaluation of decay data
by A. L. Nichols

Evaluated: July/August 2001
Re-evaluated: January 2004 and May 2010

Evaluation Procedures

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

Decay Scheme

^{212}Po is an extremely short-lived radionuclide populated via the beta decay of ^{212}Bi and the alpha decay of ^{216}Rn. 100 % alpha decay of ^{212}Po occurs directly to the ground state of ^{208}Pb (2005Br03).

Nuclear Data

Half-life

^{212}Po is an extremely short-lived radionuclide populated primarily via the alpha decay of ^{216}Rn and the beta decay of ^{212}Bi. The recommended half-life of 3.00 (2) × 10^{-7} s is the weighted mean of six sets of measurements (1949Bu09, 1962Fl03, 1963As02, 1972Mc29, 1975Sa06 and 1981Bo29).

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} *
1981Bo29	3.09 (11) x 10^{-7}
Recommended value	3.00 (2) x 10^{-7}

* Uncertainty adjusted to ± 2.7 x 10^{-9} to reduce the weighting below 50 %.

Alpha Particle

Energy

A Q-value of 8954.12 (11) keV was used (2003Au03) 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 8785.17 (11) keV has been calculated.

Emission Probability

The emission probability of the single alpha particle was defined as 100 % (2005Br03).

Alpha-particle energy and emission probability per 100 disintegrations of ^{212}Po, and hindrance factor.

E_α(keV)	P_α Recommended value*	HF
8785.17 (11)	100.0	1.00

* Only one α transition directly to the ground state of ^{208}Pb.

Data Consistency

A Q_α-value of 8954.12 (11) keV has been adopted from the atomic mass evaluation of Audi *et al.* (2003Au03) while in the course of formulating the decay scheme of ^{212}Po. This value has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{212}Po alpha-decay process:

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 8954.12\ (11)\ \text{keV}$$

Percentage deviation from the Q-value of Audi *et al.* is (0.000 ± 0.002) %, which supports the derivation of a highly consistent decay scheme.

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^{213}Po - Comments on evaluation of the decay data by Huang Xiaolong, Wang Baosong

This evaluation was completed in 2007. Literature available by December 2007 was included.

1 Decay Scheme

^{213}Po disintegrates 100 % by α emissions to levels in ^{209}Pb. ^{213}Po ground state has $J^{\pi} = 9/2^{+}$ (2007Ba19).

2 Nuclear Data

The Q value is from the 2003Au03 evaluation.

The level energies, spin and parities are from 2007Ba19.

The measured and evaluated ^{213}Po half-life values are listed in Table 1.

Table 1 - Measured half-life values of ^{213}Po and evaluated value, in μs.

$T_{1/2}$ (μs)	References	measurement method
4.2 (8)	1948Je05	
3.74 (2)	1995WaZQ	Superseded by 1998Wa25
3.70 (3)	1997VaZV	Superseded by 1998Wa25
3.75 (4)	1997Wa27	Si(Au), delayed β-α coincidences
3.65 (4)	1998Wa25	Three-dimensional single-crystal scintillation time spectrometer
3.65	2002Mo46	HPGe and 4π autocorrelation single-crystal scintillation time spectrometer. No uncertainty given
3.70 (5)		Unweighted mean of 1997Wa27 and 1998Wa25
3.70 (5)		Weighted mean of 1997Wa27 and 1998Wa25,χ^2=3.1
3.70 (5)	Recommended value	

Values given by 1995WaZQ, 1997VaZV, 1997Wa27, and 1998Wa25 have authors in common, thus, they may not be independent of each other. A recommended value of 3.70 (5) μs has been estimated by the evaluator.

2.1 g Transitions

The γ-ray transition probability is calculated using the γ-ray emission intensity and the relevant internal conversion coefficient.

Multipolarity of 778.8 keV γ-ray is from level scheme (not measured).

The internal conversion coefficient (ICC) and their associated uncertainties for γ-ray transitions have been obtained using the BRICC computer program, which uses the "Frozen Orbital" approximation (2002Ba85).

2.2 a Transitions

Measured and recommended alpha particles energies are listed in table 2. The recommended values are from 1964Va20 and 1991Ry01.

Table 2 - Measured and recommended value of α-particle energy from ^{213}Po decay

1964Va20	1982Bo04[a]	1991Ry01[b]	Recommended value
7614 (10)			7614 (10)
8377 (5)	8376 (3)	8375.9 (25)	8375.9 (25)

[a]: Original energies of 1982Bo04 have been increased by 2 keV due to changes in calibration energies (1991Ry01).
[b]: evaluation.

The measured and recommended alpha particle emission probabilities are listed in table 3. The recommended alpha particle emission probabilities have been deduced from γ-ray transition intensity balance.

Table 3 - Measured and recommended α-particle emission probabilities from ^{213}Po decay

E_α (keV)	P_α			
	1964Va20	1969LeZW	1997Ch53	Recommended
7614 (10)	0.003 (1)	0.006 (2)	0.0031 (2)	0.0050 (5)
8375.9 (25)	100	100	99.997 (31)	99.9950 (5)

P_α = 0.0031 (2) % in 1997Ch53 is from an α-particle spectrum. This very weak peak is at the low-energy tail of the intense 8376-keV α-particle group. Thus, the evaluator has considered its reported intensity to be quite inaccurate, despite the value reported in 1997Ch53.

3. Photon Emissions

There is only one γ-ray emitted from ^{213}Po α decay. Only 1989Ko26 measured the γ-ray energy: 778.8 (3) keV. The present recommended γ-ray energy has been taken from this measurement.

The recommended absolute γ-ray emission probability has been obtained as follows: 1989Ko26 measured the ratio: Iγ(779 keV) / Iγ(440 keV) (in ^{213}Bi β^- decay) = 0.000181 (18). Using Pγ(440 keV) = 26.1 (3) % and %β^- = 0.9791 (3) (2007HuXX) then Pγ(778 keV) = 0.0048 (5) %.

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^{214}Po - Comments on evaluation of decay data
by V. Chisté and M. M. Bé

This evaluation was completed in 2007. Literature available by January 2007 was included.

1 Decay Scheme

^{214}Po disintegrates by alpha emissions mainly to the ground state level of ^{210}Pb. Spins and parities are from the mass-chain evaluation of Y. A. Akovali (1995El07 for A = 214) and E. Browne (1992Br01 and 2003Br13 for A = 210).
A good agreement was found between the recommended Q value of Audi and the effective Q value (7833.24 (10) keV) calculated from decay scheme data.

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).
Experimental ^{214}Po half-life values (in μs) are given in Table 1:

Table 1: Experimental values of ^{214}Po half-life.

Reference	Experimental value (μs)	Comments
J. V. Dunworth (1939Du**)	150 (20)	Not used.
J. Rotblat (1941Ro**)	145 (5)	Not used.
A. G. Ward (1942Wa04)	148 (6)	Not used.
J. C. Jacobsen (1943Ja**)	155 (5)	Not used.
G. von Dardel (1950Vo02)	163.7 (18)	Original uncertainty increased
R. Ballini (1953Ba60)	158 (2)	
K. W. Ogilvie (1960Og01)	159.5 (30)	
T. Dobrowolski (1961Do02)	164.3 (18)	
A. Erlik (1971Er02)	165 (3)	
J. W. Zhou (1993Zh30)	160 (12)	
Recommended value	**162.3 (12)**	χ^2 = 1.6

The first four and less precise historical values were omitted from analysis. The G. von Dardel uncertainty value (1950Vo02) of 0.2, which seems not realistic, was increased to 1.8 the smallest of the other experimental values obtained with the same method.
Using the LWEIGHT computer program (version 3) with the remaining set of 6 data, the weighted average is **162.3 ms** with an external uncertainty of **1.2 ms**. The reduced-χ^2 value is 1.82.

The largest contribution to weighted average comes from the value of G. von Dardel (1950Vo02) and T. Dobrowolski (1961Do02), each of them amounting per 28 %.

2.1 a Transitions and Emissions

The energies of the α-particle transitions given in Section 2.1 were obtained from Q_α (2003Au03) and level energies.

The energy of $\alpha_{0,0}$ emission given in section 4 is the weighted average of the measured values of A. Rytz (1961Ry02) and B. Grennberg (1971Gr17), with the recommendations given by A. Rytz (1991Ry01) where the original energies given by 1961Ry02 and 1971Gr17 have been readjusted due to changes in calibration energies. For the $\alpha_{0,1}$ and $\alpha_{0,2}$, the emission energies were deduced from Q_α (2003Au03), level energy and taking the nucleus recoil into account.

The α emission probabilities have been deduced from the value of the γ-ray transition probability decay-scheme balances for the corresponding levels. (see **2.2 Gamma Transitions**).

2.2 g **Transitions**

The γ-ray transition probabilities were obtained using the γ-ray emission intensities, measured by 1976Ku08, and the relevant internal conversion coefficients (see **4.2** g **Emissions**).
Multipolarities of the γ -ray transitions (E2) are from 1992Br01 and 2003Br13.

The internal conversion coefficients (ICC) for the γ -ray transitions have been deduced using the BrIcc computer program (calculation for 'hole'), which interpolated the new values from 2006Ra03.

3 Atomic Data

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

4 Photon Emissions

4.1 X-ray Emissions

The X-ray absolute intensities were calculated from γ-ray data and ICC using the EMISSION computer program.

4.2 g **Emissions**

The γ-ray energies given in section 5.2 are from W. Kurcewicz (1976Ku08).

The absolute γ-ray emission intensities have been deduced from the relative γ-ray emission intensities measured by W. Kurcewicz (1976Ku08) in relative value and normalized with the 324.22-keV γ-ray in ^{222}Ra decay, as measured by A. Peghaire (1969Pe17) to be 2.77 (8) %. In the table 2, the relative emission intensities and the recommended values of absolute emission intensities are shown.

Table 2: Recommended (deduced) values of γ-ray absolute emission intensities

Energy (keV)	Relative Emission Intensity (%)	Recommended value
298 (1)	0.06 (2)	0.000052 (18) %
799.7 (1)	11.9 (5)	0.0104 (6) %

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^{215}Po -Comments on evaluation of decay data
by V.P. Chechev

This evaluation was done in November 2010 with a literature cut-off by the same date.

1. DECAY SCHEME

^{215}Po decays 100 % to levels of ^{211}Pb by emission of α particles and 2.3 (2) × 10^{-4} % to ^{215}At by emission of β^- particles. The structure of the adopted scheme of ^{215}Po decay is based on the experiment of 1998Li53 and the evaluation by E. Browne (2004Br45). The existence of the alpha-particle group with energy of 6950 keV, reported in 1962Wa18, 1971Gr17, was not confirmed in 1998Li53 and the relevant ^{211}Pb level of 447 keV was omitted in this evaluation. Similarly, the questionable ^{211}Pb level of 762 keV, determined by the alpha-particle group with energy of 6636 keV and intensity of ~ 3 × 10^{-4} %, has not been adopted.

The decay scheme of ^{215}Po is not completed as only approximate information is available for weak gamma transitions following α decay, their gamma-ray emission probabilities and multipolarities have not been determined, and, in fact, the ^{211}Pb levels were deduced only from measurements of alpha-particle groups. In respect of ^{215}Po β^- decay, the β^- - spectrum has not been measured and a fine structure of β^- decay is unknown.

The current evaluated data are supported by the agreement between Q(calculated) = 7526.2 (22) keV, deduced from the calculated average energies of all emissions, and Q(α) = 7526.3 (8) keV, adopted from 2003Au03. Percentage deviation of Q(calculated) from the Q(α) of Audi *et al*. (2003Au03) is (0.0 ± 0.3) %.

2. NUCLEAR DATA

Q(α) and Q(β^-) values are from Audi et al. (2003Au03).

The ^{215}Po half-life is based on the experimental results given in Table 1.

Table 1. Experimental values of ^{215}Po half-life

Reference	Author(s)	Half-life (ms)	Method
1942Wa04	Ward	1.83 (4)	Observations with a single Geiger counter
1961Vo06	Volkov et al.	1.778 (5)	Measurements with ionization alpha-spectrometer equipped by time analyzer
1971Er02	Erlik et al.	1.785 (10)	Time interval analyzer method
1971Er02	Erlik et al.	1.784 (8)	Multichannel delay coincidence method

The set of the four experimental values is consistent. The weighted average for this data set is 1.781 with the internal uncertainty of 0.0039 and an external uncertainty of 0.0033 ($\chi^2/\nu = 0.72$).

The recommended value of the **^{215}Po half-life** is **1.781 (4) ms**.

β^- branching of 2.3 (2) × 10^{-4} % was adopted from the measurement of 1950Av61. With this value the α branching is obtained to be 99.999 77 (2) %.

2.1. Alpha Transitions

The alpha transition energies have been obtained from the Q(α) value and ^{211}Pb level energies given in Table 2 from 2004Br45. The uncertainties in the energies of levels 2 - 7 have been adopted ± 3 keV taking into account the average discrepancy of experimental and calculated alpha-particle energies (Table 3) and as provided by uncertainties of gamma ray energies from 1998Li53 ≥ 1.0 keV for all γ rays, except for γ438.9 keV.

Table 2. ^{211}Pb levels populated in ^{215}Po α-decay

Level	Energy (keV)	Spin and parity	Half-life	Probability of α- transition (%)
0	0.0	9/2+	36.1(4) min	99.934 (20)
1	438.9 (2)	(7/2)+		0.06 (2)
2	584 (3)			4 (2) × 10^{-4}
3	598 (3)	(5/2+)		1.6 (5) × 10^{-3}
4	643 (3)	11/2+		8 (3) × 10^{-4}
5	733 (3)	(13/2+)		8 (3) × 10^{-4}
6	815 (3)	(9/2+)		2.0 (6) × 10^{-3}
7	894 (3)	(11/2+)		3 × 10^{-4}

The alpha transitions in ^{215}Po decay were observed in a number of works by study of an ^{223}Ra alpha emitting source (1962Wa18, 1965Va10, 1970Da09, 1998Li53). In 1962Wa18 the ^{215}Po alpha spectrum was measured with magnetic spectrometer. In 1965Va10 the coincidence of $\gamma_{1,0}$ (438.9 keV)-gamma ray with $\alpha_{0,1}$ (6.95 MeV) was observed. In 1970Da09 the alpha transition probability (P(α)) was measured for $\alpha_{0,1}$ (6.95 MeV)-transition. Most accurate and detailed data were obtained by 1998Li53 with use of α–γ coincidences. These measurement results have been adopted for the recommended P(α) and compared in Table 3 with other available poor experimental data.

Table 3. Experimental ^{215}Po alpha transition probability values (P(α))

α-particle energy (keV)	1962Wa18	1970Da09	1998Li53
7386	100		99.93
6955	≈ 0.056	≈ 0.1	0.06 (2)
6813			4 (2) × 10^{-4}
6799			1.6 (5) × 10^{-3}
6755			8 (3) × 10^{-4}
6667			8 (3) × 10^{-4}
6586			2.0 (6) × 10^{-3}
6509			~ 3 × 10^{-4}

The accurate $P(\alpha_{0,0})$ value has been deduced from $\Sigma P(\alpha_{0,i})$ = 99.999 77 (2) %, (i = 0, 1,...7) and, the individual adopted $P(\alpha_{0,i})$, (i = 1 – 7).

The α decay hindrance factors were calculated using the ALPHAD computer program from the ENSDF evaluation package with r_0 (^{211}Pb) = 1.5393 fm (2004Br45).

2.2. Gamma Transitions and Internal Conversion Coefficients

Information on the gamma-ray transition probabilities and the gamma-ray multipolarities is not available, except for γ438.9 keV (1968Br17, 1970Da09, 1998Li53, see §6.2.2). The gamma-ray transition probability $P_{\gamma+ce}$ ($\gamma_{1,0}$ - 438.9 keV) was then deduced from the probability balance: $P(\alpha_{0,1}) = P_{\gamma+ce}$ ($\gamma_{1,0}$ - 438.9 keV). The multipolarity of this gamma-ray transition has been adopted as being E2. In 1998Li53 a multipolarity higher than a pure E2 was reported from the relative intensity P(KX) / P_γ (438.9 keV) = 0.034 (10), then it was noted that a small amount of M1 cannot be ruled out.

ICCs have been interpolated using the BrIcc computer program, version v2.2a, data set BriccFO (2008Ki07).

3. ATOMIC DATA

The fluorescence yields, X-ray energies and relative probabilities, and Auger electrons energies and relative probabilities are from the SAISINUC software.

4. ALPHA EMISSIONS

The energy of the alpha-particle group $\alpha_{0,0}$ that populates the ^{211}Pb ground state is the absolute measurement result from 1971Gr17 adjusted in 1991Ry01 for change in calibration standards: $E(\alpha_{0,0})$ = 7386.1 (8) keV. Latter coincides with the value deduced by the evaluator from the adopted Q(α) taking into account the recoil energy for ^{211}Pb.

The energy of alpha-particle group $\alpha_{0,1}$ of 6955.4 (8) keV has been deduced from the Q(α) value taking into account the level energy of 439.8 (2) keV and the recoil energy for ^{211}Pb. The above value of $E(\alpha_{0,1})$ can be compared to the measured $E(\alpha_{0,1})$ of 6956.7 keV (without uncertainty) by 1962Wa18, 1971Gr17 and of 6954 (3) keV by 1998Li53 with adjustement adopted in 2004Br45.

The energies of remaining alpha-particle groups have been deduced from Q(α) and the relevant ^{211}Pb level energies. In Table 4 the deduced (recommended) E(α) are compared with the experimental values from the measurements of 1998Li53 adjusted in 2004Br45 to the adopted $E(\alpha_{0,0})$= 7386.1 (8) keV.

Table 4. Experimental and deduced (recommended) ^{215}Po alpha-particle energies (E(α))

Level	Level energy (keV)	α-transition energy	Experimental E(α) (1998Li53) [a]	Deduced E(α) (recommended)
0	0.0	7526.3 (8)	7386.1 (8)	7386.1 (8)
1	438.9 (2)	7087.4 (10)	6954 (3)	6955.4 (8)
2	584 (3)	6942 (3)	6819 (15)	6813 (3)
3	598 (3)	6928 (3)	6803 (8)	6799 (3)
4	643 (3)	6883 (3)	6754 (10)	6755 (3)

Level	Level energy (keV)	α-transition energy	Experimental E(α) (1998Li53) [a]	Deduced E(α) (recommended)
5	733 (3)	6793 (3)	6671 (10)	6667 (3)
6	815 (3)	6711 (3)	6589 (8)	6586 (3)
7	894 (3)	6632 (3)	6519 (20)	6509 (3)

[a] E(α) have been adjusted to the adopted $E(\alpha_{0,0})$ = 7386.1 (8) keV.

5. ELECTRON EMISSIONS

The energies of the conversion electrons for the γ438.9 keV transition have been obtained from the gamma-ray transition energy and the atomic electron binding energies.

The emission probabilities of the conversion electrons have been deduced using the P_γ and ICC values.

The absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program.

6. PHOTON EMISSIONS

6.1 X - Ray emissions

The absolute emission probabilities of Pb KX- and LX-rays were calculated using the EMISSION computer program. The total emission probability of Pb KX-rays in decay of ^{215}Po was determined relatively to $P_\gamma(\gamma_{1,0}$ - 438.9 keV) (1998Li53). The experimental $P(KX)/P_\gamma(\gamma_{1,0}$ - 438.9 keV) = 0.034 (10) agrees with the value of 0.029 (14) calculated with the EMISSION code.

The agreement between measured and calculated KX-ray emission probabilities supports the recommended γ-ray emission probability and assigned multipolarity for $\gamma_{1,0}$ - 438.9 keV.

6.2. Gamma emissions

6.2.1. Gamma ray energies

The gamma-ray energies (E_γ) have been taken from the measurements of 1998Li53. The uncertainties on the gamma-ray energies higher than 500 keV have been assumed being ± 3 keV (see section **2.1**). Other measurements of E ($\gamma_{1,0}$ - 438.9 keV) are reported in 1968Br17 (438.7 (3) keV) and in 1970Da09 (438.9 keV – without uncertainty).

6.2.2. Gamma ray emission probabilities

There is no available information on the gamma-ray emission probabilities, except for P(γ438.9 keV): 0.048 (5) % (1968Br17) and 0.064 (2) % (1970Da09). These discrepant values do not conflict with the recommended value of P(γ438.9 keV) = 0.058 (19) % deduced by the evaluator from the alpha transition probability $P(\alpha_{0,1})$ = 0.06 (2) % and total internal conversion coefficient α_T = 0.0405 (6) under the assumption of E2 multipolarity.

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^{216}Po – Comments on evaluation of decay data by A. L. Nichols

Evaluated: July/August 2001
Re-evaluated: January 2004 and May 2010

Evaluation Procedures

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

Decay Scheme

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 and gamma-ray 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) and a more recent study (2003Da24). Further measurements are merited to determine this value with greater confidence.

(a). 1911Mo11 used an air jet to transport and separate the positively-charged activity from an actinium-228 source by passage along a flow tube to a negatively-charged rotating disk that subsequently presented the deposited material in turn to two ionization chambers. The half-life of Po-216 (thorium A) was determined from the fall in activity on the collection plate during the time taken to rotate the disk with plate from one ionization chamber to the other. Unexpected irregularities were occasionally observed, but were never resolved, and no effort was made to identify possible impurities.

(b). 1942Wa04 adopted a coincidence circuit linked to a Geiger counter to determine the time interval between the disintegration of parent Rn-220 and Po-216; contamination was identified with the unwanted presence of Ra-224.

(c). 1963Di05 used a Si-surface detector to obtain a parent-daughter decay curve analysed in terms of Po-216 decay and the background, as shown in the relevant figure. Impurities were not considered in the analyses of the decay curves, and were effectively assumed to be negligible. The uncertainty is quoted as only being statistical, with no assessment having been made of the systematic component.

(d). 2003Da24 carried out time-amplitude analyses of the alpha spectra accumulated by means of $^{116}CdWO_4$ crystal scintillators in preparation for their ββ-decay studies. Data processing involved pulse shape definitions based on Gaussian functions in which impurities were assumed to be negligible.

There is no evidence of any change in the half-life of ^{216}Po on extreme cooling of alpha-active ^{224}Ra samples and decay products within a metallic environment (2007St23). Sources were held at temperatures at and below 1 kelvin for periods of several days, and exhibited an upper limit of change in the alpha-decay half-lives of the order of 1 %.

Reference	Half-life (s)
1911Mo01	0.145 (15)
1942Wa04	0.158 (8)
1963Di05	0.145 (2)*
2003Da24	0.144 (8)
Recommended value	0.148 (4)

* Uncertainty adjusted to ± 0.006 to reduce weighting below 50 %.

Alpha Particles

Energies

Alpha-particle energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 2005Br03 and Q-value of 6906.3 keV (2003Au03) were used to determine the energies and uncertainties of the alpha-particle transitions to the first excited and ground states of Pb-212, 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. A hindrance factor (HF) of 1.00 for the 6778.4-keV alpha-particle emission yields $r_0(^{212}Pb)$ of 1.5408 (9) fm which was adopted in the equivalent calculation of the HF for the other alpha-particle emission (1998Ak04).

Alpha-particle emission probabilities per 100 disintegrations of ^{216}Po, and hindrance factors.

E_α(keV)	P_α		HF
	1962Wa28	Recommended values*	
5988.6 (10)	0.0021 (4)	0.0019 (3)	35
6778.6 (5)	~ 100	99.9981 (3)	1.00

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

Gamma Ray

Energy

The single gamma-ray energy was based on the nuclear level energy of 804.9 (5) keV from 2005Br03.

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) of ^{224}Ra (as adopted from an equivalent DDEP evaluation of ^{224}Ra decay data, dated April 2010).

.

Published gamma-ray emission probabilities per 100 disintegrations of ^{216}Po.

E_γ (keV)	P_γ
	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_γ (keV)	P_γ^{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 (4) % (0.0412 (4)) for ^{224}Ra, as adopted from an equivalent DDEP evaluation of ^{224}Ra decay data (dated April 2010).

Multipolarity and Internal Conversion Coefficients

The decay scheme specified by 2005Br03 and 2007Wu02 has been used to define the multipolarity of the gamma transition on the basis of the assumed spins and parities of the two nuclear levels. Recommended internal conversion coefficients have been determined from the frozen orbital approximation of Kibedi *et al*. (2008Ki07), based on the theoretical model of Band *et al*. (2002Ba85, 2002Ra45).

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

E_γ (keV)	Multipolarity	α_K	α_L	α_{M+}	α_{total}
804.9 (5)	[E2]	0.007 99 (12)	0.001 732 (25)	0.000 548 (8)	0.010 27 (15)

Atomic Data

The x-ray data have been calculated using the evaluated gamma-ray data, and the atomic data from 1996Sc06, 1998ScZM and 1999ScZX. Both the x-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.01, 28 January 2003). This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

K and L X-ray emission probabilities per 100 disintegrations of ^{216}Po.

			Energy (keV)	Photons per 100 disint.
XL		(Pb)	9.184 – 15.216	5.9 (6) x 10^{-6}
	XL_l	(Pb)	9.184	2.7 (3) x 10^{-6}
	XL_α	(Pb)	10.450 – 10.551	2.53 (24) x 10^{-6}
	XL_η	(Pb)	11.349	4.9 (5) x 10^{-7}
	XL_β	(Pb)	12.142 – 13.015	4.7 (7) x 10^{-8}
	XL_γ	(Pb)	14.765 – 15.216	1.42 (18) x 10^{-7}
XK_α	$XK_{\alpha2}$	(Pb)	72.8049	4.3 (7) x 10^{-6}
	$XK_{\alpha1}$	(Pb)	74.9700	7.2 (12) x 10^{-6}
$XK'_{\beta1}$	$XK_{\beta3}$	(Pb)	84.451	)
	$XK_{\beta1}$	(Pb)	84.937	) 2.4 (4) x 10^{-6}
	$XK_{\beta5}''$	(Pb)	85.470	)
$XK'_{\beta2}$	$XK_{\beta2}$	(Pb)	87.238	)
	$XK_{\beta4}$	(Pb)	87.580	) 7.4 (12) x 10^{-7}
	$XKO_{2,3}$	(Pb)	87.911	)

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

Data Consistency

A Q_α-value of 6906.3 (5) keV has been adopted from the atomic mass evaluation of Audi *et al.* (2003Au03) while in the course of formulating the decay scheme of ^{216}Po. This value has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{216}Po alpha-decay process (i.e. α, electron, γ, etc.):

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 6906.3\ (5)\ \text{keV}$$

Percentage deviation from the Q-value of Audi *et al*. is (0.000 ± 0.010) %, which supports the derivation of a highly consistent decay scheme.

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^{218}Po - Comments on evaluation of decay data by V. Chisté and M. M. Bé

This evaluation was completed in 2007. Literature available by January 2007 was included. The half-life value was re-evaluated in Dec. 2010 in order to include the Martz's result.

1 Decay Scheme

^{218}Po disintegrates by alpha emission mainly (99.978 (3) %) to the ground state level of ^{214}Pb. A weak beta minus emission (0.022 (3) %) to At-218 has been pointed out. Spin and parity are from the mass-chain evaluation of Y. A. Akovali (1987El12, 1995El08, 1998Ak04 for A = 218 and 1995El07 for A = 214) and A. K. Jain (2006Ja03 for A = 218).
A good agreement was found between the recommended Q value of Audi and the effective Q value of 6113.33 (22) keV for the α branch, calculated from the decay scheme data.

2 Nuclear Data

The Q values (α and β^-) are from the atomic mass evaluation of Audi *et al.* (2003Au03).

Experimental ^{218}Po half-life values (in minutes) are given in Table 1:

Table 1: Experimental values of ^{218}Po half-life.

Reference	Experimental value (min)	Comments
M. Curie (1931Cu01)	3.05	Not used.
M. Blau (1924Bl02)	3.050 (18)	Uncertainty increased to take into account systematic uncertainty.
J. R. Van Hise (1982Va09)	3.11 (2)	Uncertainty increased to take into account systematic uncertainty.
G. V. Potapov (1986Po17)	3.093 (6)	Original uncertainty corresponds to two standard deviations.
D. E. Martz (1989Ma**)	3.040 (8)	Uncertainty increased to take into account systematic uncertainty.
Recommended value	**3.071 (22)**	χ^2 = 10.1

The recommended value was deduced from the four values of ^{218}Po half-life (1924Bl02, 1982Va09, 1986Po17 and 1989Ma**). The original uncertainty values given by M. Blau (1924Bl02) and D. E. Martz (1989Ma**) were multiplied by 2, in order to take into account the systematic uncertainties which were not considered by the authors. The original uncertainty value given by Van Hise (1982Va09) is for 2σ, but it seems that they did not take into account the systematic uncertainties so the original uncertainty has been maintained. The largest contribution (57 %) to the weighted average comes from the value of G. V. Potapov (1986Po17). The LWEIGHT program 3 increases the uncertainty for the 1986Po17 value from 0.006 to 0.007 in order to reduce its relative weight from 57 % to 50 %.

A weighted average of 3.071 minutes has been calculated using Lweight computer program (version 3), with an expanded uncertainty of 0.022 minute so range includes the most precise value of 1986Po17. The reduced-χ^2 value is 10.1.

2.1 α Transitions and Emissions

The energies of the α-particle transitions given in Section 2.1 were calculated from Q_α (2003Au03) and level energies.

The energy of $\alpha_{0,0}$ emission given in section 4 was measured by 1971Gr17, and following the recommendations given by A. Rytz (1991Ry01) was decreased by 0.20 keV. The $\alpha_{0,1}$, emission energy is from R. J. Walen (1958Wa16).

The $\alpha_{0,1}$ emission probability is the measured value of R. J. Walen (1958Wa16) (0.0011 (11) %).

For the $\alpha_{0,0}$ emission probability and associated uncertainty, the following relation was applied:
$P_{\alpha 0,0} + P_{\alpha 0,1} = 100 - P_{\beta-}(264\ keV)$,
where $P_{\beta-}$(264 keV) = 0.022 (3) % (given by 1952Hi60, see **2.2**) and $P_{\alpha 0,1}$ = 0.0011 (11) % (given by 1958Wa16). Taking into account these values, then $P_{\alpha 0,0}$ = 99.9769 (32) %.

2.2 β⁻ Transitions and Emissions

The maximum energy of the β^- transition in the decay of $^{218}Po \rightarrow {}^{218}At$ has been taken from Audi (2003Au03) and, without any other information, is affected to a ground state to ground state transition.

The adopted 260-keV β^- transition probability was measured by F. Hiessberger (1952Hi60), 0.022 (3) %, and is in agreement with the two values given by R. J. Walen : 0.0200 (5) % (1949Wa05) and 0.0185 % (1958Wa16), respectively.

2.3 γ Transitions and Emissions

The $\gamma_{(1,0)}$ transition probability following the α-decay of $^{218}Po \rightarrow {}^{214}Pb$ was deduced from the decay-scheme balance using the recommended experimental α-particle intensity value of 0.0011 (11) % given by R. J. Walen (1958Wa16). (see **2.1 α Transitions and Emissions**).

3 Atomic Data

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

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^{211}At - Comments on evaluation of decay data

by A. L. Nichols

Evaluated: August 2010

Evaluation Procedure

Limitation of Relative Statistical Weight Method (LWM) was applied to average the decay data when appropriate.

Decay Scheme

A reasonably simple decay scheme was constructed from the α-particle and γ-ray measurements of Hoff (1953Ho49), Gray (1956Gr11), Golovkov *et al.* (1969Go23), Jardine (1975Ja04), and Chumin *et al.* (2001Ch66), and studies of the α branching fraction by Neumann and Perlman (1951Ne02), Golovkov *et al.* (1969Go23), Afanasiev *et al.* (1970AfZZ), Jardine (1975Ja04), Yanokura *et al.* (1978Ya04), and Lambrecht and Mirzadeh (1985La17).

Nuclear Data

^{211}At is an important α-emitting radionuclide in therapeutic nuclear medicine, along with daughter ^{211}Po.

Half-life

The recommended half-life of 7.216 (7) hours has been adopted from five sets of measurements (1956Gr11, 1959Ra08, 1961Ap01, 1962Th08, 1978Ya04).

Half-life measurements

Reference	Half-life (hours)
1956Gr11	7.20 ± 0.05
1959Ra08	7.23 ± 0.04
1961Ap01	7.214 ± 0.007
1962Th08	7.17 ± 0.09
1978Ya04	7.23 ± 0.02
Recommended value	7.216 ± 0.007

A half-life of 0.516 (3) second was adopted for ^{211}Po from the DDEP evaluation of Luca (July-November 2009), while the ^{207}Bi half-life of 32.9 (14) years was taken from the DDEP evaluation of Bé and Chisté (December 2009). More recently, a further re-evaluation of the half-life of ^{207}Bi by Kondev and Lalkovski resulted in a recommended value of 31.55 (4) years (2011Ko04).

Branching fractions

Neumann and Perlman (1951Ne02), Golovkov *et al.* (1969Go23), Afanasiev *et al.* (1970AfZZ), Jardine (1975Ja04), Yanokura *et al.* (1978Ya04), and Lambrecht and Mirzadeh (1985La17) have determined the α branching fraction for ^{211}At. These data were used to derive an alpha branch of 41.78 (8) %, along with a matching electron-capture branch of 58.22 (8) %.

Reference	BF_{α}
1951Ne02	0.409 ± 0.005
1969Go23	0.418 ± 0.002
1970AfZZ	0.413 ± 0.013
1975Ja04	0.419 ± 0.005
1978Ya04	0.4174 ± 0.0010
1985La17	0.4194 ± 0.0016
Recommended value	0.4178 ± 0.0008
α branch	(41.78 ± 0.08) %

Q values

Q_{EC} of 785.4 (25) keV and Q_{α} of 5982.4 (13) keV were adopted from the evaluated tabulations of Audi *et al.* (2003Au03).

Alpha Particles

Alpha-particle measurements reveal a relatively simple α-decay mode (1969Go23, 1975Ja04, 1991Ry01, 2001Ch66). The Q_{α} of 5982.4 (13) keV (2003Au03) and nuclear level energies as defined by Kondev and Lalkovski (2011Ko04) were used to calculated the alpha-particle energies, while the alpha-particle emission probabilities were primarily adopted from the measurements of Golovkov *et al.* (1969Go23), Afanasiev *et al.* (1970AfZZ), Jardine (1975Ja04) and Chumin *et al.* (2001Ch66).

Alpha-particle emission probabilities per 100 disintegrations of ^{211}At, and hindrance factors.

E_{α}(keV)	P_{α}					HF
	1969Go23*	1970AfZZ†	1975Ja04#	2001Ch66#	Recommended value	
4895.4 (13)	–	–	–	< 0.000 04	< 0.000 04	> 9.6
4993.4 (13)	–	~ 0.000 4 ?	–	–	~ 0.000 4	~ 3.8
5140.3 (13)	0.001 7 (9)	0.001 5	0.001 0 (3)	0.001 1 (2)	0.001 1 (2)	10.1
5211.9 (13)	0.005 4 (8)	0.006 7	0.003 6 (8)	0.003 9 (3)	0.003 9 (3)	7.3
5869.0 (13)	41.8 (2)	[41.78]	41.93	41.80	41.78 (8)	1.59

* Calculated from measurements of the relative alpha-particle emission probabilities.

† Calculated from measurements of the relative alpha-particle emission probabilities, but no uncertainties listed; absolute emission probability of 41.78 % was adopted for the 5869.0-keV α particle to convert other data in this study to comparable absolute values.

\# Calculated from measurements of the relative gamma-ray emission probabilities.

An unweighted mean value of 1.422 (13) was adopted for the radius parameter $r_0(^{207}Bi)$ as derived from the equivalent data for neighboring nuclei (1998Ak04), and used in the calculation of α-hindrance factors (HF):

$$r_0(^{207}Bi) = [r_0(^{206}Pb) + r_0(^{208}Po)] / 2$$

$$= [1.40882(10) + 1.4343(34)] / 2$$

$$= 1.422\ (13)$$

Gamma Rays

Energies

All gamma-ray transition energies and uncertainties were calculated from the structural details of the proposed decay scheme. Nuclear level energies were adopted from Browne for ^{211}Po and from Kondev and Lalkovski for ^{207}Bi (2004Br45, 2011Ko04).

Emission Probabilities

The absolute emission probabilities of the 149.72-, 222.69-, 669.77-, 742.74- and 892.46-keV gamma rays from the α-decay branch were derived from a combination of the alpha-particle emission probabilities populating the ground state and 669.77-, 742.74-, 892.46- and 992.43-keV nuclear levels of ^{207}Bi (1969Go23, 1970AfZZ), relevant relative emission probabilities for these gamma rays (1975Ja04, 1985La17), theoretical internal conversion coefficients of Band *et al.* (2002Ba85, 2008Ki07), and depopulating ratios of the 149.72-, 222.69- and 892.46-keV gamma transitions as quantified by Kondev and Lalkovski (2011Ko04). A weighted mean value of 0.245 (12) was adopted for the absolute emission probability of the 687.7-keV gamma ray from the EC-decay branch, based on the gamma-ray spectroscopy studies of Jardine (1975Ja04) and Lambrecht and Mirzadeh (1985La17).

Gamma-ray emission probabilities relative to 100 % for the 569.7-keV gamma ray of daughter ^{211}Po.

E_γ (keV)	P_γ^{rel}		
	1975Ja04	1985La17	Recommended value
[569.70]	100	100.0 (14)	–
669.77 (7)	1.1 (2)	–	–
687.2 (7)	79 (4)	83.0 (20)	82 (2)
742.74 (7)	0.3 (1)	–	–

Absolute gamma-ray emission probabilities per 100 disintegrations of ^{211}At.

	E_γ (keV)	P_γ^{abs}		
		1975Ja04*	1985La17	Recommended value
$\gamma_{3,2}$ (Bi)	149.72 (10)	–	–	~ 0.000 05
$\gamma_{3,1}$ (Bi)	222.69 (10)	–	–	~ 0.000 04
$\gamma_{1,0}$ (Bi)	669.77 (7)	0.003 4 (6)	–	0.003 8 (3)
$\gamma_{1,0}$ (Po)	687.2 (7)	0.245 (12)	0.247 (26)	0.245 (12)
$\gamma_{2,0}$ (Bi)	742.74 (7)	0.000 9 (3)	–	0.001 25 (19)
$\gamma_{3,0}$ (Bi)	892.46 (7)	–	–	~ 0.000 14

* Derived from an absolute emission probability of 0.31 (2) per 100 decay of ^{211}At for the 569.70-keV gamma transition within the α decay of daughter ^{211}Po.

Multipolarities and Internal Conversion Coefficients

The nuclear level schemes specified by Browne for ^{211}Po and Kondev and Lalkovski for ^{207}Bi have been used to define the multipolarities of the gamma transitions on the basis of known spins and parities (2004Br45, 2011Ko04). All known gammas are (M1 + E2) transitions, and their mixing ratios have been derived on the basis of the studies of Astner and Alpsten (1970As07), Schmidt-Ott and Dincklage (1978Sc12), and Herzog *et al.* (1983He09). Recommended internal conversion coefficients have been determined from the frozen orbital approximation of Kibédi *et al*. (2008Ki07), based on the theoretical model of Band *et al*. (2002Ba85, 2002Ra45).

Gamma-ray emissions: recommended energies, emission probabilities, multipolarities and theoretical internal conversion coefficients (frozen orbital approximation).

	E_γ (keV)	P_γ^{abs}	Multipolarity	α_K	α_L	α_{M+}	α_{tot}	
$\gamma_{3,2}$ (Bi)	149.72 (10)	~ 0.000 05	86.2 % M1 + 13.8 % E2 δ = 0.40 (20)	2.3 (3)	0.50 (4)	0.2	3.0 (3)	α
$\gamma_{3,1}$ (Bi)	222.69 (10)	~ 0.000 04	86.2 % M1 + 13.8 % E2 δ = 0.40 (10)	0.76 (5)	0.147 (2)	0.043	0.95 (5)	α
$\gamma_{1,0}$ (Bi)	669.77 (7)	0.003 8 (3)	94.1 % M1 + 5.9 % E2 δ = 0.25 (3)	0.042 6 (8)	0.007 25 (12)	0.002 15	0.052 0 (9)	α
$\gamma_{1,0}$ (Po)	687.2 (7)	0.245 (12)	96.15 % M1 + 3.85 % E2 δ = -0.20 (2)	0.043 7 (7)	0.007 52 (12)	0.002 38	0.053 6 (9)	EC
$\gamma_{2,0}$ (Bi)	742.74 (7)	0.001 25 (19)	91.7 % M1 + 8.3 % E2 δ = 0.30 (3)	0.032 0 (6)	0.005 44 (10)	0.001 66	0.039 1 (7)	α
$\gamma_{3,0}$ (Bi)	892.46 (7)	~ 0.000 14	33.8 % M1 + 66.2 % E2 δ = 1.4 (2)	0.011 7 (11)	0.002 15 (16)	0.000 65	0.014 5 (13)	α

Electron-capture Transitions

Energies

Electron-capture energies were calculated from the nuclear level energies of Browne (2004Br45) and a Q_{EC} value of 785.4 ± 2.5 keV taken from Audi *et al.* (2003Au03).

Transition probabilities

The EC transition probabilities were calculated from BF_{EC} of 0.5822 (8) and the absolute emission probability and theoretical internal conversion coefficients of the 687.2-keV gamma ray.

EC transition probabilities per 100 disintegrations of ^{211}At.

	E_{EC} (keV)	P_{EC}	Transition type	log *ft*	P_K	P_L	P_M
$EC_{0,1}$	98.2 ± 2.6	0.258 ± 0.013	1st forbidden non-unique	5.77	0.015 (17)	0.684 (10)	0.301 (7)
$EC_{0,0}$	785.4 ± 2.5	57.96 ± 0.08	1st forbidden non-unique	5.97	0.773 1 (2)	0.169 3 (1)	0.057 58 (4)

Atomic Data

The x-ray and Auger-electron data have been calculated using the evaluated gamma-ray data, and atomic data from 1996Sc06, 1998ScZM and 1999ScZX. Both the x-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.01, 28 January 2003). This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

K and L X-ray emission probabilities per 100 disintegrations of ^{211}At.

			Energy (keV)	Photons per 100 disint.
XL		(Bi)	9.420 – 15.709	0.000 136 (14)
	XL$_l$	(Bi)	9.420	0.000 003 3 (4)
	XL$_\alpha$	(Bi)	10.731 – 10.839	0.000 063 (7)
	XL$_\eta$	(Bi)	11.712	0.000 001 03 (15)
	XL$_\beta$	(Bi)	12.480 – 13.393	0.000 057 (6)
	XL$_\gamma$	(Bi)	15.248 – 15.709	0.000 011 0 (12)
XK$_\alpha$	XK$_{\alpha2}$	(Bi)	74.8157 (9)	0.000 098 (15)
	XK$_{\alpha1}$	(Bi)	77.1088 (10)	0.000 164 (25)
XK'$_{\beta1}$	XK$_{\beta3}$	(Bi)	86.835	)
	XK$_{\beta1}$	(Bi)	87.344	) 0.000 056 (9)
	XK$''_{\beta5}$	(Bi)	87.862	)
XK'$_{\beta2}$	XK$_{\beta2}$	(Bi)	89.732	)
	XK$_{\beta4}$	(Bi)	90.074	) 0.000 017 (3)
	XKO$_{2,3}$	(Bi)	90.421	)
XL		(Po)	9.658 – 16.213	18.6 (8)
	XL$_l$	(Po)	9.658	0.465 (12)
	XL$_\alpha$	(Po)	11.016 – 11.130	8.53 (20)
	XL$_\eta$	(Po)	12.085	0.134 (4)
	XL$_\beta$	(Po)	12.823 – 13.778	7.76 (14)
	XL$_\gamma$	(Po)	15.742 – 16.213	1.53 (3)
XK$_\alpha$	XK$_{\alpha2}$	(Po)	76.864 (4)	12.66 (9)
	XK$_{\alpha1}$	(Po)	79.293 (5)	21.08 (12)
XK'$_{\beta1}$	XK$_{\beta3}$	(Po)	89.256	)
	XK$_{\beta1}$	(Po)	89.807	) 7.26 (12)
	XK$''_{\beta5}$	(Po)	90.363	)
XK'$_{\beta2}$	XK$_{\beta2}$	(Po)	92.263	)
	XK$_{\beta4}$	(Po)	92.618	) 2.26 (5)
	XKO$_{2,3}$	(Po)	92.983	)

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

Data Consistency

An effective Q-value of 2956.7 (16) keV has been adopted from the atomic mass evaluation of Audi *et al*. (2003Au03) while in the course of formulating the decay scheme of ^{211}At. This value has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{211}At alpha- and EC-decay processes (i.e. α, γ, conversion electrons, etc.):

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 2957\ (5)\ \text{keV}$$

Percentage deviation from the effective Q-value of Audi *et al.* is – (0.01 ± 0.17) %, which supports the derivation of a highly consistent decay scheme.

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^{215}At -Comments on evaluation of decay data
by V.P. Chechev

This evaluation was done in December 2010 with a literature cut-off by the same date.

1. DECAY SCHEME

^{215}At decays 100 % to levels of ^{211}Bi by emission of α particles. The adopted ^{211}Bi levels populated in the ^{215}At decay are based on the experiment of 1966Gr07 and the evaluation by Browne (2004Br45).

The decay scheme of ^{215}At seems to be incomplete as the alpha decays to higher levels in daughter ^{211}Bi, which are known from the β^- decay of ^{211}Pb (see ^{211}Bi Adopted Levels, Gammas of 2004Br45), are not observed yet.

The current evaluated data are supported by the agreement between Q(calculated) = 8178 (5) keV, deduced from the calculated average energies of all emissions, and Q(α) = 8178 (4) keV, adopted from 2003Au03.

2. NUCLEAR DATA

Q(α) is from 2003Au03 where this value has been deduced from the measurement of α-particle energy E($\alpha_{0,0}$) = 8026 (4) keV by 1982Bo04 recommended in 1991Ry01.

The ^{215}At half-life of 0.10 (2) ms is from the single measurement of 1951Me10.

2.1. Alpha Transitions

The alpha transition energies have been obtained from the Q(α) value and ^{211}Bi level energies given in Table 1 from ^{211}Bi Adopted Levels, Gammas of 2004Br45.

Table 1. ^{211}Bi levels populated in ^{215}At α-decay

Level	Energy (keV)	Spin and parity	Half-life	Probability of α-transition (%)
0	0.0	9/2–	2.14 (2) min	99.95 (2)
1	404.854 (9)	7/2–	0.317 (11) ns	0.05 (2)

The alpha transition probability P ($\alpha_{0,1}$) is from the measurement of 1966Gr07 by means of α–γ coincidence technique with surface-barrier semi-conductor and NaI(Tl) detectors. The accurate P($\alpha_{0,0}$) value has been deduced from the expression of P($\alpha_{0,0}$) + P($\alpha_{0,1}$) = 100 %.

The α decay hindrance factors have been calculated using the ALPHAD computer program from the ENSDF evaluation package with r_0 (^{211}Pb) = 1.5443 fm (2004Br45).

2.2. Gamma Transitions and Internal Conversion Coefficients

The 405-keV gamma-ray transition probability has been deduced from the intensity balance at the 405-keV level using the adopted alpha transition probability P($\alpha_{0,1}$) and total internal conversion coefficient (ICC) α_T for $\gamma_{1,0}$ (405 keV). The multipolarity (M1+E2) and E2/M1 mixing ratio (δ) of -1.1 (1) have been taken from 2004Br45. These are based on the measurements of conversion electrons in ^{211}Pb β^- decay and γ(θ) measurements with polarized ^{211}Bi nuclei. ICCs α_T, α_K, α_L, α_M have been interpolated using the BrIcc computer program, version v2.2a, data set BrIccFO (2008Ki07).

3. ATOMIC DATA

The fluorescence yields, X-ray energies and relative probabilities, and Auger electrons energies and relative probabilities are from the SAISINUC software.

4. ALPHA EMISSIONS

The energy of alpha-particle group $\alpha_{0,0}$ that populates the ^{211}Bi ground state is the measured value from 1982Bo04 recommended in 1991Ry01. In 1966Gr07 the measured value of 8.00 (1) MeV was reported.

The energy of alpha-particle group $\alpha_{0,1}$ of 7628 (4) keV has been deduced from the Q(α) value taking into account the level energy of 404.854 (9) keV and the recoil energy for ^{211}Bi. The above value of E($\alpha_{0,1}$) can be compared to the value of 7626 (15) keV as measured by 1966Gr07 and adjusted by the evaluator to the adopted E($\alpha_{0,0}$) = 8026 (4) keV (the original value of 1966Gr07 is 7.60 (1) MeV).

The earlier measured energy of α–emission in the decay of ^{215}At is 8.00 (2) MeV (1951Me10).

5. ELECTRON EMISSIONS

The energies of the conversion electrons for $\gamma_{1,0}$ (405 keV) have been obtained from the gamma-ray transition energy and the atomic electron binding energies.

The emission probabilities of the conversion electrons have been deduced using the P_γ and ICC values.

The absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program.

6. PHOTON EMISSIONS

6.1 X - Ray emissions

The absolute emission probabilities of Pb KX- and LX-rays were calculated using the EMISSION computer program.

6.2. Gamma emissions

6.2.1. Gamma ray energies

The 405-keV gamma-ray energy has been adopted from the 405-keV level energy. In 1966Gr07 this energy was obtained from the ^{215}At α decay as ≈ 404 keV.

6.2.2. Gamma ray emission probabilities

The 405-keV gamma-ray emission probability has been deduced from the alpha transition probability P($\alpha_{0,1}$) = 0.05 (2) % and total internal conversion coefficient α_T = 0.122 (8).

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^{217}At - Comments on evaluation of decay data

Huang Xiaolong, Wang Baosong

This evaluation was completed in 2007. Literature available by December 2007 was included.

1 Decay Scheme

^{217}At disintegrates 99.9933 (24) % by α emission to levels in ^{213}Bi and 0.0067 (24) % by β^- emission to levels in ^{217}Rn. ^{217}At ground state has $J^{\pi} = 9/2^-$ (2007Ba19).

The α decay scheme of ^{217}At was built based on the measurement of 1997Ch19. The β^- decay scheme of ^{217}At has not been studied.

The adopted Q(α) value of Audi(2003Au03) is good in agreement with the Q(α) value calculated from decay scheme data.

2 Nuclear Data

The Q values are from the 2003Au03 evaluation.
Level energies, have been obtained from a least-squares fit to γ-ray energies (GTOL computer code). Spin and parities are from 2007Ba19.
The measured and evaluated ^{217}At half-life values are listed in Table 1.

Table 1 Measured half-life values of ^{217}At and evaluated value

$T_{1/2}$ (ms)		References	Measurement method
21		1947En03	
18	2	1950Ha52	Alpha pulse analyzer
32.3	4	1963Di05	
32.3	4	2007Ba19	NDS, from 1963Di05
32.3	**4**	Evaluated value	from 1963Di05

The adopted value is taken from the measurement of 1963Di05.

2.1 γ Transitions

The γ transition probabilities were calculated using the γ-ray emission intensities and the relevant internal conversion coefficients.

Multipolarities and mixing ratios of γ transitions are from 1997Ch19.

The internal conversion coefficients (ICC) and the associated uncertainties for the γ-transitions have been obtained using the BrIcc computer program.

2.2 α Transitions

The measured and evaluated energies of alpha particles were listed in table 2. The evaluated values are from 1997Ch19, except as noted.

Table 2 Measured and evaluated value of α-particle energy for ^{217}At

1967Dz02	1977Vy02	1982Bo04	1997Ch19	Evaluation
	6037 3 [b]			6037 3 [c]
			6322.0 16	6322.0 16
6422 7 [a]				
6486 7			6484.7 16	6484.7 16
6541 7 [a]				
6619 7 [a]				
6772 7 [a]				
6810 7			6813.8 16	6813.8 16
6849 7 [a]				
7070 8	7062 5	7071 2	7066.9 16	7066.9 16

[a]: the α transitions reported in 1967Dz02 were not confirmed in 1997Ch19 and 1997Ch53.
[b]: 1977Vy02 assign this α transition to the ^{221}Rn decay; 1997Ch53 assign this α transition to the ^{217}At decay.
c: from 1977Vy02.

The measured and evaluated alpha particle emission probabilities were listed in table 3. The evaluated alpha particle emission probabilities were deduced from the transition probability balance. These calculated results are in good agreement with the measured emission probabilities of the main alpha transitions.

Table 3 Measured and evaluated α-particle emission probabilities for ^{217}At

E_α(keV)	P_α					
	1967Dz02	1969LeZW	1997Ch19	1997Ch53	Calc.	Evaluation
6037 3				< 0.002	< 0.002	< 0.002
6322.0 16			0.005 1	0.012 6	0.0049 4	0.0049 4
6484.7 16	0.17 3	0.02 1	0.021 2	0.022 2	0.0167 8	0.0167 8
6813.8 16	0.55 9	0.06 2	0.036 3	0.038 4	0.0384 15	0.0384 15
7066.9 16	98.5 10	99.9 1	99.9	>99.9	99.932 3	99.932 3

3. Atomic data

Atomic values(ω_K,ϖ_L, ϖ_M, η_{KL} and η_{LM}) are from Schönfeld (1996Sc06).

The X-ray and Auger electron emission probabilities have been deduced from γ-ray and conversion electron data by using the computer code RADLST.

4. Electron Emissions.

The conversion electron emission probabilities have been deduced from γ-ray transition data.

5. Photon Emissions

5.1 γ-ray energy values

The measured and evaluated γ-ray energies for ^{217}At α decay are listed in table 4. The evaluated values are from 1997Ch19. The 455 keV γ-ray is introduced by evaluators due to probabilities balance. This γ-ray was observed in 1964Va20, but not confirmed by 1997Ch19. 1997Ch53 assigned the 6037 keV α transition and introduced the 1050 keV level.

Table 4 Measured and evaluated value of γ-ray energy for ^{217}At

1981Di14	1997Ch19	Evaluation
	165.8 [a]	165.8 [a]
258.5 2	257.88 4	257.88 4
	335.33 10	335.33 10
		455 [b]
	501.0 [a]	501.0 [a]
593.1 2	593.10 10	593.1 1
	758.9 1	758.9 1

[a]: not placed in level scheme.
[b]: from 1964Va20

5.2 Absolute values of the γ-ray emission probabilities

The measured and evaluated γ-ray emission probabilities for ^{217}At α decay are listed in table 5. The evaluated values are from 1997Ch19, except as noted.

Table 5 Measured and evaluated γ-ray emission probabilities for ^{217}At

E_γ (keV)	P_γ		
	1981Di14	1997Ch19	Evaluation
165.8 [a]		<0.0002	<0.0002
257.88 4	0.065 5	0.0287 7	0.0287 7
335.33 10		0.0062 3	0.0062 3
455			<0.002 [b]
501.0 [a]		<0.0002	<0.0002
593.1 1	0.014 1	0.0115 5	0.0115 5
758.9 1		0.0049 4	0.0049 4

a: not placed in level scheme. b: from intensity balance.

6. Branching Ratio

The measured and evaluated branching ratio for ^{217}At β^- decay are listed in table 6. The evaluated β^- decay branching ratio is from 1997Ch53, that's $\%\beta^-$ = 0.0067 (24) %.

So %α = 99.9933 (24) %.

Table 6 Measured and evaluated branching ratio for ^{217}At β^- decay.

$I_{\beta-}$ (%)	References
0.0012 6	1969LeZW
0.005	1995Ch74
0.0067 24	1997Ch53
0.0067 24	Evaluated value, from 1997Ch53

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^{218}At - Comments on evaluation of decay data by V. Chisté and M. M. Bé

This evaluation was completed in 2007. Literature available by January 2007 was included.

1 Decay Scheme

^{218}At disintegrates by alpha emission (99.9 (1) %) to ^{214}Bi mainly. The γ transitions between the ^{214}Bi levels have not been observed. However, a Q value of 6811 (12) keV is calculated in the disintegration of ^{218}At to ^{214}Bi from the decay scheme data compared to a value of 6867 (3) keV from the Audi's tables. This deficiency in the calculated Q value suggests the possible existence of a weak gamma transition from the 62-keV to the ground state levels.
A weak beta minus emission (0.1 (1) %) to Rn-218 has been pointed out (1948Wa20). Spins and parities are from the mass-chain evaluation of Y. A. Akovali (1987El12, 1995El08 for A = 218 and 1995El07 for A = 214) and A. K. Jain (2006Ja03 for A = 218).

2 Nuclear Data

The Q values (α and β^-) are from the atomic mass evaluation of Audi *et al.* (2003Au03).

Experimental ^{218}At half-life values (in seconds) are given in Table 1:

Table 1: Experimental values of ^{218}At half-life.

Reference	Experimental value (s)	Comments
R. J. Walen (1949Wa05)	1.3 (2)	Uncertainty increased to take into account systematic uncertainty.
D. G. Burke (1989Bu09)	1.5 (3)	
Recommended value	**1.4 (2)**	χ^2 = 0.31

The original uncertainty value given by R. J. Walen (1949Wa05) was multiplied by 2, in order to take into account the systematic uncertainties which were not considered by 1949Wa05. A weighted average has been calculated using Lweight computer program (version 3).

The recommended value of ^{218}At half-life is the weighted average of **1.4** second with an internal uncertainty of 0.2 second. The reduced-χ^2 value is 0.31.

2.1 a Transitions and Emissions

The energies of the α-particle transitions given in Section 2.1 were calculated from Q_α (2003Au03) and level energies.

The energy of $\alpha_{0,0}$, $\alpha_{0,1}$ and $\alpha_{0,2}$ emissions given in section 3 were measured by R.J. Walen (1963Wa29 (see 1964Hy02) and 1958Wa16), the adopted values are those recommended by A. Rytz (1991Ry01) where the original energy was decreased by 1 keV, due to a change in calibration energy (1995El07).

The $\alpha_{0,0}$, $\alpha_{0,1}$ and $\alpha_{0,2}$ emission probabilities are the measured values of R. J. Walen (1958Wa16), 3.6, 90.0 and 6.4 respectively, without uncertainties. From R. J. Walen, the total α decay is 99.9 (1) %. Since, there is no precision in the Walen's paper, the uncertainty of 0.1 % from propagation of the β^- transition probability (1948Wa20) has been assigned to each α line.

2.2 b^{-} Transitions and Emissions

The maximum energy of the β^{-} transition in the decay of ^{218}At → ^{218}Rn is given by Audi (2003Au03) and, without any other information available, is affected to a ground state to ground state transition.

The adopted β^{-} transition probability was measured by R. J. Walen (1948Wa20) to be 0.1 (1) %

3 References

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^{219}At - Comments on evaluation of decay data by A. L. Nichols

Evaluated: September 2010

Evaluation Procedure

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

Decay Scheme

Very little of substance can be gleaned from the literature concerning the decay characteristics of ^{219}At (2001Br31). Although no γ or β^- emissions have been observed, an alpha group at 6.27 MeV was assigned to ^{219}At by Hyde and Ghiorso (1953Hy83). A simple decay scheme has been constructed with little confidence from this early study. Alpha and β^- feeding directly to the ground states of daughter ^{215}Bi and ^{219}Rn were assumed, but these processes were neither observed satisfactorily nor quantified experimentally. Spin and parity of $7/2^-$ were tentatively assigned to the ground state of ^{219}At to align with $5/2^+$ identified with the ground state of daughter ^{219}Rn (2001Br31), in order to define the proposed single beta-particle emission as first forbidden non-unique. Further spectral studies are required to assemble and quantify the decay scheme of ^{219}At with much greater confidence.

Nuclear Data

Part of the (4n + 3) naturally-occurring decay chain, and of relevance in quantifying the environmental impact of ^{235}U and resulting decay-chain products. Specific radionuclides in this decay chain are noteworthy because of their distinctive decay characteristics (e.g. alpha decay of ^{215}Po, ^{211}Bi and ^{211}Po).

Half-life

The recommended half-life is the weighted mean of only two measurements (1953Hy83 and 1989Bu09).

Reference	Half-life (sec)
1953Hy83	54 (6)
1989Bu09	57 (4)
Recommended value	56 (4)*

* Uncertainty adjusted upwards from ± 3 to ± 4 in line with the most precise value of this limited data set.

Q values

Q^- of 1566 (3) keV and Q_α of 6324 (15) keV were adopted from the evaluated tabulations of Audi *et al.* (2003Au03, 2009AuZZ).

Alpha particle

Energy

The alpha-particle branch of ~ 97 % was assumed to populate the ground state of ^{215}Bi directly. Both the energy and uncertainty of this proposed alpha-particle emission were calculated to be 6208 (15) keV from the evaluated Q-value of 6324 (15) keV (2003Au03, 2009AuZZ).

Emission Probability

The alpha-particle emission probability was calculated from a quoted α/β^- ratio of approximately 30, as determined from measurements of the ^{219}At/^{219}Rn peak ratio (1953Hy83). An ill-defined alpha branch of ~ 97 % can be derived from this ratio without an assigned uncertainty.

Alpha-particle emission probability per 100 disintegrations of ^{219}At, and hindrance factor

E_α(keV)	P_α	HF
	Recommended value	
6208 (15)	~ 97	~ 1.07

An unweighted mean value of 1.547 (9) was adopted for the radius parameter $r_0(^{215}Bi)$ as derived from the equivalent data for neighbouring nuclei (1998Ak04), and used in the calculation of the α-hindrance factor (HF):

$$r_0(^{215}Bi) = [r_0(^{214}Pb) + r_0(^{216}Po)] / 2$$

$$= [1.5379\ (7) + 1.5555\ (2)] / 2 = 1.547\ (9)$$

Beta particle

Energy

The beta-particle branch of ~ 3 % was assumed to populate the ground state of ^{219}Rn directly. Therefore, the recommended energy and uncertainty of this single beta-particle transition was adopted from the evaluated Q-value of 1566 (3) keV (2003Au03, 2009AuZZ).

Emission Probability

The beta-particle emission probability was calculated from a quoted α/β^- ratio of approximately 30, as determined from measurements of the ^{219}At/^{219}Rn peak ratio (1953Hy83). A single, ill-defined, first forbidden non-unique transition is proposed directly to the ground state of ^{219}Rn, with an emission probability of ~ 3 % and no assigned uncertainty.

Beta-particle emission probability per 100 disintegrations of ^{219}At, transition type and log *ft*

E_β(keV)	P_β	transition type	log *ft*
	Recommended value		
1566 (3)	~ 3	(1st forbidden non-unique)	~ 6.2

Data Consistency

An effective Q-value of 6181 (15) keV has been adopted from the atomic mass evaluation of Audi *et al*. (2003Au03, 2009AuZZ) while in the course of formulating the decay scheme of ^{219}At. This value has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{219}At alpha- and beta-decay processes:

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 6181\ (15)\ \text{keV}$$

Percentage deviation from the effective Q-value of Audi *et al*. is (0.0 ± 0.3) %, which supports the derivation of a highly consistent decay scheme.

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^{217}Rn - Comments on evaluation of the decay data by Huang Xiaolong, Wang Baosong

This evaluation was completed in 2007. Literature available by December 2007 was included.

1 Decay Scheme

^{217}Rn disintegrates 100 % by α emission to the levels in ^{213}Po. α decay of ^{217}Rn occurs directly to the ground state of ^{213}Po. ^{217}Rn ground state has $J^{\pi} = 9/2^{+}$ (2007Ba19).

2 Nuclear Data

The Q value is from the 2003Au03 evaluation.
The level energy, spin and parity are from 2007Ba19.
The measured and recommended ^{217}Rn half-life values are listed in Table 1.

Table 1 - Measured half-life values of ^{217}Rn and recommended value, in ms.

$T_{1/2}$ (ms)	References	notes
1.0 (1)	1951Me10	
0.54 (5)	1961Ru06	
0.54 (5)	2007Ba19	Nucl. Data Sheets, from 1961Ru06
0.54 (5)	Recommended value	from 1961Ru06

The recommended value is taken from the measurement of 1961Ru06.

2.1 a Transition

The measured alpha-particle energies are listed in table 2. The Q-value of 2003Au03 was used to determine the energy and uncertainty of the single alpha particle transition to the ground state of ^{213}Po.

An α transition of energy 7507 keV (no uncertainty) with ~ 0.1 % intensity was observed by 1961Ru06. The first excited state in ^{213}Po has been observed at 293 keV in ^{213}Bi decay. If the 7507 keV group belonged to ^{217}Rn, from the 7887 keV it would give 243 keV for the level energy of the first excited state. In addition 1961Ru06 did not observe any α-γ coincidence. The evaluator believes that the uncertain 7507 keV group reported by 1961Ru06 probably belongs to an impurity because no positive identification could be made by 1961Ru06.

Table 2 - Measured and recommended values of α-particle energy from ^{217}Rn decay

1961Ru06	1982Bo04	1991Ry01[a]	Adopted value
7735 (4)	7739 (2)	7741 (2)	**7742 (3)**

a: Original energies of 1982Bo04 have been increased by 2 keV due to changes in calibration energies (1991Ry01).

So the evaluated alpha particle emission probability of the single alpha particle is 100 %.

The alpha hindrance factor HF = 1.49 was calculated using a parameter R0 = 1.562 (8) (2007Ba19), average of R0(^{212}Po) = 1.5649 (8) and R0(^{214}Po) = 1.559 (8) ; (1998Ak04).

3. References

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^{218}Rn - Comments on evaluation of decay data
by V. Chisté and M. M. Bé

This evaluation was completed in 2007. Literature available by January 2007 was included.

1 Decay Scheme

^{218}Rn disintegrates by alpha emissions to the 609-keV level (0.127 (7) %) and to the ground state (99.873 (7) %) of ^{214}Po. Spins and parities are from the mass-chain evaluation of Y. A. Akovali (1987El12, 1995El08, 1998Ak04 and 2006Ja03 for A = 218 and 1995El07 for A = 214).
A good agreement was found between the recommended Q value from Audi and the effective Q value (7262.5 (20) keV) calculated from decay scheme data.

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).

Experimental ^{218}Rn half-life values (in ms) are given in Table 1:

Table 1: Experimental values of ^{218}Rn half-life, in ms.

Reference	Experimental value (ms)	Comments
M.H. Studier (1948St42)	19	
P. A. Tove (1958To25)	39 (4)	
C. P. Ruiz (1961Ru06)	30 (3)	
H. Diamond (1963Di05)	35 (2)	Original uncertainty × 2
A. Erlik (1971Er02)	39 (2)	
Recommended value	**36.0 (19)**	reduced χ^2 = 2.3, critical χ^2 = 3.8

The original uncertainty of Diamond includes statistical uncertainty only, it was multiply by 2 to try to take into account systematic components.
A weighted average has been calculated using Lweight computer program (version 3), then the recommended value of ^{218}Rn half-life is **36.0 ms** with an external uncertainty of **1.9 ms**.

2.1 a Transitions and Emissions

The energies of the α-particle transitions given in Section 2.1 were calculated from Q_α (2003Au03) and the level energies.

The energy of $\alpha_{0,0}$ emission given in section 4 is the weighted average of the two measured values of F. Asaro (1956As38) and J. D. Bowman (1982Bo04), with the recommendations given by A. Rytz (1991Ry01) where the original energy of 1956As38 was increased by 4 keV and the energy of 1982Bo04 was decreased by 4 keV, due to changes in calibration energies (1998Ak04). For the $\alpha_{0,1,}$ the emission energy was calculated from Q_α (2003Au03), the level energy and taking the nucleus recoil into account.

The α emission probabilities were deduced from the level decay-scheme balance (see **2.2 Gamma Transitions**).

2.2 g Transitions

The 609-keV γ-ray transition probability was calculated using the γ-ray emission intensity and the relevant internal conversion coefficient (see **4.2** g **Emissions**).
Multipolarity of this γ-ray transition (E2) is from 1995El04.

The internal conversion coefficient (ICC) for the 609-keV γ-ray transition has been calculated using the BrIcc computer program (calculation for 'hole'), based on the theoretical values of I. M. Band (2002Ba85).

3 Atomic Data

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

4 Photon Emissions

4.1 X-ray Emissions

The X-ray absolute intensities were calculated from γ-ray data and ICC using the EMISSION computer program.

4.2 g Emissions

The energy of the 609-keV γ-ray given in section 5.2 is from W. Kurcewicz (1976Ku08).

The emission intensity of the 609-keV γ-ray was calculated from the measured relative photon intensity of W. Kurcewicz (1976Ku08), who measured the U-230 decay chain, and from the absolute emission intensity of 2.77 (8) % for the 324.22-keV γ-ray of ^{222}Ra decay, as measured by A. Peghaire (1969Pe17). This 609-keV emission intensity was then deduced being 0.124 (7) %.
This result can be compared with the less precise measured absolute intensities of 0.20 (5) (1956As38) and 0.16 (5) (1963Le17).

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^{219}Rn – Comments on evaluation of decay data by A. L. Nichols

Evaluated: October 2010

Evaluation Procedure

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

Decay Scheme

A reasonably comprehensive decay scheme has been derived from the alpha-particle studies of 1962Wa18, 1991Ry01 and 1999Li05, and the gamma-ray measurements of 1967Da20, 1968Br17, 1970Da09, 1970Kr08 and 1999Li05.

Nuclear Data

Part of the (4n + 3) decay chain, and of relevance in quantifying the environmental impact of ^{235}U and various decay-chain products. Specific radionuclides in this decay chain are noteworthy because of their distinctive and important decay characteristics (e.g. alpha decay of ^{215}Po, ^{211}Bi and ^{211}Po).

Half-life

The recommended half-life is the weighted mean of two measurements by 1961Ro14, and an additional independent study by 1966Hu20.

Reference	Half-life (s)
1961Ro14	4.01 (6)
	4.00 (5)
1966Hu20	3.96 (1)#
Recommended value	3.98 (3)

Uncertainty adjusted to ± 0.04 to reduce weighting below 50 %.

Q value

Q_α of 6946.1 (3) keV was adopted from the evaluated tabulations of Audi *et al.* (2003Au03).

Alpha Particles

Energies

Alpha-particle energies were calculated from the structural details of the proposed decay scheme. While the energies of the alpha-particle emissions have been directly measured by 1962Wa18, 1971Gr07, 1991Ry01 and 1999Li05, the nuclear level energies of 2001Br31 and evaluated Q-value of 6946.1 (3) keV (2003Au03) were preferably used to determine the recommended energies and uncertainties of the alpha-particle transitions, taking into account the significant recoil.

Adopted nuclear levels of ^{215}Po: J^{π} and origins (2001Br31).

Nuclear level	Nuclear level energy (keV)	J^{π}	Origins
0	0.0	9/2 +	^{215}Bi β^- decay, ^{219}**Rn α decay**
1	271.228 ± 0.010	7/2 +	^{215}Bi β^- decay, ^{219}**Rn α decay**
2	293.56 ± 0.04	(11/2) +	^{215}Bi β^- decay, ^{219}**Rn α decay**
3	401.812 ± 0.010	5/2 +	^{215}Bi β^- decay, ^{219}**Rn α decay**
4	517.60 ± 0.06	7/2 +, 9/2 +	^{215}Bi β^- decay, ^{219}**Rn α decay**
5	608.30 ± 0.07	(11/2 +, 13/2 +)	^{219}**Rn α decay**
6	676.66 ± 0.07		^{215}Bi β^- decay, ^{219}**Rn α decay**
7	708.1 ± 0.5		^{219}**Rn α decay**
8	732.7 ± 0.4		^{219}**Rn α decay**
9	835.32 ± 0.22		^{215}Bi β^- decay, ^{219}**Rn α decay**
10	877.2 ± 0.6		^{219}**Rn α decay**
11	891.1 ± 0.3		^{219}**Rn α decay**
12	930 ± 1		^{219}**Rn α decay**
13	1073.7 ± 0.4	(5/2 +)	^{219}**Rn α decay**
14	1094.2 ± 1.0		^{219}**Rn α decay**

Measured and recommended energies of the alpha-particle emissions of ^{219}Ra.

	E_{α} (keV)				
	1962Wa18	**1971Gr07**	**1991Ry01**	**1999Li05**	**Recommended value***
$\alpha_{0,14}$	–	–	–	5744 (15)	5745.0 (10)
$\alpha_{0,13}$	–	–	–	5764 (8)	5765.1 (5)
$\alpha_{0,12}$	–	–	–	5900 (15)	5906.2 (10)
$\alpha_{0,11}$	–	–	–	5944 (6)	5944.4 (4)
$\alpha_{0,10}$	–	–	–	5958 (15)	5958.1 (7)
$\alpha_{0,9}$	5999.3	–	–	6000 (6)	5999.2 (4)
$\alpha_{0,8}$	6100.5	–	–	6100 (8)	6099.9 (5)
$\alpha_{0,7}$	~ 6146.2	–	–	6124 (8)	6124.1 (6)
$\alpha_{0,6}$	6157.1	–	–	6158 (4)	6154.9 (3)
$\alpha_{0,5}$	6222.1	–	–	6223 (6)	6222.0 (3)
$\alpha_{0,4}$	6310.3	–	–	6311 (3)	6311.1 (3)
$\alpha_{0,3}$	6423.2	–	6425.0 (10)	6425 (1)	6424.8 (3)
$\alpha_{0,2}$	6527.5	–	–	6530 (2)	6531.0 (3)
$\alpha_{0,1}$	6551.3	–	6552.6 (10)	6553 (1)	6553.0 (3)
$\alpha_{0,0}$	6817.5	6819.3 (3)	6819.1 (3)	6819.1 (3)	6819.2 (3)

* Determined from the nuclear level energies of 2001Br31 and evaluated Q-value of 6946.1 (3) keV (2003Au03).

Emission Probabilities

Alpha-particle emission probabilities were derived from the recommended relative emission probabilities of the gamma rays, a normalisation factor of 0.111 (5), and theoretical internal conversion coefficients (see below). The normalisation factor (F) was determined from the sum of the relative emission probabilities of the alpha particles calculated on the basis of α-γ population/depopulation balances of all the nuclear levels of ^{215}Po:

$$\sum[\text{calculated relative } P_{\alpha} \text{ to } ^{215}\text{Po excited states}]F + (\text{absolute } P_{\alpha} \text{ to } ^{215}\text{Po ground state}) = 100$$

An absolute P_α of 79.4 (10) % directly to the ^{215}Po ground state was adopted from 1991Ry01. Denoting F as the normalisation factor for the relative emission probabilities of both the gamma rays and alpha particles:

$$186.0626F + 79.4\ (10) = 100$$

$$F = 20.6\ (10) / 186.0626 = 0.1107\ (54) \rightarrow 0.111\ (5)$$

An unweighted mean value of 1.557 (2) was adopted for the radius parameter $r_0(^{215}Po)$ as derived from the equivalent data for neighbouring nuclei (1998Ak04), and used in the calculation of α-hindrance factors (HF):

$$r_0(^{215}Po) = [r_0(^{214}Po) + r_0(^{216}Po)] / 2$$

$$= [1.559(8) + 1.5555(2)] / 2 = 1.557\ (2)$$

Alpha-particle emission probabilities per 100 disintegrations of ^{219}Rn, and hindrance factors.

E_α(keV)	P_α				HF
	1962Wa18	1991Ry01	1999Li05	Recommended value*	
5745.0 (10)	–	–	< 0.0001	0.000 09 (5)	245
5765.1 (5)	–	–	0.001	0.000 94 (19)	33
5906.2 (10)	–	–	–	0.000 09 (5)	1590
5944.4 (4)	–	–	0.002	0.002 1 (3)	103
5958.1 (7)	–	–	0.0001	0.000 3 (1)	830
5999.2 (4)	0.0044	–	0.003	0.003 2 (5)	120
6099.9 (5)	0.003	–	0.001	0.001 23 (12)	880
6124.1 (6)	~ 0.0026	–	0.001	0.000 64 (12)	2170
6154.9 (3)	0.0174	–	0.018	0.018 4 (22)	103
6222.0 (3)	0.0026	–	0.004	0.004 3 (10)	860
6311.1 (3)	0.054	–	0.054	0.048 (3)	184
6424.8 (3)	7.5	7.5 (6)	7.5	7.85 (24)	3.31
6531.0 (3)	0.12	–	0.12	0.098 (5)	710
6553.0 (3)	11.5	12.9 (6)	13	12.6 (3)	6.75
6819.2 (3)	81	79.4 (10)	79.3	79.4 (10)	11.2
				Σ 100.02729 → 100.0 (11)	

* Recommended alpha-particle emission probabilities have been determined by calculating the populating alpha-particle balances of the daughter nuclear levels of ^{215}Po through individual consideration of their gamma population-depopulation, along with the adoption of a normalisation factor of 0.111 (5) for the relative emission probabilities of the observed gamma rays and derived alpha particles.

Gamma Rays

Energies

While the energies of the main gamma-ray emissions have been directly measured by 1967Da20, 1968Br17, 1970Da09, 1970Kr08, 1976Bl13 and 1999Li05, all of the recommended gamma-ray energies were calculated from the nuclear level energies of daughter ^{215}Po as adopted from 2001Br31.

Measured and recommended energies of the main gamma-ray emissions of ^{219}Ra.

	E_γ (keV)						
	1967Da20	1968Br17	1970Da09	1970Kr08	1976Bl13	1999Li05	Recommended value*
$\gamma_{3,1}(Po)$	130.9 (6)	130.5 (3)	130.7 (1)	130.6 (2)	130.588 (29)	130.6 (1)	130.58 (1)
$\gamma_{1,0}(Po)$	271.2 (5)	271.0 (2)	271.20 (5)	271.4 (1)	271.233 (10)	271.23 (5)	271.228 (10)
$\gamma_{2,0}(Po)$	293.2 (6)	293.4 (4)	294.0 (3)	293.8 (2)	293.538 (44)	293.6 (1)	293.56 (4)
$\gamma_{3,0}(Po)$	401.7 (5)	401.7 (1)	401.8 (2)	402.0 (3)	401.811 (10)	401.81 (5)	401.81 (1)
$\gamma_{4,0}(Po)$	517.1 (8)	517.4 (3)	516.5 (5)	–	517.639 (55)	517.5 (1)	517.60 (6)
$\gamma_{6,0}(Po)$	–	676.6 (3)	677.0 (10)	–	676.645 (70)	676.7 (1)	676.66 (7)

* Determined from the recommended nuclear level energies of 2001Br31.

Emission Probabilities

The emission probabilities were determined from measurements of 1967Da20, 1968Br17, 1970Da09, 1970Kr08, 1976Bl13 and 1999Li05. Weighted mean values were calculated for the relative emission probabilities of the 130.58-, 293.56-, 401.81-, 517.60-, 608.30-, 676.66- and 891.1-keV gamma rays, while all others were adopted from the more comprehensive set of data measured by 1999Li05.

Some of the reported gamma-ray emissions were of highly questionable validity, and were not considered for placement in the recommended decay scheme because of their nature and doubtful origins:

(a) 115.4-keV gamma ray was only observed by 1968Br17, and was furthermore labeled by these authors as ill-assigned – removed from consideration.
(b) 221.5-keV gamma ray was judged to be a major gamma emission from the alpha-decay mode of ^{223}Ra – removed from further consideration.
(c) 324.9-and 337.7-keV gamma-ray emission probabilities were expressed only in terms of their upper limits by 1967Da20, and not observed by 1999Li05 – removed from consideration.
(d) 370.9-keV gamma ray was observed by 1965Va10, an emission probability expressed only in terms of an upper limit by 1967Da20, and not observed by 1999Li05 – removed from consideration.
(e) 380-keV gamma ray was only observed by 1965Va10 without a quantified emission probability – removed from consideration.
(f) 438.2-keV gamma ray was judged to be a major gamma emission from the alpha-decay mode of ^{215}Po – removed from further consideration.
(g) 538.2-and 1005-keV gamma rays were observed by 1965Va10, emission probabilities quantified by 1967Da20, and not observed by 1999Li05 – removed from consideration.
(h) 665.5-keV gamma-ray emission probability was assigned an upper limit by 1967Da20 and identified as a possible doublet, and fully quantified as a singlet by 1999Li05 – retained as an unplaced gamma transition emitted in the decay of ^{219}Rn.

Although some of the other observed gamma-ray emissions possess similar origins to the above, these transitions could be more comfortably placed in the proposed decay scheme, lending support to their acceptance and inclusion in the recommended data set.

Published gamma-ray emission probabilities.

$E_γ$ (keV)	$P_γ$						
	1965Va10*	1967Da20†	1968Br17‡	1970Da09¶	1970Kr08	1976Bl13	1999Li05
115.4 (5)	–	–	0.033 (15)	–	–	–	–
130.58 (1)	observed	1.40 (14)	1.30 (25)	1.05 (25)	1.21 (10)	1.16 (12)	1.7 (2)
221.5 (3)	–	–	–	) 0.28 (7)	–	–	–
224.04 (7)	–	–	–	)	–	–	0.013 (2)
271.228 (10)	observed	100	110 (15)	100.00	100.0	105.5 (40)	100 (2)
293.56 (4)	–	0.64 (6)	0.77 (15)	0.59 (15)	0.51 (27)	0.76 (5)	0.68 (4)
322 (1)	–	–	–	–	–	–	0.0008 (4)
324.9 (10)	–	< 0.06	–	–	–	–	–
330.9 (4)	–	–	–	–	–	–	0.0090 (10)
337.7 (10)	–	< 0.08	–	–	–	–	–
370.9 (15)	observed	< 0.1	–	–	–	–	–
373.5 (3)	–	–	–	–	–	–	0.0023 (3)
~ 380	observed	–	–	–	–	–	–
383.1 (1)	–	–	–	–	–	–	0.0040 (6)
401.81 (1)	observed	58 (6)	67 (4)	65.2 (65)	69.0 (30)	61.6 (28)	59.0 (20)
405.4 (1)	–	–	–	–	–	–	0.0023 (4)
436.9 (5)	–	–	–	–	–	–	0.0028 (5)
438.2 (6)	–	0.54 (10)	–	–	–	–	–
461.5 (4)	–	–	–	–	–	–	0.0015 (3)
489.3 (3)	–	–	–	–	–	–	0.0058 (8)
517.60 (6)	observed	0.44 (10)	0.48 (4)	0.22 (5)	–	0.43 (3)	0.40 (2)
538.2 (15)	observed	0.06 (3)	–	–	–	–	–
556.1 (4)	–	–	–	–	–	–	0.0005 (3)
564.1 (2)	observed	< 0.03	–	–	–	–	0.014 (3)
576.6 (10)	–	–	–	–	–	–	0.0008 (4)
608.30 (7)	observed	0.04 (2)	–	–	–	–	0.040 (10)
619.9 (3)	–	–	–	–	–	–	0.003 (1)
665.5 (10)	–	< 0.08Δ	–	–	–	–	0.0008 (4)
671.9 (4)	observed	–	–	–	–	–	0.002 (1)
676.66 (7)	–	0.21 (3)	0.23 (2)Δ	0.06 (3)	–	0.16 (1)	0.16 (2)
708.1 (5)	–	–	–	–	–	–	0.003 (1)
732.7 (4)	–	–	–	–	–	–	0.0006 (3)
802.5 (4)	–	–	–	–	–	–	0.003 (1)
835.32 (22)	observed	–	–	–	–	–	0.015 (3)
877.2 (6)	–	–	–	–	–	–	0.003 (1)
891.1 (3)	observed	0.015 (7)	–	–	–	–	0.007 (2)
1055 (2)	observed	0.006 (3)	–	–	–	–	–
1073.7 (4)	–	–	–	–	–	–	0.003 (1)

* Quantified only in terms of percentage depopulation of a number of ill-defined nuclear levels of ^{215}Po – neither the gamma-ray energies nor this form of relative emission probability were adopted in the subsequent analyses.

† Quoted relative emission probabilities of 1967Da20 are based on Pγ(271.228 keV) of 1000, and have been adjusted to Pγ(271.228 keV) of 100.

‡ Quoted relative emission probabilities of 1968Br17 for ^{219}Rn decay are based on Pγ(271.228 keV) of 0.110 (15), and have been adjusted to Pγ(271.228 keV) of 110 (15).

¶ Uncertainties in the relative emission probabilities are not defined by 1970Da09, and have been derived from the quoted uncertainties of the absolute emission probabilities.

Δ Evidence for the existence of a doublet.

Relative gamma-ray emission probabilities: Relative to P_γ(271.228 keV) of 100 %.

	E_γ (keV)	P_γ						
		1967Da20	1968Br17	1970Da09	1970Kr08	1976Bl13	1999Li05	Recommended value
–	115.4 (5)*	–	0.030 (14)	–	–	–	–	–
$\gamma_{3,1}$	130.58 (1)	1.40 (14)	1.18 (23)	1.05 (25)	1.21 (10)	1.10 (11)	1.7 (2)	1.2 (1)
–	221.5 (3)#	–	–	) 0.28 (7)	–	–	–	–
$\gamma_{4,2}$	224.04 (7)	–	–	)	–	–	0.013 (2)	0.013 (2)
$\gamma_{1,0}$	271.228 (10)	100	100	100.00	100.0	100	100.0 (20)	100 (2)
$\gamma_{2,0}$	293.56 (4)	0.64 (6)	0.70 (14)	0.59 (15)	0.51 (27)	0.72 (5)	0.68 (4)	0.68 (3)
$\gamma_{12,5}$	322 (1)	–	–	–	–	–	0.0008 (4)	0.0008 (4)
–	324.9 (10)§	< 0.06	–	–	–	–	–	–
$\gamma_{8,3}$	330.9 (4)	–	–	–	–	–	0.0090 (10)	0.0090 (10)
–	337.7 (10)†	< 0.08	–	–	–	–	–	–
–	370.9 (15)†	< 0.1	–	–	–	–	–	–
$\gamma_{11.4}$	373.5 (3)	–	–	–	–	–	0.0023 (3)	0.0023 (3)
–	~ 380§	–	–	–	–	–	–	–
$\gamma_{6,2}$	383.1 (1)	–	–	–	–	–	0.0040 (6)	0.0040 (6)
$\gamma_{3,0}$	401.81 (1)	58 (6)	61 (4)	65.2 (65)	69 (3)	58.4 (27)	59.0 (20)	61 (2)
$\gamma_{6,1}$	405.4 (1)	–	–	–	–	–	0.0023 (4)	0.0023 (4)
$\gamma_{7,1}$	436.9 (5)	–	–	–	–	–	0.0028 (5)	0.0028 (5)
–	438.2 (6)‡	0.54 (10)	–	–	–	–	–	–
$\gamma_{8,1}$	461.5 (4)	–	–	–	–	–	0.0015 (3)	0.0015 (3)
$\gamma_{11,3}$	489.3 (3)	–	–	–	–	–	0.0058 (8)	0.0058 (8)
$\gamma_{4,0}$	517.60 (6)	0.44 (10)	0.44 (4)	0.22 (5)	–	0.41 (3)	0.40 (2)	0.39 (3)
–	538.2 (15)†	0.06 (3)	–	–	–	–	–	–
$\gamma_{13,4}$	556.1 (4)	–	–	–	–	–	0.0005 (3)	0.0005 (3)
$\gamma_{9,1}$	564.1 (2)	< 0.03	–	–	–	–	0.014 (3)	0.014 (3)
$\gamma_{14,4}$	576.6 (10)	–	–	–	–	–	0.0008 (4)	0.0008 (4)
$\gamma_{5,0}$	608.30 (7)	0.04 (2)	–	–	–	–	0.040 (10)	0.040 (9)
$\gamma_{11,1}$	619.9 (3)	–	–	–	–	–	0.003 (1)	0.003 (1)
$\gamma_{-1,1}$	665.5 (10)¶	< 0.08$^\Delta$	–	–	–	–	0.0008 (4)	0.0008 (4)
$\gamma_{13,3}$	671.9 (4)	–	–	–	–	–	0.002 (1)	0.002 (1)
$\gamma_{6,0}$	676.66 (7)	0.21 (3)	0.21 (2)	0.06 (3)	–	0.15 (1)	0.16 (2)	0.16 (2)
$\gamma_{7,0}$	708.1 (5)	–	–	–	–	–	0.003 (1)	0.003 (1)
$\gamma_{8,0}$	732.7 (4)	–	–	–	–	–	0.0006 (3)	0.0006 (3)
$\gamma_{13,1}$	802.5 (4)	–	–	–	–	–	0.003 (1)	0.003 (1)
$\gamma_{9,0}$	835.32 (22)	–	–	–	–	–	0.015 (3)	0.015 (3)
$\gamma_{10,0}$	877.2 (6)	–	–	–	–	–	0.003 (1)	0.003 (1)
$\gamma_{11,0}$	891.1 (3)	0.015 (7)	–	–	–	–	0.007 (2)	0.008 (2)
–	1055 (2)†	0.006 (3)	–	–	–	–	–	–
$\gamma_{13,0}$	1073.7 (4)	–	–	–	–	–	0.003 (1)	0.003 (1)

* Only observed by 1968Br17, and of doubtful origin – discarded.
\# Determined from the measurements of 1970Da09, but identified as a gamma-ray emission within the alpha-decay mode of ^{223}Ra – discarded.
§ Only observed in a qualitative manner by 1965Va10 and 1967Da20, and of doubtful origin – discarded.
† Derived only from the measurements of 1967Da20, and of doubtful origin – discarded.
‡ Determined from the measurements of 1967Da20, but identified as a gamma-ray emission within the alpha-decay mode of ^{215}Po – discarded.
¶ Derived only from the measurements of 1967Da20 and 1999Li05, and of doubtful origin – unplaced within the proposed ^{219}Rn decay scheme.
$^\Delta$ Evidence for the existence of a doublet.

<u>Multipolarity and Internal Conversion Coefficients</u>

The decay scheme specified by 2001Br31 has been used to define the multipolarity of specific gamma transitions on the basis of the known spins and parities of the nuclear levels. Thus, the 224.04-, 401.81 and 1073.7-keV gamma-ray emissions are adjudged to be E2 transitions. Multipolarity mixing ratios for the 130.58- and 271.228-keV gamma transitions of 0.60 (6) and 4.0 (4), respectively, were derived from the K/L and L sub-shell conversion-electron intensities determined by Davidson and Connor (1970Da09), while the 293.56-, 517.60- and 556.1-keV gamma-ray emissions were arbitrarily assigned mixing ratios of 1.0 (2) (i.e. 50%M1 + 50%E2). Recommended internal conversion coefficients have been determined from the frozen orbital approximation of Kibédi *et al*. (2008Ki07), based on the theoretical model of Band *et al*. (2002Ba85, 2002Ra45).

Gamma-ray emissions: multipolarity and theoretical internal conversion coefficients (frozen orbital approximation).

E_γ (keV)	P_γ^{abs} × 100	Multipolarity	α_K	α_L	α_{M+}	α_{total}
130.58 (1)	0.133 (11)	73.5%M1 + 26.5%E2 δ = 0.60 (6)	3.19 (16)	0.94 (4)	0.31	4.44 (13)
224.04 (7)	0.001 4 (2)	(E2)	0.129 6 (19)	0.140 7 (20)	0.048 7	0.319 (5)
271.228 (10)	11.07 (22)	(6%M1 + 94%E2) δ = 4.0 (4)	0.111 (6)	0.066 8 (11)	0.023 2	0.201 (7)
293.56 (4)	0.075 (3)	(50%M1 + 50%E2) δ = 1.0 (2)	0.25 (4)	0.062 (4)	0.028	0.34 (5)
322 (1)	0.000 09 (5)	–	–	–	–	–
330.9 (4)	0.001 00 (11)	–	–	–	–	–
373.5 (3)	0.000 25 (3)	–	–	–	–	–
383.1 (1)	0.000 44 (7)	–	–	–	–	–
401.81 (1)	6.75 (22)	E2	0.0351 (5)	0.015 28 (22)	0.005 12	0.055 5 (8)
405.4 (1)	0.000 25 (4)	–	–	–	–	–
436.9 (5)	0.000 31 (6)	–	–	–	–	–
461.5 (4)	0.000 17 (3)	–	–	–	–	–
489.3 (3)	0.000 64 (9)	–	–	–	–	–
517.60 (6)	0.043 (3)	(50%M1 + 50%E2) δ = 1.0 (2)	0.058 (9)	0.011 5 (11)	0.003 5	0.073 (10)
556.1 (4)	0.000 06 (4)	(50%M1 + 50%E2) δ = 1.0 (2)	0.048 (7)	0.009 5 (9)	0.003 5	0.061 (8)
564.1 (2)	0.001 5 (3)	–	–	–	–	–
576.6 (10)	0.000 09 (5)	–	–	–	–	–
608.30 (7)	0.004 4 (10)	(M1 + E2)	–	–	–	–
619.9 (3)	0.000 33 (11)	–	–	–	–	–
665.5 (10)	0.000 09 (5)	–	–	–	–	–
671.9 (4)	0.000 22 (11)	M1 + E2	–	–	–	–
676.66 (7)	0.018 (2)	–	–	–	–	–
708.1 (5)	0.000 33 (11)	–	–	–	–	–
732.7 (4)	0.000 07 (4)	–	–	–	–	–
802.5 (4)	0.000 33 (11)	M1 + E2	–	–	–	–
835.32 (22)	0.001 7 (3)	–	–	–	–	–
877.2 (6)	0.000 33 (11)	–	–	–	–	–
891.1 (3)	0.000 9 (2)	–	–	–	–	–
1073.7 (4)	0.000 33 (11)	E2	0.005 10 (8)	0.001 002 (14)	0.000 308	0.006 41 (9)

Atomic Data

The x-ray data have been calculated using the evaluated gamma-ray data, and the atomic data from 1996Sc06, 1998ScZM and 1999ScZX. Both the x-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.01, 28 January 2003). This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

K and L X-ray emission probabilities per 100 disintegrations of ^{219}Rn.

			Energy (keV)	Photons per 100 disint.
XL		(Po)	9.658 – 16.213	1.01 (5)
	XL_l	(Po)	9.658	0.0229 (9)
	XL_α	(Po)	11.016 – 11.130	0.420 (15)
	XL_η	(Po)	12.085	0.0095 (4)
	XL_β	(Po)	12.823 – 13.778	0.475 (13)
	XL_γ	(Po)	15.742 – 16.213	0.098 (3)
XK_α	$XK_{\alpha2}$	(Po)	76.864	0.540 (24)
	$XK_{\alpha1}$	(Po)	79.293	0.90 (4)
$XK'_{\beta1}$	$XK_{\beta3}$	(Po)	89.256	)
	$XK_{\beta1}$	(Po)	89.807	) 0.309 (15)
	$XK''_{\beta5}$	(Po)	90.363	)
$XK'_{\beta2}$	$XK_{\beta2}$	(Po)	92.263	)
	$XK_{\beta4}$	(Po)	92.618	) 0.096 (5)
	$XKO_{2,3}$	(Po)	92.983	)

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

Data Consistency

A Q_α-value of 6946.1 (3) keV has been adopted from the atomic mass evaluation of Audi *et al.* (2003Au03) while in the course of formulating the decay scheme of ^{219}Rn. This value has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{219}Rn alpha-decay process (i.e. α, electron, γ, etc.):

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 6945\ (70)\ \text{keV}$$

Percentage deviation from the Q-value of Audi *et al.* is (0.0 ± 1.0) %, which supports the derivation of a highly consistent decay scheme with a rather significant variant.

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^{220}Rn – Comments on evaluation of decay data by A. L. Nichols

Evaluated: July/August 2001
Re-evaluated: January 2004 and April 2010

Evaluation Procedures

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

Decay Scheme

A simple decay scheme has been derived from the gamma-ray studies of 1972DaZA (1973Da38), 1977Ku15, and 1984Ge07. The single 549.76-keV gamma ray had a weighted mean emission probability of 0.115 (15) % (0.001 15 (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 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 50 %.

There is no evidence of any change in the half-life of ^{220}Rn on extreme cooling of alpha-active ^{224}Ra samples and decay products within a metallic environment (2007St23). Sources were held at temperatures at and below 1 kelvin for periods of several days, and exhibited an upper limit of change in the alpha-decay half-lives of the order of 1 %.

Alpha Particles

Energies

Alpha-particle energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 2007Wu02 and evaluated Q-value of 6404.67 (10) keV (2003Au03) were used to determine the energies and uncertainties of the alpha-particle transitions, 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 (see below). A hindrance factor (HF) of 1.00 for the 6288.22-keV alpha-particle emission yields r_0(^{216}Po) of 1.5553 (3) which was adopted in the equivalent calculation of HF for the other emission.

Alpha-particle emission probabilities per 100 disintegrations of ^{220}Rn, and hindrance factors.

E_α(keV)	P_α			HF
	1962Wa28	1977Ku15#	Recommended value*	
5748.46 (11)	0.07 (2)	0.097 (8)	0.118 (15)	3.10
6288.22 (10)	~ 100	99.9	99.882 (15)	1.00

Data were deduced from gamma-ray studies.

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

Gamma Ray

Energy

The single gamma-ray energy was based on the nuclear level energy of 549.76 (4) keV from 2007Wu02.

Emission Probability

The absolute emission probability of the 549.76 (4)-keV gamma ray was determined from measurements by 1972DaZA (1973Da38), 1977Ku15 and 1984Ge07. A weighted mean value of 0.115 (15) % (0.001 15 (15)) was derived by means of the LWEIGHT code.

Published gamma-ray emission probability.

E_γ (keV)	P_γ			
	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 probability per 100 disintegrations of ^{220}Rn.

E_γ (keV)	P_γ^{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.

Uncertainty increased by a factor of 2.7 from ± 0.003 to ± 0.008 in order to reduce weighting to 50 %.

* Weighted mean value adopted, with the recommended uncertainty increased so that the range includes the most precise value of 0.130.

Multipolarity and Internal Conversion Coefficients

The decay scheme specified by 1997Ar04 and 2007Wu02 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. Recommended internal conversion coefficients have been determined from the frozen orbital approximation of Kibédi *et al.* (2008Ki07), based on the theoretical model of Band *et al.* (2002Ba85, 2002Ra45).

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

E_γ (keV)	Multipolarity	α_K	α_L	α_{M+}	α_{total}
549.76 (4)	E2	0.018 3 (3)	0.005 61 (8)	0.001 79 (2)	0.025 7 (4)

Atomic Data

The x-ray data have been calculated using the evaluated gamma-ray data, and the atomic data from 1996Sc06, 1998ScZM and 1999ScZX. Both the x-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.01, 28 January 2003). This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

K and L X-ray emission probabilities per 100 disintegrations of ^{220}Rn.

			Energy (keV)	Photons per 100 disint.
XL		(Po)	9.658 – 16.213	0.000 94 (8)
	XL_l	(Po)	9.658	0.000 022 2 (22)
	XL_α	(Po)	11.016 – 11.130	0.000 41 (4)
	XL_η	(Po)	12.085	0.000 008 1 (9)
	XL_β	(Po)	12.823 – 13.778	0.000 42 (4)
	XL_γ	(Po)	15.742 – 16.213	0.000 086 (7)
XK_α	$XK_{\alpha 2}$	(Po)	76.864	0.000 59 (8)
	$XK_{\alpha 1}$	(Po)	79.293	0.000 99 (13)
$XK'_{\beta 1}$	$XK_{\beta 3}$	(Po)	89.256	}
	$XK_{\beta 1}$	(Po)	89.807	} 0.000 34 (5)
	$XK''_{\beta 5}$	(Po)	90.363	}
$XK'_{\beta 2}$	$XK_{\beta 2}$	(Po)	92.263	}
	$XK_{\beta 4}$	(Po)	92.618	} 0.000 106 (15)
	$XKO_{2,3}$	(Po)	92.983	}

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

Data Consistency

A Q_α-value of 6404.67 (10) keV has been adopted from the atomic mass evaluation of Audi *et al.* (2003Au03) while in the course of formulating the decay scheme of ^{220}Rn. This value has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{220}Rn alpha-decay process (i.e. α, electron, γ, etc.):

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 6404.7\ (13)\ \text{keV}$$

Percentage deviation from the Q-value of Audi *et al.* is – (0.001 ± 0.020) %, which supports the derivation of a highly consistent decay scheme.

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^{222}Rn - Comments on evaluation of decay data by V. Chisté and M. M. Bé

1 Decay Scheme

^{222}Rn disintegrates by alpha emission mainly to the ground state level of ^{218}Po. Spin and parity are from the mass-chain evaluation of Y. A. Akovali (1987El12, 1995El08 for A = 218 and 1996El01 for A = 222) and A. K. Jain (2006Ja03 for A = 218).
The calculated Q value of 5590.2 (6) keV deduced from the decay scheme data is in good agreement with the adopted value from Audi *et al.*

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).

The experimental ^{222}Rn half-life values (in days) are given in Table 1:

Table 1: Experimental values of ^{222}Rn half-life.

Reference	Experimental value (d)	Comments
W. Bothe (1923Bo**)	3.824 (4)	Ionization-chamber. Revised uncertainty by N.E. Holden (1990Ho28).
I. Curie (1924Cu**)	3.823 (2)	Ionization-chamber. Revised uncertainty by N.E. Holden (1990Ho28).
J. Tobailem (1951To25)	3.825 (5)	Ionization-chamber. Revised uncertainty by N.E. Holden (1990Ho28).
J. Robert (1956Ro31)	3.825 (4)	Calorimetry. Revised uncertainty by N.E. Holden (1990Ho28).
P. C. Marin (1956Ma64)	3.8229 (17)	Revised uncertainty by N.E. Holden (1990Ho28).
N. S. Shimanskaya (1958Sh69)	3.83 (3)	Calorimetry. Outlier
D. K. Butt (1972Bu33)	3.8235 (17)	Revised uncertainty by N.E. Holden 1990Ho28.
R. Collé (1995Co**)	3.8224 (18)	Liquid scintillator.
H. Schrader (2004Sc04)	3.8195 (30)	Ionization-chamber. Outlier
Recommended value	**3.8232 (8)**	χ^2 = 0.11

For the half-life values in references from W. Bothe (1923Bo*) to D. K. Butt (1972Bu33), the retained values take into account the uncertainty recommendations given by N. E. Holden (1990Ho28). With this data set, a weighted average was calculated using LWEIGHT computer program (version 3). Based on the Chauvenet's criterion, the Shimanskaya (1958Sh69) and Schrader's (2004Sc04) values have been shown outlier and then omitted in the final calculation.

The recommended value of ^{222}Rn half-life is the weighted average of **3.8232 days** with an internal uncertainty of **0.0008 day**. The reduced-χ^2 value is 0.11 and the critical χ^2 value is 2.8.

2.1 a Transitions and Emissions

The energies of the α-particle transitions given in Section 2.1were calculated from Q_α (2003Au03) and level energies.

The energy of the $\alpha_{0,0}$ emission given in section 4 is from A. Rytz (1991Ry01). For the $\alpha_{0,1}$ and $\alpha_{0,2}$, the emission energies are given by R. J. Walen (1958Wa16).

The α-particle emission probabilities are recommended by A. Rytz (1991Ry01). For the $\alpha_{0,1}$ emission probability, the adopted value is the measured value of R. J. Walen (1958Wa16) (0.078). Existence of the $\alpha_{0,2}$ branch is questionable.

2.2 g Transitions

The $\gamma_{(1,0)}$ transition probability was deduced from the decay-scheme balance using recommended experimental α-particle intensity value of 0.078 given by R. J. Walen (1958Wa16). (see **2.1** a **Transitions and Emissions**). The multipolarity of the 510-keV γ-ray transition is from 2006Ja03.

510-keV γ-ray : [E2]

The internal conversion coefficients (ICC's) for this γ-ray transition have been calculated using the BrIcc computer program, which interpolates from theoretical values of I. M. Band (2002Ba85).

3 Atomic Data

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

4 a Emissions

See **2.1** a **Transitions and Emissions**.

5 Photon emissions

5.1 g-ray Emissions

The energy of the 510 keV γ-ray given in Section 5.1 was measured by L. Madansky (1956Ma28).
The intensity of 0,076 deduced from alpha intensity measurements is in agreement with the measured value of 0,07 obtained by L. Madansky (1956Ma28).

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^{221}Fr - Comments on evaluation of decay data
by Huang Xiaolong and Wang Baosong

This evaluation was completed in 2007. Literature available by December 2007 was included.

1 Decay Scheme

^{221}Fr disintegrates 99.9952 (15) % by α emission to levels in ^{217}At and 0.0048 (15) % by β^- emission to levels in ^{221}Ra. ^{221}Fr ground state has J^{π} =5/2$^-$ (2003Ak06).

The α decay scheme of ^{221}Fr was built based on the measurement described in 1995Sh01, 1999Gr33 and 2002Gr36. A study of 1997Ch53 showed the existence of a possible weak ß$^-$ decay of (4.8 ± 1.5) 10^{-3} % to ^{221}Ra. The β^- decay scheme of ^{221}Fr has not been studied.

The recommended Q(a) value of 6457.8 (14) keV in Audi(2003Au03) agrees with the Q(a) value of 6461.5 (25) keV, calculated by the evaluator (using program RADLST) from average radiation energies. This agreement supports the completeness and correctness of the decay scheme.

2 Nuclear Data

The Q value is from the 2003Au03 evaluation.

Level energies, have been obtained from a least-squares fit to γ-ray energies (GTOL computer code). Spin and parities are from 2003Ak06.

The measured and our evaluated ^{221}Fr half-life values are listed in Table 1. Notice that uncertainties in tables referred to the least significant digits.

Table 1 - Measured half-life values of ^{221}Fr and recommended value, in minutes

$T_{1/2}$ (min)	References	measurement method
5	1947En03	
4.8	1950Ha52	Alpha pulse analyzer
4.9 (2)	1967LoZZ	
4.79 (2)	2007Je07	From Si sample. Metallic samples(Au,W) give shorter value
4.9 (2)	2003Ak06	NDS, from 1967LoZZ
4.85 (6)		Unweighted mean of 1967LoZZ and 2007Je07
4.791 (20)		Weighted mean of 1967LoZZ and 2007Je07,χ^2=0.3
4.79 (2)	2007	Recommended value, from 2007Je07

2007Je07 measured the half-life at room temperature in different materials and obtained an improved value. As the weighted mean of 4.9 (2) min (1967LoZZ) and 4.79 (2) min (2007Je07) is very close to this most precise measurement, the value of 2007Je07 is recommended here.

2.1 g Transitions

The γ-ray transition probabilities were calculated using the γ-ray emission intensities and the relevant internal conversion coefficients.

Multipolarities and mixing ratios of γ-ray transitions are from 1968Le07 and 1995Sh01. Multipolarities in square brackets are from level scheme (they are not measured).

The internal conversion coefficients (ICC) and their associated uncertainties for γ-ray transitions have been obtained using the BrIcc computer program, which uses the “Frozen Orbital” approximation (2002Ba85).

Experimental and theoretical conversion coefficients are compared in Table 2.

Table 2 - Comparison of theoretical and measured conversion coefficients

E_g/keV	Multipolarity	a(theory)	a(exp.)	
			1995Sh01	1999Gr33
53.81	M1	α_T=14.17, α_L=10.79 (16)	α_L=8 (4)	
96.3	M1+E2	α_T=5.6 , α_L=4.1 (18)	α_L>2.5	α_T=25 (15)
100.25	M1	α_T=11.97, α_L=1.758 (25)	α_L=1.2 (6)	
117.82	M1	α_T=7.58		α_T=13.5 (86)
150.21	M1	α_T=3.8, α_K=3.08 (5)	α_K=2.6 (5)	α_T=3.5 (9)
171.83	E2	α_T=0.863, α_K=0.226 (4)	α_K=0.3 (1)	α_T=0.84 (2)
218.12	E2	α_T=0.367, α_K=0.1375 (20)	α_K=0.14	
324.10	M1	α_T=0.446, α_K=0.362 (5)	α_K=0.4 (2)	
359.86	M1	α_T=0.335, α_K=0.272 (4)	α_K=0.4 (1)	
382.34	M1	α_T=0.284, α_K=0.231 (4)	α_K=0.25 (10)	
410.64	E2	α_T=0.0548, α_K=0.0344 (5)	α_K=0.03 (1)	

2.2 a Transitions

Measured energies of alpha particles are listed in table 3. Our recommended values are from 1968Le07 and 2002Gr36.

Table 3 - Measured and recommended values of α-particle energies (in keV) from ^{221}Fr α decay

1967Dz02	1968Le07[a]	2002Gr36	Recommended
		5500 (40)	5500 (40)
		5530 (25)	5530 (25)
	5689 (3)		5689 (3)
	5697 (4)		5697 (4)
	5776 (3)		5776 (3)
	5783 (4)		5783 (4)
	5813 (3)		5813 (3)
5930 (7)	5925 (3)		5925 (3)
5940 (6)	5938.9 (20)		5938.9 (20)
5966 (6)	5965.9 (25)		5965.9 (25)
5980 (6)	5979.9 (20)		5979.9 (20)
6075 (5)	6075.9 (20)		6075.9 (20)
6125 (5)	6126.3 (15)		6126.3 (15)
6241 (6)	6243.0 (20)		6243.0 (20)
6338 (5)	6341.0 (13)		6341.0 (13)

[a]: Values were adjusted based on the calibration recommendation of 1991Ry01.

Experimental and recommended α-particle emission probabilities are listed in Table 4. Our recommended alpha particle emission probabilities are average values of measured α-particle intensities with those deduced from γ-transition probability balance at each decay scheme level.

Table 4 - Experimental, recommended α-particle emission probabilities from ^{221}Fr decay

E_a(keV)	P_a(%)				
	1967Dz02	**1968Le07**	**2002Gr36**	**Deduced from Pg**	**Recommended**†
5500 (40)			3.3 (9) E-4	0.000038 (10)	0.000038 (10)
5530 (25)			9.0 (20) E-4	0.00010 (2)	0.00010 (2)
5689 (3)		0.002 (1)		0.0026 (5)	0.0025 (5)
5697 (4)		~0.001		~0.004	~0.003
5776 (3)		0.06 (1)		0.065 (4)	0.064 (4)
5783 (4)		0.005(2)		0.0029 (6)	0.0031 (6)
5813 (3)		0.004 (2)		0.006 (1)	0.006 (1)
5925 (3)	0.05 (1)	0.03 (1)		0.0280 (16)	0.0285 (24)
5938.9 (20)	0.13 (1)	0.17 (3)		0.127 (3)	0.128 (3)
5965.9 (25)	0.12 (1)	0.08 (1)		0.053 (4)	0.064 (16)
5979.9 (20)	0.46 (5)	0.49 (3)		0.27 (3)	0.39 (7)
6075.9 (20)	0.13 (2)	0.15 (3)		0.30 (6)	0.15 (3)
6126.3 (15)	14.5 (7)	15.1 (2)		15.3 (3)	15.1 (2)
6243.0 (20)	1.35 (7)	1.34 (10)		0.9 (5)	1.34 (7)
6341.0 (13)	83.2 (20)	83.4 (8)		82.9 (5)	82.8 (2)*

† Weighted average of values from the first four columns, normalized to a total of 100 %.

* Value reduced by a covariance effect introduced by the normalization to 100 %.

3. Atomic data

Atomic fluorescence yields (ω_K,ϖ_L, ϖ_M, η_{KL} and η_{LM}) are from Schönfeld (1996Sc06).

The X-ray and Auger electron emission probabilities have been deduced from γ-ray and conversion electron data by using the computer code RADLST. The deduced K X-ray emission probabilities P_{KX} = 2.77 (19) % agree with the measured value of 2.23 (20) % in 1995Sh01, thus confirming the completeness of the decay scheme.

4. Electron Emissions

The conversion electron emission probabilities have been deduced from γ-ray transition data using theoretical internal conversion coefficients.

5. Photon Emissions

5.1 g-ray energy values

The experimental and our recommended γ-ray energies from ^{221}Fr α decay are listed in table 5. Unless otherwise specified the later are averages (or weighted averages) from values given in 1968Le07, 1994Ar23, 1995Sh01, and 1999Gr33. γ-rays of 809.3 and 891.9 keV reported only in 2002Gr36 have also been included here. Several γ-rays observed in 1995Bu17 and 1994Ar23 were interpreted as sum peaks in 1999Gr33. Values from 1995Bu17 have not been included in this averaging because this reference seems to be an earlier publication of 1999Gr33 (notice that only these two references reported the 201.4- and 208.3-keV γ-rays).

Table 5 - Measured and recommended values of γ-ray energies for ^{221}Fr α decay.

1968Le07	1994Ar23	1995Bu17	1995Sh01	1999Gr33	2002Gr36	LWM	Recommended
		53.54 (18)	53.8 (1)	53.81 (3)		53.80 (28)	53.81 (3)
		68.11 (15)					
		96.12 (18	96.3 (3)	96.3 (3)		96.20 (14)	96.3 (3)
99.5	100.63 (2)	99.52 (6)	100.2 (1)	100.25 (2)		100.40 (24)	100.25 (2)
118.2 (2)	117.67 (5)	118.18 (9)	117.8 (2)	117.82 (3)		117.80 (9)	117.82 (3)
150.0 (2)	150.43 (5)	150.04 (4)	150.0 (1)	150.21 (3)		150.20 (8)	150.21 (3)
171.3	172.05 (5)	171.68 (4)	171.6 (1)	171.83 (3)		171.80 (8)	171.83 (3)
		201.44 (50)		201.4 (6)		201.4 (4)	201.4 (6)[a]
		208.3 (5)		208.3 (6)		208.3 (4)	208.3 (6)
217.99 (4)	218.30 (2)	218.14 (3)	218.0 (1)	218.12 (2)		218.20 (11)	218.12 (2)
	250.7 (2)						
	253.15 (15)						
		263.39 (14)					
	271.91 (5						
282.8	282.25 (5)	282.36 (15)	281.9 (3)	282.12 (9)		282.20 (4)	282.12 (9)
		297.11 (40)					
		299.59 (14)					
	310.20 (5)	310.14 (16)					
		314.11 (17)					
324.1	323.99	323.99 (6)	324.0 (2)	324.10 (6)		324.00 (4)	324.10 (6)
359.1	359.90 (2)	359.92 (6)	359.0 (2)	359.86 (4)		359.90 (6)	359.86 (4)
	368.17 (2)	368.18 (10)					
381.8	382.36 (2)	381.81 (4)	381.1 (2)	382.34 (4)		382.20 (15)	382.34 (4)
409.1	410.73 (2)	409.93 (7)	410.4 (2)	410.64 (5)		410.60 (16)	410.64 (5)
	435.68 (10)		437.8 (5)	437.00 (5)		436.4 (6)	437.00 (5)
		445.07 (20)	446.3 (8)	446.30 (8)		445.7 (6)	446.30 (8)
		469.6 (2)	469.0 (5)	468.3 (7)		469.40 (18)	468.3 (7)
			496.2 (10)				
	538.02 (10)	537.0 (2)	537.5 (8)	537.8 (8)		537.5 (5)	537.8 (8)
			562.3 (12)				562.3 (12)
		568.5 (3)	568.4 (10)	568.5 (3)		568.50 (21)	568.5 (3)
	577.76 (6)	576.9 (4)	577.0 (8)	576.9 (4)		577.70 (6)	576.9 (4)
				652 (2)			652 (2)
				658 (2)			658 (2)[a]
				665 (2)			665 (2)
					809.3 (2)		809.3 (2)
					891.9 (3)		891.9 (3)

[a]: not placed in level scheme.

5.2 Relative g-ray emission probabilities

Measured relative γ-ray intensities from ^{221}Fr are listed together with our recommended values in Table 6. Several γ-rays observed in 1995Bu17 and 1994Ar23 were interpreted as sum peaks in 1999Gr33. Thus their relative intensities may not be accurate so they have not been recommended here.

Results in 1995Sh01 are in agreement with those in 1999Gr33 within their experimental uncertainties, but they are not as complete and accurate. However, their decay scheme differs only by some weak transitions. For example, 1995Sh01 did not observe the 652-0, 578-368 γ-ray transitions, thus it did not propose the 652 keV level. 1999Gr33 is the most precise measurement among the available experimental data. Unless otherwise specified, the present recommended values are weighted averages (LWM) from values given in 1999Gr33, 1995Sh05, 1994Ar23. 1968Le07, and two γ-rays from 2002Gr36.

Table 6 - Measured and recommended relative γ-ray emission probabilities for ^{221}Fr

E_g(keV)	1968Le07	1994Ar23	1995Sh01	1999Gr33	2002Gr36	Recommended[&]
53.81 (3)			0.15 (4)	0.116 (27)		0.127 (22)
96.3 (3)			<0.09	0.063 (27)		0.058 (23)
100.25 (2)	0.95 (34)	1.47 (9)	1.33 (18)	0.89 (27)		1.37 (11)
117.82 (3)	0.34 (17)	0.328 (17)	0.044 (18)	0.20 (12)		0.19 (14)
150.21 (3)	0.69 (26)	0.362 (17)	0.53 (9)	0.420 (18)		0.393 (21)
171.83 (3)	0.52 (26)	0.517 (17)	0.58 (11)	0.680 (18)		0.60 (8)
201.4 (6)[a]				0.0098 (9)		0.0098 (9)†
208.3 (6)				0.045 (9)		0.045 (9)†
218.12 (2)	100	100	100	100		100
282.12 (9)	0.086	0.056 (9)	0.071 (27)	0.063 (9)		0.060 (6)
324.10 (6)	0.17 (9)	0.138 (9)	0.106 (27)	0.170 (9)		0.152 (10)
359.86 (4)	0.34 (17)	0.319 (17)	0.32 (9)	0.358 (18)		0.337 (12)
382.34 (4)	0.34 (17)	0.302 (17)	0.27 (9)	0.295 (18)		0.298 (12)
410.64 (5)	1.21 (34)	1.034 (86)	0.97 (18)	1.055 (18)		1.054 (17)
437.00 (5)		0.034 (6)	~0.009	0.0083 (9)		0.0083 (9)†
446.30 (8)			~0.009	0.0152 (36)		0.0152 (36)†
468.3 (7)			0.018 (9)	0.0152 (27)		0.0154 (26)
537.8 (8)		0.034 (10)	0.018 (9)	0.0447 (45)		0.039 (7)
562.3 (12)			~0.044			~0.044
568.5 (3)			~0.009	0.0107 (36)		0.0107 (36)†
576.9 (4)		0.041 (6)	0.035 (9)	0.0259 (36)		0.030 (5)
652 (2)				~0.00358		~0.00358†
658 (2)[a]				~0.00626		~0.00626†
665 (2)				~0.00805		~0.00805†
809.3 (2)					9.0E-4 (20)	9.0E-4 (20)*
891.9 (3)					3.3E-4 (9)	3.3E-4 (9)*

[&] Deduced using the LWM statistical method, unless otherwise specified.

[a] not placed in level scheme.

† From 1999Gr33

* Reported only in 2002Gr36

5.3 Absolute g-ray emission probabilities

Measurements of the absolute γ-ray emission probability of the 218.12 keV transition from ^{221}Fr α decay are listed in Table7.

Values in 1968Le07, 1986He06 and 1995Sh01 are the only absolute independent measurements. Among these absolute measurements, the one given in 1986He06 is the most precise.

1986He06 measured the γ-ray emission probability in equilibrium with ^{229}Th. ^{229}Th α-decay emits a 218.15-keV γ-ray, therefore this contribution should be subtracted.

1987He28 and 2000Ga52 measured γ-ray emission probabilities from the α-decay of ^{229}Th to ^{225}Ra relatively to I_γ = 4.3 for the 193.5-keV transition. They obtained 0.18 (2) and 0.134 (20) for the 218.15-keV γ-ray, respectively.

The weighted average of these values is 0.146 (20) relative to I_γ(193.5) = 4.3. Using a conversion factor of 1.026 (14) as given by 1987He28, the absolute value is: 0.146 (20) × 1.026 (14) = 0.150 (20) %.

Thus, the corrected absolute γ-ray emission probability of the 218.15-keV γ-ray from ^{221}Fr α decay is 11.57 (15) - 0.150 (20) = 11.42 (15) %, which is our recommended value.

Taking into account the β- branching ratio (see §6), the normalization factor between relative and absolute emission probabilities is N = 11.42 (15) / 0.999952 (15) = 0.1142 (15).

Table 7 - Measured and recommended absolute γ-ray emission probability of 218.12 keV for ^{221}Fr

P_g (218.12 keV)	References	Experimental value and method
12.5 (4)	1968Le07	
13.44 (27)	1981Di14	Ge(Li)
11.57 (15)	1986He06	Ge(Li),Au-Si surface barrier,in equilibrium with ^{229}Th
11.3 (10)	1995Sh01	Ge(Li),α-γ-ce coincidence
11.18 (15)	1999Gr33	Ge(Li),αγ coincidence, using I_α(6126)=15.1 (2) %
11.42 (15)	Recommended	Evaluated value, from 1986He06

[a]: value corrected using the evaluation of 1990Ak05.

The recommended absolute γ-ray emission probabilities are the recommended relative values shown in table 6 multiplied by 0.1142 (15), as given in table 8.

Table 8 - Absolute γ-ray emission probabilities from ^{221}Fr α decay.

E_g (keV)	P_g (%)		E_g (keV)	P_g (%)
53.8	0.0145 (25)		446.3	0.0017 (4)
96.3	0.007 (3)		468.3	0.0018 (3)
100.2	0.156 (13)		537.8	0.0045 (8)
117.8	0.022 (16)		562.3	0.005 (5)
150.2	0.0449 (25)		568.5	0.0012 (4)
171.8	0.069 (9)		576.9	0.0030 (6)
201.4	0.0011 (1)		652	0.0004 (4)
208.3	0.0051 (10)		658	0.0007 (7)
218.1	11.42 (15)		665	0.0009 (9)
282.12	0.0069 (7)		809.3	0.00010 (2)
324.1	0.0174 (12)		891.9	0.000038 (10)
359.9	0.0385 (15)			
382.3	0.0340 (14)			
410.6	0.1204 (25)			
437	0.0010 (1)			

6. b- Branching Ratio

Measured and recommended branching ratios for ^{221}Fr β^- decay are listed in Table 9. Our recommended β^- decay branching ratio from 1997Ch53 is $I_{\beta-}$ = 0.0048 (15) %. Thus, I_α = 99.9952 (15) %.

Table 9 - Measured and recommended branching ratio for ^{221}Fr β^- decay.

I$_{b-}$ **(%)**	**References**
0.0011 (5)	1995Ch74
0.0048 (15)	1997Ch53
0.0048 (15)	Recommended value, from 1997Ch53

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^{223}Fr-Comments on evaluation of the decay data

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This evaluation was completed in 2008. Literature available by December 2008 was included.

1 Decay Scheme

^{223}Fr disintegrates 0.020 (4) % by α emission to levels in ^{219}At and 99.980 (4) % by β^- emission to levels in ^{223}Ra. ^{223}Fr ground state has J^π=3/2(-)(2001Br31).

The α decay scheme of ^{223}Fr was built based on the measurement of 2001Li44. The β^- decay scheme of ^{223}Fr was built based on the measurement of 1993Ab01.

The adopted Q(α) and Q(β^-) values of Audi(2003Au03) are in good agreement with the Q(α) and Q(β^-) values deduced from the decay scheme data.

2 Nuclear Data

The Q values are from the 2003Au03 atomic-mass adjustment.

Level energies have been deduced from a least-squares fit to γ-ray energies (GTOL computer code). Spin and parities are from 2001Br31 and 2001Li44.

The measured and our recommended ^{223}Fr half-life values are listed in Table 1.

Table 1 Measured half-life values of ^{223}Fr and recommended value, in minutes.

$T_{1/2}$ (min)	References	measurement method
22 (1)	1955Ad10	
21.8 (4)	1967Li17	G-M counter
22.00 (7)	1993Ab01	HPGe detector
22.00 (7)	2001Br31	NDS, weighted average of 1967Li17, 1993Ab01
21.93 (7)		Unweighted mean
21.99 (7)		LWM,χ^2=0.12
22.00 (7)		Recommended value, from 1993Ab01

The recommended value is from the measurement of 1993Ab01.

2.1 γ Transitions

The γ-ray transition probabilities were deduced using the γ-ray emission intensities and relevant theoretical internal conversion coefficients.

Multipolarities and mixing ratios of γ-ray transitions for β^- decay are from 2001Br31, for α decay from 2001Li44. The mixing ratio of the 29.78keV γ-ray is from the experimental data of 1990Br23, the uncertainty was assumed to be 10 %.

The internal conversion coefficients (ICC) and their associated uncertainties have been obtained using the BrIcc computer program, which applies the “Frozen Orbital” approximation (2002Ba85).

2.2 α Transitions

The measured and evaluated energies of alpha particles were listed in table 2. The recommended values are from 2001Li44.

Table 2. Measured and recommended values of α-particle energies from ^{223}Fr decay

1955Ad10	2001Li44	recommended
	5462 (3)	5462 (3)
	5403 (3)	5403 (3)
5340 (80)	5314 (4)	5314 (4)
	5291 (4)	5291 (4)
	5172 (5)	5172 (5)

The measured and evaluated alpha particle emission probabilities are listed in table 3. The recommended values are from 2001Li44.

Table 3. Measured and recommended α-particle emission probabilities from ^{223}Fr decay

E_α/keV	$P_\alpha(10^{-4})$		
	2001Li44	Calc.	recommended
5462 (3)	33 (15)	0	33 (15)
5403 (3)	44 (20)	95 (40)	44 (20)
5314 (4)	53 (23)	70 (35)	53 (23)
5291 (4)	60 (26)	60 (30)	60 (26)
5172 (5)	9 (5)	8 (5)	9 (5)

2.3 β^- transition

The maximum energies of the β^- transitions in the decay of ^{223}Fr have been deduced from the Q value (2003Au03) and the level energies.

The adopted ε and β^- transition probabilities and their associated uncertainties were deduced from the γ transition probability balance at each level of the decay scheme.

The electron capture subshell probabilities and *lg ft* values were calculated using the LOGFT program.

3. Atomic data

Atomic fluorescence yields (ω_K,ϖ_L, ϖ_M, η_{KL} and η_{LM}) are from Schönfeld (1996Sc06).

The X-ray and Auger electron emission probabilities have been deduced from γ-ray and conversion electron data using the computer code RADLST. Measured and calculated X-ray emission probabilities are compared in Table 4.

Table 4 Comparison of calculated and measured Ra X-ray emission intensities

	1982AlZL	Adopted (deduced)
$K_{\alpha1}$	2.4 (5)	2.3 (3)
$K_{\alpha2}$	**1.43 (28)**	1.44 (19)

The radium KX-ray emission probabilities, deduced from γ-ray data, agree with the measured values of 1982AlZL, thus confirming the completeness of the decay scheme.

4. Electron Emissions.

The conversion electron emission probabilities have been deduced from γ-ray emission probabilities and theoretical conversion coefficients.

5. Photon Emissions

5.1 γ-ray energy values

There is one measurement of γ-ray energies from ^{223}Fr α decay, that's 2001Li44. Our recommended γ-ray energies from ^{223}Fr α decay are from 2001Li44. The 24.14keV γ-ray, which was observed in ^{223}Fr decay was assigned by evaluators to ^{223}Fr α decay.

The measured and recommended γ-ray energies from ^{223}Fr β^- decay are listed in table 5. The recommended values are from 1993Ab01.

Table 5 Measured and recommended values of γ-ray energies from ^{223}Fr β^- decay

1964Yt01	1967MA19	1982ALZL	1993Ab01	recommended
			20.27 (5)	20.27 (5)
			27.27 (3)[b]	27.27 (3)[b]
			29.78 (4)	29.78 (4)
			31.69 (5)	31.69 (5)
			43.5 (2)	43.5 (2)
			44.0 (1)	44.0 (1)
			49.80 (5)	49.80 (5)
50 (2)	50.8 (5)	50.087 (12)	50.10 (2)	50.10 (2)
	61.0 (15)		61.43 (5)	61.43 (5)
			62.31 (6)	62.31 (6)
			73.5 (1)	73.5 (1)
80 (2)	80.0 (4)	79.651 (13)	79.65 (2)	79.65 (2)
		88.483 (11)	89.08 (10)	89.08 (10)
100 (5)			93.88 (5)	93.88 (5)
			111.05 (3)	111.05 (3)
136 (5)	134.4 (4)	134.641 (22)	134.60 (2)	134.60 (2)
			150.6 (4)[b]	150.6 (4)[b]
			155.5 (5)	155.5 (5)
167 (8)	173.1 (5)	173.393 (38)	173.35 (5)	173.35 (5)
	184.5 (5)	184.693 (38)	184.65 (5)	184.65 (5)
191 (15)			200.7 (2)	200.7 (2)
205 (5)	204.8 (4)	204.948 (15)	204.85 (5)	204.85 (5)
			205.6 (2)	205.6 (2)
			210.60 (5)	210.60 (5)
			218.80 (5)	218.80 (5)
			222.9 (3)[b]	222.9 (3)[b]
234 (3)	234.6 (4)	234.796 (10)	234.70 (5)	234.70 (5)
			236.05 (5)	236.05 (5)
	246 (1)	245.56 (21)	245.60 (5)	245.60 (5)
	250.6 (10)	250.12 (12)	250.25 (5)[a]	250.25 (5)[a]
			254.6 (2)	254.6 (2)
	256 (1)	256.09 (18)	256.18 (5)	256.18 (5)

1964Yt01	1967MA19	1982ALZL	1993Ab01	recommended
			262.9 (2)	262.9 (2)
			269.6 (3)[b]	269.6 (3)[b]
			272.8 (2)	272.8 (2)
			280.7 (5)[a]	280.7 (5)[a]
	286.0 (15)	285.9 (6)	286.0 (2)	286.0 (2)
289 (10)	289.6 (15)	289.73 (10)	289.67 (5)	289.67 (5)
			293.2 (2)[b]	293.2 (2)[b]
			296.5 (2)	296.5 (2)
	300.0 (15)	299.92 (20)	299.95 (5)	299.95 (5)
	304.2 (15)		304.40 (5)	304.40 (5)
	307.3 (15)	307.63 (20)	307.93 (5)[a]	307.93 (5)[a]
	313.3 (15)	312.7 (7)	312.65 (5)	312.65 (5)
			314.6 (2)	314.6 (2)
318 (10)	319.0 (5)	319.266 (22)	319.25 (5)	319.25 (5)
	330.0 (15)		329.80 (5)	329.80 (5)
	333.1 (15)		334.30 (6)	334.30 (6)
	338.7 (10)		339.50 (5)	339.50 (5)
	343.0 (15)		342.50 (7)	342.50 (7)
355 (12)			350.5 (2)	350.5 (2)
	369.0 (5)	369.46 (6)	369.32 (5)	369.32 (5)
			382.3 (2)[b]	382.3 (2)[b]
			434.4 (1)	434.4 (1)
			439.6 (3)	439.6 (3)
			444.5 (3)	444.5 (3)
			452.9 (2)[a]	452.9 (2)[a]
			457.5 (2)	457.5 (2)
			469.3 (2)[a]	469.3 (2)[a]
			475.4 (1)[a]	475.4 (1)[a]
			480.9 (3)	480.9 (3)
			493.4 (2)	493.4 (2)
			506.9 (2)	506.9 (2)
			516.7 (2)	516.7 (2)
			524.8 (2)	524.8 (2)
			533.1 (3)	533.1 (3)
			537.2 (2)[a]	537.2 (2)[a]
			539.8 (2)	539.8 (2)
			545.4 (4)	545.4 (4)
			552.3 (2)	552.3 (2)
			556.3 (3)	556.3 (3)
		568.85 (15)	569.03 (8)	569.03 (8)
			576.1 (4)	576.1 (4)
			581.3 (4)	581.3 (4)
			592.3 (2)	592.3 (2)
			596.9 (4)	596.9 (4)
			600.7 (4)	600.7 (4)

1964Yt01	1967MA19	1982ALZL	1993Ab01	recommended
			607.6 (3)	607.6 (3)
			613.6 (4)	613.6 (4)
			632.7 (3)	632.7 (3)
			663.7 (3)	663.7 (3)
			671.9 (4)	671.9 (4)
			682.3 (3)[b]	682.3 (3)[b]
			694.6 (3)[b]	694.6 (3)[b]
			708.3 (3)	708.3 (3)
	723 (1)	723.7 (7)	722.65 (5)	722.65 (5)
			724.15 (5)	724.15 (5)
			737.4 (3)	737.4 (3)
			742.4 (3)	742.4 (3)
	746.5 (15)	746.3 (9)	746.30 (5)	746.30 (5)
			753.65 (5)	753.65 (5)
	756 (2)		757.20 (5)	757.20 (5)
			762.6 (2)	762.6 (2)
	766.5 (20)	764.7 (7)	766.64 (5)	766.64 (5)
	776.0 (6)	776.0 (7)	775.83 (5)	775.83 (5)
781 (10)			780.8 (1)	780.8 (1)
	784 (2)		784.93 (5)	784.93 (5)
			787.6 (2)[a]	787.6 (2)[a]
	793 (2)		792.2 (3)	792.2 (3)
	797.5 (20)		796.22 (5)	796.22 (5)
		803.7 (7)	803.77 (5)	803.77 (5)
	804 (1)		806.0 (2)	806.0 (2)
	813 (2)	812.0 (10)	812.40 (6)	812.40 (6)
			816.5 (2)	816.5 (2)
	821.5 (25)		823.20 (7)	823.20 (7)
	826 (1)	826.4 (11)	825.95 (7)	825.95 (7)
	835 (2)		833.9 (2)	833.9 (2)
			837.5 (1)	837.5 (1)
	840.5 (20)	842.0 (9)	842.2 (1)	842.2 (1)
	847 (1)	847.7 (10)	846.85 (10)[a]	846.85 (10)[a]
	860 (2)		863.6 (1)	863.6 (1)
	864 (2)		867.4 (1)	867.4 (1)
	876.5 (10	876.2 (10)	876.5 (1)	876.5 (1)
			878.1 (2)	878.1 (2)
	892 (3)		893.1 (2)	893.1 (2)
	897.5 (20)	896.7 (10)	896.7 (2)	896.7 (2)
	908 (2)	907.7 (10)	907.6 (2)	907.6 (2)
			911.3 (2)	911.3 (2)
			913.6 (3)	913.6 (3)
			926.5 (3)	926.5 (3)
			941.2 (3)	941.2 (3)
			949.3 (4)	949.3 (4)

1964Yt01	1967MA19	1982ALZL	1993Ab01	recommended
			958.0 (7)	958.0 (7)
			969.2 (4)	969.2 (4)
			975.2 (5)	975.2 (5)
			978.7 (4)	978.7 (4)
			989.4 (5)	989.4 (5)
			994.3 (3)	994.3 (3)
			999.3 (5)	999.3 (5)
			1025.1 (5)	1025.1 (5)

a: multiply placed. b: not placed in level scheme.

5.2 Relative values of γ-ray intensities

The measured and recommended γ-ray emission probabilities from ^{223}Fr α decay are listed in table 6. The recommended values are from 2001Li44.

Table 6. Measured and recommended values of γ-ray energies and emission probabilities from ^{223}Fr α decay

E_γ (keV)		P_γ (10^{-4} %)	
2001Li44	recommended	2001Li44	recommended
	24.14 (3)		60 (26)[a]
58.9 (2)	58.9 (2)	8 (3)	8 (3)
150.9 (2)	150.9 (2)	56 (5)	56 (5)
145.3 (3)	145.3 (3)	2 (1)	2 (1)

[a]: (γ+ce), from intensity balance.

Measured values of the relative γ-ray intensities, the 234.7 keV being the reference line, from ^{223}Fr β^- decay are listed in Table 7. 1964Yt01 and 1967MA19 are replaced by 1993Ab01, these three references coming from the same group. There is no detailed experimental information in 1982AlZL and only the data table are given. It's noted that among 131 γ-rays, 87 γ-rays are new and observed in 1993Ab01. Compared to 1993Ab01, 1982AlZL did not provide the γ-rays with low energy; their γ-ray intensities are in agreement with those reported by 1993Ab01 for some γ-rays, and for most of the weak γ-rays quite different. Then, the present adopted values are from 1993Ab01.

Table 7 Measured and recommended relative γ-ray intensities from ^{223}Fr β^- decay.

E_γ/keV	I_γ				
	1964Yt01	1967MA19	1982ALZL	1993Ab01	recommended
20.27 (5)				53 (5)	53 (5)
27.27 (3)[b]				2.3 (4)	2.3 (4)
29.78 (4)				2.6 (4)	2.6 (4)
31.69 (5)				0.05	0.05
43.5 (2)				0.08	0.08
44.0 (1)				0.05	0.05
49.80 (5)				93 (8)	93 (8)
50.10 (2)	100	1000	1200 (80)	1224 (50)	1224 (50)
61.43 (5)		< 8		0.13	0.13

E_γ/keV	I_γ				
	1964Yt01	1967MA19	1982ALZL	1993Ab01	recommended
62.31 (6)				0.6 (2)	0.6 (2)
73.5 (1)				0.05 (3)	0.05 (3)
79.65 (2)	32.8 (3)	240 (24)	290 (20)	335 (20)	335 (20)
89.08 (10)			88 (3)	2.0 (1)	2.0 (1)
93.88 (5)			31 (1)	2.2 (3)	2.2 (3)
111.05 (3)			10.6 (4)	0.18 (4)	0.18 (4)
134.60 (2)	1.0 (1)	16.0 (16)	17.3 (10)	18.5 (5)	18.5 (5)
150.6 (4)[b]				0.10 (3)	0.10 (3)
155.5 (5)				0.1	0.1
173.35 (5)	0.6 (1)	4.0 (4)	3.35 (25)	4.26 (5)	4.26 (5)
184.65 (5)		9.0 (9)	7.7 (6)	8.27 (5)	8.27 (5)
200.7 (2)				0.10 (3)	0.10 (3)
204.85 (5)	2.1 (2)	34.0 (34)	30.9 (17)	33.7 (3)	33.7 (3)
205.6 (2)				0.22	0.22
210.60 (5)				0.36 (2)	0.36 (2)
218.80 (5)				0.32 (2)	0.32 (2)
222.9 (3)[b]				0.08 (2)	0.08 (2)
234.70 (5)	8.9 (8)	100	100.0 (35)	100	100
236.05 (5)				1.0 (2)	1.0 (2)
245.60 (5)		1.3 (4)	1.1 (4)	0.71 (3)	0.71 (3)
250.25 (5)[a]		1.3 (4)	1.0 (4)	0.11	0.11
250.25 (5)[a]				0.58	0.58
254.6 (2)				0.21 (2)	0.21 (2)
256.18 (5)		1.3 (4)	1.2 (4)	0.75 (3)	0.75 (3)
262.9 (2)				0.13 (3)	0.13 (3)
269.6 (3)[b]				0.03 (1)	0.03 (1)
272.8 (2)				0.15 (2)	0.15 (2)
280.7 (5)[a]				0.02	0.02
280.7 (5)[a]				0.02	0.02
286.0 (2)		0.52 (15)	0.2	0.17 (2)	0.17 (2)
289.67 (5)	1.4 (2)	7.2 (7)	7.6 (4)	7.7	7.7
293.2 (2)[b]				0.14 (3)	0.14 (3)
296.5 (2)				0.05 (1)	0.05 (1)
299.95 (5)		1.3 (4)	0.57 (13)	0.75 (4)	0.75 (4)
304.40 (5)		0.67 (20)		0.32 (2)	0.32 (2)
307.93 (5)[a]		0.90 (27)	0.7 (3)	0.45 (5)	0.45 (5)
307.93 (5)[a]				0.05 (5)	0.05 (5)
312.65 (5)		0.75 (22)	0.36 (18)	0.60 (5)	0.60 (5)
314.6 (2)				0.08 (2)	0.08 (2)
319.25 (5)	1.9 (3)	16.2 (16)	15.4 (8)	17.0 (5)	17.0 (5)
329.80 (5)		1.0 (3)		0.90 (5)	0.90 (5)
334.30 (6)		0.45 (13)		0.31 (2)	0.31 (2)
339.50 (5)		2.0 (4)		2.3 (2)	2.3 (2)
342.50 (7)		0.90 (27)		0.43 (4)	0.43 (4)

E_γ/keV	I_γ				
	1964Yt01	1967MA19	1982ALZL	1993Ab01	recommended
350.5 (2)	0.3 (1)			0.10 (5)	0.10 (5)
369.32 (5)		3.2 (3)	3.40 (33)	3.3 (2)	3.3 (2)
382.3 (2)[b]				0.03 (1)	0.03 (1)
434.4 (1)				0.08 (2)	0.08 (2)
439.6 (3)				0.011 (3)	0.011 (3)
444.5 (3)				0.04 (1)	0.04 (1)
452.9 (2)[a]				0.03	0.03
452.9 (2)[a]				0.03	0.03
457.5 (2)				0.03	0.03
469.3 (2)[a]				0.04	0.04
469.3 (2)[a]				0.04	0.04
475.4 (1)[a]				0.11	0.11
475.4 (1)[a]				0.1	0.1
480.9 (3)				0.05 (1)	0.05 (1)
493.4 (2)				0.09 (2)	0.09 (2)
506.9 (2)				0.08 (2)	0.08 (2)
516.7 (2)				0.12 (2)	0.12 (2)
524.8 (2)				0.16 (3)	0.16 (3)
533.1 (3)				0.07 (2)	0.07 (2)
537.2 (2)[a]				0.07	0.07
537.2 (2)[a]				0.12	0.12
539.8 (2)				0.22 (5)	0.22 (5)
545.4 (4)				0.011 (3)	0.011 (3)
552.3 (2)				0.10 (2)	0.10 (2)
556.3 (3)				0.04 (1)	0.04 (1)
569.03 (8)			1.9 (3)	1.8 (2)	1.8 (2)
576.1 (4)				0.04 (1)	0.04 (1)
581.3 (4)				0.05 (1)	0.05 (1)
592.3 (2)				0.12 (3)	0.12 (3)
596.9 (4)				0.03 (1)	0.03 (1)
600.7 (4)				0.020 (5)	0.020 (5)
607.6 (3)				0.08 (2)	0.08 (2)
613.6 (4)				0.04 (1)	0.04 (1)
632.7 (3)				0.08 (2)	0.08 (2)
663.7 (3)				0.04 (1)	0.04 (1)
671.9 (4)				0.020 (5)	0.020 (5)
682.3 (3)[b]				0.03 (1)	0.03 (1)
694.6 (3)[b]				0.03 (1)	0.03 (1)
708.3 (3)				0.05 (1)	0.05 (1)
722.65 (5)		1.5 (3)		1.4 (2)	1.4 (2)
724.15 (5)			1.9 (8)	0.52 (8)	0.52 (8)
737.4 (3)				0.033 (8)	0.033 (8)
742.4 (3)				0.04 (1)	0.04 (1)
746.30 (5)		0.70 (15)	0.7 (2)	0.74 (8)	0.74 (8)

E_γ/keV	I_γ				
	1964Yt01	1967MA19	1982ALZL	1993Ab01	recommended
753.65 (5)				0.35 (5)	0.35 (5)
757.20 (5)		0.40 (8)		0.28 (5)	0.28 (5)
762.6 (2)			0.7 (2)	0.09 (2)	0.09 (2)
766.64 (5)		0.80 (16)		0.83 (8)	0.83 (8)
775.83 (5)		12.3 (12)	15.1 (10)	16.8 (5)	16.8 (5)
780.8 (1)	1.9 (2)			0.11 (3)	0.11 (3)
784.93 (5)		0.70 (15)		0.32 (5)	0.32 (5)
787.6 (2)[a]				0.09 (2)	0.09 (2)
787.6 (2)[a]				0.01 (1)	0.01 (1)
792.2 (3)		0.40 (6)		0.020 (5)	0.020 (5)
796.22 (5)		0.30 (6)		0.40 (5)	0.40 (5)
803.77 (5)		1.70 (25)	2.4 (6)	2.2 (3)	2.2 (3)
806.0 (2)				0.05 (1)	0.05 (1)
812.40 (6)		0.60 (9)	0.66 (22)	0.78 (8))	0.78 (8)
816.5 (2)				0.05 (1)	0.05 (1)
823.20 (7)		0.30 (9)		0.26 (3)	0.26 (3)
825.95 (7)		1.4 (2)	2.3 (4)	2.0 (3)	2.0 (3)
833.9 (2)				0.05 (1)	0.05 (1)
837.5 (1)		0.20 (6)		0.36 (4)	0.36 (4)
842.2 (1)		0.20 (6)	0.5	0.18 (2)	0.18 (2)
846.85 (10)[a]		1.4 (2)	2.4 (11)	1.8 (3)	1.8 (3)
846.85 (10)[a]				0.2 (1)	0.2 (1)
863.6 (1)		0.10 (3)		0.14 (2)	0.14 (2)
867.4 (1)				0.06 (1)	0.06 (1)
876.5 (1)		1.3 (2)	1.4 (4)	1.4 (2)	1.4 (2)
878.1 (2)				0.12 (2)	0.12 (2
893.1 (2)		0.10 (3)		0.09 (2)	0.09 (2)
896.7 (2)		0.50 (8)	0.7 (3)	0.50 (5)	0.50 (5)
907.6 (2)		0.40 (7)	0.3	0.53 (5)	0.53 (5)
911.3 (2)				0.03 (l)	0.03 (l)
913.6 (3)				0.015 (5)	0.015 (5)
926.5 (3)				0.06 (1)	0.06 (1)
941.2 (3)				0.11 (2)	0.11 (2)
949.3 (4)				0.012 (3)	0.012 (3)
958.0 (7)				0.013 (3)	0.013 (3)
969.2 (4)				0.012 (3)	0.012 (3)
975.2 (5)				0.006 (2)	0.006 (2)
978.7 (4)				0.025 (5)	0.025 (5)
989.4 (5)				0.005 (1)	0.005 (1)
994.3 (3)				0.004 (1)	0.004 (1)
999.3 (5)				0.007 (2)	0.007 (2)
1025.1 (5)				0.005 (1)	0.005 (1)

[a]: multiply placed. [b]: not placed in level scheme.

5.3 Absolute values of γ-ray emission intensities

The reference gamma-ray line, in the table above, is 234.70 keV. But the measured absolute gamma-ray intensity was given for the 204.8 keV gamma-ray. So the normalization factor N is deduced from the 204.8 keV gamma-ray.

The calculation is:

The measured absolute gamma-ray intensity for the 204.8 keV line (1981Va28) is: P(204.8 keV) = 0.92 (18) %, the recommended relative gamma-ray intensity is I(204.8keV) = 33.7 (3).

So N = P(204.8 keV) / I(204.8 keV) = 0.92 (18) / 33.7 (3) = 0.027 (5).

This value is very close to that calculated with the formula N = 100 / ∑[I(ce+γ)(g.s.) assuming I_{β^-}(g.s.) ≤ 1 %.

So, N has been taken from 1981Va28, that's N = 0.027 (5).

The recommended absolute γ-ray emission probabilities are equal to the relative values given in table 7 multiplied by 0.027 (5).

6. Branching Ratio

The measured and recommended total branching ratios from 223Fr decay are listed in table 8. The recommended value of %α = 0.020 (4) % is from 2001Li44. Thus, %β^- = 99.980 (4) %.

Table 8 Measured and recommended α-branching ratio from ^{223}Fr decay.

I_α /%	References
0.006	1955Ad10
0.020 (4)	2001Li44
0.020 (4)	Recommended value, from 2001Li44

7. References

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^{223}Ra -Comments on evaluation of decay data by V.P. Chechev

Evaluated in December 2010 with a literature cut-off by the same date.

1. DECAY SCHEME

^{223}Ra decays 100 % to levels of ^{219}Rn by emission of α particles, with a very small branch of 6.4 (1) × 10^{-8} % by emission of ^{14}C (1991Ma16). The adopted ^{219}Rn levels populated in the ^{223}Ra α decay are based on the measurement by Sheline *et al.* (1998Sh02) and the *NDS* evaluation by Browne (2001Br31). An intense population takes place only to levels in ^{219}Rn with energy less than 500 keV (11 excited levels and ground state) and, in this part, the decay scheme is well defined, though, at some levels, there is a certain discrepancy in the P(α) values measured and deduced from probability balance.

At the same time, for a number of levels with higher energy there is disagreement between measured probabilities of alpha-transitions and the values deduced from P(γ+ce) balance. Besides, the placement of some γ-rays in the level scheme is uncertain and some observed γ-ray transitions have not been placed. Therefore, in this part the decay scheme cannot be considered as fully completed. Further measurements are needed to determine the γ-ray transitions and ^{223}Ra α decay scheme with greater precision.

The decay scheme overall consistency is verified by the comparison between Q(calc) = 6027 (133) keV, deduced from the evaluated average energies of all emissions, and Q(α) = 5978.99 (21) keV from the atomic mass evaluation of Audi *et al.* (2003Au03). Percentage deviation between Q(calc) and Q(α) is (0.8 ± 2.2) %. The deviation is not big but more than for other α decaying applied radionuclides. This indicates the need in new precise measurements of α-particle and γ-ray transitions in decay of ^{223}Ra.

2. NUCLEAR DATA

Q(α) value is from Audi *et al.* (2003Au03).

The ^{223}Ra half-life is based on the experimental results given in Table 1.

Table 1: Experimental values of ^{223}Ra half-life (in days)

Reference	Author(s)	Original value	Re-estimated	Method
1954Ha60	Hagee *et al.*	11.685 (56)		Proportional α counting
1959Ro51	Robert	11.22 (5)		Microcalorimetry
1965Ki05	Kirby *et al.*	11.4347 (11) [a]	11.4347 (44) [a]	Microcalorimetry
1965Ki05	Kirby *et al.*	11.4267 (62) [b]	11.427 (17) [b]	Proportional α counting
1967JoZX	Jordan and Blanke	11.372 (45)		Calorimetry
1987Mi10	Miller *et al.*	11.444 (46)		From α-activity following ^{227}Th decay

[a] The original value was deduced as a weighted average of the data from observations with two calorimeters: 11.4432 (57) and 11.4344 (11) days. The uncertainties are probable errors of a single observation. To take into account the contribution of possible unrecognized systematic errors associated with the method, the evaluator expanded the uncertainty to a half of the difference of the two experimental results (0.0044 day).

[b] The original value was deduced as a weighted average of the data from observations with a 2π windowless proportional counter for 10 samples. The uncertainties of the 10 measurement results include only statistical errors. To take into account the contribution of possible unrecognized systematic errors associated with the method, for the re-estimated value the evaluator used the smallest uncertainty of 0.017 d stated in the measurements.

From the six values adopted in the data analysis, the LWEIGHT computer program increased the uncertainty in the value of 11.4347 (1965Ki05) to 0.0139 to adjust weights according to the LRSW method and used a weighted average of 11.429 and an external uncertainty of 0.028 (χ^2/ν = 8.05).

The recommended value for the ^{223}Ra half-life is 11.43 (3) days.

2.1. Alpha Transitions

The energies of the alpha transitions have been obtained from the Q(α) value and ^{219}Rn level energies given in Table 2 from 2001Br31, where they were deduced from a least-squares fit to gamma-ray energies.

Table 2: ^{219}Rn levels populated in ^{223}Ra α-decay

Level	Energy (keV)	Spin and parity	Half-life	Probability of α- transition (%)
0	0.0	$5/2^+$	3.96 (1) s	1.0 (2)
1	4.47 (1)	$(9/2)^+$	15.4 (13) ns	-
2	14.37 (1)	$(7/2)^+$	875 (30) ps	0.32 (4)
3	126.77 (2)	$(11/2)^+$	402 (20) ps	10.0 (3)
4	158.64 (1)	$(7/2)^+$	42.3 (50) ps	49.6 (12)
5	269.48 (1)	$3/2^+$	14.2 (23) ps	25.8 (11)
6	338.27 (1)	$(5/2)^+$	6.1 (28) ps	10.6 (10)
7	342.78 (2)	$(5/2, 7/2)^-$		-
8	376.26 (2)	$(9/2)^+$	6.9 (38) ps	0.74 (25)
9	377.33 (6)	$(7/2, 9/2)^-$		-
10	397.1 (4)			≈ 0.008
11	445.03 (1)	$(5/2)^+$	6.2 (31) ps	1.60 (24)
12	446.82 (3)	$(5/2)^-$		0.50 (8)
13	490.92 (2)	$(5/2, 7/2, 9/2)^-$		-
14	514.5 (1)	$(9/2^+)$		≈ 0.13
15	517.7 ?			-
16	541.99 (2)	$(7/2^+)$		≈ 0.13
17	594.1 (1)	$(7/2)^-$		0.16 (4)

18	598.72 (2)	(5/2, 7/2, 9/2)$^+$		0.093
19	623.68 (4)			0.042
20	646.1 (1)			0.041
21	672.6 (5)			0.0053
22	711.3 (1)			0.026
23	732.8 (1)			0.021
24	748			≈ 0.0017
25	773			≈ 6×10^{-4}
26	800			≈ 3×10^{-4}
27	830			≈ 2×10^{-4}
28	851			≈ 4×10^{-4}
29	861			≈ 6.3×10^{-4}
30	873			≈ 4.4×10^{-4}

The recommended values of α-transition probabilities (P(α)) are based on the measurements of 1957Pi31, 1962Gi04, 1962Wa18, 1970Da08 and also on the P(α) values deduced by the evaluator from P(γ+ce) balance at the corresponding ^{219}Rn levels (Table 3).

As the lower part of the decay scheme (^{219}Rn levels with energy less than 500 keV) is reasonably complete and well defined, the probabilities of the prominent α-transitions reaching them have been deduced from P(γ+ce) balances. The uncertainties of the recommended values were expanded, where necessary, to cover the unweighted mean (UWM) of experimental P(α) values.

The probabilities of weak α-transitions (P(α) < 0.0015) have been taken mainly from the measurements of 1962Wa18 with magnetic spectrometer and also from the measurements of 1970Da08 with semiconductor detector. The P(α) values reported in 1962Wa18 have been renormalized to a sum of 100 % by 1970Da08. The uncertainties reported in 1970Da08 are only statistical (from averaging data of three measurements) and comparable with the supposed uncertainties of 1962Wa18, 1962Gi04 and 1957Pi31.

Table 3: Experimental and recommended probabilities (per 100 decays) of alpha-transitions observed in ^{223}Ra α decay

	α-particle energy	1957Pi31	1962Gi04	1962Wa18 [a]	1970Da08	UWM	Deduced from P(γ+ce) balance	**Recommended**
$\alpha_{0,0}$	5871	0.96	1.5	0.85	0.85 (4)	1.04 (16)		**1.0 (2)** [c]
$\alpha_{0,2}$	5858	0.3		0.31	0.32 (4)			**0.32 (4)** [d]
$\alpha_{0,3}$	5747	10.5	10.2	8.85 (18) [b]	9.50 (58)	9.8 (4)	10.0 (3)	**10.0 (3)** [e]
$\alpha_{0,4}$	5716	50.4	48.0	52.2 (11) [b]	52.5 (8)	50.8 (10)	49.6 (9)	**49.6 (12)** [e]
$\alpha_{0,5}$	5607	23.6	25.7	25.3 (5) [b]	24.2 (4)	24.7 (5)	25.8 (6)	**25.8 (11)** [e]
$\alpha_{0,6}$	5540	10.3	10.2	8.85 (18) [b]	9.16 (30)	9.6 (4)	10.60 (17)	**10.6 (10)** [e]
$\alpha_{0,8}$	5502	0.86	1.3	0.78	1.00 (15)	0.99 (11)	0.74 (3)	**0.74 (25)** [e]
$\alpha_{0,10}$	5481			≈ 0.008			0.0007 (4)	**≈ 0.008**
$\alpha_{0,11}+\alpha_{0,12}$	5434	2.4	2.5	2.24	2.27 (20)	2.35 (6)	2.10 (9)	**2.10 (25)** [e]

	α-particle energy	1957Pi31	1962Gi04	1962Wa18 [a]	1970Da08	UWM	Deduced from P(γ+ce) balance	**Recommended**
$\alpha_{0,14}$	5366	0.20	} Σ 0.25	0.108	≈ 0.13	0.15 (3)	0.014 (7)	**≈ 0.13** [d]
$\alpha_{0,16}$	5339	0.07		0.098	≈ 0.13	0.099 (17)	0.089 (6)	**≈ 0.13** [d]
$\alpha_{0,17}$	5287	} Σ 0.3	} Σ 0.3	0.126	≈ 0.16		0.16 (4)	**0.16 (4)** [e]
$\alpha_{0,18}$	5283			0.093				**0.093**
$\alpha_{0,19}$	5259			0.042			0.079 (8)	**0.042**
$\alpha_{0,20}$	5236			0.041			0.022 (4)	**0.041**
$\alpha_{0,21}$	5212			0.0053			0.0011 (6)	**0.0053**
$\alpha_{0,22}$	5173			0.026			0.013 (4)	**0.026**
$\alpha_{0,23}$	5152			0.021			0.0134 (27)	**0.021**
$\alpha_{0,24}$	5135			≈ 0.0017				**≈ 0.0017**
$\alpha_{0,25}$	5112			≈ 0.0006				**≈ 0.0006**
$\alpha_{0,26}$	5086			≈ 0.0003				**≈ 0.0003**
$\alpha_{0,27}$	5056			≈ 0.0002				**≈ 0.0002**
$\alpha_{0,28}$	5036			≈ 0.0004				**≈ 0.0004**
$\alpha_{0,29}$	5026			≈ 0.00063				**≈ 0.00063**
$\alpha_{0,30}$	5014			≈ 0.00044				**≈ 0.00044**

[a] Authors did not report individual uncertainties for intensity of each α-particle group but stated the relative uncertainty of 2 % for intense α-lines and 10 % for weak α-lines.

[b] Uncertainty given by Rytz (1991Ry01).

[c] Value recommended by Rytz (1991Ry01)

[d] Adopted from 1970Da08.

[e] Deduced from P(γ+ce) balance. Uncertainties were expanded to cover UWM of experimental P_α values.

The α decay hindrance factors have been calculated using the ALPHAD computer program from the ENSDF evaluation package with $r_0(^{219}Rn)$ = 1.543 fm (2001Br31).

2.2. Gamma Transitions and Internal Conversion Coefficients

The recommended energies of the gamma-ray transitions are the same as those of the gamma-ray energies corrected by the minor nuclear recoil of ^{219}Rn.

The gamma-ray transition probabilities (P(γ+ce)) have been deduced from their evaluated gamma-ray emission probabilities (P(γ)) and total internal conversion coefficients (ICCs).

ICCs have been interpolated using the BrIcc computer program, version v2.2a, with the "frozen orbital" approximation (2008Ki07). Multipolarities of the gamma-ray transitions and E2/M1 mixing ratios (δ) are those deduced by 2001Br31, on the basis of measurements of conversion electrons (ce) by 1970Da08, 1970Kr01, 1972HeYM, 1974Ri05, and 1998Sh02.

P(γ+ce) values for the gamma-ray transitions $\gamma_{1,0}$ (4.4 keV), $\gamma_{9,7}$ (34.5 keV) and $\gamma_{22,18}$ (112.6 keV) have been deduced from probability balances at the ^{219}Rn ground state (level '0'), level '7' (342.8 keV) and level '18' (598.7 keV), respectively.

3. ATOMIC DATA

The fluorescence yields, X-ray energies and relative probabilities, and Auger energies and relative probabilities are from the SAISINUC software.

4. ALPHA EMISSIONS

The recommended energies of alpha particles have been deduced from the Q(α) value, taking into account the recoil energies for ^{219}Rn.

The recommended α-particle energies are compared in Table 4 with the experimental results from spectrometric measurements by 1957Pi31, 1961Ry02, 1962Wa18, 1964Wa19, 1970Da08, and 1971Gr17.

Table 4: Experimental and recommended α-particle energies (keV) in the decay of ^{223}Ra [a]

	1957Pi31	1961Ry02	1962Wa18 [b]	1964Wa19	1970Da08	1971Gr17	**Recommended**
$\alpha_{0,0}$	5870 (2)		5871.6 (10)	5869.5 (17)	5871 (3)		**5871.63 (21)**
$\alpha_{0,2}$	5856		5857.5 (10)		5857 (3)		**5857.52 (21)**
$\alpha_{0,3}$	5745 (2)	5745.5	5747.4		5747 (3)	5747.0 (4)	**5747.14 (21)**
$\alpha_{0,4}$	5715	5714.3	5716.1		5715 (3)	5716.23 (29)	**5715.84 (21)**
$\alpha_{0,5}$	5605	5605.3	5607.1		5606 (3)	5606.73 (30)	**5606.99 (21)**
$\alpha_{0,6}$	5537	5537.1	5539.6		5537 (3)	5539.8 (9)	**5539.43 (21)**
$\alpha_{0,8}$	5500		5501.6 (10)		5501 (3)		**5502.12 (21)**
$\alpha_{0,11}$	5432		5433.6 (5)		5435 (3)		**5434.59 (21)**
$\alpha_{0,14}$	5363		5365.6 (10)		5367 (3)		**5366.37 (23)**
$\alpha_{0,16}$	5337		5338.7 (10)		5339 (3)		**5339.37 (21)**
$\alpha_{0,17}$	5287		5287.3 (10)		5288 (3)		**5288.19 (23)**

[a] Authors' experimental values have been adjusted for changes in calibration energies following 1977Ma31 and 1991Ry01.

[b] Uncertainties of 1962Wa18 are the values estimated by 1977Ma31.

5. ELECTRON EMISSIONS

The energies of the conversion electrons have been obtained from the gamma-ray transition energies and the atomic electron binding energies from 1977La19. The emission probabilities of the conversion electrons have been deduced using the evaluated P(γ) and ICC values. Measurements of the ^{219}Rn conversion electrons were carried out by 1969Be67, 1970Da08, 1970Kr01, 1972HeYM, 1974Ri05, and 1998Sh02.

The total absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program (1996Sc06, 2000Sc47).

6. PHOTON EMISSIONS

6.1 X - Ray emissions

The absolute emission probabilities of Rn KX- and LX-rays were calculated using the EMISSION computer program (Table 5). In 1976Bl13 the emission probabilities of Rn KX-rays were measured relatively to Pγ ($\gamma_{5,0}$ 269.5 keV). The experimental absolute P(KX) values are given in Table 5 using the evaluated Pγ ($\gamma_{5,0}$ 269.5 keV) = 14.23 (15) %.

Table 5: Experimental (1976Bl13) and calculated absolute Rn KX-ray emission probabilities (%)

	1976Bl13	Calculated
$K\alpha_2$ (Rn)	11.5 (13)	14.86 (23)
$K\alpha_1$ (Rn)	19.4 (24)	24.5 (4)
$K\beta'_1$ (Rn)	9.4 (7)	8.50 (18)
$K\beta'_2$ (Rn)	1.71 (14)	2.72 (7)

6.2. Gamma emissions

6.2.1. Gamma-ray energies

The gamma-ray energies (E_γ) for $\gamma_{1,0}$ (4.5 keV), $\gamma_{2,1}$ (9.9 keV), $\gamma_{2,0}$ (14.4 keV), $\gamma_{4,3}$ (31.9 keV), $\gamma_{12,7}$ (104.0 keV), $\gamma_{4,2}$ (144.3 keV), $\gamma_{8,3}$ (249.5 keV), $\gamma_{7,0}$ (342.8 keV), $\gamma_{8,2}$ (361.9 keV), $\gamma_{9,1}$ (372.9 keV), $\gamma_{8,0}$ (376.3 keV), $\gamma_{16,4}$ (383.4 keV), $\gamma_{12,2}$ (432.4 keV), $\gamma_{16,0}$ (542.0 keV), and $\gamma_{19,0}$ (623.7 keV) have been deduced directly from the adopted ^{219}Rn level energies.

The remaining gamma-ray energies have been taken mainly from 2001Br31. They are weighted averages of the experimental values from 1998Sh02, 1976Bl13, 1972HeYM, 1970Da08, 1970Kr01, and 1968Br17, except as specified otherwise in footnotes of Table 6. The most precise measurements of E_γ from 1976Bl13 with Ge(Li) detector dominate the weighted averages.

Less accurate measurements of E_γ were reported in 1957Pi31, 1957Pa07, 1966Po02, 1969Be67, they were not used in the evaluation.

It should be noted that in 2001Br31 many questionable unplaced gamma-ray transitions are given from some spectrometric measurement results published in the above references, but they have not been yet confirmed by other authors. Observation of such gamma-ray transitions may be assigned to daughters of ^{223}Ra or other isotope impurities and most of these gamma-rays have not been included in the current evaluation. The criterion for their inclusion was an observation in α-γ high resolution coincidence with planar and high efficiency coaxial Ge detectors in the latest experiment by 1998Sh02.

6.2.2. Gamma-ray emission probabilities

The experimental and evaluated relative emission probabilities (I_γ) of gamma-rays in decay of ^{223}Ra are presented in Table 6. The adopted values are the weighted means of the experimental values except when noted. The statistical processing was done using the LWEIGHT computer program. The uncertainties assigned in this evaluation to the recommended values are always greater than or equal to the smallest uncertainty in any of the experimental values used in the calculation.

The normalization factor (N) was obtained from the probability balance to the ^{219}Rn ground state (level ‘0’) and excited levels ‘1’ (4.5 keV) and ‘2’ (14.4 keV):

$\Sigma(1+\alpha T)I_\gamma\,(\gamma_{i,0}\,,\,\gamma_{j,1}\,,\,\gamma_{k,2}) + P(\alpha_{0,0}) + P(\alpha_{0,2}) = 1$

where i = 4, 5, 6, 7, 8, 11, 16, 17, 18, 19, 20, 22, 23;

j = 3, 4, 6, 8, 9, 14, 16, 19, 20, 23;

k=4, 5, 6, 7, 8, 9, 11, 12, 14, 16, 17, 18, 19, 20, 22, 23.

N = P(γ) (269.5 keV) = 0.1423 (15).

This adopted value can be compared with the measured Pγ (269.5 keV) of 0.140 (15) (1968Br17) and the value of 0.136 (10) (1970Da08) deduced from an α-feed of the 269 keV level in ^{219}Rn.

The absolute gamma-ray emission probabilities (P(γ)) have been deduced from the evaluated relative gamma-ray emission probabilities (Table 6) using the derived normalization factor of 0.1423 (15).

P(γ) values for the gamma-ray transitions $\gamma_{2,1}$ (9.9 keV) and $\gamma_{2,0}$ (14.4 keV) have been obtained directly from probability balance at the ^{219}Rn level ‘2’ (14.4 keV) and the ratio of $P(\gamma_{2,1}$ - 9.9 keV)/$P(\gamma_{2,0}$ - 14.4 keV) = 0.86 (9) deduced from measured ratio of intensities of conversion electrons (1974Ri05) and the ratio of theoretical ICCs.

Pγ value for the gamma-ray transition $\gamma_{1,0}$ (4.5 keV) has been estimated from Pγ+ce using the total theoretical ICC α_T.

Table 6: Recommended energies (E_γ) and experimental and evaluated relative emission probabilities (I_γ) of gamma-rays in decay of ^{223}Ra

	Recommended E_γ (keV)	1968Br17	1970Kr01	1970Da08	1972HeYM	1976Bl13	1998Sh02	Evaluated I_γ
$\gamma_{1,0}$	**4.47 (1)** [a]							
$\gamma_{2,1}$	**9.90 (2)** [a]							
$\gamma_{2,0}$	**14.37 (1)** [a]							
$\gamma_{4,3}$	**31.87 (2)** [a]		0.000 74 (15)				0.001	**0.000 74 (15)**
$\gamma_{9,7}$	**34.5 (2)** [b]							
$\gamma_{12,9}$	**69.5 (1)** [b]						0.05 (2)	**0.05 (2)**
$\gamma_{15,12}$	**70.9 (2)** [b]						0.025 (8)	**0.025 (8)**
$\gamma_{11,7}$	**102.2 (2)** [b]						0.006 (3)	**0.006 (3)**
$\gamma_{17,13}$	**103.2 (2)** [b]	0.100 (14) [e]			0.12 (7) [e]		0.04 (2)	**0.04 (2)**
$\gamma_{12,7}$	**104.04 (4)** [a]					0.134 (15)	0.14 (2)	**0.136 (15)**
$\gamma_{11,6}$	**106.78 (3)**	0.164 (29)	0.14 (3)	0.16 (4)	0.19 (6)	0.157 (15)	0.17 (1)	**0.164 (10)**
$\gamma_{12,6}$	**108.5 (2)** [b]						0.04 (2)	**0.04 (2)**
$\gamma_{5,4}$	**110.856 (10)**	0.40 (6)	0.331 (29) [f]	0.41 (4)	0.21 (9) [f]	0.40 (4)	0.42 (3)	**0.41 (3)**
$\gamma_{22,18}$	**112.6** [c]							
$\gamma_{13,8}$	**114.7 (2)**				0.07 (4)		0.07 (3)	**0.07 (3)**
$\gamma_{3,1}$	**122.319 (10)**	8.2 (11)	8.75 (15)	9.8 (10)	8.7 (4)	7.5 (8)	8.7 (1)	**8.70 (10)**
$\gamma_{20,14}$	**131.6 (2)**				0.037 (22)		0.04 (2)	**0.04 (2)**
$\gamma_{14,8}$	**138.3 (3)** [b]						0.012 (5)	**0.012 (5)**
$\gamma_{4,2}$	**144.27 (2)** [a]	22.1 (21)	23.8 (5)	23.0 (24)	27.4 (18) [f]	21.6 (22)	23.5 (5)	**23.6 (5)**
$\gamma_{17,12}$	**147.2 (2)** [b]						0.04 (2)	**0.04 (2)**
$\gamma_{4,1}$	**154.208 (10)**	38.6 (29)	41.1 (8)	38 (4)	44.4 (26)	38 (4)	41 (1)	**41.0 (8)**
$\gamma_{4,0}$	**158.635 (10)**	5.0 (5)	5.02 (10)	5.6 (6)	5.3 (4)	4.6 (4)	5.0 (1)	**5.01 (10)**
$\gamma_{16,8}$	**165.8 (2)**				0.037 (22)		0.04 (2)	**0.038 (20)**

	Recommended E_γ (keV)	1968Br17	1970Kr01	1970Da08	1972HeYM	1976Bl13	1998Sh02	Evaluated I_γ
$\gamma_{11,5}$	**175.65 (15)**		0.10 (3)		0.15 (4)		0.14 (3)	**0.12 (3)**
$\gamma_{12,5}$	**177.3 (1)**	0.21 (7)	0.34 (3)		0.35 (6)		0.34 (3)	**0.33 (3)**
$\gamma_{6,4}$	**179.54 (6)**	1.07 (29)	1.07 (29)	1.10 (13)	1.16 (15)	1.01 (10)	1.1 (1)	**1.08 (10)**
$\gamma_{20,12}$	**199.3 (3)**				0.022 (15)		0.02 (1)	**0.021 (10)**
$\gamma_{18,9}$	**221.32 (24)**	0.25 (7)	0.22 (4)		0.25 (4)		0.26 (4)	**0.25 (4)**
$\gamma_{19,8}$	**247.2 (5)**				0.066 (22)		0.07 (2)	**0.068 (20)**
$\gamma_{8,3}$	**249.49 (3)** [a]	0.26 (7)			0.29 (13)		0.28 (7)	**0.27 (7)**
$\gamma_{17,7}$	**251.6 (3)**	0.49 (11)	0.27 (7)	0.42 (15)	0.49 (15)	0.47 (7)	0.3 (1)	**0.39 (7)**
$\gamma_{5,2}$	**255.2 (2)**	0.43 (11)		0.37 (15)	0.24 (7)	0.33 (7)	0.38 (5)	**0.34 (5)**
$\gamma_{17,6}$	**255.7 (3)**				0.037 (22)		0.04 (2)	**0.039 (20)**
$\gamma_{18,6}$	**260.4 (3)**				0.044 (22)		0.05 (2)	**0.047 (20)**
$\gamma_{5,0}$	**269.463 (10)**	100 (11)	100 (2)	100 (7)	100 (4)	100 (4)	100 (2)	**100 (2)**
$\gamma_{10,3}$	**270.3 (4)** [b]						0.005 (3)	**0.005 (3)**
$\gamma_{23,12}$	**286.0 (4)** [b]						0.008 (4)	**0.008 (4)**
$\gamma_{12,4}$	**288.18 (3)**	1.14 (14)	1.16 (5)	1.08 (12)	0.93 (13) [f]	1.07 (5)	1.15 (3)	**1.13 (3)**
$\gamma_{6,2}$	**323.871 (10)**	26.5 (29)	29.4 (6)	26.5 (26)	26.8 (11)	26.8 (13)	28.7 (5)	**28.5 (5)**
$\gamma_{7,2}$	**328.38 (3)** [a]	1.43 (14)	1.52 (7)	1.19 (24)	1.18 (18)	1.40 (8)	1.5 (5)	**1.43 (7)**
$\gamma_{6,1}$	**334.01 (6)**	0.61 (9)	0.76 (6)	0.91 (18)	0.69 (11)	0.54 (7)	0.73 (4)	**0.70 (4)**
$\gamma_{6,0}$	**338.282 (10)**	19.3 (18)	21 (5)	19.0 (20)	19.2 (7)	18.5 (9)	20.4 (4)	**20.0 (4)**
$\gamma_{7,0}$	**342.78 (2)** [a]	1.43 (14)	1.70 (9)	1.5 (4)	0.71 (16) [f]	1.49 (12)	1.6 (1)	**1.59 (9)**
$\gamma_{23,9}$	**355.5 (2)** [b]						0.03 (1)	**0.03 (1)**
$\gamma_{14,4}$	**355.7 (2)** [b]						0.02 (1)	**0.02 (1)**
$\gamma_{8,2}$	**361.89 (2)** [a]	0.29 (7)	0.34 (4)	0.37 (7)	0.24 (6)	0.298 (22)	0.20 (5)	**0.20 (5)** [g]
$\gamma_{9,2}$	**362.9 (2)** [b]						0.11 (5)	**0.11 (5)**
$\gamma_{22,7}$	**368.56 (12)**				0.06 (3)		0.06 (3)	**0.06 (3)**
$\gamma_{8,1}$	**371.676 (15)**	3.9 (4)	3.56 (7)	4.0 (6)	4.2 (4)	3.14 (16)	3.5 (1)	**3.51 (7)**

	Recommended E_γ (keV)	1968Br17	1970Kr01	1970Da08	1972HeYM	1976Bl13	1998Sh02	Evaluated I_γ
$\gamma_{9,1}$	**372.86 (1)** [a,b]	≈ 0.7				0.73 (8)	0.36	**0.36** [i]
$\gamma_{8,0}$	**376.26 (2)** [a]			0.088 (29)			0.09 (3)	**0.09 (3)**
$\gamma_{16,4}$	**383.35 (2)** [a]	≈ 0.04		0.11 (4)	0.029 (22)		-	**0.05 (3)**
$\gamma_{14,3}$	**387.7 (2)**				0.10 (4)		0.11 (4)	**0.11 (4)**
$\gamma_{23,7}$	**390.1 (2)**	≈ 0.05			0.022 (15)		0.05 (2)	**0.032 (15)**
$\gamma_{11,2}$	**430.6 (3)**				0.14 (4)		0.14 (4)	**0.14 (4)**
$\gamma_{12,2}$	**432.45 (3)** [a]	0.24 (3)	0.26 (4)	≈0.22	0.24 (6)	0.186 (30) [f]	0.25 (2)	**0.25 (2)**
$\gamma_{11,0}$	**445.033 (12)**	8.7 (4)	11.0 (8) [f]	9.3 (10)	9.2 (7)	8.5 (4)	9.3 (3)	**9.0 (3)**
$\gamma_{20,4}$	**487.5 (2)**	0.071 (14)	0.10 (4)	≈0.11	0.08 (4)		0.08 (1)	**0.08 (1)**
$\gamma_{-1,1}$	**490.8 (3)** [b]						0.012 (5)	**0.012 (5)**
$\gamma_{14,2}$	**500.0 (4)** [b]						0.010 (4)	**0.010 (4)**
$\gamma_{14,1}$	**510.0 (4)** [b]						0.003 (2)	**0.003 (2)**
$\gamma_{-1,2}$	**523.2 (4)** [b]						0.010 (4)	**0.010 (4)**
$\gamma_{16,2}$	**527.611 (13)**	0.50 (5)	0.54 (5)	0.51 (10)	0.47 (11)	0.410 (22) [f]	0.51 (3)	**0.51 (3)**
$\gamma_{-1,3}$	**532.9 (4)** [b]						0.010 (4)	**0.010 (4)**
$\gamma_{16,1}$	**537.6 (1)** [b]						0.015 (5)	**0.015 (5)**
$\gamma_{16,0}$	**541.99 (2)** [a,b]						0.010 (4)	**0.010 (4)**
$\gamma_{21,3}$	**545.8 (5)** [b]						0.008 (4)	**0.008 (4)**
$\gamma_{23,4}$	**574.1 (7)** [b]						0.008 (4)	**0.008 (4)**
$\gamma_{17,2}$	**579.6 (3)** [b]						0.010 (4)	**0.010 (4)**
$\gamma_{18,2}$	**584.3 (3)** [b]						0.010 (4)	**0.010 (4)**
$\gamma_{17,0}$	**594.0 (3)** [b]						0.010 (4)	**0.010 (4)**
$\gamma_{18,0}$	**598.721 (24)**	0.57 (6)	0.76 (7)	0.68 (11)	0.66 (13)	0.626 (30)	0.68 (3)	**0.65 (3)**
$\gamma_{19,2}$	**609.31 (4)**	0.36 (4)	0.54 (7)	0.46 (7)	0.30 (11)	0.373 (22)	0.41 (2)	**0.40 (2)**
$\gamma_{19,1}$	**619.1 (4)** [b]						0.025 (8)	**0.025 (8)**
$\gamma_{19,0}$	**623.68 (4)** [a]	0.057 (29)					0.06 (3)	**0.06 (3)**

	Recommended E_γ (keV)	1968Br17	1970Kr01	1970Da08	1972HeYM	1976Bl13	1998Sh02	Evaluated I_γ
$\gamma_{20,2}$	**631.7 (7)**			0.22 (7)			0.003 (2)	**0.003 (2)**
$\gamma_{20,1}$	**641.7 (4)** [b]						0.012 (5)	**0.012 (5)**
$\gamma_{20,0}$	**646.1 (5)** [b]						0.003 (3)	**0.003 (3)**
$\gamma_{22,2}$	**696.9 (7)** [b]						0.005 (2)	**0.005 (2)**
$\gamma_{22,0}$	**711.3 (2)** [b]	0.025 (7)					0.026 (7)	**0.026 (7)**
$\gamma_{23,2}$	**718.4 (4)** [b]						0.010 (4)	**0.010 (4)**
$\gamma_{23,1}$	**728.4 (8)** [b]						0.002 (1)	**0.002 (1)**
$\gamma_{23,0}$	**732.8 (6)** [b]						0.004 (2)	**0.004 (2)**
$\gamma_{-1,4}$	**737.2 (8)** [b]						0.002 (1)	**0.002 (1)**

[a] From the adopted ^{219}Rn level energies.
[b] From 1998Sh02; new gamma-ray transition observed.
[c] Reported only by 1998Sh02 without uncertainty in energy and without intensity value.
[d] Not reported by 1998Sh02 but observed in 1968Br37, 1970Da08, 1972HeYM, 1976Bl13.
[e] Reported γ-ray with energy of 103.7 keV that may be a sum of 103.2 keV and 104.0 keV γ-rays.
[f] Omitted on Chauvenet’s criterion.
[g] Adopted from 1998Sh02 because of possible contribution of impurity Pb γ-rays in measurements of single γ-spectra.
[h] Adopted from 1998Sh02 because of contribution of unplaced 373.3 keVγ-ray observed in measurements of single γ-spectra and not observed in α-γ coincidences.

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^{224}Ra – Comments on evaluation of decay data
by A. L. Nichols

Evaluated: July/August 2001
Re-evaluated: January 2004 and April 2010

Evaluation Procedures

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

Decay Scheme

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) 10^{-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 least-squares weighted mean of two somewhat elderly studies (1962Ll02 and 1971Jo14) and a much more recent measurement (2004Sc04). Further measurements are required to determine this half-life with greater confidence.

Reference	Half-life (d)
1962Ll02	3.62 (1)
1971Jo14	3.665 (38)
2004Sc04	3.6319 (23)
Recommended value	3.631 (2)

There is no evidence of any change in the half-life of ^{224}Ra on extreme cooling of ^{224}Ra samples within a metallic environment (2007St23). Sources were held at temperatures at and below 1 kelvin for periods of several days, and exhibited an upper limit of change in the alpha-decay half-life of the order of 1 %.

Alpha Particles

Energies

All alpha-particle energies were derived from the structural details of the proposed decay scheme. While the energies of the two main alpha-particle emissions have been directly measured by 1962Ba19, 1962Wa28, 1971Gr07 and 1991Ry01, the nuclear level energies of 1997Ar04 and evaluated Q-value of 5788.85 (15) keV (2003Au03) were used to determine the recommended energies and uncertainties of the alpha-particle emissions, and by allowing for the significant recoil components.

Adopted nuclear levels of ^{220}Rn: J$^{\pi}$ and origins (1997Ar04).

Nuclear level	Nuclear level energy (keV)	J$^{\pi}$	Origins
0	0.0	0 +	^{220}At β^{-} decay, ^{224}**Ra α decay**
1	240.986 ± 0.006	2 +	^{220}At β^{-} decay, ^{224}**Ra α decay**
2	533.69 ± 0.10	4 +	^{220}At β^{-} decay, ^{224}**Ra α decay**
3	645.44 ± 0.09	1 –	^{220}At β^{-} decay, ^{224}**Ra α decay**
4	663.03 ± 0.10	(3 –)	^{220}At β^{-} decay, ^{224}**Ra α decay**

Measured and recommended energies of the main alpha-particle emissions of ^{224}Ra.

	E$_{\alpha}$ (keV)				
	1962Ba19	**1962Wa28**	**1971Gr07**	**1991Ry01**	**Recommended value***
$\alpha_{0,1}$	5447.2 (12)	5447	–	5448.6 (9)	5448.80 (15)
$\alpha_{0,0}$	5684.0 (12)	5684	5685.56 (20)	5685.37 (15)	5685.48 (15)

* Determined from the nuclear level energies of 1997Ar04 and evaluated Q-value of 5788.85 (15) keV (2003Au03).

Emission Probabilities

The alpha-particle emission probability to the first excited state of ^{220}Rn has been directly measured by 1969Pe17, 1971So15, 1984Bo15 and 1993Ba72. These data were also used to calculate the alpha-particle emission probability directly to the ground state of ^{220}Rn:

The emission probability data of 1969Pe17 for the 5685.48- and 5448.80-keV alpha particles have been effectively normalized to 94.95 (5) % and 5.05 (5) %, similarly for the equivalent data of 1971So15 with normalized values of 95.1 (4) % and 4.9 (4) %, and 1984Bo15 with normalized values of 94.94 (4) % and 5.06 (4) %. Equivalent relative emission probabilities measured by 1993Ba72 also require normalization to give P$_{\alpha}$(5448.80 keV) of 4.93 (4) % and P$_{\alpha}$(5685.48 keV) of 95.10 (4) %. These alpha spectrometry measurements by 1969Pe17, 1971So15, 1984Bo15 and 1993Ba72 can be used to determine a weighted mean P$_{\alpha}$(5685.48 keV) of 95.00 (4) % (0.9500 (4)) that can be matched with a value of 5.01 (4) % (0.0501 (4)) for P$_{\alpha}$(5448.80 keV). However, these data were not adopted – both the measurement and spectral analysis techniques used to determine the gamma-ray emission probabilities were judged to be more reliable, and therefore preference was given to alpha-particle emission probabilities derived by calculation from the recommended gamma-ray emission probabilities and their theoretical internal conversion coefficients.

Alpha-particle emission probabilities per 100 disintegrations of ^{224}Ra.

E$_{\alpha}$(keV)	P$_{\alpha}$						
	1953As31	**1962Wa28**	**1969Pe17**	**1971So15**	**1977Ku15#**	**1984Bo15**	**1993Ba72**
5034.29 (18)	-	0.0031	-	-	0.0029 (5)	-	-
5051.56 (17)	-	0.0072	-	-	0.0073 (10)	-	-
5161.32 (18)	-	0.0073	-	-	0.0069 (8)	-	-
5448.80 (15)	4.9	5.5	5.05 (5)	4.9 (4)	[5.00 (16)]	5.06 (4)	[4.93 (3)]¶
5685.48 (15)	95.1	94	94.95 (5)	95.1 (4)	[94.98 (16)]	94.94 (4)	[95.1 (6)]¶

Data were deduced from gamma-ray studies.

¶ Data are relative, and were adjusted to P_{α}^{abs} (5685.50 keV) of 95.10 (4) and P_{α}^{abs} (5448.80 keV) of 4.93 (4).

Alpha-particle emission probabilities per 100 disintegrations of ^{224}Ra, and hindrance factors.

E_α(keV)	P_α						HF
	1969Pe17	1971So15	1984Bo15	1993Ba72	LWM value#	Recommended value*	
5034.29 (18)	-	-	-	-	-	0.0030 (5)	6.4
5051.56 (17)	-	-	-	-	-	0.0076 (10)	3.7
5161.32 (18)	-	-	-	-	-	0.0072 (8)	17.9
5448.80 (15)	5.05 (5)	4.9 (4)	5.06 (4)	4.93 (4)	5.01 (4)	5.25 (5)	1.04
5685.48 (15)	94.95 (5)	95.1 (4)	94.94 (4)	95.10 (4)	95.00 (4)	94.73 (5)	1.00

Limitation of relative statistical weight method applied to the measured alpha-particle emission probabilities, with the uncertainty adjusted from ± 0.03 to ± 0.04 so as not to fall below the lowest measured uncertainty.

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

There is an unsatisfactory lack of agreement between derivations of the decay scheme by means of the measured gamma-ray emission probabilities, compared with an equivalent procedure involving the measured alpha-particle emission probabilities:

(i) assuming that the measured gamma-ray emission probabilities are absolute (as quoted in the various references), the LWM of P_γ(240.986 keV) is 0.0412 (4), NF = 1.000, and balanced population-depopulation of the 240.986-keV nuclear level of ^{220}Rn provides a means of determining P_α(5685.48 keV) of 0.9473 (5):

P_α(5448.80 keV)

$$= P_\gamma(240.986 \text{ keV})[1 + \alpha_{tot}(240.986 \text{ keV})] - [\Sigma P_{\gamma i}(1 + \alpha_i) \text{ populating nuclear level}]$$

$$= [0.0412\ (4) \times 1.276\ (4)] - 0.000\ 124\ (11) = 0.0524\ (5),$$

and P_α(5685.48 keV) = 0.9473 (5).

(ii) if an absolute least-squares weighted mean value for P_α(5685.48 keV) of 0.9500 (4) is adopted from the alpha-particle measurements of 1969Pe17, 1971So15, 1984Bo15 and 1993Ba72, NF = 0.95 (5) and P_γ(240.986 keV) is 0.0392 (4) (also defined as 3.92 (4) %).

The measured gamma-ray emission probability data were judged to be more reliable – this important decision is based on the assumed superiority of the gamma-ray spectroscopic procedures and spectral analysis techniques in the 1970s/1980s. Thus, the recommended alpha-particle emission probabilities were determined from the gamma-ray data and theoretical internal conversion coefficients, rather than the available alpha-particle measurements. These gamma-ray calculations resulted in an absolute emission probability of 0.0525 (5) for the 5448.80-keV alpha particle (compared with a least-squares weighted mean value of 0.0501 (4) from the alpha-particle measurements that represents a difference of 4.6 %), and 0.9473 (5) for the 5685.48-keV alpha particle (compared with a least-squares weighted mean value of 0.9500 (4) from the alpha-particle measurements that represents a difference of only 0.3 %). Although not recommended, note is also made that combining the two different sets of data results in weighted means of 0.0513 (12) for P_α(5448.80 keV), and 0.9487 (13) for P_α(5685.48 keV).

A hindrance factor (HF) of 1.00 for the 5685.48-keV alpha-particle emission yields r_0(^{220}Rn) of 1.5421 (1), which was adopted in the equivalent HF calculations for the other alpha emissions.

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.

<u>Emission Probabilities</u>

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 39 500 (1 300) 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_γ (keV)	P_γ^{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 (10)	-	-	0.0063 (7)	-	-
404.45 (9)	-	-	0.0022 (5)	-	-
422.04 (10)	-	-	0.0030 (5)	-	-
645.44 (9)	-	~ 0.007	0.0054 (9)	-	-

E_γ (keV)	P_γ^{abs} (cont.)				
	1983Va22	**1984Bo15**	**1984Ge07**	**1992Li05**	**Recommended value***
240.986 (6)	4.05 (9)	4.05 (9)	4.17 (4)	4.11 (12)	4.12 (4)
292.70 (10)	-	-	-	-	0.0063 (7)
404.45 (9)	-	-	-	-	0.0022 (5)
422.04 (10)	-	-	-	-	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.

<u>Multipolarities and Internal Conversion Coefficients</u>

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. All of the recommended internal conversion coefficients have been determined from the frozen orbital approximation of Kibédi *et al*. (2008Ki07), based on the theoretical model of Band *et al*. (2002Ba85, 2002Ra45). Uncertainties of ± 1.5 % were adopted for all of the E1 and E2 gamma transitions.

Gamma-ray emissions: multipolarities and theoretical internal conversion coefficients (frozen orbital approximation).

E_γ (keV)	Multipolarity	α_K	α_L	α_{M+}	α_{total}
240.986 (6)	E2	0.110 9 (16)	0.122 0 (17)	0.043 1	0.276 (4)
292.70 (10)	E2	0.072 7 (11)	0.056 4 (8)	0.019 6	0.148 7 (21)
404.45 (9)	E1	0.014 01 (20)	0.002 41 (4)	0.000 75	0.017 17 (24)
422.04 (10)	(E1)	0.012 80 (18)	0.002 19 (3)	0.000 68	0.015 67 (22)
645.44 (9)	E1	0.005 46 (8)	0.000 894 (13)	0.000 276	0.006 63 (10)

Atomic Data

The x-ray and Auger-electron data have been calculated using the evaluated gamma-ray data, and atomic data from 1996Sc06, 1998ScZM and 1999ScZX. Both the x-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.01, 28 January 2003). This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

K and L X-ray emission probabilities per 100 disintegrations of ^{224}Ra.

			Energy (keV)	Photons per 100 disint.
XL		(Rn)	10.137 – 17.280	0.373 (16)
	XL_l	(Rn)	10.137	0.007 74 (20)
	XL_α	(Rn)	11.598 – 11.726	0.138 (4)
	XL_η	(Rn)	12.855	0.004 13 (11)
	XL_β	(Rn)	13.520 – 14.565	0.191 (5)
	XL_γ	(Rn)	16.770 – 17.280	0.042 4 (9)
XK_α	$XK_{\alpha 2}$	(Rn)	81.07	0.130 (3)
	$XK_{\alpha 1}$	(Rn)	83.78	0.214 (4)
$XK'_{\beta 1}$	$XK_{\beta 3}$	(Rn)	94.247	)
	$XK_{\beta 1}$	(Rn)	94.868	) 0.074 3 (18)
	$XK''_{\beta 5}$	(Rn)	95.449	)
$XK'_{\beta 2}$	$XK_{\beta 2}$	(Rn)	97.48	)
	$XK_{\beta 4}$	(Rn)	97.853	) 0.023 8 (7)
	$XKO_{2,3}$	(Rn)	98.357	)

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

Data Consistency

A Q_α-value of 5788.85 (15) keV has been adopted from the atomic mass evaluation of Audi *et al.* (2003Au03) while in the course of formulating the decay scheme of ^{224}Ra. This value has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{224}Ra alpha-decay process (i.e. α, electron, γ, etc.):

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 5788.7\ (40)\ \text{keV}$$

Percentage deviation from the Q-value of Audi *et al.* is (0.00 ± 0.07) %, which supports the derivation of a highly consistent decay scheme.

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^{225}Ra - Comments on evaluation of decay data by Huang Xiaolong and Wang Baosong

This evaluation was completed in 2007. Literature available by May 2007 was included.

1 Decay Scheme

^{225}Ra disintegrates 100 % by β^- emission to levels in ^{225}Ac. ^{225}Ra ground state has $J^\pi = 1/2^+$ (1990Ak03).

The recommended Q(β^-) value of 356 (5) keV in Audi (2003Au03) agrees with the Q(β^-) value of 353 (8) keV, calculated by the evaluator (using program RADLST) from average radiation energies. This agreement supports the completeness and correctness of the decay scheme.

2 Nuclear Data

The Q(β-) value is from the mass adjustment in 2003Au03.
Level energies, spin and parities are from 1990Ak03.
The measured and recommended ^{225}Ra half-life values are listed in Table 1.

Table 1: Measured half-life values of ^{225}Ra and recommended value.

$T_{1/2}$ (d)	References	Measurement method
14	1947En03	
14.8 (2)	1950Ha52	Alpha pulse analyser, 10 $T_{1/2}$
15.02 (56)	1987Mi10	Solid-state detector, linear least squares fit
14.91 (11)		Unweighted mean
14.82 (19)		Weighted mean, χ^2=0.14
14.82 (19)	Recommended value	From weighted mean

The half-life weighted average has been calculated using the LWM computer program. The recommended half-life is from LWM result. Further measurements are needed to determine this value with greater precision.

2.1 β^- Transitions

The maximum energies of the β^- transitions in the decay of ^{225}Ra have been deduced from the Q(β-) value (2003Au03) and the level energies.

The adopted β^- transition probabilities and their associated uncertainties to the 40-keV level and to the ground state were deduced from P(γ) = 30.0 (7) % and α_T = 1.293 (19) for the 40-keV γ-ray. No β^- transitions to the 120.8- and 155.6- keV levels were observed. Based on Ac KX-ray intensities an upper limit of < 0.01 % for the respective β^- transitions to these levels was reported in 1984Ah01.

The *logft* values and average β^- energies have been calculated with the program LOGFT.

2.2 γ Transitions

The transition probability of the 40-keV γ-ray was calculated using its γ-ray emission intensity and the relevant total internal conversion coefficient.

The multipolarity of this γ-ray transition is from 1990Ak03.

The internal conversion coefficient (ICC) (and its associated uncertainty) for the 40-keV γ-ray transition has been interpolated from theoretical values based on the "Frozen Orbital" approximation (2002Ba85) using the BrIcc computer program (2008Ki07).

3 Atomic Data

Atomic fluorescence yields (ω_K,ϖ_L, ϖ_M, η_{KL} and η_{LM}) are from Schönfeld (1996Sc06).

The X-ray and Auger electron emission probabilities have been deduced from γ-ray and conversion electron data by using the computer code RADLST.

4 Electron emissions

The conversion electron emission probabilities have been deduced from γ-ray transition data using theoretical internal conversion coefficients.

5 Photon emissions

5.1 γ-ray energy

Measurements of the 40-keV γ-ray energy from ^{225}Ra are listed in Table 2 together with their weighted mean value. The recommended value is from the weighted mean value.

Table 2: Measured and recommended γ-ray energy from ^{225}Ra β^- decay.

1955Ma61	1955St04	1981Di14	1987Ah05	LWM	Evaluation
41 (2)	40 (1)	40.12 (5)	40.09 (5)	40.11 (4)	40.11 (4)

5.2 Absolute values of the γ-ray emission probability

The measurements of the absolute γ-ray emission probabilities from ^{225}Ra decay are listed in Table 3. The present recommended value is taken from a precise measurement in equilibrium with ^{229}Th (1986He06).

Table 3: Measured and recommended absolute γ-ray emission probability of 40.09keV for ^{225}Ra.

P_γ (40.09 keV) (%)	References	Measurement method
33	1955Ma61	Scintillation spectrometry
29	1955St04	
39.3 (12)	1981Di14	Ge(Li)
30.0 (7)	1986He06	Ge(Li) and Au-Si surface barrier, in equilibrium with ^{229}Th
30.0 (7)		Recommended value from 1986He06

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^{226}Ra - Comments on evaluation of decay data
by V. Chisté and M. M. Bé

This evaluation was completed in 2006. This updated version was done in January 2007. The literature available by this date is included.

1 Decay Scheme

^{226}Ra disintegrates by alpha emissions mainly to the 186 keV level and to the ground state level of ^{222}Rn. Spin and parity are from the mass-chain evaluation of Y. A. Akovali (1996El01 and 1996Ak02).
A certain number of measurements of the 186-keV gamma intensity were carried out and the adopted data set is consistent, so the deduced intensity can be considered having a good level of confidence. Therefore, the decay scheme here was built from the gamma-ray intensity measurements.
A good agreement was found between the effective Q value (4870.5 (27) keV) calculated from the decay scheme data and the adopted and recommended value from Audi.

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).

Experimental ^{226}Ra half-life values (in years) are given in Table 1:

Table 1: Experimental values of ^{226}Ra half-life.

Reference	Experimental value (a)	Comments
S. W. Watson (1928Wa**)	1608	Not used: no uncertainty. Calorimetry.
H. J. J. Braddick (1928Br**)	1603	Not used: no uncertainty. α current.
I. Curie (1928Cu**)	1590	Not used: no uncertainty. Ion current.
F. A. B. Ward (1929Wa**)	1599	Not used: no uncertainty. Number α's emitted.
L. Meitner (1930Me**)	1590	Not used: no uncertainty. Calorimetry.
E. Gleditsch (1935Gl02)	1691	Not used: no uncertainty. Growth rate.
P. Günther (1939Gü**)	1603	Not used: no uncertainty. He production.
T. P. Kohman (1949Ko01)	1622 (13)	Number α's emitted.
W. Sebaoun (1956Se10)	1617 (12)	Number α's emitted.
G. V. Gorshkov (1959Go80)	1577 (9)	Calorimetry.
G. Martin (1959Ma12)	1602 (8)	Calorimetry.
H. Ramthun (1966Ra13)	1599 (7)	Calorimetry.
Recommended value	**1600 (7)**	$\chi^2 = 2.87$

The weighted average was calculated with LWEIGHT computer program (version 3).

The evaluators have chosen to take into account the only five experimental values with uncertainty found in the literature: 1949Ko01, 1956Se10, 1959Go80, 1959Ma12 and 1966Ra13. With this data set, the largest contribution to the weighted average comes from the value of Ramthun amounting to 33 %. The weighted average of **1600 a** and the external uncertainty of **7 a** is the half-life adopted value. The reduced-χ^2 value is 2.87.

2.1 a Transitions

The transition energies of the α-particles given in Section 2.1 were calculated from Q_α (2003Au03) and level energies.

2.2 g Transitions

The transitions probabilities were calculated using the γ-ray emission intensities and the relevant internal conversion coefficients (see **6.2 Gamma Emissions**).

Multipolarities of these γ-ray transitions are from 1996El01.

186-keV γ-ray : E2
262-keV γ-ray : [E2]
414-keV γ-ray : [E1]
449-keV γ-ray : [E1]
600-keV γ-ray : [E1]

The internal conversion coefficients (ICC's) for these γ-ray transitions have been interpolated from theoretical values of I. M. Band (2002Ba85) using the BrIcc computer program (calculation for 'hole'). Theoretical values are compared with measured values below:

	De Pinho (1973De50)	Band (Icc99v3a computer program, no hole)[a]	BrIcc program (recommended values)
α_K	0.200 (9)	0.186 (6)	0.190 (3)
α_{L1}	0.031 (6)	0.0319 (10)	0.0321 (5)
α_{L2}	0.226 (16)	0.208 (6)	0.208 (3)
α_{L3}	0.124 (8)	0.1196 (36)	0.1196 (17)
α_L	0.380 (20)	0.360 (11)	0.360 (5)

[a] The evaluators have used a fractional uncertainty of 3 % for all Band conversion coefficients.

The results of De Pinho (1973De50) and the theoretical values calculated with two different programs (Icc99v3a (calculation for 'no hole') and BrIcc) are consistent to each other. The recommended values are the BrIcc values for the all conversion coefficients.

3 Atomic Data

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

4 a Emissions

The α-particle energies for the $\alpha_{0,2}$, $\alpha_{0,3}$ and $\alpha_{0,4}$ are from G. Bastin-Scoffier (1963Ba62), with uncertainties given by A. Rytz (1991Ry01). For the $\alpha_{0,0}$ and $\alpha_{0,1}$ emissions, the energies are from A. Rytz (1991Ry01).

The emission intensities of the α-particles have been deduced from the P(γ + ce) decay scheme balance at each level. In Table 2, the calculated and recommended values of the emission intensities are compared with the experimental results. For the two most important lines a slight agreement was found between the experimental results given by 2001La14 and the recommended values deduced from the decay scheme balance. For the three weak lines the calculated alpha emission intensities deduced from γ ray measurements are in good agreement with the measured values of Bastin-Scoffier.

Table 2: Experimental and recommended (deduced) values of the α-particles emission intensities.

Energy (keV)	G. Bastin-Scoffier (1963Ba62)	S. LaMont (2001La14)	Recommended values
4784.34 (25)	94.45 (5)[a]	93.84 (11)	94.038 (40)
4601 (1)	5.55 (5)[a]	6.16 (3)	5.950 (40)
4340 (1)	0.0065 (3)		0.0066 (22)
4191 (2)	0.0010 (1)		0.0008
4160 (2)	0.00027 (5)		0.0002

[a] uncertainties as given by Rytz.

5 Electron Emissions

The conversion electrons emission intensities have been calculated from γ-ray data using the EMISSION computer program.

6 Photon emissions

6.1 X-rays

The X-ray absolute intensities have been calculated from γ-ray data and ICC using the EMISSION computer program. In Table 3, the recommended values of ^{222}Rn X-ray emission intensities are compared with the experimental results.

Table 3: Experimental and recommended values of X-ray emission intensities.

	Delgado (2002De03)	Schötzig (1983Sc13)	De Pinho (1973De50)[a]	Recommended values
$K\alpha_1$	0.215 (3)			0.317 (6)
$K\alpha_2$	0.156 (39)			0.192 (4)
Kα	0.371 (39)	0.418 (21)		0.509 (7)
$K\beta_1$	0.079 (5)			0.1098 (25)
$K\beta_2$	0.020 (4)			0.0351 (10)
Kβ	0.099 (6)	0.145 (9)		0.1449 (27)
XK	0.47 (4)	0.563 (23)	0.693 (26)	0.654 (8)
XL1			0.0181 (25)	0.0147 (4)
XL2			0.420 (28)	0.427 (10)
XL3			0.401 (14)	0.365 (9)
XL			0.839 (43)	0.807 (13)

[a] Calculated with I_γ (186) = 3.555 (19)

The calculated recommended values and 1973De50 values, based on the assumption that I_γ (186) = 3.555 (19), are significantly greater than those measured by Delgado (2002De03) or Schötzig (1983Sc13).

The recommended data are in agreement, within the uncertainty values, with the experimental ones of 1973De50, who used a ^{226}Ra source from which the descendants were removed, since Schötzig and Delgado carried out measurements with sources in equilibrium with their daughters.

6.2 g-ray Emissions

The energies of the γ-ray emissions given in Section 6.2 are from Y. A. Akovali (1996El01).

The experimental relative γ emission intensities in ^{222}Rn are based on all available relative and absolute measurements of gamma-rays for the ^{226}Ra decay chain. The normalization factor to convert the relative emission intensities to absolute intensities is the weighted average of the measured absolute gamma-ray emission intensities (Table 4) of the most intense line in ^{226}Ra decay chain, presents in the ^{214}Bi disintegration namely the 609.3-keV line.

Table 4: Experimental 609.3 keV absolute gamma-ray emission intensities.

References	Experimental values (%)	Comments
E. W. A. Lingeman (1969Li10)	42.8 (40)	
D. G. Olson (1983Ol01)	45.0 (7)	
U. Schötzig (1983Sc13)	44.6 (5)	
W. –J. Lin (1991Li11)	46.1 (5)	
J. Morel (1998Mo14)	44.8 (6)	Superseded by 2004Mo07
J. Morel (2004Mo07)	45.57 (18)	
Recommended value	**45.49 (19)**	χ^2 = 1.45

The recommended normalization factor is the weighted average of the five experimental values: 45.49 with an external uncertainty of 0.19.

The experimental relative γ emission intensities of 186- and 262-keV given in Table 5 are relative to the ^{214}Bi 609-keV γ-ray.

Table 5: Experimental data set of the 186- and 262- keV relative γ emission intensities.

References	186-keV γ-ray	262-keV γ-ray	Comments
K. Ya. Gromov (1969Gr33)	9.5 (10)		Not used by the evaluators.
G. Wallace (1969Wa27)	9.91 (31)		Not used by the evaluators.
R.S. Mowatt (1970Mo28)	8.20 (12)		outlier
V. S. Aleksandrov (1974AlZT)	8.87 (30)		outlier
V. Zobel (1977Zo01)	9.00 (10)		Not used by the evaluators.
M. A. Farouk (1982Fa10)	9.07 (14)		Not used by the evaluators.
D. G. Olson (1983Ol01)	7.69 (11)		
U. Schötzig (1983Sc13)	7.72 (14)		
G. Mouze (1990MoZP)	8.58 (5)	0.012 (4)	outlier
W. –J. Lin (1991Li11)	7.89 (14)		
D. Sardari (2000Sa32)	7.6 (8)	0.012 (4)	
J. U. Delgado (2002De03)	7.812 (31)		
G. L. Molnar (2002MoZP)	7.85 (5)		
J. Morel (2004Mo07)	7.812 (31)		Not used by the evaluators.
Recommended values	**7.815 (25)**	**0.012 (4)**	
χ^2	0.52		

Were omitted from analysis:

a) four values: A. Hachem (1975Ha31), G. Mouze (1981Mo28), H. Akcay (1982Ak03) and O. Diallo (1993Di09), because these values comes from the same laboratory of G. Mouze (1990MoZP).
b) the sets of values from K. Ya. Gromov (1969Gr33), G. Wallace (1969Wa27) and M. A. Farouk (1982Fa10), because of lack in the articles concerning their experimental measurements.
c) the set of values from V. Zobel (1977Zo01), because these values have changed the consistency of the data set when they were introduced in the preliminary calculation with Lweight program and produced inconsistent weighted average for gamma emission intensity.

For the 186-keV γ-ray, the evaluators have chosen to take into account the nine values with associated uncertainty for the calculation. The relative γ emission intensity value given by 2004Mo07 is the same one that those measured by J. U. Delgado (2002De03). In 2004Mo07 article, the author measured the 609.3 keV absolute emission probability (Table 4) and normalized the 2002De03 data set with this value of 45.57 (18), so the value given in 2004Mo07 was omitted. The weighted average of the remaining values above was calculated using LWEIGHT computer program (version 3). Based on the Chauvenet's criterion, Mowatt (1970Mo28), Aleksandrov (1974AlZT) and Mouze (1990MoZP) were shown outlier values by the Lweight program, then they have been omitted.

The adopted relative value is the weighted mean of the six remaining values: *7.815*, with an internal uncertainty of *0.025* and a reduced χ^2 of 0.52, so this data set is consistent. The largest contribution comes from the value of Delgado (2002De03), amounting to 63 %.

For the 414-, 449- and 600-keV γ-rays, the evaluators used the measured ratios of Lourens (1971Lo19): I_{414}/I_{186} = 0,00086 ; I_{449}/I_{186} = 5,5 $\times 10^{-5}$; I_{600}/I_{186} =0,00014 and the absolute value I_γ(186) = 3.555 (19) %, to determine their absolute emission intensities.

The evaluated relative and absolute γ-ray emission intensities are given in Table 6.

Table 6: Evaluated relative and absolute γ-ray emission intensities.

Energy (keV)	Relative emission intensity (%)	Absolute emission intensity (%)
186.211 (13)	7.815 (25)	3.555 (19)
262.27 (5)	0.012 (4)	0.0055 (18)
414.60 (5)		0.0003
449.37 (10)		0.0002
600.66 (5)		0.0005

6 References

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^{228}Ra – Comments on Evaluation of Decay Data by A. Luca

This evaluation was completed in June 2009. The literature available by December 31st, 2008 was included.

1. Evaluation Procedures

The Limitation of Relative Statistical Weight (LWM) method was applied for averaging numbers throughout this evaluation; this method was implemented by using the computer code LWEIGHT, ver. 4 (designed for Excel, MS Office). The uncertainty assigned to an average value in this evaluation is never lower than the lowest uncertainty of any of the experimental input values.

2. Decay Scheme

^{228}Ra decays 100 % by beta minus particle emissions populating ^{228}Ac excited states. The decay scheme was studied by a few authors (1961To10, 1972HeYY, 1995So11). The most recent evaluation of the ^{228}Ra nuclear structure and decay data, published in Nuclear Data Sheets, was done by A. Artna-Cohen (1997). In the present evaluation, the spin, parity and energy of ^{228}Ac excited levels, and the multipolarities of the γ-ray transitions, have been adopted from the above mentioned A=228 ENSDF mass-chain evaluation (1997Ar08).

3. Nuclear Data

The adopted beta decay energy value Q(β) = 45.8 (7) keV, is from 2003Au03. This value is in very good agreement with the effective Q(β) value of 46 (6) keV, deduced from average radiation energies from the decay scheme data, by using the SAISINUC software, version 2008 April.

3.1. Half-life

In the literature, only three measured ^{228}Ra half-life ($T_{1/2}$) values are reported; these measurements are very old (the most recent is from 1962), so new half-life measurements are needed to improve the quality of the evaluation. The half-life values and their uncertainties are presented in Table 1; the value recommended by Curie et al. (1931), with an estimated uncertainty added by the evaluator, has been also included. A critical review of the half-life (weighted average of 7 values) from reference 1962Ma58, has been done here by using the computer code LWEIGHT, ver.4. The set of data is consistent and the recommended value, 5.75 years, with an uncertainty of 0.04 year, is the weighted average (LWM, χ^2_ν=4.6) of the three input values. The reference *Nuclear Science References* (NSR) keynumbers are:

Table 1 : ^{228}Ra Half-life values

$T_{1/2}$ (years)	Uncertainty of $T_{1/2}$ (years)	Reference
6.7	1	1931Cu01
5.7	0.2	1960Du11
5.75	0.04	1962Ma58

3.2. Beta transitions and emissions

The most complete reference reporting measurements of energy and emission intensities for ^{228}Ra beta minus transitions is 1995So11.

For this evaluation, the beta transitions energies were calculated from Q(β-) and the energies of the decay scheme levels. The intensities of the beta branches were deduced from γ-ray transition intensity balance at each level, with the exception of the lowest energy branch (12.7 keV maximum energy) which was adopted from the measurements reported in 1995So11; also, the intensity ratio of the two highest energy beta branches (39.1 keV and 39.5 keV) was adopted from the same reference.

Using the gamma-ray emission probabilities for the 13.52 keV and 12.88 keV photons measured by 1995So11, a new intensity value of the 25.6 keV beta branch was computed by the evaluator (see Table 2); this was done because the 20 % beta intensity gives a negative gamma-ray emission probability for the 12.88 keV photons, according to the intensity balance of the 20.19 keV ^{228}Ac excited level. The normalization condition of the beta emissions (the sum of the all the beta transitions intensities must be 100 %) was checked. The adopted energy and intensity values of the beta transitions, as well as their Log ft values are shown in Table 2.

Table 2: ^{228}Ra β^- Energies and Emission Probabilities

Level energy (keV)	$E_{\beta-}$ (keV)	Uncertainty $E_{\beta-}$ (keV)	Emission probability (%)	Emission probability (%), from 1995So11	Log ft
33.07	12.7	0.7	30 (10)	30 (10)	5.11
20.19	25.6	0.7	8.7 (9)	20 (6)	6.2
6.67	39.1	0.7	49 (10)	40 (10)	6.45
6.28	39.5	0.7	12 (10)	10	7.07

3.3. γ- transitions: γ rays and internal conversion electrons

The only paper that reports measurements of the γ-ray energies and some emission intensities following the ^{228}Ra decay (only for 13.52 keV and 12.88 keV) is 1995So11. Using the measured 13.52 keV gamma-ray emission probability of 1.6 % (with a 0.1 % estimated uncertainty, added by the evaluator), the 12.88 keV photons measured emission probability of 0.30 (6) % and the internal conversion coefficients, the corresponding absolute gamma-ray emission probabilities and their uncertainties were computed for all the γ rays, according to the intensity balance for each level; these data are given below in Table 3. The internal conversion coefficients were computed with the program BrIcc, version 2.2b/20-Jan-2009, using the "Frozen Orbitals" approximation.

Other possible gamma-ray transitions observed only by Sood et al. (1995So11), but were not placed in the level scheme, are: 15.15 keV, 15.5 keV, 16.2 keV and 30.6 keV.

Table 3: ^{228}Ra γ-ray Energies and Absolute Emission Probabilities

E_γ (keV)	Uncertainty E_γ (keV)	Absolute Emission Probability (%)	Uncertainty of absolute emission probability (%)	Total ICC (α_T) and uncertainty
6.28	0.03	$1.8\cdot10^{-6}$	$1.5\cdot10^{-6}$	$6.68\ (19)\cdot10^{6}$
6.67	0.02	$5.7\cdot10^{-5}$	$0.9\cdot10^{-5}$	$1.560\ (40)\cdot10^{6}$
12.88	0.11	0.30	0.06	6.67 (18)
13.52	0.04	1.6	0.1	5.86 (10)
26.40	0.11	0.14	0.05	201 (4)

4. Atomic data

The K-shell fluorescence yield (ω_K), the mean L-shell fluorescence yield (ϖ_L) and the mean number of vacancies in the L-shell produced by one vacancy in the K-shell (η_{KL}) were determined using the computer program EMISSION v.3.10, 28-Jan-2003: 0.969 (4), 0.464 (18) and 0.799 (5) respectively.

4.1. Auger electrons and X-rays

Because the decay energy, Q, is very low, there are no electron emissions from the ^{228}Ac K-shell (Auger electrons or internal conversion electrons). The emission probability of the L Auger electrons (energy from 0.1 keV to 19.69 keV) was computed using the same EMISSION computer program: 12 (5) %. The energy range for the L Auger electrons was filled-in by the SAISINUC program, version 2008 April.

For the same reason mentioned above, there are no K X-rays emitted by ^{228}Ac, following the ^{228}Ra decay. The absolute emission probability values of the different groups of L X-rays (L_L, L_α, L_η, L_β and L_γ) were determined using the EMISSION program; the total L X-rays emission probability is 9.6 (19) %, for an energy range between 10.87 keV and 18.92 keV. The energy range values of the L X-rays groups are from the tables linked to SAISINUC. Neither measurements of X-ray energies nor of emission probabilities were found in the literature, in order to compare them with the results of this evaluation.

5. Main production mode

The main production mode of ^{228}Ra is by alpha-particle decay of the ^{232}Th nuclei (^{228}Ra is the daughter of ^{232}Th), present in important quantities in many natural ores.

6. References

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^{225}Ac - Comments on evaluation of the decay data

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This evaluation was completed in 2008. Literature available by December 2008 was included.

1 Decay Scheme

^{225}Ac disintegrates 100 % by α emission to levels in ^{221}Fr. ^{225}Ac ground state has J^{π}=(3/2$^-$)(1990Ak03).

The ^{225}Ac α decay scheme was built from the experimental conversion-electron data of 1971DzZP, 1972Dz14 and 2000Ar23, the α-γ coincidence data of 2003Ku44, the γ-γ coincidence data of 1990Ko14, and the experimental singles γ-rays data of 2000Ar23 and 2003Ku44.

The recommended Q(α) value of 5935.1 (14) keV in Audi (2003Au03) agrees with the Q(α) value of 5932.5 (16) keV, calculated by the evaluator (using program RADLST) from average radiation energies. This agreement supports the completeness and correctness of the decay scheme.

2 Nuclear Data

The Q value is from the mass adjustment in 2003Au03.

Level energies, have been obtained from a least-squares fit to γ-ray energies (GTOL computer code). Spin and parities are from 1990Ak03, 2000Ar23 and 2003Ku44.

The measured and recommended ^{225}Ac half-life values are listed in Table 1.

Table 1 Measured half-life values of ^{225}Ac and recommended value, in days

$T_{1/2}$ (d)	References	Measurement method
10	1947En03	
10.0 (1)	1950Ha52	Alpha pulse analyzer, 10 $T_{1/2}$
10.0 (1)	Recommended value	From 1950Ha52

The recommended value is taken from the measurement of 1950Ha52. Further measurements are merited to determine this value with greater confidence.

2.1 γ Transitions

The γ-ray transition probabilities were calculated using the γ-ray emission intensities and the relevant internal conversion coefficients.

Multipolarities and mixing ratios of γ-ray transitions are from 1971DzZP, 1972Dz14, 1977Vy02, 1990ArZZ and 2003Ku44. The multipolarity marked in square brackets for other γ transition are from the level scheme (they are not measured).

The internal conversion coefficients (ICC) and their associated uncertainties for γ-ray transitions have been obtained using the BrIcc computer program, which uses the “Frozen Orbital” approximation (2002Ba85). Experimental and theoretical conversion coefficients are compared in Table 2.

Table 2 Comparison of theoretical and measured conversion coefficients

E_γ (keV)	Multipolarity	α(theory)	α(exp.)
			2003Ku44
78.8	M1	α_T = 5.63, α_L = 4.27	α_T = 5.1 (11)
87.41	M1	α_T = 4.16, α_L = 3.16	α_T = 2.8 (6)
114	M1	α_T = 9.86, α_L = 7.93	α_T = 13.0 (17)
139.6	M1+E2	α_T = 3.9, α_K = 2.4	α_T = 3.2 (5)
145.16	(E1)	α_T = 0.191	$\alpha_T \le 0.1$
153.92	E1	α_T = 0.166	$\alpha_T \le 0.35$
197.5	E1	α_T = 0.0908	$\alpha_T \le 0.04$

2.2 α Transitions

The level energies of ^{221}Fr are determined from the least-squares fit to the recommended γ-ray energies. The level energies of ^{221}Fr and Q-values (2003Au03) were used to determine the energies and uncertainties of the alpha particle transitions to the various levels.

The recommended energies of alpha particles were calculated from the proposed decay scheme and listed in table 3. The recommended values are in good agreement with the measurements of 1967Dz02. Other measurements are 1964Gr11, 1967Ba51, and 1972Go29.

Table 3 Measured and recommended value of α-particle energy for ^{225}Ac (keV)

1964Gr11	1967Ba51[a]	1967Dz02[b]	1972Go29	1991Ry01	Recommended
5829 (5)	5829 (2)	5829 (2)		5829.6 (14)	5829.6 (14)
	5804 (2)				5804.2 (14)
5792 (5)	5793 (3)	5792 (3)	5792.5 (22)	5793.1 (21)	5793.1 (21)
	5791 (4)		5790.6 (22)		5791.7 (14)
5732 (5)	5731 (2)	5731 (3)		5731.9 (17)	5731.9 (17)
					5731.6 (14)
					5730.5 (14)
5724 (5)	5722.6 (25)	5723 (3)			5723.1 (14)
					5686.4 (14)
5683 (5)	5681 (2)	5681 (3)			5682.2 (14)
5638 (5)	5636.2 (20)	5637 (3)			5637.3 (14)
5610 (5)	5607.6 (30)	5608 (3)			5609.0 (14)
	5597.5 (40)				5599.3 (14)
5581 (5)	5579.1 (30)	5577 (3)			5580.5 (14)
	5561.6 (40)				5563.3 (14)
	5552.6 (40)				5555.3 (14)
	5544.1 (40)				5546.5 (14)
	5538.5 (40)	5540 (5)			5540.1 (14)
	5521.5 (70)	5526 (5)			5523.7 (14)
	5514.5 (7)	(5519)			5515.2 (14)
5494 (10)		5497 (4)			5497.4 (14)
		5489 (4)			5487.4 (14)
		(5468)			5468.4 (14)
5448 (10)	5441.1 (40)	5444 (3)			5443.3 (14)
	5433.5 (40)	5437 (4)			5435.8 (14)

1964Gr11	1967Ba51[a]	1967Dz02[b]	1972Go29	1991Ry01	Recommended
					5430.1 (14)
	5419 (7)	5427 (4)			5428.3 (14)
		5411 (4)			5414.5 (14)
5398		5391 (4)			5391.2 (14)
5367		(5377)			5379.0 (14)
		(5355)			5356.2 (14)
		(5342)			5341.9 (14)
5328 (10)	5318 (4)	5322 (3)			5321.2 (14)
5295 (10)	5285 (4)	5286 (3)			5287.6 (14)
	5266.5 (40)	5271 (4)			5269.1 (14)
	5229 (7)	5238 (4)			5239.3 (14)
5225	5209.3 (50)	5211 (3)			5210.2 (14)
	5205.5 (50)	5201 (5)			5203.3 (14)
		(5192)			5195.1 (14)
		5160 (5)			5162.1 (14)
		5130 (5)			5129.0 (14)
		5091 (4)			5094.1 (14)
					5076.8 (14)
		5066 (5)			5064.1 (14)
		(5030)			5035.5 (14)
					5025.5 (14)
		(5020)			5019.3 (14)
					4992.7 (14)
		4901 (5)			4903.6 (14)

a: Original energies should be increased by 1 keV due to changes in calibration energies (recommended by 1979Ry03).

b: Original energies should be decreased by 0.3 keV due to changes in calibration energies (recommended by 1979Ry03)

The evaluated alpha particle emission probabilities were deduced from the transition intensity balance and listed in table 4. These calculated results are in good agreement with the measured emission probabilities of the main alpha transitions. The measurements are from 1964Gr11, 1967Ba51, 1967Dz02, 1972Go29, and 2003Ku4.

Table 4 Measured and recommended α-particle emission probabilities for ^{225}Ac

E_α (keV)	P_α					
	1964Gr11	1967Ba51	1967Dz02	1972Go29	2003Ku44	Evaluation
5829.6 (14)	52 (3)	50.65 (15)	51.6 (15)			52.4 (24)
5804.2 (14)		0.3				0.3
5793.1 (21)	28 (3)	24.3 (1)	26.7 (10)	18.1 (20)	20.2 (11)	18.9 (20)
5791.7 (14)		2.50 (1)			8.4 (5)	6.2 (9)
5731.9 (17)	12 (2)	10.10 (3)	10.0 (1)	8.6 (9)	8.5 (4)	9.0 (5)
5731.6 (14)					1.6 (2)	1.24 (10)
5730.5 (14)					1.05 (8)	1.6 (3)
5723.1 (14)		3.40 (1)	2.9 (5)		3.77 (19)	2.03 (23)

E_{α} (keV)	P_{α}					
	1964Gr11	1967Ba51	1967Dz02	1972Go29	2003Ku44	Evaluation
5686.4 (14)					0.095 (4)	0.021 (14)
5682.2 (14)	1.3 (3)	1.250 (4)	1.4 (2)		1.08 (5)	1.31 (4)
5637.3 (14)	4.2 (3)	4.350 (13)	4.5 (3)		3.7 (1)	4.16 (23)
5609.0 (14)	1.0 (3)	1.20 (1)	1.1 (1)		0.86 (3)	1.09 (5)
5599.3 (14)		0.0410 (1)			0.099 (4)	0.114 (7)
5580.5 (14)	1.0 (3)	1.20 (4)	1.2 (1)		0.89 (3)	0.95 (4)
5563.3 (14)		0.0340 (1)			0.0034 (5)	0.017 (7)
5555.3 (14)		0.1000 (3)			0.089 (4)	0.084 (10)
5546.5 (14)		0.0310 (1)			0.075 (3)	0.055 (12)
5540.1 (14)		0.0150 (5)	0.04 (1)		0.0070 (7)	0.0072 (8)
5523.7 (14)		~ 0.005	0.010 (2)			0.013 (6)
5515.2 (14)		~ 0.005	≤ 0.02			0.0052 (19)
5497.4 (14)	~ 0.02		0.003 (1)			0.0022 (7)
5487.4 (14)			0.0020 (7)			0.0020 (3)
5468.4 (14)			≤ 0.001			0.00052 (18)
5443.3 (14)	0.15 (5)	0.150 (1)	0.13 (1)		0.086 (4)	0.098 (19)
5435.8 (14)		0.0710 (2)	0.07 (2)		0.029 (2)	0.0083 (6)
5430.1 (14)						0.0028 (8)
5428.3 (14)			0.008 (3)		0.0010 (1)	0.0023 (3)
5414.5 (14)		~ 0.003	0.0020 (5)			0.0030 (4)
5391.2 (14)	~ 0.01		0.0010 (5)			0.0006 (4)
5379.0 (14)	~ 0.01		≤ 0.001			0.0020 (5)
5356.2 (14)			≤ 0.001			9.7E-5 (2)
5341.9 (14)			≤ 0.001		0.0009 (3)	0.0027 (8)
5321.2 (14)	0.07 (3)	0.080 (2)	0.068 (8)		0.054 (2)	0.007 (7)
5287.6 (14)	0.2 (1)	0.300 (1)	0.23 (1)		0.17 (1)	0.214 (10)
5269.1 (14)		0.0180 (5)	0.009 (2)		0.0086 (8)	0.048 (19)
5239.3 (14)			0.0030 (8)		0.00019 (8)	0.0026 (5)
5210.2 (14)	~ 0.02	0.0250 (1)	0.003 (3)		0.022 (2)	0.022 (1)
5203.3 (14)		0.0130 (1)	0.0020 (5)		0.0044 (6)	0.0101 (10)
5195.1 (14)			≤ 0.002			0.00015 (5)
5162.1 (14)			0.0020 (8)			0.00066 (12)
5129.0 (14)			0.0020 (8)		0.0013 (3)	0.0058 (8)
5094.1 (14)			0.006 (1)		0.0054 (15)	0.015 (7)
5076.8 (14)						0.0038 (19)
5064.1 (14)			0.003 (1)		0.0014 (2)	0.00114 (18)
5035.5 (14)			≤ 0.001			0.0021 (3)
5025.5 (14)						0.00083 (21)
5019.3 (14)			≤ 0.001		~ 0.00004	0.00015 (5)
4992.7 (14)						0.0013 (3)
4903.6 (14)			0.0020 (5)			0.0011 (4)

3. Atomic data

Atomic fluorescence yields (ω_K,ϖ_L, ϖ_M, η_{KL} and η_{LM}) are from Schönfeld (1996Sc06).

The X-ray and Auger electron emission probabilities have been deduced from γ-ray and conversion electron data by using the computer code RADLST. Measured and calculated X-ray emission probabilities are compared in Table 5.

Table 5 Comparison of the calculated and measured X-ray emission probabilities

	1972Dz14	Adopted (deduced)
$K_{\alpha1}$	1.5 (2)	1.64 (12)
$K_{\alpha2}$	**1.0 (1)**	1.00 (8)

The deduced KX-ray emission probabilities agree with the measured value of 1972Dz14, thus confirming the completeness of the decay scheme.

4. Electron Emissions.

The conversion electron emission probabilities have been deduced from γ-ray transition data.

5. Photon Emissions

5.1 γ-ray energy values

There are many measured γ-ray energies of ^{225}Ac. The present evaluated values are taken from the LWM average value of 1972Dz14, 2000Ar23 and 2003Ku44. The measurements of 1990ArZZ were replaced by 2000Ar23. The experimental and our recommended γ-ray energies from ^{225}Ac α decay are listed in table 6.

Table 6 Measured and recommended value of γ-ray energy for ^{225}Ac (keV)

1972Dz14	1990ArZZ	2000Ar23	2003Ku44	LWM	Evaluation
		10.6	10.6		10.6
26.0 (1)	26.05 (10)	26.0 (1)	26.0	26.0 (1)	26.0 (1)
36.6 (1)	36.65 (3)	36.70 (3)	36.7 (1)	36.69 (3)	36.69 (3)
38.5 (1)	38.53 (3)	38.60 (4)	38.5 (1)	38.58 (4)	38.58 (4)
	46.24 (5)	46.24 (5)	46.2 (2)	46.24 (5)	46.24 (5)
49.0 (2)	49.09 (5)	49.13 (4)	49.1 (2)	49.12 (4)	49.12 (4)
		50.2			50.2
53.8 (1)		53.01 (5)		53.4 (4)	53.4 (4)
57.8 (1)	57.75 (5)	57.69 (4)	57.8 (2)	57.71 (4)	57.71 (4)
		62.6 (3)			62.6 (3)
62.90 (5)	62.95 (3)	62.96 (3)	62.9 (1)	62.94 (3)	62.94 (3)
		63.5 (3)			63.5 (3)
64.1 (1)	64.28 (5)	64.28 (3)	64.3 (1)	64.27 (3)	64.27 (3)
69.8 (1)	69.8 (2)	69.87 (5)		69.86 (5)	69.86 (5)
71.7 (1)	71.74 (3)	71.72 (4)	71.4 (3)	71.71 (4)	71.71 (4)
73.6 (1)	73.5 (1)	73.36 (20)	73.5	73.55 (9)	73.55 (9)
73.83 (5)	73.86 (2)	73.85 (4)	73.9 (1)	73.85 (3)	73.85 (3)
74.9 (2)	74.9 (2)	74.82 (5)	74.6 (4)	74.82 (5)	74.82 (5)
			78.8		78.8
					82.6[ab]
87.38 (5)	87.41 (3)	87.42 (3)	87.4 (1)	87.41 (3)	87.41 (3)

1972Dz14	1990ArZZ	2000Ar23	2003Ku44	LWM	Evaluation
94.9 (2)	94.90 (5)	94.90 (3)	94.9 (1)	94.90 (2)	94.90 (2)
96.3 (2)	96.15 (5)	96.15 (5)	96.7 (5)	96.16 (5)	96.16 (5)
99.55 (10)	99.63 (5)	99.71 (6)	99.6	99.67 (5)	99.67 (5)
99.8 (1)	99.91 (5)	100.07 (10)	99.8 (1)	99.89 (6)	99.89 (6)
100.8 (1)	100.96 (5)	100.87 (4)	100.8 (2)	100.86 (4)	100.86 (4)
	103.46 (10)	103.44 (12)	103.6 (2)	103.48 (10)	103.48 (10)
108.4 (1)	108.41 (3)	108.38 (3)	108.4 (1)	108.38 (3)	108.38 (3)
111.5 (1)	111.54 (3)	111.52 (3)	111.5 (1)	111.52 (3)	111.52 (3)
	112.8 (2)	112.8 (2)	112.8	112.8 (2)	112.8 (2)
			114		114
		119.09 (6)			119.09 (6)[b]
119.9 (1)	119.87 (5)	119.84 (3)	119.9 (1)	119.85 (3)	119.85 (3)
		121.06 (7)			121.06 (7)
123.8 (1)	123.75 (5)	123.73 (4)	123.8 (1)	123.75 (4)	123.75 (4)
124.8 (1)	124.82 (5)	124.81 (3)	124.8 (1)	124.81 (3)	124.81 (3)
	126.15 (10)	126.09 (5)	126.2 (2)	126.10 (5)	126.10 (5)
	129.2 (2)	129.22 (7)	129.2 (2)	129.22 (7)	129.22 (7)
	133.64 (5)	133.60 (4)	133.6 (1)	133.60 (3)	133.60 (3)
134.8 (1)	134.86 (5)	134.85 (3)	134.9 (1)	134.85 (3)	134.85 (3)
		137.40 (10)	137.6		137.40 (10)
					138.2[ab]
			139.6		139.6
		144.7 (2)	144.7		144.7 (2)
145.0 (2)	145.17 (5)	145.15 (3)	145.2 (1)	145.15 (3)	145.15 (3)
150.09 (5)	150.04 (2)	150.02 (4)	150.1 (1)	150.05 (3)	150.05 (3)
	152.63 (5)	152.64 (3)	152.6 (2)	152.64 (3)	152.64 (3)
154.0 (1)	153.92 (5)	153.91 (3)	153.9 (1)	153.92 (3)	153.92 (3)
157.25 (5)	157.26 (2)	157.24 (3)	157.3 (2)	157.25 (3)	157.25 (3)
		161.35 (7)			161.35 (7)
	169.1 (2)	169.18 (4)	169.1	169.18 (4)	169.18 (4)
			169.9		169.9
170.6 (1)	170.7 (2)	170.83 (6)	170.7 (2)	170.77 (5)	170.77 (5)
			173.4		173.4
	178.4 (1)	178.29 (3)	178.3 (2)	178.29 (3)	178.29 (3)
	179.8 (2)	179.78 (4)	179.8 (3)	179.78 (4)	179.78 (4)
			183		183
			186.1		186.1
186.1 (1)	186.2 (1)	186.31 (3)	186.3	186.29 (3)	186.29 (3)
			187.2		187.2
188.0 (1)	188.00 (5)	187.95 (3)	188.0 (1)	187.96 (3)	187.96 (3)
			193.2		193.2
195.69 (7)	195.78 (5)	195.74 (3)	195.8 (2)	195.74 (3)	195.74 (3)
		197.50 (3)	197.4		197.50 (3)
	197.7 (1)		197.9		197.7 (1)
198.70 (7)	198.7 (1)	198.23 (8)	198.4 (3)	198.47 (23)	198.47 (23)

1972Dz14	1990ArZZ	2000Ar23	2003Ku44	LWM	Evaluation
		205.12 (11)	204.7 (3)	205.07 (11)	205.07 (11)
	216.90 (5)	216.89 (3)	216.9 (2)	216.89 (3)	216.89 (3)
		220.43 (8)			220.43 (8)
224.56 (7)	224.64 (5)	224.58 (3)	224.7 (1)	224.59 (3)	224.59 (3)
			228.2 (4)		228.2 (4)
	231.3 (2)	231.14 (7)	231.3 (2)	231.16 (7)	231.16 (7)
			236.0 (6)		236.0 (6)
		238.64 (8)			238.64 (8)
	240.8 (1)	240.68 (3)	240.7 (2)	240.68 (3)	240.68 (3)
	243.2 (1)	243.11 (5)	243.2 (2)	243.12 (5)	243.12 (5)
	249.5 (2)	249.60 (3)	249.6 (2)	249.60 (3)	249.60 (3)
253.50 (7)	253.54 (5)	253.45 (3)	253.5 (1)	253.46 (3)	253.46 (3)
		256.0 (2)	256		256.0 (2)
	279.25 (10)	279.18 (3)	279.3 (3)	279.18 (3)	279.18 (3)
	282.1 (2)				282.1 (2)
	284.8 (1)	284.75 (3)	284.8 (3)	284.75 (3)	284.75 (3)
		298.32 (5)	298.6 (3)	298.33 (5)	298.33 (5)
		317.23 (18)	317.4		317.23 (18)
		321.77 (4)	321.8 (4)	321.77 (4)	321.77 (4)
	348.5 (1)	348.33 (4)	348.2 (4)	348.33 (4)	348.33 (4)
	354.8 (2)	354.54 (6)	354.9 (3)	354.56 (6)	354.56 (6)
			356.6		356.6
	362.5 (1)	362.38 (3)	362.2 (4)	362.38 (3)	362.38 (3)
		367.72 (12)	368.3 (6)	367.74 (12)	367.74 (12)
	375.2 (1)	374.98 (5)	375.0 (7)	374.98 (5)	374.98 (5)
		388.07 (7)			388.07 (7)
	403.1 (1)	403.1 (1)	403.4 (3)	403.13 (10)	403.13 (10)
	406.1 (1)	405.95 (3)	406.2 (3)	405.95 (3)	405.95 (3)
	418.1 (1)	417.90 (3)	417.9 (3)	417.90 (2)	417.90 (2)
		429.80 (18)			429.80 (18)
		434.81 (5)	435.0 (3)	434.82 (5)	434.82 (5)
		442.16 (8)			442.16 (8)
		443.43 (10)			443.43 (10)
		446.31 (10)			446.31 (10)
		451.04 (5)	450.1 (7)	451.04 (5)	451.04 (5)
452.4 (1)	452.4 (1)	452.21 (3)	452.4 (2)	452.23 (3)	452.23 (3)
	458.8 (2)	458.79 (8)	458.8 (4)	458.79 (8)	458.79 (8)
	462.4 (4)	462.43 (13)	462.4 (6)	462.43 (13)	462.43 (13)
	469.5 (3)	469.48 (5)	469.5 (3)	469.48 (5)	469.48 (5)
	481.05 (5)	480.84 (3)	481.1 (2)	480.85 (3)	480.85 (3)
		491.42 (10)	492.6 (6)	491.45 (10)	491.45 (10)
	496.9 (3)				496.9 (3)
			498.6 (6)		498.6 (6)
			512.5 (7)		512.5 (7)
	515.40 (5)	515.12 (3)	515.3 (2)	515.13 (3)	515.13 (3)

1972Dz14	1990ArZZ	2000Ar23	2003Ku44	LWM	Evaluation
	517.78 (5)	517.50 (3)	517.9 (2)	517.51 (3)	517.51 (3)
	522.3 (1)	522.14 (4)	522.1 (2)	522.14 (4)	522.14 (4)
	526.09 (5)	525.77 (3)	526.1 (1)	525.94 (17)	525.94 (17)
		527.29 (5)			527.29 (5)[b]
	529.9 (1)	529.59 (3)	529.7 (3)	529.59 (3)	529.59 (3)
	531.3 (1)	530.86 (4)	531.2 (3)	530.87 (4)	530.87 (4)
		532.11 (9)			532.11 (9)
	538.1 (1)				538.1 (1)
			545.8 (6)		545.8 (6)
	552.0 (1)	551.78 (3)	552.0 (2)	551.79 (3)	551.79 (3)
		564.31 (11)	565.6 (7)	564.34 (11)	564.34 (11)
		567.47 (5)	568.3 (6)	567.48 (5)	567.48 (5)
	571.0 (1)	570.68 (3)	571.0 (2)	570.69 (3)	570.69 (3)
		590.41 (5)	591.4 (7)	590.42 (5)	590.42 (5)
	594.2 (1)	593.86 (4)	594.6 (3)	593.87 (4)	593.87 (4)
	601.1 (1)	600.92 (3)	601.0 (3)	600.92 (3)	600.92 (3)
	603.3 (1)	603.09 (4)	603.5 (5)	603.09 (4)	603.09 (4)
		628.93 (10)	629.9 (7)	628.95 (10)	628.95 (10)
			637.1 (7)		637.1 (7)
		645.87 (13)	646.3 (3)	645.94 (12)	645.94 (12)
	649.2 (1)	649.01 (4)	649.5 (2)	649.03 (4)	649.03 (4)
			653.5 (4)		653.5 (4)[b]
		656.18 (11)			656.18 (11)
		657.88 (5)			657.88 (5)
		667.10 (8)	668.1 (4)	667.14 (8)	667.14 (8)
		675.51 (18)	674.3 (4)	674.9 (3)	674.9 (3)
	679.7 (1)	679.35 (6)	680.4 (6)	679.36 (6)	679.36 (6)
		697.54 (13)	698.4 (4)	697.62 (12)	697.62 (12)[b]
		702.00 (14)			702.00 (14)
	747.0 (1)	747.0 (1)	747	747.0 (1)	747.0 (1)
		752.46 (12)			752.46 (12)
	753.7 (3)	754.04 (13)	753.7	754.04 (13)	754.04 (13)
	758.7 (1)				758.7 (1)[b]
		767.6 (4)	768.4 (5)	767.9 (3)	767.9 (3)
			780.6 (6)		780.6 (6)
		808.48 (10)			808.48 (10)
			824.2 (7)		824.2 (7)

a: from 1969Le09. b: not placed in level scheme.

5.2 Relative values of the γ-ray intensities

The results of measurements of the relative γ-ray intensities of ^{225}Ac are listed in table 7. The recommended values are taken from the LWM average of the measured values of 2000Ar23 and 2003Ku44. The measurements of 1990ArZZ were replaced by 2000Ar23; measurements of 1994Gr20 were replaced by 2003Ku44.

Table 7 Measured and recommended relative γ-ray intensities for ^{225}Ac

E_γ (keV)	I_γ							
	1967Le23	1972Dz14	1990ArZZ	1994Gr20	2000Ar23	2003Ku44	LWM	Evaluation
10.6								2.17 (28)*
26.0 (1)		~ 0.21	< 1.4		0.23 (3)	0.25 (8)	0.23 (3)	0.23 (3)
36.69 (3)	~ 4.1	~ 2.1	2.19 (27)	2.63 (36)	2.65 (33)	2.58 (27)	2.61 (21)	2.61 (21)
38.58 (4)		1.4	1.64 (14)	1.84 (50)	1.48 (23)	1.57 (16)	1.54 (13)	1.54 (13)
46.24 (5)			0.55 (27)		0.82 (17)	0.65 (11)	0.70 (9)	0.70 (9)
49.12 (4)		0.7	0.96 (27)	1.07 (36)	1.3 (2)	1.10 (13)	1.16 (11)	1.16 (11)
50.2					~ 0.09			~ 0.09
53.4 (4)		2.68 (56)			< 0.58			< 0.58
57.71 (4)		0.7	0.55 (27)	0.71 (36)	0.88 (19)	0.65 (14)	0.73 (11)	0.73 (11)
62.6 (3)					0.77 (17)			0.77 (17)
62.94 (3)	58 (7)	77.5 (70)	56.2 (27)	69.1 (52)	69.5 (87)	71.7 (49)	71.2 (42)	71 (4)
63.5 (3)					3.0 (4)			3.0 (4)
64.27 (3)		8.5 (28)	4.1 (4)	5.4 (5)	6.8 (7)	6.83 (75)	6.8 (5)	6.8 (5)
69.86 (5)		0.7	0.68 (27)	0.89 (36)	0.68 (17)		0.68 (17)	0.68 (17)
71.71 (4)		1.4	1.78 (14)	1.96 (48)	1.87 (20)	2.10 (43)	1.91 (18)	1.91 (18)
73.55 (9)		2.8	1.23 (27)		2.17 (72)	4.2 (12)	2.7 (6)	2.7 (6)
73.85 (3)	55 (10)	45.1 (42)	39.6 (18)	43.0 (34)	46.3 (58)	44.0 (36)	44.6 (31)	44.6 (31)
74.82 (5)		5.6	2.19 (27)		1.88 (43)	3.7 (12)	2.1 (4)	2.1 (4)
78.8				3.0 (13)		1.78 (27)		1.78 (27)
82.6$^{\times}$	21 (5)							21 (5)
87.41 (3)	< 6.8	40.8 (42)	31.9 (15)	40.5 (29)	44.9 (58)	37.7 (29)	39.1 (26)	39.1 (26)
94.90 (2)		22.5 (85)	11.9 (11)	12.5 (14)	18.8 (27)	14.0 (15)	15.1 (13)	15.1 (13)
96.16 (5)	4 (1)	4.2 (14)	3.84 (41)		< 4.3	4.7 (9)		4.7 (9)
99.67 (5)	301 (55)	95.8 (99)	78.1 (41)	243 (2)	197 (27)	117 (12)	110 (7)	110 (7)
99.89 (6)		239 (28)	127.4 (68)		38 (14)	167 (20)	156 (11)	156 (11)
100.86 (4)		7.0	8.8 (14)	10.9 (27)	17.5 (19)	12.5 (12)	13.9 (10)	13.9 (10)
103.48 (10)	~ 1.4		0.55 (27)		0.94 (27)	0.38 (9)	0.44 (9)	0.44 (9)
108.38 (3)	38 (7)	39.4 (42)	31.5 (14)	37.9 (27)	39.1 (43)	36.0 (26)	36.8 (22)	36.8 (22)
111.52 (3)	44 (7)	45.1 (42)	39.9 (18)	48.0 (36)	49.2 (58)	44.0 (32)	45.2 (28)	45.2 (28)
112.8 (2)			0.27 (13)		< 0.43	0.30 (4)		0.30 (4)
114						0.125 (18)		0.125 (18)
119.09 (6)$^{\times}$					2.6 (4)			2.6 (4)
119.85 (3)	9.6 (27)	8.5 (14)	9.3 (8)	12.1 (13)	14.0 (14)	11.0 (7)	11.6 (6)	11.6 (6)
121.06 (7)					2.5 (7)			2.5 (7)
123.75 (4)		26.8 (28)	9.0 (8)	10.9 (14)	14.2 (14)	12.0 (9)	12.6 (8)	12.6 (8)
124.81 (3)	29 (7)	7.0 (14)	3.3 (3)	4.6 (9)	4.6 (4)	4.0 (3)	4.22 (24)	4.22 (24)

E_γ (keV)	I_γ							
	1967Le23	1972Dz14	1990ArZZ	1994Gr20	2000Ar23	2003Ku44	LWM	Evaluation
126.10 (5)			0.96 (27)		1.06 (20)	1.17 (12)	1.14 (10)	1.14 (10)
129.22 (7)			0.41 (14)		0.48 (16)	0.37 (7)	0.39 (7)	0.39 (7)
133.60 (3)			1.78 (27)	2.7 (4)	13.9 (27)	2.83 (22)		2.83 (22)
134.85 (3)	5.5 (27)	5.6 (14)	3.84 (41)	5.0 (5)	4.8 (7)	4.5 (4)	4.6 (4)	4.6 (4)
137.40 (10)					0.43 (19)	0.32 (4)	0.33 (4)	0.33 (4)
138.2$^{\times}$	2.7 (14)							2.7 (14)
139.6						0.20 (3)		0.20 (3)
144.7 (2)	21 (4)				~ 0.07	0.067 (17)		0.067 (17)
145.15 (3)		18.3 (42)	18.4 (8)	21.8 (18)	21.4 (22)	21.0 (15)	21.1 (12)	21.1 (12)
150.05 (3)	100	100	100	100	100	100	100	100
152.64 (3)			2.2 (3)	2.7 (4)	2.39 (27)	3.17 (23)	2.84 (18)	2.84 (18)
153.92 (3)	23 (4)	26.8 (70)	23.6 (11)	27.7 (30)	28.2 (29)	30.3 (21)	29.6 (17)	29.6 (17)
157.25 (3)	51 (10)	43.7 (42)	45.2 (27)	55.4 (5)	50.7 (58)	53.3 (43)	52.4 (35)	52.4 (35)
161.35 (7)					0.52 (13)			0.52 (13)
169.18 (4)			2.33 (27)	2.86 (36)	2.29 (27)	1.17 (18)	1.7 (6)	1.7 (6)
169.9						2.0 (2)		2.0 (2)
170.77 (5)	5.5 (28)	1.4	0.96 (41)		1.06 (19)	2.83 (22)	1.9 (9)	1.9 (9)
173.4$^{\times}$						1.67 (19)		1.67 (19)
178.29 (3)	2.7 (14)		1.78 (14)		2.32 (26)	2.33 (20)	2.33 (16)	2.33 (16)
179.78 (4)			0.96 (27)	1.25 (36)	1.53 (19)	1.57 (13)	1.56 (11)	1.56 (11)
183$^{\times}$						1.22 (19)		1.22 (19)
186.1						1.83 (19)		1.83 (19)
186.29 (3)		2.8	2.47 (55)		2.74 (30)	0.60 (6)		0.60 (6)[b]
187.2						1.48 (9)		1.48 (9)
187.96 (3)	81 (8)	64.8 (70)	67.8 (34)	78.6 (5)	78.1 (87)	75 (5)	75.8 (44)	76 (4)
193.2$^{\times}$						0.28 (5)		0.28 (5)
195.74 (3)	19 (4)	19.7 (28)	20.5 (14)	25.2 (13)	23.4 (23)	20.5 (14)	21.3 (12)	21.3 (12)
197.50 (3)				3.6 (7)		3.83 (39)		3.8 (4)[b]
197.7 (1)			7.53 (68)	4.1 (9)	7.8 (10)	5.5 (6)		5.5 (6)[b]
198.47 (23)	4.1 (12)	2.8	3.01 (68)	3.8 (9)	2.55 (26)	2.83 (22)	2.71 (17)	2.71 (17)
205.07 (11)					0.27 (10)	0.18 (7)	0.21 (6)	0.21 (6)
216.89 (3)	47 (14)		39.7 (82)	53 (10)	47.8 (43)	45.2 (33)	46.2 (27)	46.2 (27)
220.43 (8)					0.87 (26)			0.87 (26)
224.59 (3)	15 (4)	11.3 (14)	12.1 (12)	14.8 (14)	15.6 (17)	16.3 (12)	16.1 (10)	16.1 (10)
228.2 (4)						0.67 (17)		0.67 (17)
231.16 (7)			0.27 (13)		0.30 (7)	1.10 (12)	0.7 (4)	0.7 (4)
236.0 (6)						0.25 (4)		0.25 (4)
238.64 (8)					0.14 (4)			0.14 (4)
240.68 (3)	2.7 (13)		0.96 (27)		1.71 (19)	1.67 (19)	1.69 (14)	1.69 (14)
243.12 (5)			0.16 (7)		0.39 (7)	0.50 (6)	0.45 (5)	0.45 (5)
249.60 (3)	2.7 (13)		1.51 (68)		1.9 (2)	2.0 (2)	1.95 (14)	1.95 (14)
253.46 (3)	21 (5)	14.1 (14)	15.5 (7)	18.4 (9)	18.5 (19)	19.3 (14)	19.0 (11)	19.0 (11)
256.0 (2)					0.05 (1)	0.100 (34)	0.054 (10)	0.054 (10)
279.18 (3)	4.1 (12)		2.33 (27)		4.63 (43)	4.17 (39)	4.4 (3)	4.4 (3)

E_γ (keV)	I_γ							
	1967Le23	1972Dz14	1990ArZZ	1994Gr20	2000Ar23	2003Ku44	LWM	Evaluation
282.1 (2)			0.55 (27)					0.079 (6)*
284.75 (3)	~ 1.4		0.55 (27)	0.71 (36)	1.09 (13)	1.05 (10)	1.07 (8)	1.07 (8)
298.33 (5)					0.29 (4)	0.30 (9)	0.29 (4)	0.29 (4)[c]
317.23 (18)					0.06 (3)	> 0.018		0.06 (3)[c]
321.77 (4)					0.46 (7)	0.50 (7)	0.48 (5)	0.48 (5)[c]
348.33 (4)			0.41 (14)		0.46 (7)	0.42 (5)	0.43 (4)	0.43 (4)
354.56 (6)			0.21 (5)	0.25 (7)	0.19 (3)	0.38 (5)	0.29 (10)	0.29 (10)
356.6						0.037 (15)		0.037 (15)
362.38 (3)			0.82 (27)		0.9 (1)	0.70 (8)	0.78 (6)	0.78 (6)
367.74 (12)					0.05 (3)	0.10 (3)	0.075 (25)	0.075 (25)
374.98 (5)			0.41 (14)		0.027 (4)	0.28 (7)		0.28 (7)
388.07 (7)					0.18 (3)			0.18 (3)
403.13 (10)			0.18 (5)		< 0.29	0.027 (23)		0.027 (23)
405.95 (3)			0.96 (27)		1.14 (13)	1.12 (9)	1.13 (7)	1.13 (7)
417.90 (2)			0.68 (14)		0.82 (10)	0.80 (8)	0.81 (6)	0.81 (6)
429.80 (18					0.055 (27)			0.055 (27)
434.82 (5)					0.46 (7)	0.40 (5)	0.42 (4)	0.42 (4)
442.16 (8)					0.65 (10)			0.65 (10)
443.43 (10)					~ 0.014			~ 0.014[d]
443.43 (10)					0.20 (7)			0.20 (7)[d]
446.31 (10)					0.09 (5)			0.09 (5)
451.04 (5)					0.41 (7)	0.53 (14)	0.43 (6)	0.43 (6)
452.23 (3)	15 (5)	15.5 (14)	14.8 (12)		17.1 (19)	14.8 (11)	15.4 (10)	15.4 (10)
458.79 (8)			0.68 (27)		0.07 (2)	0.097 (37)	0.076 (18)	0.076 (18)
462.43 (13)			2.2 (11)		0.055 (16)	0.125 (45)	0.063 (15)	0.063 (15)
469.48 (5)			0.55 (14)		0.26 (10)	0.47 (6)	0.41 (5)	0.41 (5)
480.85 (3)	4.1 (12)		4.1 (4)		4.9 (6)	4.83 (41)	4.85 (34)	4.9 (3)
491.45 (10)					0.06 (2)	0.037 (23)	0.05 (2)	0.05 (2)
496.9 (3)			0.21 (10)					0.21 (10)
498.6 (6)						0.12 (3)		0.12 (3)
512.5 (7)						0.08 (3)		0.08 (3)
515.13 (3)	~ 1.4		2.47 (27)		2.95 (30)	3.17 (23)	3.09 (18)	3.09 (18)
517.51 (3)			1.78 (27)		2.1 (2)	2.5 (2)	2.30 (14)	2.30 (14)
522.14 (4)			0.21 (5)		0.30 (3)	0.30 (5)	0.30 (2)	0.30 (2)
525.94 (17)	~ 1.4		3.97 (41)		4.63 (43)	5.50 (43)	5.1 (3)	5.1 (3)
527.29 (5)[×]					0.27 (4)			0.27 (4)
529.59 (3)			0.82 (41)		1.01 (12)	1.18 (13)	1.09 (9)	1.09 (9)
530.87 (4)			0.55 (14)		0.68 (9)	0.67 (9)	0.68 (6)	0.68 (6)
532.11 (9)					0.11 (3)			0.11 (3)
538.1 (1)			0.55 (14)					0.55 (14)
545.8 (6)						0.077 (20)		0.077 (20)
551.79 (3)			0.55 (14)		0.56 (7)	0.93 (8)	0.75 (19)	0.75 (19)
564.34 (11)					~ 0.014	0.032 (13)		0.032 (13)
567.48 (5)					0.13 (2)	0.22 (5)	0.18 (5)	0.18 (5)

E_γ (keV)	I_γ							
	1967Le23	1972Dz14	1990ArZZ	1994Gr20	2000Ar23	2003Ku44	LWM	Evaluation
570.69 (3)			0.55 (14)		0.59 (7)	0.53 (9)	0.57 (6)	0.57 (6)
590.42 (5)					0.12 (2)	0.12 (3)	0.12 (2)	0.12 (2)
593.87 (4)			0.22 (11)		0.41 (4)	0.47 (10)	0.42 (4)	0.42 (4)
600.92 (3)			0.47 (14)		0.35 (6)	0.62 (15)		0.35 (6)[ad]
600.92 (3)					~ 0.87			~ 0.87[ad]
603.09 (4)			0.27 (13)		0.25 (3)	0.27 (7)	0.25 (3)	0.25 (3)
628.95 (10)					0.049 (13)	0.043 (14)	0.046 (10)	0.046 (10)
637.1 (7)						~ 0.017		~ 0.017
645.94 (12)					0.032 (10)	0.017 (7)	0.022 (6)	0.022 (6)
649.03 (4)			0.18 (5)		0.27 (3)	0.20 (5)	0.25 (3)	0.25 (3)
653.5 (4)[×]						0.025 (7)		0.025 (7)
656.18 (11)					0.07 (3)			0.07 (3)
657.88 (5)					0.20 (4)			0.20 (4)
667.14 (8)					0.56 (13)	0.040 (12)	0.30 (26)	0.30 (26)
674.9 (3)					0.019 (9)	0.012 (7)	0.015 (6)	0.015 (6)
679.36 (6)			0.11 (3)		0.09 (2)	0.102 (26)	0.095 (16)	0.095 (16)[c]
697.62 (12)[×]					0.035 (13)	0.028 (8)	0.030 (7)	0.030 (7)
702.00 (14)					0.023 (10)			0.023 (10)
747.0 (1)			0.16 (5)		< 0.29	< 0.017		0.16 (5)
752.46 (12)					0.038 (10)			0.038 (10)
754.04 (13)			0.11 (3)		0.033 (10)	< 0.017		0.033 (10)
758.7 (1)[×]			0.68 (14)					0.68 (14)
767.9 (3)					0.049 (13)	0.040 (12)	0.044 (9)	0.044 (9)
780.6 (6)						0.008 (2)		0.008 (2)
808.48 (10)					0.30 (4)			0.30 (4)
824.2 (7)						~ 0.007		~ 0.007

a: From 2000Ar23.
b: From 2003Ku44.
c: Multiply placed, intensity not divided.
d: Multiply placed, intensity suitable divided.
*: From intensity balance.
×: Not placed in level scheme.

5.3 Absolute values of the γ-ray emission probabilities

Measured absolute γ-ray emission probabilities for the 150.04 keV line for ^{225}Ac are compiled and listed in Table 8.

2000Ar23 gives the value 0.691 (16) %, which was obtained from correction of the intensity of 1986He06 using the measured value 0.053 (6) % (2000Ga52) for the 149.89 keV transition in ^{229}Th α-decay and the measured value 0.051 (10) % (1995Sh01) for the 150.14 keV transition in ^{221}Fr α-decay.

Conversely, to correct the measured intensity of 1986He06, if using the measured value 0.053 (6) % (2000Ga52) for the 149.89 keV transition in ^{229}Th α-decay and the evaluated value 0.0478 (23) % (1990Ak05) for the 150.14 keV transition in ^{221}Fr α decay, the value would be then 0.695 (13) %. These corrected values are in good agreement with the measured value in 1995Ch74.

The recommended absolute γ-ray emission probability of the 150.04 keV γ-ray is from the measurement of 1995Ch74 and adopted as the normalization factor N, with N = 0.00693 (12). The recommended absolute γ-ray emission probabilities are the relative values evaluated in table 7 multiplied by 0.00693 (12).

Table 8 Measured and recommended absolute γ-ray emission probability of 150.04 keV for ^{225}Ac

P_γ (150.04 keV) (%)	References	measurement method
0.981 (3)	1981Di14	Ge(Li)
0.796 (11)	1986He06	Ge(Li),Au-Si surface barrier, in equilibrium with ^{229}Th
0.693 (12)	1995Ch74	Ge(Li),αγ-coincidence
0.691 (16)	2000Ar23	From 1986He06 corrected by 2000Ga52 and 1995Sh01
0.693 (12)		Recommended value from 1995Ch74

6. References

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^{227}Ac – Comments on evaluation of decay data by V. P. Chechev and N.K. Kuzmenko

This evaluation was completed in June 2008 with a literature cut off by the same date. The SAISINUC software and associated supporting computer programs were used in assembling the data following the established protocol within DDEP (2002Be).

1. Decay Scheme

The ^{227}Ac decay scheme is based on the evaluation of Browne (2001Br31). ^{227}Ac disintegrates (1,380 (4) %) by alpha transitions to the ground state and excited states of ^{223}Fr and (98,620 (4) %) by beta transitions to the ground state and excited states of ^{227}Th. The decay scheme cannot be considered well established since only approximate values are available for beta and gamma transition probabilities in the $ß^-$-decay of ^{227}Ac and the measurements of weak alpha transitions probabilities in the α-decay of ^{227}Ac are not sufficiently accurate.

2. Nuclear Data

Q(α) value is from 2003Au03.

The evaluated half-life of ^{227}Ac is based on the experimental results given in Table 1.

Table 1. Experimental values of the ^{227}Ac half-life (in years)

Reference	Author(s)	Value
1950Ho79	Hollander and Leininger	22,0 (3)
1955To07	Tobailem	21,6 (4)
1956Sh43	Shimanskaya and Yashugina	21,2 (8)
1959Ro51	Robert	21,6 (3)
1963Ei10	Eichelberger et al.	21,7714 (+56 −33)
1967JoZX	Jordan and Blanke	21,7728 (+29 −32)

The weighted mean of the 6 values is 21,772. The internal uncertainty is 0,0022, if we use the smallest uncertainties from 1963Ei10 and 1967JoZX, and 0,0028, if we use the largest uncertainties from these measurements. χ^2/ν = 0,34 and 0,33, respectively.

Our recommended value for the ^{227}Ac half-life is 21,772 (3) years.

2.1 Alpha Transitions

The energies of the alpha transitions have been obtained from Q(α) value and the level energies given in Table 2 from 2001Br31 where they were deduced from a least squares fit to gamma-ray energies.

The comparison of the adopted energies of alpha particles for most intense transitions with the measured values is shown in Table 3 (columns 3 and 4). The measured energies of the alpha particles (Table 3) have been adjusted for changes in the calibration standards (1986Ry04, 1991Ry01): +3,5 keV correction for values from 1966Ba19, +5 keV correction for values from 1959No41.

Table 2. ^{223}Fr levels populated in the ^{227}Ac α-decay

Level	Level energy, keV	Spin and parity	Half-life	a-transition energy, keV	Probability of alpha transitions (×100)
0	0	3/2(⁻)	22,00 (7) min	5042,19 (14)	0,658 (14)
1	12,89 (5)	(5/2⁻)		5029,30 (15)	0,546 (17)
2	54,97 (7)	½(⁻)		4987,22 (16)	0,0015
3	82,13 (6)	(7/2⁻)		4960,06 (15)	0,087 (7)
4	99,63 (6)	(3/2⁻)		4942,56 (15)	} 0,08 (1)
5	101,00 (6)	(5/2⁻)		4941,19 (15)	
6	134,51 (6)	(3/2⁺)		4907,68 (15)	0,001
7	149,3 (3)	(1/2⁺)			
8	160,48 (7)	(3/2⁺)		4881,71 (16)	0,014 (7)
9	172,08 (6)	(5/2⁺)		4870,11 (15)	0,0011
10	187,18 (10)	(5/2⁻)		4855,01 (17)	} 0,025 (7)
11	189,10 (7)	(7/2⁻)		4853,09 (16)	
12	219,61 (9)	(7/2⁺)		4822,58 (17)	} 0,0012
13	222,75 (10)	(7/2⁺)		4819,44 (17)	
14	242,63 (7)	(5/2)		4799,56 (16)	} 0,006 (3)
15	243,85 (13)	(5/2)		4798,34 (19)	
16	244,66 (15)	(7/2⁻)		4797,53 (21)	
17	298,7 (3)	(9/2⁻)			
18	365,47 (10)			4676,72 (17)	$\approx 3\cdot10^{-4}$
19	379 (7)			4663 (7)	$\approx 4\cdot10^{-5}$
20	449 (5)			4593 (5)	$\approx 4\cdot10^{-5}$
21	503 (7)			4539 (7)	$\approx 7\cdot10^{-5}$
22	515,20 (22)	3/2⁻		4526,99 (26)	$\approx 7\cdot10^{-4}$
23	540,74 (25)	(5/2⁺)		4501,45 (29)	$\approx 8\cdot10^{-5}$
24	601 (7)	(5/2⁻)		4441,19 (16)	$\approx 4\cdot10^{-5}$

The recommended probabilities of the $\alpha_{0,i}$-transitions with i = 0, 1, 3, 4, 8, 11, 14 are from 1959No41. The remaining ones are from 1966Ba19. A comparison of the α-transition probabilities, taken directly from measurements of 1959No41, 1966Ba19 with those deduced from P(γ+ce) intensity balance, is given in Table 3. The total probability of α-transitions is from 1970Ki12 (1,3800 (36) %), see also 1974Mo05 (1,359 (14) %). The α-decay hindrance factors have been calculated using the ALPHAD computer program from the ENSDF evaluation package with r_0 = 1,538 fm, average of $r_0(^{222}Rn)$ = 1,5397 (4) fm, $r_0(^{222}Ra)$ = 1,5383 (8) fm and $r_0(^{224}Ra)$ = 1,5332 (8) fm, see 2001Br31.

Table 3. Energies and probabilities (×100) of most intense α-transitions in the ^{227}Ac decay

Level	Level energy, keV	Energies of a-particles, obtained from Q(α), keV	Measured energies of a-particles, keV	Probabilities (×100), adopted from 1959No41, 1966Ba19	Probabilities (×100), deduced from intensity balance
0	0	4953,23 (14)	4953,26 (14)	0,658 (14)	0,48 (24)
1	12,89 (5)	4940,57 (15)	4940,7 (8)	0,546 (16)	0,63 (15)
3	82,13 (6)	4872,55 (15)	4872,7 (2)	0,087 (7)	0,09 (3)
4	99,63 (6)	4855,36 (15)	4855 (2)	} 0,08 (1)	} 0,10 (6)
5	101,00 (6)	4854,01 (15)			
6	134,51 (6)	4821,09 (15)	4822 (4)	0,014 (7)	0,0090 (26)
10	187,18 (10)			} 0,025 (7)	} 0,028 (10)
11	189,10 (7)	4767,47 (15)	4768 (3)		

2.2 Beta Transitions

The energies of β^- transitions have been obtained from Q^-(^{227}Ac) and ^{227}Th level energies given in Table 4. The β^--emission probabilities per 100 β^- particles in ^{227}Ac β^--decay have been taken from 1995Li04. The value of $\Sigma P_{\beta-}$ (i) has been obtained as (100 % - ΣPa (i)) = 98,620 (4) %. This is the total probability of beta transitions to the ground state and excited states of ^{227}Th.

Table 4. ^{227}Th levels populated in the ^{227}Ac β^--decay

Level	Level Energy, keV	Spin and Parity	Half-life	β^--emission probability per 100 β^- particles
0	0,0	1/2 +	18,68 (9) d	≈ 54
1	9,3	(5/2+)		≈ 35
2	24,5	3/2+		≈ 10
3	37,9	3/2-		0,3

2.3 Gamma Transitions and Internal Conversion Coefficients

The evaluated energies of the gamma-ray transitions are virtually the same as the gamma-ray energies because nuclear recoil is negligible.

The gamma-ray transition probabilities in ^{223}Fr have been deduced from their gamma-ray emission probabilities and the calculated total ICCs. The gamma-ray transition probabilities in ^{227}Th have been adopted from 1995Li04. ICCs have been calculated by a program supplied with the SAISINUC software (2002Be). This code uses interpolated values of Band et al. (2002Ba85). The multipolarities and mixing ratios δ of the gamma-ray transitions in ^{223}Fr and ^{227}Th have been taken from 2001Br31. The uncertainties in the ICCs for pure multipolarities have been taken as 2 %.

3. Atomic Data

The atomic data (fluorescence yields, X-ray energies and relative probabilities, Auger electrons energies and relative probabilities) were obtained using the SAISINUC software (2002Be).

4.1 Alpha Emissions

Details are given in Section 2.1.

4.2 Beta Emissions

Details are given in Section 2.2.

5. Photon Emissions

5.1 X-Ray Emissions

The absolute emission probabilities of Fr KX and LX-rays and Th LX-rays have been calculated using the EMISSION code (2000Schönfeld). An experimental Fr KX-rays intensity value of 0,0136 (16) % (from 1995Sh03) agrees well with 0,0145 (24) %, deduced by the evaluators.

5.2 Gamma-Ray Emissions

Gamma-Ray Energies

The energies of gamma-rays in ^{223}Fr have been adopted from 1995Sh03. The energies of gamma-rays $\gamma_{1,0}$ and $\gamma_{2,1}$ in ^{227}Th have been adopted from 1959No41. The energies of gamma-rays $\gamma_{2,0}$ and $\gamma_{3,1}$ in ^{227}Th have been adopted from 1997Mu08.

Gamma-Ray Emission Probabilities

The absolute emission probabilities of gamma-rays in ^{223}Fr are from 1995Sh03. The absolute emission probabilities of gamma-rays in ^{227}Th have been deduced from the absolute β^--emission probabilities in the ^{227}Ac β^--decay and α_T using the ratio of P(γ37,9-keV) / P(γ28,6-keV) = 9,0 (12) / 7,7 (10) = 1,17 (22) from ^{227}Pa EC decay (1995Li04), and the value of P(γ24,3-keV) / P(γ15,2-keV) = 20 / 0,44 = 45,5 from alpha decay of ^{231}U (2001Br31).

6. Electron Emissions

The energies of conversion electrons have been obtained from the gamma transition energies and atomic electron binding energies. The emission probabilities of conversion electrons have been deduced from the evaluated P(γ) and ICC values.

The number of K- and L- Auger electrons per 100 disintegrations has been calculated using the EMISSION code (2000Schönfeld).

Average β^- energies have been calculated using the LOGFT computer program.

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^{228}Ac - Comments on Evaluation Decay Data
By Andy Pearce

This evaluation was completed in September 2009 drawing in part from the mass-chain evaluation of Artna-Cohen[1]. The literature available up until January 2009 was included. There is some evidence the decay scheme is not complete based upon the calculated beta emissions.

1 Decay Scheme

^{228}Ac decays almost entirely by beta- decay to excited states in ^{228}Th. The decay scheme (energies, half lives, spins and parities of levels in ^{228}Th) are based upon the adopted levels and gammas from Artna-Cohen[1], which in turn are largely derived from the work of Dalmasso et al[2]. The assignments of gammas to levels are also largely derived from Dalmasso et al.

Baltzer et al[3] place gammas at 56.8 keV and 137.4 keV originating from a 1588 keV 4- level in ^{228}Pa decay. Gamma emissions of similar energies have been observed in ^{228}Ac decay but not placed, and it is assumed these are the same transitions. Inserting this level in the ^{228}Ac decay allows for alternative placement of the 356 keV gamma, for which the predicted multipolarity (E2) did not match the measured conversion coefficient[4] (α=0.3-4). Placement from the 1945 keV level to the 1588 keV level indicates a multipolarity of E1+M2; the mixing ratio has been tentatively estimated at δ=0.5 giving α_T=0.35.

Decay via alpha emission to ^{224}Fr has been reported[5] with a probability of $(5.5 \pm 2.2) \times 10^{-6}$ per 100 decays, but this is unconfirmed.

2 Nuclear Data

For the purposes of this evaluation it is assumed ^{228}Ac decays entirely to ^{228}Th and any alpha branching present is negligibly small. The Q-value of beta decay is taken from Audi, Wapstra & Thibault[6] and is 2123.8 (27) keV. The effective Q-value calculated from the individual decay rates and energies calculated with the RADLST[7] program is 2010 (100) keV; this is low compared with the value from Audi, Wapstra & Thibault and serves to confirm that the decay scheme is incomplete.

There have been only two measurements of the half life reported in the open literature, Hahn and Erbacher[8] at 6.13 hours (quoted in Curie[9], however the corresponding publication could not be identified) and Skanemarg & Skalberg[10] at 6.15 (3) hours. No uncertainty is given for the value of Hahn & Erbacher, but it serves to give confidence in the recommended value of 6.15 (3) hours taken from Skanemarg and Skalberg. From an evaluators' point of view more data are required to provide a definitive half life, however in practice this radionuclide will generally be encountered in secular equilibrium with either the ^{228}Ra or ^{232}Th decay parents, and the exact value of the half life will likely be of no great concern to the user.

3 Atomic Data

All values of atomic data (ω_K, ω_L, η_{KL}, relative probabilities of X-ray and Auger emissions) were derived from Schönfeld and Janßen[11].

4 Gamma-ray Transitions and Internal Conversion Coefficients

Gamma-ray transition energies are calculated from the differences in level energies from Artna-Cohen[1].

Internal conversion coefficients have been determined using the BrIcc code[12], with the gamma-ray multipolarities and mixing ratios from the evaluation of Artna-Cohen[1]. For many emissions the multipolarity is undetermined, and no conversion coefficients could be calculated. Where a multipolarity is available but no mixing ratio given, a default value of 1 is assumed and the uncertainty of the derived conversion coefficients is increased accordingly.

Internal conversion coefficients have been measured by Herment and Vieu[4] and Mahajan and Bidarkundi[13] and these are compared in table 3 with the recommended values calculated with BrIcc. The agreement of the total conversion coefficients for the K and L shells is generally good. The 204 keV transition has been reassigned to M2 based upon the measured K conversion coefficient in 1982Ma52; the authors assign 96 % M2 + 4% E1 however the theoretical coefficients calculated using BrIcc for pure M2 are very close to the measured values.

Devare and Devare[24] have measured accurately the L_{II}/L_{I} conversion ratios for the 184 keV transition from the 1153 keV level and have assigned the multipolarity as predominantly E0 + M1 with a mixing ratio of $\delta \approx 0.3$. It is not possible with BrIcc to calculate conversion coefficients of mixed type transitions incorporating an E0 element, therefore the K-shell conversion coefficient has been estimated at 80 (30) from the measured data as the median of values measured by Herment and Vieu and Mahajan and Bidarkundi and the total coefficient of 100 (40) calculated from the calculated K/total ratio derived from BrIcc with the multipolarity and mixing ratio as above.

5 Electron Emissions

5.1 Beta-particle Emissions

There are no published measurements of the beta emissions in the open literature. Beta-particle transition energies have therefore been determined from the Q-value and level energies, and the emission probabilities from the balance of the decay scheme using the program 'GTOL'[14].

A normalisation factor for the gamma emission probabilities of 0.0454 (11) has been used to determine absolute gamma emission intensities; however, applying this same value when deriving level feedings implies a ~7 % feeding direct to the ground state. Such a transition would be a 2nd forbidden unique decay and such a high branching seems unreasonable. By assuming negligible feeding to the ground state leads a normalisation factor of 0.0475 (11) is calculated, and this value is used to calculate beta particle emission intensities with GTOL. There is therefore an unexplained ~7 % discrepancy between the beta and gamma emissions in this decay; Artna-Cohen[1] suggests there are missing gammas in the decay scheme. Given the available data it seems such gammas would need to decay direct to the ground state and be of such character as to be difficult to detect, for example low energy or E0 transitions. Further measurements of the gamma data, particularly at low energy, would be of benefit, as would coincidence studies to validate the placement of gammas in the level scheme.

The Q-value coupled with the presence of a level in the decay scheme at 2123.1 (3) keV implies a beta emission with an end-point energy of 0.7 keV; it seems unlikely such a low energy emission could have a significant emission probability. This may indicate a deficiency in either the placement of gammas in the decay scheme or in the Q-value.

5.2 Auger & Conversion Electron Emissions

Auger and conversion electron emissions per 100 decays were calculated from the gamma-ray data and conversion coefficients according to the method of Schönfeld and Janßen[11] using version 3.10 of the code EMISSION.

6 Photon Emissions

6.1 X-ray Emissions

The X-ray intensities per 100 decays have been calculated from the gamma-ray data and conversion coefficients using version 3.10 of the code EMISSION. No measurements of the X-ray emissions have been published so it is not possible to make a comparison of calculated and measured data. A comparison with values in the NUDAT database is given in table 4.

6.2 Gamma-ray Emissions

The gamma-ray emission energies have been taken from Helmer[15] where possible, in which precise measurements were made by measuring energy differences against accepted calibration standards. Only the directly measured values have been taken, as the decay scheme used to derive further values was incomplete. These values have been adjusted to reflect the updated calibration standards given in Helmer and van der Leun[16]. Where gamma-ray lines are not present in Helmer[15], weighted means of the values in Herment and Vieu[4], Taylor[17], Kurcewicz et al[18], Borner et al[19], Dalmasso et al[2] and Baltzer et al[3] were taken. The uncertainties of Borner et al were expanded based upon the detector resolution stated in the publication. The values in these publications were first rescaled by a least-squares fit to be compatible with Helmer[15]. In most cases the energy shift incurred by doing so was very small.

Gamma emission probabilities were determined by a weighted mean of values in Arnoux and Gizon[20], Herment and Vieu[4], Mahajan and Bidarkundi[13], Sadasivan and Raghunath[21], Schötzig and Debertin[22], Dalmasso et al[2], Lin and Harbottle[23] and Baltzer et al[3]. Uncertainties were expanded to match the minimum input uncertainty where appropriate. Values were first renormalised to 100 for the 463 keV emission. Baltzer et al relates to ^{228}Pa decay, however additional information could be obtained from this publication for relative gamma emission probabilities originating from the 1431 keV level. Measured and evaluated relative emission probabilities are compared in appendices II and III. While there are several publications covering some of the emissions the intensities of many transitions have been derived solely from Dalmasso et al; where alternative data exists the agreement is often poor.

Several of the gamma emission probabilities measured by Mahajan and Bidarkundi have been rejected on technical grounds. The radionuclides used for calibration stated by the authors were ^{152}Eu, ^{160}Tb and ^{192}Ir. The lowest energy of any gamma line which could reliably be used for efficiency calibration belongs to ^{152}Eu at 122 keV; therefore, gamma emission intensities reported below this energy were rejected. Furthermore, in the energy region 321 keV to 338 keV there seems to be a consistent high bias to the data (see appendix I); two out of three measurements were rejected by Chauvenet’s criterion. The remaining measurement passed Chauvenet’s criterion but appears high and was rejected due to the obvious trend.

It is not clear that the data in Arnoux and Gizon[20] and Herment and Vieu[4] are independent; in many cases, the data are numerically identical, and appear to correspond to the work of the same research group. In cases where the same emission has been reported by both authors, only the data from the latter publication have been used in the analysis.

Absolute gamma emissions were measured by Schötzig and Debertin[22] and Lin and Harbottle[23]. The intensities of the 463 keV emissions were used to derive normalisation factors and these values are 0.0450 (12) and 0.0441 (11) respectively. The weighted mean of these two values at 0.0445 (11) was used to convert relative intensities into absolute intensities. However, this value is not consistent with expected beta decay characteristics (see section 5.1), suggesting deficiencies in either the adopted decay scheme or the measured data.

There are twenty gammas which cannot be placed in the level scheme. The total intensity is less than 0.25 % (accounting for some internal conversion). These are listed in table 2. The intensity of these gamma emissions is insufficient to account for the discrepancies observed in the decay scheme.

The 18.4 keV gamma has been observed but the probability not directly measured in ^{228}Ac decay; a nominal value of 0.14 (3) for the total transition probability has been derived based upon coincidence measurements on ^{228}Pa[16]. This implies a gamma emission probability of 0.019 (4).

Several doublets have been reported in ^{228}Ac decay. The measured gamma emission intensities have been divided between the components where possible by comparing with ^{228}Pa decay[3]:

168.53 (12) keV

The 1344 keV level has not being reported in ^{228}Pa decay, therefore the intensity of the 168 keV emission from the 1928 keV level was derived from the ratio of the 168 keV emission to the 1741 keV and 1870 keV emissions in ^{228}Pa:

Intensity 168 keV (^{228}Ac, 1928 keV) = intensity 168 keV ^{228}Pa / intensity 1741 keV ^{228}Pa × intensity 1741 keV ^{228}Ac

and:

Intensity 168 keV (^{228}Ac, 1928 keV) = intensity 168 keV ^{228}Pa / intensity 1870 keV ^{228}Pa × intensity 1870 keV ^{228}Ac

The calculated values are 0.0715 (18) and 0.0407 (43) respectively; these are not consistent so a median of the two values is taken, with an uncertainty large enough to cover the difference.

The assigned relative intensities are 0.056 (15) from the 1928 keV level and 0.25 (6) from the 1344 keV keV level. The absolute intensities are therefore 0.0025 (7) and 0.0111 (27) respectively.

278.80 (15) keV

The total relative intensity is 5.28 (28) determined by LRSW weighted mean of the measured data[2,13,20]. The intensity has been split between transitions from the 1153 keV and 1431 keV levels by comparing the emission intensities in ^{228}Ac decay and ^{228}Pa decay. The relative intensities are therefore 4.6 (5) and 0.69 (7) for transitions from the 1153 keV and 1431 keV levels respectively.

649.02 (12) keV

The measured relative intensity is 0.94 (10) from Dalmasso et al[2]. The intensity has been split between transitions from the 1168 keV and 1617 keV levels by comparing the emission intensities in ^{228}Ac decay and ^{228}Pa decay. The relative intensities are therefore 0.75 (8) and 0.189 (20) for transitions from the 1168 keV and 1617 keV levels respectively.

666.451 (46) keV

The measured relative intensity is 2.4 (2) from Dalmasso et al[2]. The intensity has been split between transitions from the 1645 keV and 1892 keV levels by comparing the emission intensities in ^{228}Ac decay and ^{228}Pa decay. The relative intensities are therefore 2.27 (23) and 0.128 (13) for transitions from the 1645 keV and 1892 keV levels respectively.

688.117 (42) keV

Dalmasso et al[2] suggests this emission originates from the 874 keV level; Baltzer et al[4] suggest dual placement from the 874 keV and 1016 keV levels. The measured relative intensity is 1.58 (14) from Dalmasso et al. The intensity has been split by comparing the emission intensities in ^{228}Ac decay and ^{228}Pa decay. The relative intensities are therefore 0.161 (16) and 1.42 (14) for transitions from the 1645 keV and 1892 keV levels respectively.

791.43 (8) keV

The measured relative intensity is 0.54 (17) from Dalmasso et al[2]. The intensity has been split between transitions from the 1760 keV and 1944 keV levels by comparing the emission intensities in ^{228}Ac decay and ^{228}Pa decay. The relative intensities are therefore 0.23 (7) and 0.31 (10) for transitions from the 1760 keV and 1944 keV levels respectively.

853.96 (8) keV

Artna-Cohen[1] indicates a doublet between an unplaced transition and a transition originating from the 1944 keV level. The energy measured by Dalmasso et al[2] is 853.19 (10) keV however a transition of this energy does not readily fit in to the level scheme as it stands. In the absence of confirmatory measurements it is assumed this transition is the same as that observed at 853.96 keV by Baltzer et al[4] in ^{228}Pa decay. The entire measured intensity of 0.0124 (20) is assigned to the 1944 keV level, and the energy is determined from ^{228}Pa decay.

921.87 (12) keV

Artna-Cohen indicates a doublet between the 979 keV and 1925 keV levels. However, the transition from the 1925 keV level was reported separately by Baltzer et al[4] in ^{228}Pa decay at an energy of 922.5 keV. Based upon the reported energy, it is assumed the transition measured in ^{228}Ac decay is predominantly from the 979 keV level. This emission has therefore been assigned in it's entirety to decay from the 979 keV level.

930.99 (6) keV

The total measured intensity is 0.0129 (20) from 1987Da28. The intensity has been split between transitions from the 1450 keV and 1899 keV levels by comparing the emission intensities in ^{228}Ac decay and ^{228}Pa decay. The absolute intensities are therefore 0.0040 (10) and 0.0025 (23) for transitions from the 1760 keV and 1944 keV levels respectively.

1016.44 (8) keV

Observed in both ^{228}Ac and ^{228}Pa decay. Dalmasso et al[2] suggests a multiple placing, originating from both the 1016 keV and 1344 keV levels of ^{228}Th. Baltzer et al[4] gives only a "less than" value for the 1016 keV transition. The 1344 keV level is not indicated as being fed in ^{228}Pa decay, and assuming the intensity in ^{228}Pa decay is half the "less than" value gives a branching ratio very similar to that observed in ^{228}Ac decay. The intensity has therefore been assigned in its entirety to the transition from the 1016 keV level.

1110.604 (9) keV

The total measured intensity is 0.311 (24) from a weighted mean of Arnoux and Gizon[20] and Dalmasso et al[2]. The intensity has been split between transitions from the 1168 keV and 1297 keV levels by comparing the emission intensities in ^{228}Ac decay and ^{228}Pa decay (1995Ba42). The relative intensities are therefore 6.4 (5) and 0.60 (5) for transitions from the 1168 keV and 1297 keV levels respectively.

Table 1. Comparison of beta transition probabilities calculated using the gamma normalisation factor derived from measurements using a normalisation factor of 0.0445 (11) [A] and from assuming zero feeding to the ground state with a normalisation factor of 0.0474 (11) [B]. Where the calculated beta transition probability is within one standard deviation of zero, a "less than" value is stated. In these cases the emission is not assumed to occur with significant probability. The values calculated assuming zero feeding to the ground state have been recommended.

Level energy /keV	Beta endpoint energy /keV	Feeding /per 100 decays		log *ft*	Transition type
		[A]	[B]		
ground state	2123.8 (27)	7 (3)	<6	-	2nd forbidden unique
57.759 (4)	2066.0 (27)	6 (4)	6 (4)	9.0 (4)	allowed
186.823 (4)	1937.0 (27)	0.6 (5)	0.6 (5)	10 (4)	allowed
328.003 (4)	1795.8 (27)	0.67 (22)	0.72 (23)	10.65 (20)	1st forbidden unique
378.179 (10)	1745.6 (27)	0.138 (19)	0.147 (21)	12.29 (16)	2nd forbidden unique
396.078 (5)	1727.7 (27)	11.6 (5)	12.4 (5)	8.40 (15)	1st forbidden unique
519.192 (6)	1604.6 (27)	<0.07	<0.07	-	1st forbidden unique
831.823 (10)	1292.0 (27)	<0.01	<0.05	-	1st forbidden unique
874.473 (18)	1249.3 (27)	0.16 (10)	0.17 (10)	9.7 (3)	allowed
938.58 (7)	1185.2 (27)	<0.01	<0.01	-	2nd forbidden unique
944.196 (13)	1179.6 (27)	0.081 (15)	0.087 (16)	9.95 (17)	allowed /1t forbidden
968.369 (20)	1155.4 (27)	0.17 (3)	0.18 (3)	9.60 (16)	1st forbidden
968.968 (5)	1154.8 (27)	29 (3)	31 (4)	7.37 (16)	allowed
979.499 (14)	1144.3 (27)	0.224 (19)	0.238 (20)	9.47 (15)	allowed
1016.406 (21)	1107.4 (27)	0.36 (6)	0.39 (6)	9.20 (16)	allowed/1st forbidden
1022.527 (6)	1101.3 (27)	2.8 (4)	3.0 (4)	8.31 (16)	allowed
1059.93 (3)	1063.9 (27)	0.093 (11)	0.099 (11)	9.74 (15)	1st forbidden
1091.017 (8)	1032.8 (27)	0.16 (7)	0.16 (7)	9.48 (24)	allowed
1122.951 (6)	1000.8 (27)	6.27 (17)	6.67 (18)	7.81 (15)	1st forbidden
1153.467 (10)	970.3 (27)	6 (3)	6 (3)	7.8 (3)	allowed
1168.375 (5)	955.4 (27)	3.18 (11)	3.39 (11)	8.04 (15)	1st forbidden
1174.508 (18)	949.3 (27)	<	<		allowed
1175.39 (5)	948.4 (27)	0.155 (18)	0.166 (19)	9.34 (15)	allowed
1226.565 (7)	897.2 (27)	0.63 (7)	0.67 (8)	8.65 (15)	1st forbidden
1297.423 (10)	826.4 (27)	1.37 (10)	1.46 (11)	8.18 (15)	1st forbidden unique
1344.078 (11)	779.7 (27)	0.208 (18)	0.208 (18)	8.94 (15)	1st forbidden
1416.11 (6)	707.7 (27)	0.060 (8)	0.060 (8)	9.34 (16)	allowed /1st forbidden
1431.979 (6)	691.8 (27)	1.6 (5)	1.6 (5)	7.88 (20)	allowed
1450.394 (10)	673.4 (27)	0.25 (8)	0.26 (9)	8.63 (21)	1st forbidden
1531.474 (6)	592.3 (27)	<3	<3	-	allowed
1539.21 (9)	584.6 (27)	<0.01	0.030 (6)	9.36 (17)	allowed
1588.335 (14)	535.5 (27)	8.2 (22)	8.8 (23)	6.77 (19)	1st forbidden
1617.78 (7)	506.0 (27)	0.067 (10)	0.071 (10)	8.78 (16)	allowed
1638.284 (9)	485.5 (27)	1.16 (6)	1.23 (6)	7.48 (15)	allowed
1643.125 (15)	480.7 (27)	0.82 (3)	0.82 (3)	7.64 (15)	1st forbidden
1645.954 (12)	477.8 (27)	4.12 (20)	4.12 (20)	6.94 (15)	allowed
1682.81 (3)	441.0 (27)	1.21 (4)	1.21 (4)	7.35 (15)	allowed
1683.82 (5)	440.0 (27)	0.20 (3)	0.20 (3)	8.13 (16)	1st forbidden
1688.394 (11)	435.4 (27)	2.50 (16)	2.50 (16)	7.02 (15)	allowed
1724.283 (6)	399.5 (27)	1.81 (8)	1.93 (8)	7.01 (15)	allowed
1735.45 (25)	388.4 (27)	0.140 (10)	0.149 (11)	8.08 (15)	allowed
1743.89 (3)	379.9 (27)	0.355 (15)	0.378 (16)	7.65 (15)	allowed
1758.24 (12)	365.6 (27)	0.056 (8)	0.06 (8)	8.39 (16)	allowed
1760.218 (24)	363.6 (27)	0.130 (11)	0.139 (12)	8.02 (15)	allowed
1795.90 (10)	327.9 (27)	0.033 (5)	0.035 (6)	8.48 (16)	allowed
1797.65 (8)	326.2 (27)	0.048 (8)	0.051 (8)	8.30 (16)	allowed
1892.996 (17)	230.8 (27)	0.102 (8)	0.109 (8)	7.50 (15)	allowed
1899.95 (4)	223.9 (27)	0.064 (7)	0.069 (8)	7.65 (15)	allowed

Level energy /keV	Beta endpoint energy /keV	Feeding /per 100 decays		log *ft*	Transition type
		[A]	[B]		
1906.64 (10)	217.2 (27)	0.023 (5)	0.025 (5)	8.05 (17)	allowed
1928.57 (6)	195.2 (27)	0.057 (7)	0.061 (7)	7.52 (16)	allowed
1937.16 (9)	186.6 (27)	0.050 (6)	0.053 (6)	7.52 (15)	allowed
1944.895 (11)	178.9 (27)	0.289 (20)	0.307 (22)	6.70 (15)	allowed
1958.72 (22)	165.1 (27)	0.0035 (8)	0.0038 (8)	8.50 (17)	allowed
1964.98 (7)	158.8 (27)	0.0124 (13)	0.0132 (14)	7.91 (15)	allowed
1987.46 (10)	136.3 (27)	0.07 (4)	0.07 (4)	7.0 (3)	allowed
2010.11 (5)	113.7 (27)	0.224 (14)	0.238 (15)	6.20 (15)	allowed
2013.6 (3)	110.2 (27)	0.0030 (9)	0.0032 (10)	8.03 (20)	allowed
2022.84 (10)	101.0 (27)	0.057 (6)	0.061 (6)	6.64 (16)	allowed/1st forbidden
2029.84 (16)	94.0 (27)	0.024 (4)	0.026 (4)	6.91 (16)	allowed
2036.99 (17)	86.8 (27)	0.0065 (11)	0.0069 (10)	7.38 (17)	allowed
2123.1 (3)	0.7 (27)	0.0044 (10)	0.0047 (11)	≤3.3	allowed

Table 2. Unplaced gamma emissions. The following gamma emissions have not been unambiguously placed in the level scheme. The energy lost from the decay scheme is insufficient to explain the deviation in Q_{eff} and the total probability is insufficient to explain the anomalous feeding to the ground state.

Energy /keV	Emission probability per 100 decays	Observed in	Comments
466.40 (10)	0.0299 (34)	1987Da28	-
481.5 (5)	0.024 (5)	1987Da28, 1995Ba42	Placed at 1450 keV level by 1995Ba42, however unreasonable multipolarity of M2 or E3 results (from Artna-Cohen).
634.18 (10)	0.0111 (22)	1987Da28	-
1337.33 (20)	0.0051 (16)	1987Da28	-
1378.23 (10)	0.0062 (19)	1987Da28	-
1385.39 (10)	0.0111 (22)	1987Da28	-
1434.22 (15)	0.0084 (25)	1987Da28	-
1438.01 (10)	0.0062 (17)	1987Da28	-
1480.38 (15)	0.0170 (34)	1987Da28, 1995Ba42	-
1529.01 (34)	0.059 (6)	1969Ar16, 1987Da28, 1995Ba42	Assigned by 1995Ba42 to 1925 keV level, this level not listed in ^{228}Ac decay. If present 1738 keV may be multiply placed.
1671.67 (15)	0.0043 (14)	1987Da28	-
1684.04 (20)	0.0154 (49)	1987Da28	-
1721.49 (30)	0.0059 (19)	1987Da28	-
1745.32 (20)	0.0067 (9)	1987Da28	-
1784.40 (30)	0.0062 (11)	1987Da28, 1995Ba42	-
1787.20 (20)	0.0013 (5)	1987Da28	May correspond to transition placed from 1974 keV level in ^{228}Pa decay
1916.34 (33)	0.00081 (27)	1987Da28, 1995Ba42	May correspond to transition placed from 1974 keV level in ^{228}Pa decay
1919.54 (30)	0.0022 (6)	1987Da28, 1995Ba42	-
1944.24 (20)	0.0022 (6)	1987Da28	-
2001.0 (5)	0.00108 (28)	1987Da28	-
Total Intensity	0.22 (7)		

Table 3. Comparison of experimental and calculated conversion coefficients for selected gamma transitions.

Transition energy /keV	Multipolarity	Subshell	Publication	Measured conversion coefficient	Calculated (BrIcc)
57.759 (4)	E2	L_I+L_{II}	1982Ma52	50 (4)	61.8 (9)
		L_{III}	1982Ma52	35 (3)	50.4 (7)
		L-total	1971He23	117 (6)	112.2 (16)
99.495 (8)	M1	L_I	1982Ma52	1.9 (1)	2.58 (4)
		L_{II}	1982Ma52	0.12 (1)	0.305 (5)
		L_{III}	1982Ma52	0.17 (3)	0.01646 (20)
		L-total	1971He23	2.8 (1)	2.90 (4)
129.064 (6)	E2	L_I	1982Ma52	0.17 (3)	0.1025 (15)
		L_{II}	1982Ma52	1.6 (1)	1.494 (21)
		L_{III}	1982Ma52	~0.97	0.943 (14)
		L-total	1971He23	2.45 (15)	2.54 (4)
137.941 (17)	M1	K	1971He23	4.1 (14)	6.00 (9)
		L-total	1971He23	0.8 (4)	1.146 (16)
204.038 (9)	M2	K	1982Ma52	7.5 (8)	7.26 (11)

Table 4 Comparison of X-rays calculated using EMISSION with those in the NUDAT database. Note X-ray emission probabilities for this evaluation are generally within uncertainties of, but consistently higher than the NUDAT values.

Transition	**NUDAT**		**DDEP**	
	Energy /keV	**Probability /%**	**Energy /keV**	**Probability /%**
K-α1	93.35	3.1 (4)	93.351	4.0 (11)
K-α2	89.957	1.9 (3)	89.954	2.5 (7)
L-total	~13.0	33.7 (21)	11.1-19.5	37 (4)

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Appendix I. Tables of gamma emission energies

Energies have been taken from 1979He10[15] where possible, adjusted using the later reference energies of Helmer[16]. All other energies have been taken from a weighted mean of data from 1971He23[4], 1973Ta25[17], 1977Ku01[18], 1979Bo30[19], 1987Da28[2] and 1995Ba42[5]. All energies have been adjusted to be on the same energy scale as 1979He10[15] before taking means. Nominal energies given in table headings are taken from the evaluation of Artna-Cohen[1].

Nominal Energy /keV	**42.46**	**56.86**	**57.766**	**77.34**	**99.509**
1979He10	-	-	57.752 (13)	-	99.505 (12)
1971He23	-	-	57.74 (8)	-	99.49 (11)
1973Ta25	-	-	57.78 (6)	-	99.45 (8)
1977Ku01	-	-	57.77 (7)	-	-
1979Bo30	-	-	-	-	-
1987Da28	42.457 (50)	56.96 (5)	57.761 (6)	77.338 (30)	99.497 (6)
1995Ba42	42.46 (10)	56.852 (32)	57.752 (22)	77.35 (10)	99.461 (61)
LWEIGHT4	42.46 (5)	56.88 (5)	57.760 (13)	77.340 (30)	99.496 (6)
Adopted	**42.46 (5)**	**56.88 (5)**	**57.752 (13)**	**77.34 (3)**	**99.505 (12)**
Comments	wtd mean	wtd mean	1979He10	wtd mean	1979He10

Nominal Energy /keV	**100.41**	**114.54**	**129.065**	**135.51**	**137.95**
1979He10	-	-	129.0652 (30)	-	-
1971He23	100.39 (11)	-	129.09 (11)	135.49 (20)	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	129.07 (7)	-	-
1979Bo30	-	-	129.07 (16)	-	-
1987Da28	100.408 (30)	114.56 (7)	129.067 (7)	135.539 (50)	137.91 (5)
1995Ba42	100.41 (10)	-	129.051 (22)	135.501 (22)	137.941 (22)
LWEIGHT4	100.410 (30)	-	129.071 (8)	135.507 (20)	137.936 (22)
Adopted	**100.41 (3)**	**114.56 (7)**	**129.065 (3)**	**135.507 (22)**	**137.936 (22)**
Comments	wtd mean	1987Da28	1979He10	wtd mean	wtd mean

Nominal Energy /keV	**141.01**	**145.849**	**153.977**	**168.65**	**173.964**
1979He10	-	-	-	-	173.964 (26)
1971He23	140.89 (20)	146.19 (20)	153.99 (20)	-	174.00 (20)
1973Ta25	-	-	-	-	-
1977Ku01	141.0 (5)	-	-	-	-
1979Bo30	-	-	153.956 (19)	-	-
1987Da28	141.019 (30)	145.848 (11)	153.977 (11)	168.650 (11)	173.980 (10)
1995Ba42	140.991 (22)	145.811 (22)	153.941 (22)	168.41 (9)	174.011 (41)
LWEIGHT4	140.999 (20)	145.842 (20)	153.967 (8)	168.53 (12)	173.995 (28)
Adopted	**140.999 (20)**	**145.842 (20)**	**153.967 (11)**	**168.53 (12)**	**173.96 (3)**
Comments	wtd mean	wtd mean	wtd mean	wtd mean	wtd mean

Nominal Energy /keV	**184.54**	**191.353**	**199.407**	**204.026**	**209.253**
1979He10	-	-	-	-	-
1971He23	184.50 (11)	192.10 (30)	-	-	209.20 (20)
1973Ta25	-	-	-	-	-
1977Ku01	-	190.99 (20)	-	-	209.50 (50)
1979Bo30	-	-	-	-	209.238 (21)
1987Da28	184.540 (20)	191.353 (11)	199.408 (15)	204.027 (11)	209.254 (7)
1995Ba42	184.60 (5)	191.341 (21)	199.391 (21)	204.041 (21)	209.251 (21)
LWEIGHT4	184.547 (19)	191.351 (17)	199.402 (12)	204.029 (9)	209.248 (5)
Adopted	**184.547 (19)**	**191.351 (17)**	**199.402 (15)**	**204.029 (11)**	**209.248 (7)**
Comments	wtd mean	wtd mean	wtd mean	wtd mean	wtd mean

Nominal Energy /keV	**214.85**	**223.8**	**231.42**	**257.7**	**263.62**
1979He10	-	-	-	-	-
1971He23	-	223.70	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	214.85 (10)	223.85 (10)	231.42 (10)	257.52 (10)	263.58 (10)
1995Ba42	214.92 (10)	223.791 (21)	231.49 (5)	257.481 (21)	-
LWEIGHT4	214.89 (7)	223.793 (21)	231.477 (45)	257.482 (21)	-
Adopted	**214.89 (10)**	**223.793 (21)**	**231.42 (10)**	**257.482 (21)**	**263.58 (10)**
Comments	wtd mean	wtd mean	1987Da28	wtd mean	1987Da28

The value of 231.49 (5) keV line observed by 1995Ba42 is believed to relate to a separate gamma transition and has not been used.

Nominal Energy /keV	**270.245**	**278.95**	**282.0**	**321.646**	**326.04**
1979He10	270.245 (7)	-	282.022 (40)	321.646 (8)	-
1971He23	270.20 (50)	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	270.19 (21)	-	-	-	-
1979Bo30	270.235 (14)	-	-	-	-
1987Da28	270.245 (7)	278.952 (50)	281.922 (50)	321.653 (50)	326.04 (20)
1995Ba42	270.241 (21)	278.651 (21)	282.001 (21)	321.701 (31)	-
LWEIGHT4	270.255 (7)	278.80 (15)	281.989 (28)	321.688 (26)	-
Adopted	**270.245 (7)**	**278.80 (15)**	**282.02 (4)**	**321.646 (8)**	**326.04 (20)**
Comments	1979He10	wtd mean	1979He10	1979He10	1987Da28

Nominal Energy /keV	**327.44**	**328.00**	**332.37**	**338.32**	**340.98**
1979He10	-	-	332.371 (6)	338.320 (5)	-
1971He23	-	-	-	338.31 (40)	-
1973Ta25	-	-	-	-	-
1977Ku01	-	327.89 (22)	332.29 (10)	338.09 (22)	-
1979Bo30	-	328.003 (11)	-	338.321 (10)	-
1987Da28	-	328.004 (7)	332.374 (50)	338.324 (6)	340.964 (50)
1995Ba42	327.45 (4)	328.02 (4)	332.360 (21)	338.310 (21)	340.970 (21)
LWEIGHT4	-	328.004 (7)	332.366 (35)	338.342 (18)	340.969 (19)
Adopted	**-**	**328.004 (7)**	**332.371 (6)**	**338.320 (5)**	**340.969 (21)**
Comments	not used	wtd mean	1979He10	1979He10	wtd mean

The 327.44 keV line is listed in Artna-Cohen based upon expected presence inferred from ^{228}Pa EC decay. However, only lines directly observed in ^{228}Ac decay are considered here.

Nominal Energy /keV	**356.94**	**372.57**	**377.99**	**384.47**	**389.12**
1979He10	-	-	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	356.94 (10)	372.57 (20)	377.99 (10)	384.63 (20)	389.12 (15)
1995Ba42	356.35 (10)	372.590 (31)	377.98 (10)	384.43 (10)	389.40 (10)
LWEIGHT4	356.65 (30)	372.590 (30)	377.99 (7)	384.47 (9)	389.32 (13)
Adopted	**356.7 (3)**	**372.59 (3)**	**377.99 (10)**	**384.47 (9)**	**389.32 (13)**
Comments	wtd mean	wtd mean	wtd mean	wtd mean	wtd mean

Nominal Energy /keV	**397.94**	**399.62**	**409.462**	**416.3**	**419.4**
1979He10	-	-	409.460 (13)	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	409.487 (33)	-	-
1987Da28	397.95 (10)	399.63 (10)	409.456 (10)	416.31 (20)	419.43 (10)
1995Ba42	-	399.93 (7)	409.440 (21)	415.90 (8)	419.34 (10)
LWEIGHT4	-	399.83 (14)	409.464 (25)	415.96 (14)	419.38 (7)
Adopted	**397.95 (10)**	**399.83 (14)**	**409.460 (13)**	**415.96 (14)**	**419.38 (7)**
Comments	1987Da28	wtd mean	1979He10	wtd mean	wtd mean

Nominal Energy /keV	**440.44**	**449.21**	**452.51**	**457.35**	**463.004**
1979He10	440.450 (24)	449.11 (6)	-	-	463.002 (6)
1971He23	-	-	-	-	463.33 (41)
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	463.002 (13)
1987Da28	440.446 (50)	449.26 (10)	452.47 (10)	457.18 (15)	463.023 (10)
1995Ba42	440.390 (40)	449.22 (30)	452.51 (6)	-	463.01 (50)
LWEIGHT4	440.418 (35)	449.24 (7)	452.50 (5)	-	463.048 (15)
Adopted	**440.450 (24)**	**449.11 (6)**	**452.50 (6)**	**457.18 (15)**	**463.002 (6)**
Comments	1979He10	1979He10	wtd mean	1987Da28	wtd mean

Nominal Energy /keV	**466.4**	**470.2**	**471.76**	**474.79**	**478.4**
1979He10	-	-	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	478 (1)
1979Bo30	-	-	-	-	-
1987Da28	466.40 (10)	470.26 (20)	471.77 (15)	474.76 (10)	478.337 (50)
1995Ba42	-	469.89 (50)	-	475.09 (30)	478.440 (40)
LWEIGHT4	-	470.21 (19)	-	474.79 (10)	478.399 (37)
Adopted	**466.40 (10)**	**470.21 (20)**	**471.77 (15)**	**474.79 (10)**	**478.40 (5)**
Comments	1987Da28	wtd mean	1987Da28	wtd mean	wtd mean

Nominal Energy /keV	**480.94**	**490.33**	**492.37**	**497.64**	**503.823**
1979He10	-	-	-	-	503.819 (23)
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	503.60 (33)
1979Bo30	-	-	-	-	-
1987Da28	480.95 (20)	490.33 (15)	492.38 (10)	497.50 (15)	503.83 (50)
1995Ba42	482.03 (5)	-	492.21 (10)	497.70 (10)	503.69 (20)
LWEIGHT4	481.5 (5)	-	492.29 (8)	497.64 (9)	503.67 (18)
Adopted	**481.5 (5)**	**490.33 (15)**	**492.29 (8)**	**497.64 (10)**	**503.819 (23)**
Comments	wtd mean	1987Da28	wtd mean	wtd mean	1979He10

Nominal Energy /keV	**508.959**	**515.06**	**520.151**	**523.131**	**540.76**
1979He10	508.955 (13)	-	520.16 (3)	523.129 (22)	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	508.968 (50)	515.07 (10)	520.18 (5)	523.118 (50)	540.77 (10)
1995Ba42	509.12 (8)	515.19 (11)	520.16 (8)	523.15 (11)	540.650 (50)
LWEIGHT4	509.04 (8)	515.12 (7)	520.17 (6)	523.13 (8)	540.674 (48)
Adopted	**508.955 (13)**	**515.12 (7)**	**520.16 (3)**	**523.129 (22)**	**540.67 (5)**
Comments	1979He10	wtd mean	1979He10	1979He10	wtd mean

Nominal Energy /keV	**546.45**	**548.73**	**555.12**	**562.5**	**570.91**
1979He10	-	-	-	562.496 (7)	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	547 (1)	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	546.479 (50)	548.74 (15)	555.13 (10)	562.529 (30)	570.91 (10)
1995Ba42	546.440 (21)	548.73 (11)	554.59 (30)	562.490 (40)	570.870 (40)
LWEIGHT4	546.445 (19)	548.73 (9)	555.07 (16)	562.509 (29)	570.876 (37)
Adopted	**546.445 (21)**	**548.73 (11)**	**555.07 (16)**	**562.496 (7)**	**570.88 (4)**
Comments	wtd mean	wtd mean	wtd mean	1979He10	wtd mean

Nominal Energy /keV	**572.14**	**583.41**	**590.4**	**610.64**	**616.2**
1979He10	572.10 (5)	-	-	-	616.212 (30)
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	572.30 (10)	583.419 (50)	-	610.65 (10)	616.27 (10)
1995Ba42	572.290 (21)	583.390 (10)	590.64 (11)	-	616.139 (50)
LWEIGHT4	572.290 (20)	583.391 (10)	-	-	616.20 (7)
Adopted	**572.10 (5)**	**583.391 (10)**	**-**	**610.65 (10)**	**616.21 (3)**
Comments	1979He10	wtd mean	not used	wtd mean	1979He10

Nominal Energy /keV	**620.38**	**623.27**	**627.23**	**629.4**	**634.18**
1979He10	-	-	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	620.390 (50)	623.27 (20)	627.24 (20)	629.410 (50)	634.18 (10)
1995Ba42	620.259 (50)	623.7 (2)	626.69 (10)	629.39 (20)	-
LWEIGHT4	620.32 (7)	623.48 (22)	626.80 (22)	629.409 (49)	-
Adopted	**620.32 (7)**	**623.48 (22)**	**626.80 (22)**	**629.41 (5)**	**634.18 (10)**
Comments	wtd mean	wtd mean	wtd mean	wtd mean	1987Da28

Nominal Energy /keV	**640.34**	**648.84**	**651.5**	**660.1**	**663.88**
1979He10	640.317 (37)	-	651.526 (28)	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	640.371 (50)	648.85 (10)	651.461 (50)	660.11 (30)	663.83 (10)
1995Ba42	640.319 (50)	649.11 (7)	651.49 (20)	660.17 (30)	663.91 (8)
LWEIGHT4	640.345 (36)	649.02 (12)	651.48 (14)	660.14 (21)	663.88 (6)
Adopted	**640.32 (4)**	**649.02 (12)**	**651.53 (3)**	**660.1 (3)**	**663.88 (8)**
Comments	1979He10	wtd mean	1979He10	wtd mean	wtd mean

Nominal Energy /keV	**666.47**	**672.0**	**674.76**	**677.07**	**684.0**
1979He10	666.451 (46)	-	674.625 (40)	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	666.46 (10)	672.01 (15)	674.61 (10)	677.12 (10)	-
1995Ba42	666.459 (40)	671.93 (10)	674.76 (10)	676.89 (20)	683.99 (30)
LWEIGHT4	666.46 (7)	671.95 (8)	674.69 (7)	677.08 (9)	-
Adopted	**666.45 (5)**	**671.95 (8)**	**674.63 (4)**	**677.08 (10)**	**-**
Comments	1979He10	wtd mean	1979He10	wtd mean	not used

Nomina Energy /keV	**688.11**	**692.47**	**699.08**	**701.747**	**707.41**
1979He10	-	-	-	701.742 (15)	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	688.112 (50)	-	699.09 (15)	701.752 (50)	707.422 (50)
1995Ba42	688.13 (8)	692.46 (7)	698.94 (10)	701.709 (40)	707.39 (30)
LWEIGHT4	688.117 (42)	-	698.99 (8)	701.731 (35)	707.421 (49)
Adopted	**688.12 (4)**	**-**	**698.99 (10)**	**701.742 (15)**	**707.42 (5)**
Comments	wtd mean	not used	wtd mean	1979He10	wtd mean

Nominal Energy /keV	**718.48**	**726.863**	**737.72**	**755.315**	**770.2**
1979He10	-	727.317 (15)	-	755.313 (9)	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	718.49 (15)	726.876 (15)	737.733 (50)	755.325 (15)	-
1995Ba42	718.299 (21)	726.89 (10)	737.79 (20)	755.309 (21)	770.2 (2)
LWEIGHT4	718.303 (26)	726.88 (7)	737.736 (49)	755.317 (15)	-
Adopted	**718.30 (3)**	**726.88 (10)**	**737.74 (5)**	**755.313 (9)**	**-**
Comments	wtd mean	wtd mean	wtd mean	1979He10	not used

The 684 keV, 692 keV and 770 keV emissions have not been observed directly in ^{228}Ac decay and are not included in this evaluation.

There is a considerable discrepancy between data measured for the 727 keV line by 1979He10 and the mean of values measured by 1987Da28 and 1995Ba42. The value measured by 1979He10 is not consistent with the decay scheme; this is possibly due to interference from the ^{212}Bi decay daughter. The weighted mean of 1987Da28 and 1995Ba42 is used instead.

Nominal Energy /keV	**772.291**	**774.1**	**776.52**	**778.1**	**782.142**
1979He10	772.291 (7)	-	-	-	782.140 (6)
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	772.294 (10)	774.11 (20)	776.57 (10)	-	782.154 (50)
1995Ba42	772.269 (21)	774.06 (10)	776.509 (30)	778.09 (20)	782.09 (20)
LWEIGHT4	772.282 (25)	774.07 (9)	776.514 (29)	-	782.12 (14)
Adopted	**772.291 (7)**	**774.07 (10)**	**776.51 (3)**	**-**	**782.140 (6)**
Comments	1979He10	wtd mean	wtd mean	not used	1979He10

Nominal Energy /keV	**791.44**	**792.8**	**794.947**	**813.77**	**816.62**
1979He10	-	-	794.942 (14)	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	817 (1)
1979Bo30	-	-	794.94 (14)	-	-
1987Da28	791.50 (25)	792.8 (10)	794.940 (10)	813.78 (15)	816.71 (10)
1995Ba42	791.42 (9)	792.69 (10)	794.959 (20)	813.92 (10)	816.92 (10)
LWEIGHT4	791.43 (8)	792.69 (10)	794.951 (14)	813.88 (8)	816.82 (7)
Adopted	**791.43 (9)**	**792.69 (10)**	**794.942 (14)**	**813.88 (10)**	**816.82 (10)**
Comments	wtd mean	wtd mean	1979He10	wtd mean	wtd mean

Nominal Energy /keV	**824.934**	**830.486**	**835.71**	**840.377**	**853.17**
1979He10	824.931 (25)	830.481 (8)	835.704 (8)	840.372 (9)	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	824.87 (10)	830.476 (20)	835.708 (20)	840.370 (20)	853.19 (10)
1995Ba42	-	830.469 (30)	835.639 (21)	840.349 (40)	853.96 (8)
LWEIGHT4	-	830.472 (22)	835.674 (35)	840.366 (18)	-
Adopted	**824.931 (25)**	**830.481 (8)**	**835.704 (8)**	**840.372 (9)**	**853.96 (8)**
Comments	1979He10	1979He10	1979He10	1979He10	1995Ba42

The values of the 853 keV line from 1987Da28 and 1995Ba42 are clearly discrepant; the value of 1995Ba42 has been preferred as it better fits the level scheme.

Nominal Energy /keV	**870.45**	**873.11**	**874.45**	**877.39**	**880.76**
1979He10	870.47 (7)	-	874.45 (8)	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	870.456 (50)	873.17 (15)	874.41 (15)	877.48 (10)	880.76 (10)
1995Ba42	870.438 (21)	872.99 (20)	874.49 (20)	877.34 (7)	-
LWEIGHT4	870.441 (19)	873.10 (12)	874.44 (12)	877.38 (6)	-
Adopted	**870.47 (7)**	**873.10 (15)**	**874.45 (8)**	**877.38 (7)**	**880.76 (10)**
Comments	1979He10	wtd mean	1979He10	wtd mean	1987Da28

Nominal Energy /keV	**887.33**	**901.26**	**904.19**	**911.204**	**919.01**
1979He10	-	-	904.20 (5)	911.196 (6)	-
1971He23	-	-	-	911.27 (25)	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	911.166 (40)	-
1987Da28	887.34 (10)	901.25 (15)	904.197 (50)	911.233 (11)	918.99 (10)
1995Ba42	887.18 (10)	90.388 (31)	904.178 (31)	911.188 (21)	919.39 (30)
LWEIGHT4	887.26 (8)	901.383 (30)	904.183 (26)	911.221 (13)	919.03 (12)
Adopted	**887.26 (10)**	**901.38 (3)**	**904.20 (5)**	**911.196 (6)**	**919.03 (12)**
Comments	wtd mean	wtd mean	1979He10	1979He10	wtd mean

Nominal Energy /keV	**921.98**	**924.03**	**930.93**	**939.87**	**944.196**
1979He10	-	-	-	-	944.191 (30)
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	922.00 (10)	-	930.95 (10)	939.89 (15)	944.178 (50)
1995Ba42	921.75 (10)	924.29 (20)	931.01 (7)	-	944.30 (6)
LWEIGHT4	921.87 (12)	-	930.99 (6)	-	944.23 (6)
Adopted	**921.87 (12)**	**-**	**930.99 (7)**	**939.89 (15)**	**944.19 (3)**
Comments	wtd mean	not used	wtd mean	1987Da28	1979He10

Nominal Energy /keV	**947.982**	**958.61**	**964.766**	**968.971**	**975.98**
1979He10	947.976 (24)	958.591 (38)	964.786 (8)	968.960 (9)	-
1971He23	-	-	964.48 (43)	968.88 (34)	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	964.68 (9)	969.161 (34)	-
1987Da28	947.968 (50)	958.638 (50)	964.783 (11)	968.989 (11)	975.978 (50)
1995Ba42	-	958.68 (11)	964.788 (21)	968.668 (21)	975.987 (50)
LWEIGHT4	-	958.645 (46)	964.783 (36)	968.90 (10)	975.983 (36)
Adopted	**947.976 (24)**	**958.59 (4)**	**964.786 (8)**	**968.960 (9)**	**975.98 (5)**
Comments	1979He10	1979He10	1979He10	1979He10	wtd mean

Nominal Energy /keV	**979.48**	**987.88**	**988.63**	**1000.69**	**1013.58**
1979He10	-	-	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	979.50 (10)	987.73 (10)	988.65 (20)	1000.71 (15)	1013.60 (20)
1995Ba42	979.39 (40)	987.91 (10)	-	1000.67 (10)	1013.53 (13)
LWEIGHT4	979.49 (10)	987.87 (9)	-	1000.68 (8)	1013.55 (11)
Adopted	**979.49 (10)**	**987.87 (10)**	**988.65 (20)**	**1000.68 (10)**	**1013.55 (13)**
Comments	wtd mean	wtd mean	1987Da28	wtd mean	wtd mean

Nominal Energy /keV	**1016.44**	**1017.92**	**1019.86**	**1033.248**	**1039.84**
1979He10	-	-	-	1033.244 (23)	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1016.46 (15)	1017.94 (20)	1019.88 (10)	1033.240 (20)	1039.67 (15)
1995Ba42	1016.4 (10)	-	-	1033.26 (7)	1039.86 (6)
LWEIGHT4	1016.44 (8)	-	-	1033.241 (19)	1039.83 (7)
Adopted	**1016.44 (10)**	**1017.94 (20)**	**1019.88 (10)**	**1033.244 (23)**	**1039.83 (7)**
Comments	wtd mean	1987Da28	1987Da28	1979He10	wtd mean

Nominal Energy /keV	**1040.92**	**1053.09**	**1054.22**	**1062.55**	**1065.19**
1979He10	-	-	-	-	1065.168 (15)
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1040.94 (15)	1053.11 (20)	1054.13 (20)	1062.57 (15)	1065.200 (50)
1995Ba42	-	-	-	-	1065.20 (7)
LWEIGHT4	-	-	-	-	1065.200 (41)
Adopted	**1040.94 (15)**	**1053.11 (20)**	**1054.13 (20)**	**1062.57 (15)**	**1065.168 (15)**
Comments	1987Da28	1987Da28	1987Da28	1987Da28	1979He10

Nominal Energy /keV	**1074.71**	**1088.18**	**1095.679**	**1103.43**	**1110.61**
1979He10	-	-	1095.671 (23)	-	1110.604 (9)
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1074.73 (15)	1088.20 (15)	1095.711 (50)	1103.43 (10)	-
1995Ba42	-	-	1095.73 (14)	-	1110.537 (51)
LWEIGHT4	-	-	1095.713 (47)	-	-
Adopted	**1074.73 (15)**	**1088.20 (15)**	**1095.671 (23)**	**1103.43 (10)**	**1110.604 (9)**
Comments	1987Da28	1987Da28	1979He10	1987Da28	1979He10

Nominal Energy /keV	**1117.63**	**1135.24**	**1142.85**	**1148.16**	**1153.52**
1979He10	-	-	-	-	1153.266 (35)
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1117.65 (10)	1135.26 (15)	1142.87 (15)	1148.14 (15)	1153.502 (50)
1995Ba42	-	1135.4 (10)	1142.8 (10)	1148.19 (14)	1153.59 (30)
LWEIGHT4	-	1135.26 (15)	1142.87 (15)	1148.17 (10)	1153.505 (50)
Adopted	**1117.65 (10)**	**1135.26 (15)**	**1142.87 (15)**	**1148.17 (14)**	**1153.27 (4)**
Comments	1987Da28	wtd mean	wtd mean	wtd mean	1979He10

Nominal Energy /keV	**1157.14**	**1164.55**	**1175.31**	**1190.83**	**1217.03**
1979He10	-	-	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1157.16 (15)	1164.52 (7)	1175.33 (10)	1190.83 (20)	1217.03 (10)
1995Ba42	-	1164.57 (7)	-	1190.9 (10)	-
LWEIGHT4	-	1164.55 (7)	-	1190.83 (20)	-
Adopted	**1157.16 (15)**	**1164.55 (7)**	**1175.33 (10)**	**1190.83 (20)**	**1217.03 (10)**
Comments	1987Da28	wtd mean	1987Da28	wtd mean	1987Da28

Nominal Energy /keV	**1229.4**	**1245.16**	**1247.08**	**1250.04**	**1276.69**
1979He10	-	-	1247.10 (5)	1250.062 (44)	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1229.42 (15)	1245.07 (20)	1247.065 (50)	1249.77 (15)	1276.72 (10)
1995Ba42	-	1245.16 (6)	1247.056 (51)	1249.69 (20)	-
LWEIGHT4	-	1245.15 (6)	1247.061 (36)	1249.74 (12)	-
Adopted	**1229.42 (15)**	**1245.15 (6)**	**1247.10 (5)**	**1250.06 (5)**	**1276.72 (10)**
Comments	1987Da28	wtd mean	1979He10	1979He10	1987Da28

Nominal Energy /keV	**1286.27**	**1287.78**	**1309.71**	**1315.31**	**1337.33**
1979He10	-	-	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1286.30 (20)	1287.71 (20)	1309.74 (20)	1315.37 (10)	1337.33 (20)
1995Ba42	1286.29 (30)	1287.78 (8)	1310.2 (10)	1315.19 (20)	-
LWEIGHT4	1286.29 (17)	1287.77 (7)	1309.76 (20)	1315.33 (10)	-
Adopted	**1286.29 (20)**	**1287.77 (8)**	**1309.76 (20)**	**1315.33 (10)**	**1337.33 (20)**
Comments	wtd mean	wtd mean	wtd mean	wtd mean	1987Da28

Nominal Energy /keV	**1344.59**	**1347.5**	**1357.78**	**1365.71**	**1374.24**
1979He10	-	-	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1344.62 (15)	1347.50 (15)	1357.81 (15)	1365.73 (15)	1374.24 (7)
1995Ba42	1344.6 (10)	-	-	1365.71 (12)	1374.25 (7)
LWEIGHT4	1344.62 (15)	-	-	1365.71 (12)	1374.24 (6)
Adopted	**1344.62 (15)**	**1347.50 (15)**	**1357.81 (15)**	**1365.71 (12)**	**1374.24 (7)**
Comments	wtd mean	1987Da28	1987Da28	wtd mean	1987Da28

Nominal Energy /keV	**1378.23**	**1385.39**	**1401.49**	**1415.55**	**1430.95**
1979He10	-	-	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1378.23 (10)	1385.39 (10)	1401.52 (10)	1415.69 (10)	1430.98 (10)
1995Ba42	-	-	-	1415.41 (10)	1432.0 (10)
LWEIGHT4	-	-	-	1415.55 (14)	1430.99 (10)
Adopted	**1378.23 (10)**	**1385.39 (10)**	**1401.52 (10)**	**1415.55 (14)**	**1430.99 (10)**
Comments	1987Da28	1987Da28	1987Da28	wtd mean	wtd mean

Nominal Energy /keV	**1434.22**	**1438.01**	**1451.4**	**1459.138**	**1469.71**
1979He10	-	-	-	1459.131 (22)	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1434.22 (15)	1438.01 (10)	1451.43 (15)	1459.15 (15)	1469.74 (15)
1995Ba42	-	-	1451.4 (10)	1459.19 (20)	-
LWEIGHT4	-	-	1451.43 (15)	1459.16 (12)	-
Adopted	**1434.22 (15)**	**1438.01 (10)**	**1451.43 (15)**	**1459.131 (22)**	**1469.74 (15)**
Comments	1987Da28	1987Da28	wtd mean	1979He10	1987Da28

Nominal Energy /keV	**1480.37**	**1495.93**	**1501.57**	**1529.02**	**1537.87**
1979He10	-	1495.904 (16)	-	1529.010 (34)	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1480.37 (15)	1495.80 (5)	1501.600 (51)	-	1537.92 (10)
1995Ba42	1480.4 (3)	1496.14 (6)	1501.49 (20)	1529.01 (6)	1537.79 (20)
LWEIGHT4	1480.38 (15)	1495.97 (17)	1501.59 (5)	-	1537.89 (10)
Adopted	**1480.38 (15)**	**1495.904 (16)**	**1501.59 (5)**	**1529.01 (4)**	**1537.89 (10)**
Comments	wtd mean	1979He10	wtd mean	1979He10	wtd mean

Nominal Energy /keV	**1548.65**	**1557.1**	**1559.78**	**1571.52**	**1573.26**
1979He10	1548.65 (6)	1557.13 (7)	-	-	1573.23 (8)
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1548.64 (10)	1557.102 (51)	1559.88 (20)	1571.55 (20)	1573.39 (10)
1995Ba42	-	1557.05 (6)	-	-	1573.29 (30)
LWEIGHT4	-	1557.079 (39)	-	-	1573.38 (10)
Adopted	**1548.65 (6)**	**1557.13 (7)**	**1559.88 (20)**	**1571.55 (20)**	**1573.23 (8)**
Comments	1979He10	1979He10	1987Da28	1987Da28	1979He10

Nominal Energy /keV	**1580.53**	**1588.19**	**1609.41**	**1625.06**	**1630.627**
1979He10	1580.531 (25)	1588.200 (25)	-	1625.092 (35)	1630.618 (20)
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1580.522 (51)	1588.202 (51)	1609.44 (15)	1625.023 (51)	1630.663 (51)
1995Ba42	1580.49 (30)	1588.136 (52)	-	1624.99 (20)	1630.62 (6)
LWEIGHT4	1580.52 (5)	1588.170 (36)	-	1625.021 (49)	1630.644 (39)
Adopted	**1580.531 (25)**	**1588.200 (25)**	**1609.44 (15)**	**1625.09 (4)**	**1630.618 (20)**
Comments	1979He10	1979He10	1987Da28	1979He10	1979He10

Nominal Energy /keV	**1638.281**	**1666.523**	**1671.64**	**1677.67**	**1684.01**
1979He10	1638.272 (23)	1666.514 (13)	-	1677.66 (6)	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1638.304 (51)	1666.55 (51)	1671.67 (15)	1677.704 (51)	1684.04 (20)
1995Ba42	1638.29 (7)	1666.52 (6)	-	-	-
LWEIGHT4	1638.297 (41)	1666.52 (6)	-	-	-
Adopted	**1638.272 (23)**	**1666.514 (13)**	**1671.67 (15)**	**1677.66 (6)**	**1684.04 (20)**
Comments	1979He10	1979He10	1987Da28	1979He10	1987Da28

Nominal Energy /keV	**1686.12**	**1700.59**	**1702.44**	**1706.17**	**1713.49**
1979He10	1686.22 (11)	-	1702.40 (8)	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1686.095 (51)	1700.62 (20)	1702.57 (10)	1706.23 (10)	1713.51 (20)
1995Ba42	1686.14 (7)	-	1702.59 (30)	1706.15 (7)	1713.1 (10)
LWEIGHT4	1686.11 (4)	-	1702.57 (10)	1706.17 (6)	1713.49 (20)
Adopted	**1686.22 (11)**	**1700.62 (20)**	**1702.40 (8)**	**1706.17 (7)**	**1713.49 (20)**
Comments	1979He10	1987Da28	1979He10	wtd mean	wtd mean

Nominal Energy /keV	**1721.4**	**1724.2**	**1738.22**	**1740.4**	**1742.09**
1979He10	-	1724.188 (43)	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1721.49 (30)	1724.28 (10)	1738.26 (25)	1740.46 (30)	1742.09 (30)
1995Ba42	-	1723.99 (20)	1738.465 (52)	-	-
LWEIGHT4	-	1724.22 (12)	1738.46 (5)	-	-
Adopted	**1721.5 (3)**	**1724.19 (5)**	**1738.46 (5)**	**1740.5 (3)**	**1742.1 (3)**
Comments	1987Da28	1979He10	wtd mean	1987Da28	1987Da28

Nominal Energy /keV	**1745.28**	**1750.54**	**1758.11**	**1772.2**	**1784.4**
1979He10	-	-	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1745.32 (20)	1750.58 (20)	1758.15 (10)	1772.22 (30)	1784.40 (30)
1995Ba42	-	-	1758.095 (53)	-	-
LWEIGHT4	-	-	1758.106 (47)	-	-
Adopted	**1745.32 (20)**	**1750.58 (20)**	**1758.11 (5)**	**1772.2 (3)**	**1784.4 (3)**
Comments	1987Da28	1987Da28	wtd mean	1987Da28	1987Da28

Nominal Energy /keV	**1787.2**	**1795.15**	**1797.5**	**1800.86**	**1823.21**
1979He10	-	-	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1787.30 (50)	1795.14 (50)	1797.50 (50)	1800.90 (20)	1823.26 (10)
1995Ba42	1787.18 (20)	1795.13 (6)	-	-	1823.17 (10)
LWEIGHT4	1787.20 (20)	1795.13 (6)	-	-	1823.22 (7)
Adopted	**1787.20 (20)**	**1795.13 (6)**	**1797.5 (5)**	**1800.90 (20)**	**1823.22 (10)**
Comments	wtd mean	wtd mean	1987Da28	1987Da28	wtd mean

Nominal Energy /keV	**1826.7**	**1835.29**	**1842.14**	**1850.13**	**1870.81**
1979He10	-	-	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1826.78 (30)	1835.47 (10)	1842.17 (10)	1850.17 (20)	1870.87 (9)
1995Ba42	-	1835.244 (53)	1842.13 (8)	-	1870.78 (9)
LWEIGHT4	-	1835.29 (9)	1842.15 (6)	-	1870.82 (7)
Adopted	**1826.8 (3)**	**1835.29 (10)**	**1842.15 (8)**	**1850.17 (20)**	**1870.82 (9)**
Comments	1987Da28	wtd mean	wtd mean	1987Da28	wtd mean

Nominal Energy /keV	**1879.6**	**1887.12**	**1900.14**	**1907.13**	**1916.6**
1979He10	-	-	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1879.60 (30)	1887.139 (51)	1900.11 (20)	1907.22 (20)	1915.94 (40)
1995Ba42	-	1887.113 (53)	1900.28 (30)	1907.11 (11)	1916.58 (30)
LWEIGHT4	-	1887.127 (37)	1900.16 (17)	1907.14 (10)	1916.34 (33)
Adopted	**1879.6 (3)**	**1887.13 (5)**	**1900.16 (20)**	**1907.14 (11)**	**1916.3 (4)**
Comments	1987Da28	wtd mean	wtd mean	wtd mean	wtd mean

Nominal Energy /keV	**1919.5**	**1929.78**	**1936.2**	**1944.2**	**1952.37**
1979He10	-	-	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1919.54 (30)	1929.78 (20)	1936.34 (30)	1944.24 (20)	1952.37 (15)
1995Ba42	-	-	-	-	1952.37 (10)
LWEIGHT4	-	-	-	-	1952.37 (8)
Adopted	**1919.5 (3)**	**1929.78 (20)**	**1936.3 (3)**	**1944.24 (20)**	**1952.37 (10)**
Comments	1987Da28	1987Da28	1987Da28	1987Da28	wtd mean

Nominal Energy /keV	**1955.9**	**1958.4**	**1965.22**	**1971.9**	**1979.3**
1979He10	-	-	-	-	-
1971He23	-	-	-	-	-
1973Ta25	-	-	-	-	-
1977Ku01	-	-	-	-	-
1979Bo30	-	-	-	-	-
1987Da28	1955.94 (50)	1958.41 (30)	1965.28 (20)	1971.96 (30)	1979.32 (30)
1995Ba42	-	-	1965.20 (12)	-	-
LWEIGHT4	-	-	1965.22 (10)	-	-
Adopted	**1955.9 (5)**	**1958.4 (3)**	**1965.22 (12)**	**1972.0 (3)**	**1979.3 (3)**
Comments	1987Da28	1987Da28	wtd mean	1987Da28	1987Da28

Nominal Energy /keV	**2000.9**	**2029.4**
1979He10	-	-
1971He23	-	-
1973Ta25	-	-
1977Ku01	-	-
1979Bo30	-	-
1987Da28	2000.98 (50)	2029.39 (50)
1995Ba42	-	-
LWEIGHT4	-	-
Adopted	**2001.0 (5)**	**2029.4 (5)**
Comments	1987Da28	1987Da28

Appendix II. Relative emission probabilities

Normalised to 100 for the 463 keV emission. Values marked with an asterisk (*) have been rejected from the weighted mean based on statistical evidence or on technical grounds. Where multiplets occur, the intensity is listed here once (in italics) and is the total measured intensity. Normalised values are also given - note the normalisation factor of 0.0445 (11) has been applied before rounding.

Nominal Energy /keV	**18.4**	**42.46**	**56.88**	**57.752**	**77.34**	**99.505**
1969Ar16	-	-	-	10.5 (5)*	-	30.6 (5)*
1971He23	-	-	-	10.5 (3)	-	28.3 (3)
1982Ma52	-	-	-	6.2 (4)*	-	36.5 (8)*
1982Sa36	-	-	-	11.4 (9)	-	31.0 (22)
1983Sc13	-		-	-	-	-
1987Da28	-	0.212 (61)	0.454 (94)	10.2 (11)	0.60 (12)	26.7 (33)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	-	10.57 (28)	-	28.33 (30)
Adopted	**calc.**	**0.21 (6)**	**0.45 (9)**	**10.6 (3)**	**0.60 (12)**	**28.3 (3)**
Normalised	-	0.009 (3)	0.020 (5)	0.470 (17)	0.027 (6)	1.26 (4)
Comments	no data	1987Da28	1987Da28	wtd mean	1987Da28	wtd mean

Nominal Energy /keV	**100.41**	**114.56**	**129.065**	**135.507**	**137.936**	**141.000**
1969Ar16	-	-	56.4 (4)*	-	-	0.80 (20)
1971He23	2.60 (10)	-	56.4 (4)	0.70 (10)	0.70 (10)	0.80 (20)
1982Ma52	-	-	54.1 (11)	-	-	-
1982Sa36	-	-	64.3 (56)	-	-	-
1983Sc13	-	-	49.6 (34)	-	-	-
1987Da28	2.18 (32)	0.23 (5)	61.2 (67)	0.41 (9)	0.55 (11)	1.18 (19)
1992Li05	-	-	55.3 (43)	-	-	~0.94
1995Ba42	-	-	-	-	-	-
LWEIGHT4	2.56 (12)	-	56.1 (5)	0.54 (14)	0.63 (10)	1.00 (19)
Adopted	**2.56 (12)**	**0.23 (5)**	**56.1 (5)**	**0.54 (14)**	**0.63 (10)**	**1.00 (19)**
Normalised	0.114 (6)	0.0102 (22)	2.50 (7)	0.024 (6)	0.028 (4)	0.045 (9)
Comments	wtd mean	1987Da28	wtd mean	wtd mean	wtd mean	wtd mean

Nominal Energy /keV	**145.82**	**153.967**	***168.53***	**173.964**	**184.547**	**191.351**
1969Ar16	3.6 (3)*	18.5 (4)*	-	-	2.2 (10)	3.9 (7)
1971He23	3.80 (10)	17.1 (4)	-	0.80 (20)	1.9 (6)	3.1 (3)
1982Ma52	-	17.1 (4)	-	-	0.70 (20)	-
1982Sa36	3.81 (30)	18.8 (15)	-	-	-	2.86 (27)
1983Sc13	-	15.6 (8)	-	-	-	-
1987Da28	3.6 (4)	18.2 (20)	*0.30 (6)*	0.82 (13)	1.64 (20)	3.03 (34)
1992Li05	-	15.8 (13)	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	3.79 (9)	16.94 (40)	-	0.81 (11)	1.21 (43)	2.98 (27)
Adopted	**3.79 (10)**	**16.9 (4)**	***0.30 (6)***	**0.81 (13)**	**1.2 (4)**	**3.0 (3)**
Normalised	0.169 (6)	0.754 (23)	-	0.036 (5)	0.054 (19)	0.133 (8)
Comments	wtd mean	wtd mean	*1987Da28*	wtd mean	wtd mean	wtd mean

Nominal Energy /keV	**199.402**	**204.029**	**209.248**	**214.890**	**223.793**	**231.477**
1969Ar16	6.0 (5)	3.0 (5)	93 (4)	-	1.6 (5)	-
1971He23	-	-	93 (4)*	-	-	-
1982Ma52	-	2.4 (2)	-	-	-	-
1982Sa36	7.4 (6)	2.38 (26)	93 (6)	-	-	-
1983Sc13	-	-	84.7 (34)	-	-	-
1987Da28	7.4 (8)	3.09 (34)	98 (9)	0.69 (11)	1.27 (14)	0.58 (9)
1992Li05	-	-	89.1 (35)	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	6.7 (5)	2.56 (17)	89.3 (19)	-	1.30 (13)	-
Adopted	**6.7 (5)**	**2.56 (20)**	**89 (4)**	**0.69 (11)**	**1.30 (14)**	**0.58 (9)**
Normalised	0.299 (23)	0.114 (8)	3.97 (13)	0.031 (5)	0.058 (6)	0.026 (4)
Comments	wtd mean	wtd mean	wtd mean	1987Da28	wtd mean	1987Da28

Nominal Energy /keV	**257.482**	**263.580**	**270.245**	***278.80***	**282.022**	**321.646**
1969Ar16	-	-	76.0 (40)	*5.6 (5)*	-	5.0 (10)
1971He23	-	-	78.0 (40)	-	-	-
1982Ma52	-	-	82.3 (20)	*6.0 (4)*	-	7.9 (5)
1982Sa36	-	-	79 (6)	-	2.62 (27)	5.24 (54)
1983Sc13	-	-	76.4 (29)	-	-	5.44 (53)
1987Da28	0.70 (8)	0.94 (11)	78 (7)	*4.49 (37)*	1.46 (14)	5.09 (44)
1992Li05	-	-	80.0 (27)	-	-	6.08 (12)
1995Ba42	0.626 (44)	0.97 (7)	-	-	-	-
LWEIGHT4	0.642 (39)	0.96 (6)	79.9 (13)	*5.28 (49)*	2.0 (6)	5.22 (28)
Adopted	**0.64 (5)**	**0.96 (7)**	**79.9 (20)**	***5.3 (5)***	**2.0 (6)**	**5.2 (5)**
Normalised	0.0286 (19)	0.043 (3)	3.55 (10)	*0.235 (22)*	0.09 (3)	0.232 (14)
Comments	wtd mean	wtd mean	wtd mean	*wtd mean*	wtd mean	wtd mean

Nominal Energy /keV	**326.040**	**328.004**	**332.370**	**338.320**	**340.969**	**356.65**
1969Ar16	-	68.0 (20)	7.2 (5)	250 (5)	10 (4)	-
1971He23	-	-	-	255 (5)	-	-
1982Ma52	-	78.3 (20)	-	282 (6)	-	-
1982Sa36	-	69.0 (58)	9.3 (11)	255 (17)	9.0 (10)	-
1983Sc13	-	-	6.2 (7)	250 (9)	9.0 (6)	-
1987Da28	0.78 (13)	69.7 (50)	9.8 (8)	256 (18)	7.7 (7)	0.400 (47)
1992Li05	-	-	10.57 (56)	260 (9)	9.8 (18)	-
1995Ba42	-	-	-	-	9.2 (6)	-
LWEIGHT4	-	68.3 (18)	8.4 (12)	255.1 (38)	9.09 (39)	-
Adopted	**0.78 (13)**	**68.3 (20)**	**8.4 (12)**	**255 (5)**	**9.1 (6)**	**0.40 (5)**
Normalised	0.035 (6)	3.04 (11)	0.37 (6)	11.4 (4)	0.405 (20)	0.0178 (21)
Comments	1987Da28	wtd mean	wtd mean	wtd mean	wtd mean	1987Da28

Nominal Energy /keV	**372.590**	**377.99**	**384.47**	**389.32**	**397.95**	**399.83**
1969Ar16	-	-	-	-	-	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	0.158 (37)	0.576 (67)	0.158 (37)	0.242 (38)	0.642 (68)	0.691 (75)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	-	-	-	-
Adopted	**0.16 (4)**	**0.58 (7)**	**0.16 (4)**	**0.24 (4)**	**0.64 (7)**	**0.69 (8)**
Normalised	0.0070 (17)	0.026 (3)	0.0070 (17)	0.0108 (17)	0.029 (3)	0.031 (4)
Comments	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28

Nominal Energy /keV	**409.46**	**415.96**	**419.38**	**440.45**	**449.11**	**452.50**
1969Ar16	44 (2)	-	-	3.0 (5)	-	-
1971He23	-	-	-	-	-	-
1982Ma52	46.5 (10)	-	-	-	-	-
1982Sa36	42.9 (31)	-	-	-	-	-
1983Sc13	43.3 (19)	-	-	-	-	-
1987Da28	44.8 (33)	0.309 (51)	0.48 (8)	2.85 (23)	1.12 (13)	0.36 (12)
1992Li05	45.1 (23)	-	-	-	-	-
1995Ba42	44.7 (32)	-	-	-	-	0.456 (42)
LWEIGHT4	45.3 (7)	-	-	2.87 (21)	-	0.466 (40)
Adopted	**45.3 (10)**	**0.31 (5)**	**0.48 (8)**	**2.87 (23)**	**1.12 (13)**	**0.47 (4)**
Normalised	2.02 (6)	0.0138 (23)	0.022 (3)	0.128 (10)	0.050 (6)	0.0199 (19)
Comments	wtd mean	1987Da28	1987Da28	wtd mean	wtd mean	wtd mean

Nominal Energy /keV	**457.18**	**466.40**	**470.21**	**471.77**	**474.79**
1969Ar16	-	-	-	-	-
1971He23	-	-	-	-	-
1982Ma52	-	-	-	-	-
1982Sa36	-	-	-	-	-
1983Sc13	-	-	-	-	-
1987Da28	0.352 (57)	0.67 (8)	0.30 (6)	0.76 (8)	0.52 (8)
1992Li05	-	-	-	-	-
1995Ba42	-	-	-	-	-
LWEIGHT4	-	-	-	-	-
Adopted	**0.35 (6)**	**0.67 (8)**	**0.30 (6)**	**0.76 (8)**	**0.52 (8)**
Normalised	0.016 (3)	0.30 (4)	0.014 (3)	0.034 (4)	0.023 (4)
Comments	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28

Nominal Energy /keV	**478.399**	**481.50**	**490.34**	**492.29**	**497.64**	**503.819**	**508.955**
1969Ar16	5.7 (10)	-	-	-	-	3.0 (5)	12.0 (10)
1971He23	-	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	4.2 (9)	-
1987Da28	4.91 (44)	0.55 (11)	0.261 (56)	0.552 (61)	0.139 (43)	4.24 (37)	10.7 (12)
1992Li05	-	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-	-
LWEIGHT4	5.04 (40)	-	-	-	-	3.85 (41)	11.5 (8)
Adopted	**5.0 (5)**	**0.55 (11)**	**0.26 (6)**	**0.55 (6)**	**0.14 (4)**	**3.9 (4)**	**11.5 (10)**
Normalised	0.224 (19)	0.024 (5)	0.0116 (25)	0.025 (3)	0.0062 (19)	0.171 (19)	0.51 (4)
Comments	wtd mean	wtd mean	1987Da28	1987Da28	1987Da28	wtd mean	wtd mean

Nominal Energy /keV	**515.12**	**520.159**	**523.129**	**540.674**	**546.445**	**548.73**	**555.07**
1969Ar16	-	-	3.0 (1)	-	4.0 (5)	-	-
1971He23	-	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-	-
1987Da28	1.14 (13)	1.58 (14)	2.42 (22)	0.61 (7)	4.73 (38)	0.54 (8)	1.08 (12)
1992Li05	-	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-	-
LWEIGHT4	-	-	2.90 (22)	-	4.46 (35)	-	-
Adopted	**1.13 (13)**	**1.58 (14)**	**2.90 (22)**	**0.61 (7)**	**4.5 (4)**	**0.54 (8)**	**1.08 (12)**
Normalised	0.051 (6)	0.070 (7)	0.129 (10)	0.027 (3)	0.199 (16)	0.024 (4)	0.048 (6)
Comments	1987Da28	1987Da28	wtd mean	wtd mean	wtd mean	wtd mean	1987Da28

Nominal Energy /keV	**562.496**	**570.876**	**572.10**	**583.391**	**610.65**	**616.212**
1969Ar16	21 (2)	6.5 (10)	-	3.0 (5)	-	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	21.4 (26)	-	-	-	-	-
1983Sc13	19.8 (12)	-	-	-	-	-
1987Da28	18.8 (15)	3.82 (41)	3.52 (40)	2.61 (27)	0.54 (11)	1.88 (15)
1992Li05	20.3 (10)	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	20.0 (6)	4.2 (9)	-	2.70 (24)	-	-
Adopted	**20.0 (10)**	**4.2 (9)**	**3.5 (4)**	**2.7 (3)**	**0.54 (11)**	**1.88 (15)**
Normalised	0.89 (4)	0.19 (5)	0.156 (18)	0.120 (11)	0.024 (5)	0.084 (7)
Comments	wtd mean	wtd mean	1987Da28	wtd mean	1987Da28	1987Da28

Nominal Energy /keV	**620.32**	**623.48**	**626.80**	**629.409**	**634.18**	**640.317**
1969Ar16	-	-	-	-	-	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	1.88 (15)	0.26 (6)	0.33 (7)	1.06 (12)	0.248 (50)	1.27 (14)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	-	-	-	-
Adopted	**1.88 (15)**	**0.26 (6)**	**0.33 (7)**	**1.06 (12)**	**0.25 (5)**	**1.27 (14)**
Normalised	0.084 (7)	0.012 (3)	0.015 (3)	0.047 (5)	0.0111 (22)	0.057 (6)
Comments	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28

Nominal Energy /keV	***649.02***	**651.526**	**660.14**	**663.88**	***666.451***	**671.95**
1969Ar16	-	-	-	-	-	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	*0.94 (10)*	2.12 (21)	0.121 (6)	0.66 (14)	*1.45 (14)*	0.61 (18)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	-	-	-	-
Adopted	***0.94 (10)***	**2.12 (21)**	**0.121 (6)**	**0.66 (14)**	***1.45 (14)***	**0.61 (18)**
Normalised	*0.042 (5)*	0.094 (10)	0.0054 (3)	0.029 (6)	*0.065 (6)*	0.027 (8)
Comments	*1987Da28*	1987Da28	1987Da28	1987Da28	*1987Da28*	1987Da28

Nominal Energy /keV	**674.625**	**677.08**	***688.117***	**698.99**	**701.742**	**707.421**
1969Ar16	~3	-	-	-	~2.7	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	2.36 (22)	1.45 (14)	*1.58 (14)*	0.86 (13)	4.06 (31)	3.64 (40)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	-	-	-	-
Adopted	**2.36 (22)**	**1.45 (14)**	***1.58 (14)***	**0.86 (13)**	**4.1 (3)**	**3.6 (4)**
Normalised	0.105 (10)	0.065 (6)	*0.070 (7)*	0.038 (6)	0.181 (15)	0.162 (18)
Comments	1987Da28	1987Da28	*1987Da28*	1987Da28	1987Da28	1987Da28

Nominal Energy /keV	**718.303**	**727.317**	**737.736**	**755.313**	**772.291**	**774.07**
1969Ar16	-	18 (4)	-	22 (3)	40 (4)	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	23.8 (26)	38.1 (30)	-
1983Sc13	-	-	-	23.6 (15)	32.2 (16)	-
1987Da28	0.44 (9)	14.5 (20)	0.87 (9)	21.8 (16)	33.9 (25)	1.39 (7)
1992Li05	-	-	-	23.4 (11)	34.0 (12)	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	15.2 (18)	-	23.1 (7)	34.1 (10)	-
Adopted	**0.44 (9)**	**15.2 (20)**	**0.87 (9)**	**23.1 (11)**	**34.1 (12)**	**1.39 (7)**
Normalised	0.019 (4)	0.68 (8)	0.039 (5)	1.03 (4)	1.52 (6)	0.062 (4)
Comments	1987Da28	wtd mean	1987Da28	wtd mean	wtd mean	1987Da28

Nominal Energy /keV	**776.514**	**782.14**	***791.43***	**792.69**	**794.942**	**813.88**
1969Ar16	-	17 (3)	-	-	105 (10)	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	100 (7)	-
1983Sc13	-	10.7 (14)	-	-	96.4 (35)	-
1987Da28	0.44 (14)	11.3 (8)	*0.54 (17)*	1.82 (9)	98 (7)	0.164 (37)
1992Li05	-	10.8 (13)	-	-	95.2 (34)	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	11.3 (7)	-	-	96.9 (22)	-
Adopted	**0.44 (14)**	**11.3 (8)**	***0.54 (17)***	**1.82 (9)**	**97 (4)**	**0.16 (4)**
Normalised	0.020 (6)	0.50 (4)	*0.024 (7)*	0.081 (5)	4.31 (14)	0.0073 (17)
Comments	1987Da28	1987Da28	*1987Da28*	1987Da28	wtd mean	wtd mean

Nominal Energy /keV	**816.82**	**824.931**	**830.481**	**835.481**	**840.372**	***853.57***
1969Ar16	-	-	16.5 (10)	39.5 (10)	23.0 (10)	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	15.0 (20)	42.9 (31)	22.1 (20)	-
1983Sc13	-	-	11.1 (12)	34.0 (22)	21.6 (13)	-
1987Da28	0.70 (8)	1.18 (13)	12.7 (9)	37.6 (26)	20.0 (16)	*0.279 (45)*
1992Li05	-	-	-	35.4 (20)	18.6 (24)	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	13.7 (12)	38.3 (12)	21.7 (7)	-
Adopted	**0.70 (8)**	**1.18 (13)**	**13.7 (12)**	**38.3 (12)**	**21.7 (10)**	***0.28 (5)***
Normalised	0.031 (4)	0.053 (6)	0.61 (6)	1.70 (7)	0.97 (4)	*0.0124 (20)*
Comments	1987Da28	1987Da28	wtd mean	wtd mean	wtd mean	*wtd mean*

Nominal Energy /keV	**870.47**	**872.99**	**874.45**	**877.38**	**880.76**	**887.26**
1969Ar16	-	-	-	-	-	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	1.03 (11)	0.73 (15)	1.12 (25)	0.32 (6)	0.145 (43)	0.64 (7)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	-	-	-	-
Adopted	**1.03 (11)**	**0.73 (15)**	**1.12 (25)**	**0.32 (6)**	**0.15 (5)**	**0.64 (7)**
Normalised	0.046 (5)	0.032 (7)	0.050 (11)	0.014 (3)	0.0065 (19)	0.029 (3)
Comments	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28

Nominal Energy /keV	**901.383**	**904.2**	**911.196**	**919.03**	***921.87***	***930.99***
1969Ar16	-	-	590 (30)	-	-	-
1971He23	-	-	580 (20)	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	19.0 (25)	605 (42)	-	-	-
1983Sc13	-	17.6 (10)	591 (22)	-	-	-
1987Da28	0.38 (8)	17.0 (15)	606 (29)	0.64 (7)	*0.345 (51)*	*0.291 (45)*
1992Li05	-	-	573 (20)	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	17.5 (8)	588 (12)	-	-	-
Adopted	**0.38 (8)**	**17.5 (10)**	**588 (20)**	**0.64 (7)**	***0.35 (5)***	***0.29 (5)***
Normalised	0.017 (4)	0.78 (4)	26.2 (8)	0.028 (3)	*0.0154 (23)*	*0.0129 (20)*
Comments	1987Da28	wtd mean	wtd mean	wtd mean	*1987Da28*	*1987Da28*

Nominal Energy /keV	**939.89**	**944.191**	**947.976**	**958.591**	**964.786**	**968.96**
1969Ar16	-	-	-	-	100 (10)	360 (20)
1971He23	-	-	-	-	100 (10)	350 (10)
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	3.8 (14)	124 (9)	360 (26)
1983Sc13	-	-	-	-	112.2 (43)	361 (13)
1987Da28	0.21 (6)	2.24 (21)	2.49 (22)	6.8 (6)	118 (8)	372 (26)
1992Li05	-	-	-	-	110.4 (42)	349 (13)
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	-	6.4 (11)	112.1 (26)	357 (7)
Adopted	**0.21 (6)**	**2.24 (21)**	**2.49 (22)**	**6.4 (11)**	**112 (5)**	**357 (10)**
Normalised	0.009 (3)	0.100 (10)	0.111 (10)	0.29 (5)	4.99 (17)	15.9 (5)
Comments	1987Da28	1987Da28	1987Da28	wtd mean	wtd mean	wtd mean

Nominal Energy /keV	**975.983**	**979.49**	**987.87**	**988.65**	**1000.68**	**1013.55**
1969Ar16	-	-	4.3 (3)	-	-	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	1.16 (13)	0.62 (7)	1.82 (32)	1.82 (32)	0.121 (6)	0.109 (31)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	3.1 (12)	-	-	-
Adopted	**1.16 (13)**	**0.62 (7)**	**3.1 (12)**	**1.8 (4)**	**0.121 (6)**	**0.11 (3)**
Normalised	0.052 (6)	0.028 (3)	0.14 (6)	0.081 (14)	0.0054 (3)	0.0049 (14)
Comments	1987Da28	1987Da28	wtd mean	1987Da28	1987Da28	1987Da28

Nominal Energy /keV	**1016.44**	**1017.94**	**1019.88**	**1033.244**	**1039.83**	**1040.94**
1969Ar16	-	1.3 (3)	-	4.5 (3)	2.0 (4)	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	0.44 (6)	0.133 (31)	0.49 (10)	4.73 (38)	1.05 (22)	1.05 (22)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	-	-	1.27 (40)	-
Adopted	**0.44 (6)**	**0.7 (6)**	**0.49 (10)**	**4.59 (24)**	**1.3 (4)**	**1.05 (22)**
Normalised	0.019 (3)	0.03 (3)	0.022 (5)	0.204 (12)	0.056 (18)	0.047 (10)
Comments	1987Da28	wtd mean	1987Da28	wtd mean	wtd mean	1987Da28

Nominal Energy /keV	**1053.11**	**1054.13**	**1062.57**	**1065.168**	**1074.73**	**1088.20**
1969Ar16	~1	-	-	3.0 (2)	-	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	0.32 (9)	0.42 (13)	0.24 (7)	3.09 (29)	0.24 (7)	0.139 (31)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	-	3.03 (16)	-	-
Adopted	**0.32 (9)**	**0.42 (13)**	**0.24 (7)**	**3.03 (20)**	**0.24 (7)**	**0.14 (3)**
Normalised	0.014 (4)	0.019 (6)	0.011 (4)	0.135 (8)	0.011 (4)	0.0062 (14)
Comments	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28

Nominal Energy /keV	**1095.671**	**1103.43**	**1110.604**	**1117.65**	**1135.26**	**1142.87**
1969Ar16	2.6 (3)	-	6.5 (10)	1.6 (3)	-	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	3.03 (28)	0.35 (6)	7.2 (6)	1.27 (19)	0.230 (38)	0.242 (50)
1992Li05	-	-	-	-	-	-
1995Ba42	-	0.224 (11)	-	-	-	-
LWEIGHT4	2.83 (22)	0.228 (24)	6.98 (51)	1.37 (16)	-	-
Adopted	**2.8 (3)**	**0.228 (24)**	**7.0 (6)**	**1.37 (19)**	**0.23 (4)**	**0.24 (5)**
Normalised	0.126 (10)	0.0102 (11)	0.311 (24)	0.061 (7)	0.0102 (17)	0.0108 (22)
Comments	wtd mean	wtd mean	wtd mean	wtd mean	1987Da28	1987Da28

Nominal Energy /keV	**1148.17**	**1153.266**	**1157.16**	**1164.55**	**1175.33**	**1190.83**
1969Ar16	-	4.0 (10)	-	~1.5	-	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	0.139 (31)	3.27 (29)	0.164 (31)	1.52 (14)	0.56 (8)	0.146 (37)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	3.33 (28)	-	-	-	-
Adopted	**0.14 (3)**	**3.3 (3)**	**0.16 (3)**	**1.52 (14)**	**0.56 (8)**	**0.15 (4)**
Normalised	0.0062 (14)	0.148 (13)	0.0073 (14)	0.067 (7)	0.025 (4)	0.0065 (17)
Comments	1987Da28	wtd mean	1987Da28	1987Da28	1987Da28	1987Da28

Nominal Energy /keV	**1217.03**	**1229.42**	**1245.15**	**1247.10**	**1250.062**	**1276.72**
1969Ar16	-	-	-	-	-	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	0.50 (8)	0.176 (55)	2.24 (44)	11.21 (55)	1.46 (14)	0.33 (7)
1992Li05	-	-	-	11.5 (14)	-	-
1995Ba42	-	-	2.50 (18)	-	-	-
LWEIGHT4	-	-	2.46 (17)	11.78 (46)	-	-
Adopted	**0.50 (8)**	**0.18 (6)**	**2.46 (18)**	**11.8 (5)**	**1.46 (14)**	**0.33 (7)**
Normalised	0.022 (4)	0.0078 (25)	0.110 (8)	0.524 (24)	0.065 (6)	0.015 (3)
Comments	1987Da28	1987Da28	wtd mean	wtd mean	1987Da28	1987Da28

Nominal Energy /keV	**1286.29**	**1287.77**	**1309.76**	**1315.33**	**1337.33**	**1344.62**
1969Ar16	-	3.0 (2)	-	-	-	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	1.17 (24)	1.88 (38)	0.44 (15)	0.35 (7)	0.115 (37)	0.212 (44)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	2.44 (56)	-	-	-	-
Adopted	**1.17 (24)**	**2.4 (6)**	**0.44 (15)**	**0.35 (7)**	**0.12 (4)**	**0.21 (5)**
Normalised	0.052 (11)	0.109 (25)	0.020 (7)	0.015 (3)	0.0051 (16)	0.0094 (20)
Comments	1987Da28	wtd mean	1987Da28	1987Da28	1987Da28	1987Da28

Nominal Energy /keV	**1347.50**	**1357.81**	**1365.71**	**1374.24**	**1378.23**	**1385.39**
1969Ar16	-	-	-	-	-	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	0.36 (8)	0.48 (10)	0.32 (7)	0.32 (9)	0.139 (43)	0.248 (50)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	0.447 (22)	-	-
LWEIGHT4	-	-	-	0.440 (29)	-	-
Adopted	**0.36 (8)**	**0.48 (10)**	**0.32 (7)**	**0.44 (3)**	**0.14 (5)**	**0.25 (5)**
Normalised	0.016 (4)	0.021 (5)	0.014 (3)	0.0196 (14)	0.0062 (19)	0.0111 (22)
Comments	1987Da28	1987Da28	1987Da28	wtd mean	1987Da28	1987Da28

Nominal Energy /keV	**1401.52**	**1415.55**	**1430.99**	**1434.22**	**1438.01**	**1451.43**
1969Ar16	-	-	-	-	-	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	0.29 (6)	0.50 (10)	0.82 (17)	0.188 (55)	0.139 (37)	0.248 (50)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	-	-	-	-
Adopted	**0.29 (6)**	**0.50 (10)**	**0.82 (17)**	**0.19 (6)**	**0.14 (4)**	**0.25 (5)**
Normalised	0.013 (3)	0.022 (5)	0.037 (8)	0.0084 (25)	0.0062 (17)	0.0111 (22)
Comments	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28

Nominal Energy /keV	**1459.131**	**1469.74**	**1480.38**	**1495.904**	**1501.59**	**1529.01**
1969Ar16	20.0 (5)	-	-	21.0 (4)	11.6 (2)	~1
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	17.3 (10)	-	-	18.7 (16)	9.6 (11)	-
1987Da28	18.8 (15)	0.47 (9)	0.38 (8)	21.2 (16)	11.2 (10)	1.33 (14)
1992Li05	24.3 (17)	-	-	18.9 (13)	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	19.5 (11)	-	-	20.73 (43)	11.53 (25)	-
Adopted	**19.5 (11)**	**0.47 (9)**	**0.38 (8)**	**20.7 (5)**	**11.53 (25)**	**1.33 (14)**
Normalised	0.87 (5)	0.021 (5)	0.017 (4)	0.92 (3)	0.513 (17)	0.059 (6)
Comments	wtd mean	1987Da28	1987Da28	wtd mean	wtd mean	1987Da28

Nominal Energy /keV	**1537.89**	**1548.65**	**1557.13**	**1559.88**	**1571.55**	**1573.23**
1969Ar16	~0.8	~0.7	3.8 (2)	-	-	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	1.10 (12)	0.89 (10)	4.18 (37)	0.48 (10)	0.133 (37)	0.77 (9)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	3.89 (18)	-	-	-
Adopted	**1.10 (12)**	**0.89 (10)**	**3.89 (20)**	**0.48 (10)**	**0.13 (4)**	**0.77 (9)**
Normalised	0.049 (6)	0.040 (5)	0.173 (9)	0.021 (5)	0.0059 (17)	0.034 (4)
Comments	1987Da28	1987Da28	wtd mean	1987Da28	1987Da28	1987Da28

Nominal Energy /keV	**1580.531**	**1588.20**	**1609.44**	**1625.092**	**1630.618**	**1638.272**
1969Ar16	17 (3)	71 (3)	-	7.0 (20)	33.0 (20)	10.0 (10)
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	11.6 (20)	72.4 (29)	-	-	34.0 (22)	10.2 (9)
1987Da28	14.5 (14)	76.4 (52)	0.182 (37)	6.00 (51)	38.8 (31)	11.0 (10)
1992Li05	13.7 (14)	66.0 (17)	-	-	33.8 (12)	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	13.9 (9)	68.8 (20)	-	6.06 (50)	34.1 (9)	10.43 (55)
Adopted	**13.9 (14)**	**68.8 (20)**	**0.182 (37)**	**6.1 (5)**	**34.1 (12)**	**10.4 (9)**
Normalised	0.62 (4)	3.06 (12)	0.0081 (17)	0.270 (23)	1.52 (6)	0.46 (3)
Comments	wtd mean	1987Da28	1987Da28	wtd mean	wtd mean	wtd mean

Nominal Energy /keV	**1666.514**	**1671.67**	**1677.66**	**1684.04**	**1686.22**	**1700.62**
1969Ar16	3.8 (2)	-	~1.2	-	2.0 (2)	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	4.18 (37)	0.091 (31)	1.27 (14)	0.35 (11)	2.24 (21)	0.236 (56)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	3.89 (18)	-	-	-	2.11 (15)	-
Adopted	**3.89 (20)**	**0.9 (3)**	**1.27 (14)**	**0.35 (11)**	**2.11 (20)**	**0.24 (6)**
Normalised	0.173 (9)	0.0043 (14)	0.057 (6)	0.015 (5)	0.094 (7)	0.0105 (25)
Comments	wtd mean	1987Da28	1987Da28	1987Da28	wtd mean	1987Da28

Nominal Energy /keV	**1702.40**	**1706.17**	**1713.49**	**1721.49**	**1724.188**	**1738.46**
1969Ar16	1.5 (2)	-	-	-	~0.5	~0.6
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	1.13 (12)	0.200 (26)	0.127 (25)	0.133 (43)	0.68 (8)	0.41 (9)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	1.23 (17)	-	-	-	-	-
Adopted	**1.23 (17)**	**0.20 (3)**	**0.127 (25)**	**0.13 (5)**	**0.68 (8)**	**0.41 (9)**
Normalised	0.055 (7)	0.0089 (12)	0.0057 (11)	0.0059 (19)	0.030 (4)	0.018 (4)
Comments	wtd mean	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28

Nominal Energy /keV	**1740.46**	**1742.09**	**1745.32**	**1750.58**	**1758.11**	**1772.22**
1969Ar16	-	~0.5	-	-	~0.8	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	0.26 (8)	0.188 (55)	0.152 (20)	0.188 (20)	0.81 (9)	0.042 (12)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	-	-	-	-
Adopted	**0.26 (8)**	**0.19 (6)**	**0.152 (20)**	**0.188 (20)**	**0.81 (9)**	**0.042 (12)**
Normalised	0.011 (4)	0.0084 (25)	0.0067 (9)	0.0084 (9)	0.036 (4)	0.0019 (5)
Comments	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28

Nominal Energy /keV	**1784.40**	**1787.20**	**1795.13**	**1797.50**	**1800.90**	**1823.22**
1969Ar16	-	-	-	-	-	1.00 (10)
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	0.139 (25)	0.030 (12)	0.048 (18)	0.048 (18)	0.103 (19)	1.03 (12)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	-	-	-	1.01 (8)
Adopted	**0.139 (25)**	**0.030 (12)**	**0.048 (18)**	**0.048 (18)**	**0.103 (19)**	**1.01 (10)**
Normalised	0.0062 (11)	0.0013 (5)	0.0022 (8)	0.0022 (8)	0.0046 (8)	0.046 (5)
Comments	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28	wtd mean

Nominal Energy /keV	**1826.78**	**1835.29**	**1842.15**	**1850.17**	**1870.82**	**1879.60**
1969Ar16	-	0.80 (10)	0.70 (10)	-	0.60 (10)	-
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	0.048 (18)	0.89 (10)	0.98 (11)	0.103 (19)	0.57 (6)	0.030 (12)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	0.84 (7)	0.83 (14)	-	0.578 (52)	-
Adopted	**0.048 (18)**	**0.84 (10)**	**0.83 (14)**	**0.103 (19)**	**0.58 (5)**	**0.030 (12)**
Normalised	0.0022 (8)	0.038 (4)	0.037 (6)	0.0046 (8)	0.0257 (24)	0.0013 (5)
Comments	1987Da28	wtd mean	wtd mean	wtd mean	wtd mean	1987Da28

Nominal Energy /keV	**1887.13**	**1900.16**	**1907.14**	**1916.34**	**1919.54**	**1929.78**
1969Ar16	2.1 (2)	-	~0.3	-	-	~0.4
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	2.12 (21)	0.067 (13)	0.279 (28)	0.018 (6)	0.048 (12)	0.467 (54)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	2.11 (14)	-	-	-	-	-
Adopted	**2.11 (20)**	**0.067 (13)**	**0.28 (3)**	**0.018 (6)**	**0.048(12)**	**0.47 (6)**
Normalised	0.094 (7)	0.0030 (6)	0.0124 (13)	0.008 (3)	0.0022 (6)	0.0208 (24)
Comments	wtd mean	1987Da28	1987Da28	1987Da28	1987Da28	1987Da28

Nominal Energy /keV	**1936.34**	**1944.24**	**1952.37**	**1955.90**	**1958.41**	**1965.22**
1969Ar16	-	-	1.4 (2)	-	-	0.60 (10)
1971He23	-	-	-	-	-	-
1982Ma52	-	-	-	-	-	-
1982Sa36	-	-	-	-	-	-
1983Sc13	-	-	-	-	-	-
1987Da28	0.048 (12)	0.048 (12)	1.39 (14)	0.018 (6)	0.036 (12)	0.478 (48)
1992Li05	-	-	-	-	-	-
1995Ba42	-	-	-	-	-	-
LWEIGHT4	-	-	1.40 (11)	-	-	0.502 (48)
Adopted	**0.048 (12)**	**0.048 (12)**	**1.40 (14)**	**0.018 (6)**	**0.036 (12)**	**0.50 (5)**
Normalised	0.0022 (6)	0.0022 (6)	0.062 (5)	0.008 (3)	0.0016 (5)	0.0223 (22)
Comments	1987Da28	1987Da28	wtd mean	1987Da28	1987Da28	wtd mean

Nominal Energy /keV	**1971.96**	**1979.32**	**2001.0**	**2029.4**
1969Ar16	-	-	-	-
1971He23	-	-	-	-
1982Ma52	-	-	-	-
1982Sa36	-	-	-	-
1983Sc13	-	-	-	-
1987Da28	0.085 (19)	0.042 (12)	0.024 (6)	0.042 (12)
1992Li05	-	-	-	-
1995Ba42	-	-	-	-
LWEIGHT4	-	-	-	-
Adopted	**0.085 (19)**	**0.042 (12)**	**0.024 (6)**	**0.042 (12)**
Normalised	0.0038 (8)	0.0019 (5)	0.0011 (3)	0.0019 (5)
Comments	1987Da28	1987Da28	1987Da28	1987Da28

^{228}Th – Comments on evaluation of decay data by A. L. Nichols

Evaluated: July/August 2001
Re-evaluated: January 2004 and April 2010

Evaluation Procedures

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

Decay Scheme

^{228}Th ($T_{½}$ = 698.6 days) decays 100 % by alpha-particle emission (Q(α) = 5520.08 (22) keV) to various excited levels and the ground state of ^{224}Ra ($T_{½}$ = 3.631 days). A reasonably well-defined decay scheme was derived from the alpha-particle studies of 1969Pe17, 1970Ba20, 1976BaZZ and 1993Ba72, and the gamma-ray measurements of 1977Ku15 and 1984Ge07. An additional gamma transition was added to the proposed decay scheme from equivalent studies of ^{224}Fr decay by 1981Ku02: 908.28-keV gamma ray depopulating the 992.65-keV nuclear level of ^{224}Ra. Weighted mean relative emission probabilities were calculated for the 131.612-, 166.410-, 205.99- and 215.985-keV gamma rays, while equivalent data for the other gamma transitions were adopted from the measurements of 1977Ku15; all of these relative emission probabilities were defined in terms of the 84.373-keV gamma ray (100 %).

^{20}O cluster decay has been observed by 1993Bo20 to be 1.13 (22) E-13. Subsequent reviews by 1995Ar33 and 1997Tr17 list a cluster-decay branching fraction of 1.13 (22) E-13 and 1.1 (2) E-13, respectively, based primarily on the earlier measurement.

Nuclear Data

The ^{228}Th decay chain is important in quantifying the environmental impact of the decay of naturally-occurring ^{232}Th. Certain radionuclides in this decay chain are noteworthy because of their decay characteristics: ^{224}Ra alpha decay to ^{220}Rn; ^{212}Bi and ^{208}Tl gamma-ray emissions. ^{208}Tl in particular emits high-energy gamma rays that represent a well-defined spectroscopic signature for this decay chain.

Half-life

The measurements of 1956Ki16, 1962Ma57, 1971Jo14 and 2002Un02 were adopted to give a least-squares weighted mean half-life of 698.55 (32) days. ^{228}Th half-life quoted in 2002Un02 is also listed within 1992Un01. Woods has recommended a half-life of 698.60 (23) days (2007BeZP), but without due consideration of the calculated uncertainty with respect to the measured values, see relevant footnotes.

Reference	Half-life (d)*
1918Me01	695.8 [1.905 y]†
1956Ki16	697.6 (7) [1.910 (2) y]
1962Ma57	696.9 (15) [1.908 (4) y]
1962Ma57	703 (7) [1.924 (20) y]‡
1971Jo14	698.77 (32)
2002Un02	698.60 (36)
Recommended value	698.55 (32)§

* Conversion factor: 1 tropical year ≡ 365.2422 days.
† Uncertainty not specified – not included in weighted mean analysis of the data set.
‡ Defined as an outlier.
§ Recommended uncertainty adjusted from ± 0.22 to ± 0.32, in alignment with the smallest uncertainty of the values used to calculate the average value.

Alpha Particles

Energies

All alpha-particle energies were derived from the structural details of the proposed decay scheme. While the energies of the main alpha-particle emissions have been directly measured by 1953As31, 1970Ba20, 1971Gr07, 1976BaZZ and 1991Ry01, the nuclear level energies of 1997Ar05 and evaluated Q-value of 5520.08 (22) keV (2003Au03) were used to determine the recommended energies and uncertainties of the alpha-particle emissions, while allowing for the significant recoil components.

Adopted nuclear levels of ^{224}Ra: J$^{\pi}$ and origins (1997Ar05).

Nuclear level	Nuclear level energy (keV)	J$^{\pi}$	Origins
0	0.0	0 +	^{224}Fr β$^-$ decay, ^{224}Ac EC decay, **^{228}Th α decay**, ^{226}Ra(p,t), ^{226}Ra(α,α'2nγ), ^{226}Ra(^{58}Ni,^{60}Ni)
1	84.373 ± 0.003	2 +	^{224}Fr β$^-$ decay, ^{224}Ac EC decay, **^{228}Th α decay**, ^{226}Ra(p,t), ^{226}Ra(α,α'2nγ), ^{226}Ra(^{58}Ni,^{60}Ni)
2	215.985 ± 0.004	1 –	^{224}Fr β$^-$ decay, ^{224}Ac EC decay, **^{228}Th α decay**, ^{226}Ra(p,t), ^{226}Ra(α,α'2nγ), ^{226}Ra(^{58}Ni,^{60}Ni)
3	250.783 ± 0.005	4 +	^{224}Fr β$^-$ decay, ^{224}Ac EC decay, **^{228}Th α decay**, ^{226}Ra(α,α'2nγ), ^{226}Ra(^{58}Ni,^{60}Ni)
4	290.36 ± 0.04	(3) –	^{224}Fr β$^-$ decay, ^{224}Ac EC decay, **^{228}Th α decay**, ^{226}Ra(α,α'2nγ), ^{226}Ra(^{58}Ni,^{60}Ni)
5	433.07 ± 0.10	(5) –	^{224}Fr β$^-$ decay, **^{228}Th α decay**, ^{226}Ra(α,α'2nγ), ^{226}Ra(^{58}Ni,^{60}Ni)
6	479.20 ± 0.18	(6 +)	**^{228}Th α decay**, ^{226}Ra(p,t), ^{226}Ra(α,α'2nγ), ^{226}Ra(^{58}Ni,^{60}Ni)
7	916.34 ± 0.07	0 +	^{224}Fr β$^-$ decay, **^{228}Th α decay**, ^{226}Ra(p,t)
8	992.65 ± 0.06	(2 +)	^{224}Fr β$^-$ decay, **^{228}Th α decay**

Measured and recommended energies of the main alpha-particle emissions of ^{228}Th.

	E$_{\alpha}$ (keV)					
	1953As31	1970Ba20	1971Gr07	1976BaZZ	1991Ry01	Recommended value*
$\alpha_{0,8}$	–	–	–	–	–	4448.00 (23)
$\alpha_{0,7}$	–	–	–	–	–	4522.97 (23)
$\alpha_{0,6}$	–	–	–	–	–	4952.5 (3)
$\alpha_{0,5}$	–	–	–	–	–	4997.76 (24)
$\alpha_{0,4}$	–	5136.1	–	–	–	5137.97 (22)
$\alpha_{0,3}$	5173	5171.5	–	–	–	5176.86 (22)
$\alpha_{0,2}$	5208	5208.9	–	–	–	5211.05 (22)
$\alpha_{0,1}$	5388.5 (10)	5338.6	5340.54 (15)	5339.2 (10)	5340.36 (15)	5340.35 (22)
$\alpha_{0,0}$	5421 (1)	5420.0	5423.33 (22)	5420.6 (10)	5423.15 (22)	5423.24 (22)

* Determined from the nuclear level energies of 1997Ar05 and evaluated Q-value of 5520.08 (22) keV (2003Au03).

Emission Probabilities

An alpha-particle emission probability of 73.4 (5) % was derived for alpha decay directly to the ground state of ^{224}Ra, based on the various alpha-particle studies. This value and the gamma-ray data were used in conjunction with the theoretical internal conversion coefficients to determine a normalisation factor of 0.0119 (3) per 100 disintegrations for the relative emission probabilities of the gamma rays (see below).

Published alpha-particle emission probabilities per 100 disintegrations of ^{228}Th.

E$_{\alpha}$(keV)	P$_{\alpha}$				
	1953As31	1969Pe17	1970Ba20	1976BaZZ	1993Ba72
4448.00 (23)	-	-	-	-	-
4522.97 (23)	-	-	-	-	-
4952.5 (3)	-	-	-	-	-
4997.76 (24)	-	-	-	-	-
5137.97 (22)	-	-	~ 0.05	-	-
5176.86 (22)	0.2	-	0.18	-	-
5211.05 (22)	0.4	-	0.36	-	-
5340.35 (22)	28	26.7 (2)	26.7	26.6 (5)	26.0 (8)
5423.24 (22)	71	[73.3 (2)]	72.7	72.4 (10)	74.0 (6)

Alpha-particle emission probability data of 1969Pe17 are effectively normalised to 73.3 (2) % and 26.7 (2) %.

1976BaZZ measurements require re-normalisation to (100 – 0.36 – 0.18 – 0.05) = 99.41 %

(72.4 + 26.6) N = 99.41

N = 1.00414 to give P_α(5423.24 keV) of 72.7 %, and uncertainty of ± 1.0;

and P_α(5340.35 keV) of 26.7 %, and uncertainty of ± 0.5.

1993Ba72 studies also require re-normalisation to give P_α(5423.24 keV) of 73.6 % and uncertainty of ± 0.6; and P_α(5340.35 keV) of 25.8 %, and uncertainty of ± 0.8.

A weighted mean value of 73.4 (5) % (0.734 (5)) was determined for P_α(5423.24 keV) from the data of 1976BaZZ and 1993Ba72, which has been matched against a value of 26.0 (5) % (0.260 (5)) for P_α(5340.35 keV).

The absolute emission probabilities of the majority of the other alpha particles were calculated from population-depopulation of the nuclear level of ^{224}Ra and the gamma-ray normalisation factor. Although a consistent decay scheme was derived, further detailed alpha-particle measurements are required to develop and support the overall correctness of the proposed decay scheme. A hindrance factor (HF) of 1.000 for the 5423.24-keV alpha-particle emission yields r_0(^{224}Ra) of 1.5339 (3) fm, whereas the recommended value is 1.5332 (8) fm (1998Ak04).

Adjusted alpha-particle emission probabilities per 100 disintegrations of ^{228}Th, and hindrance factors.

E_α(keV)	P_α						HF
	1953As31	1969Pe17	1970Ba20	1976BaZZ	1993Ba72	Recommended value*	
4448.00 (23)	-	-	-	-	-	4.5 (7) x 10^{-6}	7.2
4522.97 (23)	-	-	-	-	-	1.7 (3) x 10^{-5}	7.0
4952.5 (3)	-	-	-	-	-	2.4 (5) x 10^{-5}	4600
4997.76 (24)	-	-	-	-	-	1.0 (2) x 10^{-5}	21400
5137.97 (22)	-	-	~ 0.05	-	-	0.036 (6)	44
5176.86 (22)	0.2	-	0.18	-	-	0.218 (4)	12.5
5211.05 (22)	0.4	-	0.36	-	-	0.408 (7)	10.7
5340.35 (22)	28	26.7 (2)	26.7	26.7 (5)	25.8 (8)	26.0 (5)	0.958
5423.24 (22)	71	[73.3 (2)]	72.7	72.7 (10)	73.6 (6)	73.4 (5)‡	1.000
						Σ100.1 (7)	

* Recommended emission probabilities of the low-intensity α transitions were derived from the evaluated gamma-ray emission probabilities and theoretical internal conversion coefficients.

‡ P_α(5423.24 keV) of 73.4 (5) % is effectively the weighted mean of the re-normalised studies (1976BaZZ, 1993Ba72), which has been subsequently matched with P_α(5340.35 keV) of 26.0 (5) %.

Gamma Rays

Energies

Although energies of the gamma-ray emissions have been measured by 1968Da21 and 1997Ku15 in particular, the well-defined nuclear level energies of 1997Aro5 were used to determine the recommended energies and associated uncertainties of the gamma-ray emissions between the various populated-depopulated levels because of their more extensive origins.

Measured and recommended gamma-ray energies.

E_γ (keV)			
1968Da21	**1977Ku15**	**1977Ku25**	**Recommended value***
-	74.4 (1)‡	-	74.38 (4)
-	84.371 (3)†	84.371 (3)	84.373 (3)
131.6 (8)	131.610 (4)†	131.610 (4)	131.612 (5)
-	142.0 (5)‡	-	142.71 (11)
166.5 (8)	166.407 (4)†	166.407 (4)	166.410 (6)
-	182.2 (2)‡	-	182.29 (10)
-	205.93 (5)	-	205.99 (4)
216.1 (6)	215.979 (5)†	215.979 (5)	215.985 (4)
-	228.5 (2)	-	228.42 (18)
-	700.5 (5)‡	-	700.36 (7)
-	742.2 (5)	-	741.87 (6)
-	832.0 (2)	-	831.97 (7)
-	-	-	908.28 (6)
-	992.9 (10)	-	992.65 (6)

† Identical value and uncertainty also reported by 1977Ku25.
‡ Data derived from coincidence measurements.
* Determined from the nuclear level energies of 1997Ar05.

Emission Probabilities

Gamma-ray emission probabilities have been partially or fully determined in the measurements of 1977Ku15, 1982Sa36 and 1984Ge07. However, the data derived by 1982Sa36 are significantly lower by 20 % to 30 % compared with the equivalent values measured by 1977Ku15 and 1984Ge07, and therefore they were set aside from in the weighted mean analysis. Weighted mean relative emission probabilities were calculated for the 131.612-, 166.410-, 205.99- and 215.985-keV gamma rays, while equivalent data for the other gamma emissions were directly adopted from the measurements of 1977Ku15. An additional gamma transition was added to the proposed decay scheme from the equivalent studies of ^{224}Fr decay by 1981Ku02 as a 908.28-keV gamma ray depopulating the 992.65-keV nuclear level of ^{224}Ra - this gamma transition may have been observed in the α decay of ^{228}Th by 1977Ku15, but was adjudged by them to be background radiation (within the 911.2-keV peak). All of these relative emission probabilities were defined in terms of the emission probability of the 84.373-keV gamma ray (100.0 %).

Published gamma-ray emission probabilities.

E_γ (keV)	P_γ			
	1969Pe17*	**1977Ku15†**	**1982Sa36‡**	**1984Ge07§**
74.38 (4)	-	4.0 (14)	-	-
84.373 (3)	1.21(6)	12100 (600)	1.9 (1)	100.0 (16)
131.612 (5)	-	1240 (60)	0.17 (2)	10.70 (15)
142.71 (11)	-	0.013 (4)	-	-
166.410 (6)	-	960 (50)	0.13 (1)	8.49 (12)
182.29 (10)	-	0.052 (18)	-	-
205.99 (4)	-	184 (9)	-	-
215.985 (4)	-	2390 (130)	0.30 (2)	1.61 (5)
228.42 (18)	-	0.18(3)	-	20.78 (25)
700.36 (7)	-	~ 0.03	-	-
741.87 (6)	-	0.014 (4)	-	-
831.97 (7)	-	0.14 (2)	-	-
908.28 (6)	-	-	-	-
992.65 (6)	-	~ 0.015	-	-

* Emission probability expressed in terms of photons per 100 disintegrations.
† Emission probabilities expressed in terms of photons per 10^6 disintegrations.
‡ Emission probabilities published relative to Pγ(238.63 keV) for ^{212}Pb of 43.0 %.
§ Emission probabilities published relative to Pγ(84.373 keV) of 100.0 %.

Measured and recommended gamma-ray emission probabilities relative to Pγ(84.373 keV) of 100 %.

E_γ (keV)	P_γ^{rel}			
	1977Ku15	1982Sa36	1984Ge07	Recommended value*
74.38 (4)	0.033 (12)	-	-	0.033 (12)
84.373 (3)	100 (5)	100 (5)	100.0 (16)	100.0 (16)
131.612 (5)	10.25 (50)	8.9 (10)†	10.70 (15)	10.7 (2)
142.71 (11)	0.000 11 (3)	-	-	0.000 11 (3)
166.410 (6)	7.9 (4)	6.8 (5)†	8.49 (12)	8.44 (12)
182.29 (10)	0.000 43 (15)	-	-	0.000 43 (15)
205.99 (4)	1.52 (7)	-	1.61 (5)	1.58 (4)
215.985 (4)	19.8 (11)	15.8 (11)†	20.78 (25)	20.7 (3)
228.42 (18)	0.001 5 (3)	-	-	0.001 5 (3)
700.36 (7)	~ 0.000 25	-	-	0.000 25 (8)
741.87 (6)	0.000 12 (3)	-	-	0.000 12 (3)
831.97 (7)	0.001 2 (2)	-	-	0.001 2 (2)
908.28 (6)	-	-	-	0.000 14 (4)
992.65 (6)	~ 0.000 12	-	-	0.000 12 (3)

* Weighted mean values adopted when judged appropriate.
† Significantly lower than equivalent data of 1977Ku15 and 1984Ge07 by 20 % to 30 %; judged to be an outlier, and therefore not considered in any weighted mean analysis.

Multipolarities and Internal Conversion Coefficients
The nuclear level scheme specified by Artna-Cohen has been used to define the multipolarities of the gamma transitions on the basis of known spins and polarities (1997Ar05). Limited studies of the internal conversion coefficients support the proposed transition types: E2 for both the 84.373- and 166.410-keV gamma rays (1953As31, 1966Co40, 1968Du06, 1969Pe17 and 1970SpZW).

Internal conversion coefficients as determined by measurement.

Reference	E_γ (keV)	α					Measurement technique
		α_L	α_{L2}	α_{L3}	α_{M+}	α_{total}	
1953As31	84.373 (3)	-	-	-	-	16	deduced from measured P_γ and P_α populating 84.37-keV nuclear level of ^{224}Ra
	166.410 (4)	-	-	-	-	1.2	deduced from measured P_γ and P_α populating 251-keV nuclear level of ^{224}Ra
1966Co40	84.373 (3)	14 (3)	7.6	6.3	3.8 (9)	18 (4)	P_{ce} measured by means of photographic emulsion technique
1968Du06	84.373 (3)	-	-	-	-	19.6 (14)	deduced from α-gated γ-ray spectra
1969Pe17	84.373 (3)	-	-	-	-	21.4 (9)	deduced from α-gated γ-ray spectra

Conversion electron spectra: Measurements of L- and M-subshell internal conversion ratios (1970SpZW).

E_γ (keV)	L_1/L_2	L_1/L_3	L_2/L_3	M_1/M_2	M_1/M_3	M_2/M_3
84.373 (3)	0.0388 (19)	0.0519 (21)	1.343 (10)	0.0471 (46)	0.0571 (57)	1.2187 (85)

The 908.28-keV gamma ray was identified as the only mixed multipolarity (M1 + E2), and was arbitrarily assigned a mixing ratio of 1.0 with an uncertainty of ± 0.2. Recommended internal conversion coefficients have been determined from the frozen orbital approximation of Kibédi *et al*. (2008Ki07), based on the theoretical model of Band *et al*. (2002Ba85, 2002Ra45). Uncertainties of ± 1.5 % were adopted for all of the E1 and E2 gamma transitions (with minor upward adjustments associated with the significant figures for α_L and α_{M+}).

Gamma-ray emissions: multipolarities and theoretical internal conversion coefficients (frozen orbital approximation).

E_γ (keV)	Multipolarity	α_K	α_L	α_{M+}	α_{total}
74.38 (4)	[E2]	–	28.3 (4)	10.3	38.6 (6)
84.373 (3)	E2	–	15.57 (22)	5.63	21.2 (3)
131.612 (5)	E1	0.194 (3)	0.0406 (6)	0.0124	0.247 (4)
142.71 (11)	[E2]	0.279 (4)	1.368 (20)	0.493	2.14 (3)
166.410 (6)	E2	0.225 (4)	0.691 (10)	0.248	1.164 (17)
182.29 (10)	[E1]	0.089 4 (13)	0.017 57 (25)	0.005 63	0.112 6 (16)
205.99 (4)	(E1)	0.067 1 (10)	0.012 92 (18)	0.004 08	0.084 1 (12)
215.985 (4)	E1	0.060 0 (9)	0.011 48 (16)	0.003 72	0.075 2 (11)
228.42 (18)	[E2]	0.124 4 (18)	0.178 (3)	0.063 6	0.366 (6)
700.36 (7)	E1	0.005 02 (7)	0.000 834 (12)	0.000 256	0.006 11 (9)
741.87 (6)	[E2]	0.011 96 (17)	0.003 22 (5)	0.001 07	0.016 25 (23)
831.97 (7)	E2	0.009 70 (14)	0.002 40 (4)	0.000 79	0.012 89 (18)
908.28 (6)	[50%M1 + 50%E2] δ = 1.0 (2)	0.019 0 (24)	0.003 6 (4)	0.001 4	0.024 (3)
992.65 (6)	[E2]	0.007 05 (10)	0.001 569 (22)	0.000 511	0.009 13 (13)

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

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

[Σ $P_{\gamma i}$ (1 + α_i) to ground state] NF + 0.734 (5) = 1.00
NF = 0.000 119 (3)

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

[P_γ(84.373 keV)(1 + α(84.373 keV)) - $\Sigma P_{\gamma i}$ (1 + α_i) to 84.373-keV level] NF = 0.260 (5)
NF = 0.000 119 (3)

(iii) all α emissions

Σ P_α NF = 1.00, and adopting α-particle emission probability to ^{224}Ra ground state of 0.734 (5) (see section on alpha-particle emissions)
NF = 0.000 119 (3)

Thus, a normalization factor of 0.000 119 (3) has been adopted in the determination of the absolute gamma-ray emission probabilities.

Atomic Data

The x-ray and Auger-electron data have been calculated using the evaluated gamma-ray data, and atomic data from 1996Sc06, 1998ScZM and 1999ScZX. Both the x-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.01, 28 January 2003). This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

K and L X-ray emission probabilities per 100 disintegrations of ^{228}Th.

			Energy (keV)	Photons per 100 disint.
XL		(Ra)	10.622 – 18.412	8.6 (4)
	XL_l	(Ra)	10.622	0.166 (6)
	XL_α	(Ra)	12.196 – 12.339	2.86 (9)
	XL_η	(Ra)	13.662	0.109 (4)
	XL_β	(Ra)	14.236 – 15.447	4.67 (15)
	XL_γ	(Ra)	17.848 – 18.412	1.09 (4)
XK_α	$XK_{\alpha2}$	(Ra)	85.43	0.018 0 (3)
	$XK_{\alpha1}$	(Ra)	88.47	0.029 5 (5)
$XK'_{\beta1}$	$XK_{\beta3}$	(Ra)	99.432	}
	$XK_{\beta1}$	(Ra)	100.13	} 0.010 34 (21)
	$XK''_{\beta5}$	(Ra)	100.738	}
$XK'_{\beta2}$	$XK_{\beta2}$	(Ra)	102.89	}
	$XK_{\beta4}$	(Ra)	103.295	} 0.003 39 (9)
	$XKO_{2,3}$	(Ra)	103.74	}

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

Data Consistency

A Q_α-value of 5520.08 (22) keV has been adopted from the atomic mass evaluation of Audi *et al.* (2003Au03) while in the course of formulating the decay scheme of ^{228}Th. This value has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{228}Th alpha-decay process (i.e. α, electron, γ, etc.):

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 5523\ (40)\ \text{keV}$$

Percentage deviation from the Q-value of Audi *et al.* is − (0.1 ± 0.7) %, which supports the derivation of a highly consistent decay scheme with a significant variant.

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^{229}Th – Comments on evaluation of decay data by G. Mukherjee

This evaluation was completed in May 2011, and the literature available at this date has been included here. ^{229}Th is a member of the ^{233}U decay series. This was recognized by Hagemann et al. (1947Ha02). ^{233}Th β^- decay → ^{233}Pa β^-decay → ^{233}U α decay → ^{229}Th.

1. Decay Scheme

^{229}Th is a part of the 4n+1 series of Neptunium decay chain which decays 100 % by the emission of α particles to the ground and the excited states in ^{225}Ra. 5 (1) % populates the ground state of ^{225}Ra. Important impurities in the production of ^{229}Th are U-238 and U-232.

The decay scheme is reasonably complete and consistent. Its overall consistency is verified by the comparison between Q(calc), deduced from the evaluated average energies of all emissions, and Q(alpha) from the atomic mass evaluation of Audi et al. (2003Au03). A percentage deviation between Q(calc) and Q(alpha) is 0.32 %. There are, however, 26 unplaced gamma rays observed in this decay scheme. The level energies, spins, parities along with the multipolarities and mixing ratios of the γ-rays presented in this evaluation are from 2009Ja03.

2. Nuclear Data

The Q value (5167.6 ± 1.0 keV) is from the atomic mass evaluation of Audi et al. (2003Au03). The experimental half-life values of ^{229}Th are given in Table-1

Table-1: Experimental values of ^{229}Th half-life

Reference	$T_{1/2}$ Values (10^3 a)	comments
1947HA02	7	Not used
1947EN03	5	Not used
1950HA52	7.340 (217)	Indirect method. 2 % greater $T_{1/2}$ used for ^{233}U. Modified uncertainty.
1989GO19	7.880 (120)	Isotope dilution mass spectrometry.
Recommended value	**7.88 (12)**	**Value reported by 1989GO19**

The experimental half-life values of ^{229}Th are given in Table 1. The first measurement available in the literature is by 1947Ha02 and 1947En03 who reported a value of 7 10^3 a and 5 10^3 a respectively without the uncertainty or the details of the measurement. These values have been excluded from the averaging. The value reported in 1950Ha52 was an indirect method done in 1950. Known amount of ^{233}U was allowed to decay for a measured period of time and then the activity of the daughter ^{229}Th was determined. 1989Go19 had measured specific activity with mass spectrometry. This value is about 7 % larger than 7340 (160) a reported in 1950Ha52. In the later one, they used a half-life of 1.62 10^5 a for ^{233}U which is about 2 % greater than the presently adopted value. Consequently, an extra uncertainty of 2 % must be included in that value. Still there remains a discrepancy of about 5 % which may be due to an underestimation of the effect of impurities. Considering these, the experimental value of 7.880 (120) 10^3 a reported in 1989GO19 has been recommended by the evaluator. The compilation of 1979Ry03 and 1991Ry01 give a value of 7.3 10^3 a for the half life of ^{229}Th.

The experimental half-life values of the daughter nucleus ^{225}Ra (decays by β^- decay) are given in Table 2. The first measurement available in the literature is by 1947Ha02 who reported a value of 14.8 d without uncertainty or the details of the measurement. This value has been excluded from the averaging.

Table-2: Experimental values of ^{225}Ra half-life

Reference	$T_{1/2}$ Values (d)	comments
1947Ha02	14.8	Not used.
1950Ha52	14.8 (2)	Indirect method; following growth and decay of α-activity. $T_{1/2}$ = 10 d assumed for the daughter ^{225}Ac
1987Mi10	15.02 (56)	Photo disintegration of ^{232}Th.
Recommended value	**14.82 (19)**	**LWEIGHT, Reduced χ^2 = 0.14**

The computer program LWEIGHT (v3) has been used to calculate the weighted mean of the chosen experimental values which yields a mean of 14.82 d and an internal uncertainty of *0.19 d* with reduced chi-square of 0.14.

3. α Particles

The energies of the α-particle transitions have been calculated from the Q_α (2003Au03) and level energies. The level energies of ^{225}Ra as deduced in 2009Ja03 has been adopted. The adopted values of the level energies, their spin and parities, the half-lives of the levels (wherever available), the energies and the probabilities of the alpha transitions are given in Table-3 below. The alpha particle energies and the absolute probabilities (per 100 decays) are evaluated values from 2009Ja03.

Table-3: Levels of ^{225}Ra populated by α-decay of ^{229}Th

Level	Level Energy (keV)	Spin & Parity	Half-life	Energy of α-particle (keV)	Probability of α-transition (%)
0	0.	$1/2^+$	14.8 (2) d	5078 (2)	0.05
1	25.41 (2)	$5/2^+$	0.88 (4) ns	5053 (2)	6.5 (1)
2	31.56 (3)	$3/2^-$	2.1 (5) ns	5047 (2)	< 0.2
3	42.77 (3)	$3/2^+$	< 3 ns	5036 (2)	0.23 (2)
4	55.16 (6)	$(1/2^-)$		5023 (2)	0.009 (3)
5	69.36 (6)	$(7/2^-)$		5009 (2)	0.09 (1)
6	100.5 (6)	$9/2^+$		4978.5 (12)	3.23 (4)
7	101.72	$(3/2^+)$			
8	111.6 (5)	$7/2^+$		4967.5 (12)	5.91 (6)
9	120.36 (6)	$5/2^-$			
10	149.96 (6)	$3/2^+$		4930 (2)	0.16 (5)
11	159.59				
12	179.75 (2)	$5/2^+$		4901.0 (12)	10.09 (8)
13	203.47	$(9/2^-)$		~4878	~0.03
14	216.28			~4865	~0.03
15	220.55 (7)	$(7/2^+,9/2^+)$		4861 (2)	0.27 (10)
16	225.08				
17	226.9 (3)	$(11/2^+)$		~4852	~0.03
18	236.25 (2)	$5/2^+$		4845.3 (12)	55.6 (2)
19	243.56 (4)	$7/2^+$		4838 (2)	4.9 (2)
20	248.63			~4833	~0.28
21	260.18	$(5/2)^-$			
22	267.92 (5)	$7/2^+$		4814.6 (12)	9.20 (8)
23	272.15 (15)			~4809	~0.21
24	284.49 (5)	$7/2^+$		4797.8 (12)	1.5 (2)
25	292.72				
26	321.76 (8)	$(9/2^+)$		4761 (2)	1.0 (4)
27	327.71			~4754	~0.05
28	335.4			~4748	~0.005
29	349.43			~4737	~0.01
30	390.21	$(11/2^+)$		4694 (2)	0.12 (2)
31	394.24				
32	394.45	$(5/2)^+$			
33	394.72 (13)	$(3/2,5/2,7/2)^+$		4690 (2)	0.22 (8)
34	399.54				
35	403.5				
36	416.77			~4667	~0.001
37	446.45				
38	478.1			4608 (2)	0.050 (8)
39	486.82	$(5/2^+)$			
40	487.22 (3)	$(13/2^+)$		4599 (3)	0.02 (1)
41	535.25	$(5/2^+)$			
42	592.79				
43	604.51			4484 (2)	0.03 (2)
44	608.93			4478 (3)	~0.005

The alpha particle energies have been deduced from the alpha transition energies taking in to account the recoil energy for ^{225}Ra. The deduced values of the alpha particle energies along with the values from the 1987He28 and 1970Ba20 are given in Table 4.

Table-4: Energy and probability of α-particles from the decay of ^{229}Th

Level	Level Energy (keV)	Energy of α-particle (keV)			Probability of α-transition (%)		
		Deduced	1987He28	1970Ba20	Adopted	1987He28	1970Ba20
0	0.	5077.3 (10)	5077 (2)	5077	0.05	0.05	0.01
1	25.41 (2)	5052.4 (10)	5053 (2)	5052	6.5 (1)	6.6 (1)	1.6
2	31.56 (3)	5046.3 (10)		5050	< 0.2		5.2
3	42.77 (3)	5035.3 (10)	5036 (2)	5033	0.23 (2)	0.24 (2)	0.24
4	55.16 (6)	5023.1 (10)	5023 (2)		0.009 (3)	0.009 (3)	
5	69.36 (6)	5009.1 (10)	5009 (2)		0.09 (1)	0.09 (1)	
6	100.5 (6)	4978.6 (10)	4979 (2)	4977.9 (12)	3.23 (4)	3.4 (1)	3.2
7	101.72						
8	111.6 (5)	4967.7 (10)	4968 (2)	4966.9 (12)	5.91 (6)	7.0 (1)	6.4
9	120.36 (6)						
10	149.96 (6)	4929.9 (10)	4930 (2)	4929	0.16 (5)	0.21 (2)	0.11
11	159.59						
12	179.75 (2)	4900.7 (10)	4901 (2)	4900.4 (12)	10.09 (8)	10.6 (2)	10.8
13	203.47	4877.4 (10)		~4878	~0.03		~0.03
14	216.28	4864.8 (10)		~4865	~0.03		~0.03
15	220.55 (7)	4860.7 (10)	4860 (2)	~4861	0.27 (10)	0.38 (4)	0.18
16	225.08						
17	226.9 (3)	4854.4 (10)		~4852	~0.03		~0.03
18	236.25 (2)	4845.2 (10)	4845 (2)	4844.7 (12)	55.6 (2)	53.0	56.2
19	243.56 (4)	4838.0 (10)	4838 (2)	~4837	4.9 (2)	5.2	4.8
20	248.63	4833.1 (10)		~4833	~0.28		~0.29
21	260.18						
22	267.92 (5)	4814.1 (10)	4815 (2)	4814.0 (12)	9.20 (8)	9.6 (2)	8.4
23	272.15 (15)	4810.0 (10)		~4809	~0.21		~0.22
24	284.49 (5)	4797.8 (10)	4798 (2)	4797.2 (12)	1.5 (2)	1.70 (5)	1.27
25	292.72						
26	321.76 (8)	4761.2 (10)	4760 (2)	4761	1.0 (4)	1.40 (4)	0.63
27	327.71	4755.4 (10)		~4754	~0.05		~0.05
28	335.4	4747.8 (10)		~4748	~0.005		~0.005
29	349.43	4734.0 (10)		~4737	~0.01		~0.01
30	390.21	4693.9 (10)	4695 (2)	4692	0.12 (2)	0.14 (2)	~0.08
31	394.24						
32	394.45						
33	394.72 (13)	4689.5 (10)	4690 (2)	~4688	0.22 (8)	0.31 (2)	0.15
34	399.54						
35	403.5						
36	416.77	4667.8 (10)		~4667	~0.001		~0.001
37	446.45						
38	478.1	4607.6 (10)	4608 (2)		0.050 (8)	0.050 (8)	
39	486.82						
40	487.22 (3)	4598.6 (10)	4600 (2)	4598	0.02 (1)	0.029 (5)	~0.007
41	535.25						
42	592.79						
43	604.51	4483.4 (10)	4484 (2)	4484	0.03 (2)	0.050 (7)	~0.009
44	608.93	4479.1 (10)		4478	~0.005		~0.005

4. γ Transitions

The gamma-ray transitions in ^{229}Th following the ^{233}U decay is presented in section 2.2 along with the multipolarity of the gamma rays and the internal conversion coefficients. The recommended γ-ray energies and absolute emission probabilities are from the evaluated values in 2009Ja03 which uses mostly the values reported in 1987He28 and 2000Ga52. The energies and intensities of the gamma rays in ^{225}Ra produced by the α-decay of ^{229}Th are given in Table-5 and Table-6 from different measurements.

Table-5: Energy of γ-rays in ^{225}Ra from the decay of ^{229}Th

	2000Ga52	1987He28	1983Ra01	1981Di14
$\gamma_{8,6}$	11.1 (1)	11.1		
$\gamma_{43,42}$	11.79 (20)			
$\gamma_{3,1}$	17.25 (10)	17.36 (3)		
[a]	19.08 (20)			
[a]	21.60 (10)	21.58 (2)		
$\gamma_{4,2}$		23.6		
$\gamma_{1,0}$	25.42 (10)	25.39 (2)		
[a]		27.50 (2)		
$\gamma_{23,19}$	28.68 (10)	30.3	28.50 (14)	
$\gamma_{10,9}$	29.9 (1)			
$\gamma_{6,5}$	31.43 (10)	31.10 (5)	31.13 (3)	31.24
$\gamma_{2,0}$		31.50 (5)	31.53 (4)	
$\gamma_{22,18}$		31.57 (9)		
$\gamma_{25,21}$	33.04 (20)			
[a]	34.02 (20)			
$\gamma_{5,2}$	37.78 (20)	37.8 (1)		
$\gamma_{8,5}$	42.24 (10)	42.3 (1)		
$\gamma_{3,0}$	42.77 (10)	42.82 (5)	42.63 (2)	42.79
$\gamma_{5,1}$	43.99 (5)	43.990 (10)	43.96 (2)	
$\gamma_{22,15}$	46.52 (10)	46.52 (4)		
$\gamma_{26,23}$	49.74 (10)	49.75 (8)		
$\gamma_{9,5}$	50.98 (10)	50.99 (4)		
[a]		53.2 (1)		
$\gamma_{26,22}$	53.84 (10)	53.75 (20)	53.84 (9)	
$\gamma_{4,0}$	55.20 (10)	55.11 (3)		
$\gamma_{18,12}$	56.52 (5)	56.518 (5)	56.50 (3)	56.57
$\gamma_{12,9}$	59.33 (10)			
$\gamma_{24,15}$	63.7	63.7 (2)		
$\gamma_{9,4}$	64.96 (10)			
$\gamma_{25,17}$	65.91 (10)			
$\gamma_{12,8}$	68.1 (1)	68.09 (4)	68.05 (8)	
$\gamma_{30,26}$	68.2			
$\gamma_{15,11}$	68.80 (10)		68.80 (7)	
$\gamma_{8,3}$		68.83 (1)		
$\gamma_{33,26}$	72.81 (10)	72.739 (10)		
$\gamma_{6,1}$		75.10 (10)	75.10 (5)	
$\gamma_{16,10}$	75.19 (10)			
[a]		75.3 (1)		
[a]	76.67 (20)			
$\gamma_{9,3}$	77.60 (10)	77.63 (5)		

	2000Ga52	1987He28	1983Ra01	1981Di14
$\gamma_{26,19}$	78.53 (10)	78.3 (2)		
$\gamma_{8,1}$	86.33 (4)	86.25 (4)		
$\gamma_{18,10}$		86.40 (5)	86.35 (4)	86.38
$\gamma_{9,2}$	89.09 (20)			
$\gamma_{29,21}$	89.09 (20)			
$\gamma_{26,17}$	94.70 (10)			
$\gamma_{10,4}$		94.73 (2)	94.72 (2)	
$\gamma_{9,1}$		94.92 (8)		
$\gamma_{40,30}$	97.01 (12)			
$\gamma_{20,10}$	98.86 (10)			
$\gamma_{26,15}$	100.8 (2)	101.1 (2)		
$\gamma_{7,0}$	101.58 (10)			
$\gamma_{27,16}$	102.54 (2)		103.71 (3)	
$\gamma_{24,12}$	104.32 (10)	104.6 (2)		
$\gamma_{10,3}$	107.11 (10)	107.108 (8)	107.15 (2)	107.20
$\gamma_{15,8}$	109.10 (10)	109.2	109.21 (6)	
$\gamma_{12,5}$	110.33 (5)	110.332 (8)	110.38 (3)	
$\gamma_{42,38}$	114.75 (10)	115.3 (4)		
$\gamma_{14,6}$	115.85 (10)	115.98 (10)		
$\gamma_{10,2}$	118.10 (10)	117.99 (15)	118.21 (9)	
$\gamma_{15,6}$	120.08 (5)	119.98 (2)	120.16 (8)	
$\gamma_{19,9}$	123.21 (2)	123.193 (13)	123.19 (3)	
$\gamma_{10,1}$	124.58 (5)	124.55 (5)	124.59 (2)	124.68
$\gamma_{18,8}$		124.65 (5)		
$\gamma_{11,0}$	126.06 (20)	126.4 (2)		
$\gamma_{17,6}$	126.48 (10)	126.5 (3)	126.76 (9)	
[a]		129.04 (3)		
$\gamma_{19,8}$	131.89 (5)	131.926 (5)		132.00
[a]		132.6 (1)		
$\gamma_{13,5}$	134.19 (10)	134.2 (1)	134.33 (8)	
[a]		135.71 (7)		
$\gamma_{12,3}$	136.97 (5)	136.990 (4)	136.99 (3)	137.06
$\gamma_{20,8}$	137.0 (1)			
$\gamma_{21,9}$	139.8 (1)	140.3 (2)		
$\gamma_{26,12}$		142.0 (1)		
$\gamma_{19,6}$	142.94 (5)	142.962 (5)	142.97 (3)	143.05
[a]		146.8		
$\gamma_{22,9}$	147.65 (5)	147.64 (5)	147.66 (3)	
$\gamma_{12,2}$	148.15 (5)	148.15 (4)	148.17 (3)	148.18
$\gamma_{10,0}$	149.89 (10)	150.04 (2)	149.91 (4)	
$\gamma_{33,19}$	151.6 (3)	151.6 (3)		
$\gamma_{12,1}$	154.34 (5)	154.336 (10)	154.37 (2)	154.36
$\gamma_{22,8}$	156.38 (5)	156.409 (9)	156.41 (2)	156.45
$\gamma_{33,18}$	158.35 (10)	158.42 (12)	158.42 (4)	
$\gamma_{23,8}$		160.6	160.48 (56)	
$\gamma_{30,17}$	163.15 (20)	163.34 (17)		
$\gamma_{18,5}$	166.92 (5)	166.976 (7)		
$\gamma_{22,6}$	167.49 (10)	167.45 (5)	167.14 (4)	
$\gamma_{30,15}$	169.2 (3)	169.09 (3)		
[a]		171.5 (2)		
$\gamma_{23,6}$	171.76 (5)	171.75 (2)	171.59 (7)	

	2000Ga52	1987He28	1983Ra01	1981Di14
$\gamma_{24,8}$	172.91 (10)	172.926 (18)	172.91 (4)	173.01
$\gamma_{33,15}$	174.05 (11)	174.22 (11)		
$\gamma_{37,23}$	174.7 (2)			
$\gamma_{12,0}$	179.76 (5)	179.757 (7)	179.75 (3)	179.85
$\gamma_{16,3}$	182.12 (10)			
$\gamma_{35,15}$	183.0 (1)			
$\gamma_{24,6}$	183.93 (10)	183.928 (8)	183.95 (3)	184.0
$\gamma_{28,10}$	185.6 (1)			
$\gamma_{37,21}$	186.1 (1)			
$\gamma_{42,35}$	189.25 (6)			
$\gamma_{21,5}$	190.63 (20)	190.2 (2)		
$\gamma_{16,2}$	193.52 (5)			
$\gamma_{18,3}$	193.52 (5)	193.509 (5)	193.53 (2)	193.59
$\gamma_{15,1}$	194.94 (20)	194.3 (3)		
$\gamma_{19,3}$	200.80 (10)	200.807 (16)	200.81 (3)	
$\gamma_{18,2}$	204.69 (5)	204.690 (5)	204.70 (2)	204.74
$\gamma_{26,8}$	210.32 (5)	210.15 (8)	210.31 (5)	
$\gamma_{18,1}$	210.89 (3)	210.853 (3)	210.90 (5)	210.93
[a]	211.47 (10)			
$\gamma_{41,26}$	213.48 (5)			
$\gamma_{24,5}$	215.13 (10)	215.100 (10)	215.16 (8)	
$\gamma_{27,8}$	216.0 (1)			
$\gamma_{21,3}$	217.41 (10)			
$\gamma_{19,1}$	218.15 (5)	218.154 (17)	218.15 (4)	
$\gamma_{34,12}$	219.8 (1)			
$\gamma_{26,6}$	221.23 (10)	221.22 (5)	221.31 (9)	
$\gamma_{16,0}$	225.26 (10)	225.149 (19)	225.25 (6)	
$\gamma_{21,2}$	228.6 (1)			
$\gamma_{21,1}$	234.8 (1)			
$\gamma_{18,0}$	236.29 (5)	236.249 (8)	236.31 (6)	
$\gamma_{22,1}$	242.6 (2)	242.269 (14)	242.61 (7)	
$\gamma_{31,10}$	244.4 (1)			
$\gamma_{25,3}$	250.1 (1)			
$\gamma_{26,5}$	252.44 (5)	252.43 (3)	252.49 (5)	
$\gamma_{24,1}$	259.05 (10)	259.08 (4)	259.15 (5)	
$\gamma_{25,1}$	267.4 (1)			
$\gamma_{33,9}$	274.1 (1)			
$\gamma_{43,27}$	276.85 (10)			
$\gamma_{30,8}$	278.65 (5)			
$\gamma_{44,27}$	281.27 (10)			
$\gamma_{33,8}$	282.6 (1)			
$\gamma_{30,6}$	289.62 (5)	289.50 (16)		
[a]	292.27 (5)			
$\gamma_{33,6}$	293.78 (10)			
$\gamma_{26,1}$	296.21 (10)	296.2 (2)		
$\gamma_{38,12}$	298.72 (12)			
$\gamma_{28,2}$	303.75 (10)			
$\gamma_{39,12}$	307.3 (1)			
$\gamma_{28,1}$	310.1 (1)			
$\gamma_{45,29}$	313.3 (1)			
$\gamma_{29,2}$	317.8 (1)			

	2000Ga52	1987He28	1983Ra01	1981Di14
$\gamma_{42,23}$	320.8 (1)			
$\gamma_{31,5}$	324.6 (1)			
$\gamma_{27,0}$	327.9 (1)			
$\gamma_{38,10}$	328.2 (1)			
$\gamma_{34,5}$	329.9 (2)			
$\gamma_{37,8}$	334.74 (10)			
$\gamma_{43,22}$	336.7 (1)			
$\gamma_{45,26}$	341.1 (1)			
$\gamma_{34,4}$	344.3 (3)			
$\gamma_{36,5}$	347.4 (4)			
$\gamma_{29,0}$	349.4 (4)			
$\gamma_{32,3}$	351.7 (1)			
$\gamma_{38,9}$	358.0 (1)			
$\gamma_{43,19}$	361.0 (1)			
$\gamma_{38,8}$	366.5 (1)			
$\gamma_{43,18}$	368.1 (1)			
$\gamma_{31,1}$	368.9 (1)			
$\gamma_{39,8}$	375.1 (1)			
$\gamma_{38,6}$	377.4 (4)			
$\gamma_{43,16}$	379.4 (1)			
$\gamma_{39,6}$	386.4 (1)			
$\gamma_{32,0}$	395.3 (2)			
$\gamma_{34,0}$	399.9 (2)			
$\gamma_{35,0}$	403.3 (1)			
$\gamma_{38,5}$	408.5 (1)			
$\gamma_{41,9}$	414.61 (10)			
$\gamma_{39,5}$	417.4 (1)			
$\gamma_{45,19}$	419.9 (2)			
[a]	422.8 (1)			
$\gamma_{43,12}$	424.8 (1)			
$\gamma_{38,3}$	435.3 (1)			
$\gamma_{39,3}$	444.1 (1)			
$\gamma_{38,1}$	452.6 (1)			
$\gamma_{43,10}$	454.76 (10)			
[a]	455.85 (10)			
$\gamma_{44,10}$	459.1 (3)			
$\gamma_{39,1}$	461.4 (1)			
$\gamma_{41,5}$	465 (1)			
$\gamma_{38,0}$	478.0 (1)			
$\gamma_{45,12}$	483.7 (1)			
$\gamma_{39,0}$	487.3 (2)			
$\gamma_{43,8}$	492.9 (1)			
$\gamma_{41,2}$	503.6 (1)			
$\gamma_{45,10}$	513.5 (2)			
$\gamma_{42,5}$	523.5 (1)			
$\gamma_{41,0}$	535.1 (1)			
$\gamma_{45,9}$	543.0 (3)			
$\gamma_{42,3}$	549.8 (5)			
$\gamma_{45,8}$	551.7 (2)			
$\gamma_{43,3}$	561.8 (1)			
$\gamma_{44,3}$	565.7 (3)			

	2000Ga52	1987He28	1983Ra01	1981Di14
$\gamma_{43,2}$	573.0 (1)			
$\gamma_{43,1}$	579.2 (2)			
$\gamma_{42,0}$	592.5 (1)			
$\gamma_{45,5}$	594.4 (3)			
[a]	603.6 (2)			

[a] unplaced gamma rays.

γ-ray intensity normalization: Absolute γ intensities were measured by 1986He06 with absolutely calibrated Ge(Li) detector. Normalization of relative photon intensities to I(193γ) = 4.41 (6) %, as measured by 1986He06, yields Iγ normalization = 1.026 (14). Other absolute γ intensity determinations: I(193γ) = 4.5 % (1970Tr04), 5.89 (18) % (1981Di14), 3.77 (8) % (1983Ra01). The value of Pγ+ce for the 11.1 keV (8,6) transition was deduced by 1987He28 from γγ coincidence data where 11.1γ is an unobserved transition. The value of $P\gamma_{8,6}$ (11.1 keV) has been obtained by considering a M1+E2 transition from the decay scheme.

Table-6: Intensity of γ-rays in ^{225}Ra from the decay of ^{229}Th

	2000Ga52[b]	1987He28[b]	1986He06	1983Ra01	1981Di14
$\gamma_{8,6}$	12 (2)[c]				
$\gamma_{43,42}$	~0.0005				
$\gamma_{3,1}$	0.22 (10)				
[a]	0.22 (3)				
[a]	0.08 (2)	0.007 (10)			
$\gamma_{4,2}$		0.0012 (1)			
$\gamma_{1,0}$	0.011 (2)				
[a]		0.034 (17)			
$\gamma_{23,19}$	0.10 (3)			0.117 (24)	
$\gamma_{10,9}$	0.11 (2)	0.038 (13)			
$\gamma_{6,5}$	0.62 (8)	0.82 (8)		0.896 (80)	1.43 (5)
$\gamma_{2,0}$	1.86 (20)	1.16 (8)	2.45 (6)	1.692 (85)	
$\gamma_{22,18}$	0.022 (10)	0.066 (10)			
$\gamma_{25,21}$	~0.01				
[a]	~0.01				
$\gamma_{5,2}$	0.0030 (2)				
$\gamma_{8,5}$	0.077 (8)	0.080 (8)	0.199 (6)		
$\gamma_{3,0}$	0.17 (2)	0.16 (1)		0.188 (10)	0.272 (11)
$\gamma_{5,1}$	0.67 (7)	0.64 (3)	0.762 (17)	0.604 (20)	
$\gamma_{22,15}$	0.0009 (2)	0.020 (2)			
$\gamma_{26,23}$	0.0107 (17)	0.021 (2)			
$\gamma_{9,5}$	0.0108 (16)	0.017 (4)			
$\gamma_{26,22}$	0.020 (3)	0.011 (3)		0.017 (3)	
$\gamma_{4,0}$	0.015 (3)	0.0026 (4)			
$\gamma_{18,12}$	0.33 (3)	0.28 (2)	0.312 (7)	0.246 (6)	0.427 (15)
$\gamma_{12,9}$	0.012 (2)				
$\gamma_{9,4}$	0.085 (11)				
$\gamma_{25,17}$	0.157 (17)				
$\gamma_{12,8}$		0.067 (10)		0.052 (14)	
$\gamma_{15,11}$	0.12 (3)			0.060 (13)	

	2000Ga52[b]	1987He28[b]	1986He06	1983Ra01	1981Di14
$\gamma_{8,3}$		0.133 (13)			
$\gamma_{33,26}$	0.012 (3)	0.14 (2)			
$\gamma_{6,1}$		0.59 (13)		0.420 (43)	
$\gamma_{16,10}$	0.52 (5)				
[a]	0.035 (8)				
$\gamma_{9,3}$	0.054 (6)	0.044 (6)			
$\gamma_{26,19}$	0.044 (5)	0.008 (2)			
$\gamma_{8,1}$	0.7 (2)	1.3 (2)			
$\gamma_{18,10}$	3.2 (4)	2.5 (1)		2.732 (74)	2.94 (9)
$\gamma_{9,2}$	~0.14				
$\gamma_{29,21}$	~0.01				
$\gamma_{26,17}$	0.26 (2)				
$\gamma_{10,4}$		0.26 (2)	0.465 (8)	0.232 (6)	
$\gamma_{9,1}$		0.013 (3)			
$\gamma_{40,30}$	0.011 (3)				
$\gamma_{20,10}$	0.117 (15)				
$\gamma_{26,15}$	0.018 (3)	0.018 (3)			
$\gamma_{7,0}$	0.048 (7)				
$\gamma_{27,16}$	0.156 (19)			0.451 (35)	
$\gamma_{24,12}$	0.038 (7)	0.009 (3)			
$\gamma_{10,3}$	0.85 (8)	0.79 (4)	0.809 (13)	0.656 (9)	0.95 (3)
$\gamma_{15,8}$	0.029 (3)	0.043 (8)		0.023 (4)	
$\gamma_{12,5}$	0.121 (12)	0.121 (12)	0.128 (3)	0.107 (4)	
$\gamma_{42,38}$	0.0147 (22)	0.027 (4)			
$\gamma_{14,6}$	0.010 (3)	0.017 (3)			
$\gamma_{10,2}$	0.013 (4)	0.013 (4)		0.015 (5)	
$\gamma_{15,6}$	0.034 (4)	0.05 (2)		0.017 (3)	
$\gamma_{19,9}$	0.155 (16)	0.147 (7)	0.197 (3)	0.120 (4)	
$\gamma_{10,1}$	0.78 (6)	0.67 (6)	1.449 (20)	1.040 (12)	1.62 (5)
$\gamma_{18,8}$	0.66 (6)	0.72 (6)			
$\gamma_{11,0}$	0.0298 (10)	0.02 (1)			
$\gamma_{17,6}$	0.014 (4)	0.011 (5)		0.013 (4)	
[a]		0.016 (10)			
$\gamma_{19,8}$	0.38 (4)	0.327 (12)	0.327 (5)		0.433 (15)
$\gamma_{13,5}$	0.015 (4)	0.012 (3)		0.015 (3)	
$\gamma_{12,3}$	1.21 (12)	1.15 (3)	1.171 (16)	0.904 (18)	1.51 (5)
$\gamma_{20,8}$	0.04 (1)				
$\gamma_{21,9}$	0.0045 (10)				
$\gamma_{26,12}$		0.011 (3)			
$\gamma_{19,6}$	0.40 (4)	0.394 (12)	0.401 (6)	0.314 (6)	0.532 (19)
[a]		0.016 (8)			
$\gamma_{22,9}$	0.23 (2)	0.20 (2)	1.091 (15)	0.183 (14)	
$\gamma_{12,2}$	0.87 (9)	0.86 (6)		0.708 (17)	1.26 (4)
$\gamma_{10,0}$	0.053 (6)	<0.06		0.0042 (3)	
$\gamma_{33,19}$	~0.025				
$\gamma_{12,1}$	0.73 (7)	0.75 (2)	0.922 (13)[d]	0.612 (12)	1.13 (4)
$\gamma_{22,8}$	1.16 (11)	1.16 (3)	1.237 (18)	0.972 (18)	1.26 (4)

	2000Ga52[b]	1987He28[b]	1986He06	1983Ra01	1981Di14
$\gamma_{33,18}$	0.040 (4)	0.047 (5)		0.034 (3)	
$\gamma_{23,8}$				0.005 (3)	
$\gamma_{30,17}$	0.0161 (21)	0.020 (7)			
$\gamma_{18,5}$	0.222 (22)	0.200 (10)			
$\gamma_{22,6}$	0.04 (1)	0.05 (1)		0.113 (10)	
$\gamma_{16,4}$	0.0039 (14)				
[a]		0.018 (5)			
$\gamma_{23,6}$	0.039 (4)	<0.04		0.020 (5)	
$\gamma_{24,8}$	0.123 (12)	0.11 (1)		0.093 (6)	0.130 (6)
$\gamma_{33,15}$	0.0065 (18)	0.009 (5)			
$\gamma_{37,23}$	0.030 (3)				
$\gamma_{12,0}$	0.196 (20)	0.192 (15)	0.215 (4)	0.176 (5)	0.262 (10)
$\gamma_{16,3}$	0.0054 (11)				
$\gamma_{35,15}$	0.0069 (12)				
$\gamma_{24,6}$	0.147 (15)	0.138 (7)		0.118 (6)	0.091 (9)
$\gamma_{28,10}$	<0.002				
$\gamma_{37,21}$	0.013 (5)				
$\gamma_{42,35}$	0.0101 (21)				
$\gamma_{21,5}$	0.0098 (20)				
$\gamma_{16,2}$	0.0007 (3)				
$\gamma_{18,3}$	4.3	4.3	4.41 (6)	3.769 (75)	5.89 (18)
$\gamma_{15,1}$	0.0162 (23)	0.03 (2)			
$\gamma_{19,3}$	0.073 (8)	0.067 (3)		0.066 (5)	
$\gamma_{18,2}$	0.57 (4)	0.58 (3)	0.595 (9)	0.495 (12)	0.75 (4)
$\gamma_{26,8}$	0.26 (3)	0.19 (4)	3.18 (4)	0.210 (33)	
$\gamma_{18,1}$	2.77 (3)	2.7 (3)		2.467 (63)	4.00 (13)
[a]	0.044 (12)				
$\gamma_{41,26}$	0.0085 (16)				
$\gamma_{24,5}$	0.145 (14)	0.134 (10)		0.146 (16)	
$\gamma_{27,8}$	0.052 (6)				
$\gamma_{21,3}$	0.0063 (11)				
$\gamma_{19,1}$	0.134 (12)	0.18 (2)		0.149 (37)	
$\gamma_{34,12}$	0.0033 (8)				
$\gamma_{26,6}$	0.024 (2)	0.022 (6)		0.022 (3)	
$\gamma_{16,0}$	0.061 (6)	0.070 (10)		0.048 (4)	
$\gamma_{21,2}$	0.0006 (2)				
$\gamma_{21,1}$	0.0008 (2)				
$\gamma_{18,0}$	0.174 (15)	0.170 (9)		0.158 (28)	
$\gamma_{22,1}$	0.081 (8)	0.092 (14)		0.065 (7)	
$\gamma_{31,10}$	0.00127 (32)				
$\gamma_{25,3}$	0.00033 (16)				
$\gamma_{26,5}$	0.093 (9)	0.093 (12)		0.089 (5)	
$\gamma_{24,1}$	0.023 (5)	0.033 (5)		0.033 (11)	
$\gamma_{25,1}$	0.0008 (3)				
$\gamma_{33,9}$	0.0007 (2)				
$\gamma_{43,27}$	0.0041 (10)				
$\gamma_{30,8}$	0.0066 (8)				

	2000Ga52[b]	1987He28[b]	1986He06	1983Ra01	1981Di14
$\gamma_{44,27}$	0.007 (1)				
$\gamma_{33,8}$	0.0037 (7)				
$\gamma_{30,6}$	0.0146 (17)	0.006 (4)			
[a]	0.0055 (8)				
$\gamma_{33,6}$	0.0064 (8)				
$\gamma_{26,1}$	0.0161 (17)	0.012 (10)			
$\gamma_{38,12}$	0.0068 (8)				
$\gamma_{28,2}$	0.0017 (3)				
$\gamma_{39,12}$	0.006 (3)				
$\gamma_{28,1}$	0.00199 (28)				
$\gamma_{45,29}$	0.00036 (11)				
$\gamma_{29,2}$	0.00053 (14)				
$\gamma_{42,23}$	0.00016 (7)				
$\gamma_{31,5}$	0.00042 (13)				
$\gamma_{27,0}$	0.016 (3)				
$\gamma_{38,10}$	0.0020 (8)				
$\gamma_{34,5}$	0.0006 (2)				
$\gamma_{37,8}$	0.00042 (11)				
$\gamma_{43,22}$	0.0080 (1)				
$\gamma_{45,26}$	0.0008 (2)				
$\gamma_{34,4}$	<0.0001				
$\gamma_{36,5}$	0.0006 (1)				
$\gamma_{29,0}$	0.0004 (1)				
$\gamma_{32,3}$	0.0005 (1)				
$\gamma_{38,9}$	0.006 (1)				
$\gamma_{43,19}$	0.0006 (1)				
$\gamma_{38,8}$	0.0004 (1)				
$\gamma_{43,18}$	0.0019 (3)				
$\gamma_{31,1}$	0.0019 (3)				
$\gamma_{39,8}$	0.0003 (1)				
$\gamma_{38,6}$	0.0028 (3)				
$\gamma_{43,16}$	0.0013 (2)				
$\gamma_{39,6}$	0.0008 (2)				
$\gamma_{32,0}$	0.0008 (1)				
$\gamma_{34,0}$	0.00014 (6)				
$\gamma_{35,0}$	0.0018 (2)				
$\gamma_{38,5}$	0.0010 (1)				
$\gamma_{41,9}$	0.0003 (1)				
$\gamma_{39,5}$	0.0014 (2)				
$\gamma_{45,19}$	0.0006 (1)				
[a]	0.0005 (1)				
$\gamma_{43,12}$	0.0032 (3)				
$\gamma_{38,3}$	0.0031 (4)				
$\gamma_{39,3}$	0.0005 (1)				
$\gamma_{38,1}$	0.0017 (2)				
$\gamma_{43,10}$	0.0102 (11)				
[a]	0.0114 (14)				

	2000Ga52[b]	1987He28[b]	1986He06	1983Ra01	1981Di14
$\gamma_{44,10}$	~0.001				
$\gamma_{39,1}$	0.0076 (8)				
$\gamma_{41,5}$	~0.0001				
$\gamma_{38,0}$	0.0036 (4)				
$\gamma_{45,12}$	0.0018 (2)				
$\gamma_{39,0}$	0.0004 (1)				
$\gamma_{43,8}$	0.00148 (16)				
$\gamma_{41,2}$	0.00012 (5)				
$\gamma_{45,10}$	0.0007 (2)				
$\gamma_{42,5}$	0.0005 (1)				
$\gamma_{41,0}$	0.0013 (2)				
$\gamma_{45,9}$	~0.0001				
$\gamma_{42,3}$	~0.0001				
$\gamma_{45,8}$	0.00011 (4)				
$\gamma_{43,3}$	0.0019 (2)				
$\gamma_{44,3}$	0.0009 (1)				
$\gamma_{43,2}$	0.0027 (3)				
$\gamma_{43,1}$	0.0006 (1)				
$\gamma_{42,0}$	0.0003 (1)				
$\gamma_{45,5}$	~0.0001				
[a]	0.0009 (2)				

[a] unplaced gamma rays
[b] For absolute intensity per 100 decays multiply by 1.026 (14)
[c] Total transition intensity $I_{\gamma+ce}$
[d] value includes contribution from daughter activity.

5. Atomic Data

The Atomic data of Fluorescence yields were obtained from 1996Sc06. The energies of the K-Auger electrons were obtained from the reference 1998ScZM while the energies of and the yield of Ra X-rays were obtained from 1999ScZX.The X-ray and Auger electron emission probabilities have been calculated by using the computer program EMISSION (V3.10, 28-Jan-2003) described in 2000Sc47. The energies of the internal conversion electrons have been calculated using the electron binding energies from 1977La19 and 1996FIZX. Absolute conversion electron emission probabilities have been calculated by using the conversion coefficient of the γ-rays and their absolute emission probabilities.

5.1 Electron Emission

The energies of the conversion electrons have been obtained from the gamma transition energies and the electron binding energies. The emission probabilities of conversion electrons have been deduced from the evaluated P(γ) and ICC values. The number of K- and L- Auger electrons per 100 disintegrations has been deduced using the evaluated XK- and XL- emission probabilities.

5.2 X-ray Emission

The calculated X-rays' emission probabilities have been compared with the ones measured by 1983Ra01 and 1987He28 in Table 7.

Table 7: Comparison of calculated and measured intensities of Ra X-rays

	X-ray Energy (keV)	1983Ra01	1987He28	Deduced
XL	10.62 – 18.41	78.922[a]		106 (7)
$XK\alpha_2$	85.43	9.820 (17)		14.3 (6)
$XK\alpha_1$	88.47	16.681 (251)		23.4 (9)
$XK\beta_3$	99.432	2.245 (70)		
$XK\beta_1$	100.13	3.927 (86)		8.2 (4)
$XK\beta_5^{//}$	100.738		49.3 (20)	
$XK\beta_2$	102.89	1.443 (46)		
$XK\beta_4$	103.295			2.69 (12)
$XKO_{2,3}$	103.74			

[a] The intensity does not include the LX-rays below 12.3 keV.

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^{231}Th -Comments on evaluation of decay data
by Huang Xiaolong , Wang Baosong

This evaluation was completed in 2007. Literature available by May 2007 was included.

1 Decay Scheme

^{231}Th disintegrates 100 % by β^- emission to levels in ^{231}Pa. ^{231}Th ground state has $J^{\pi} = 5/2^+$(2001Br31).

The adopted Q(β^-) value of 391.6 (15) keV from Audi(2003Au03) is good in agreement with the Q(β^-) value of 372 (59) keV, calculated by the evaluator (using program RADLST) from average radiation energies and decay scheme data.

2 Nuclear Data

The Q value is from the 2003Au03 evaluation.

Level energies, spin and parities are from 2001Br31.

Measured and evaluated ^{231}Th half-life values are listed in Table 1.

Table 1 Measured half-life values of ^{231}Th and recommended value

$T_{1/2}$ (h)	References	measurement method
25.51 (23)	1949Kn09	Geiger counters,weighted average of 5 samples,10 $T_{1/2}$
25.64 (10)	1951Ja17	G-M tube, ,unweighted average of 2 samples, 6 $T_{1/2}$
25.52 (1)	1958Ca19	4pß counter, unweighted average of 18 sources,4 $T_{1/2}$
25.7 (2)	1971Ko48	Ge(Li), γ-rays
25.76 (21)	1983Ch06	Ge(Li), 84keV γ-ray, 6 $T_{1/2}$
25.63 (5)		Unweighted mean
25.522 (10)		Weighted mean,χ^2=0.88
25.52 (1)	recommended value	Weighted mean

A weighted half-life average has been calculated using the LWM program.

2.1 b$^-$ transitions

The maximum energies of the β^- transitions in the decay of ^{231}Th have been deduced from the Q value (2003Au03) and the level energies.

The adopted β^- transition probabilities and their associated uncertainties were deduced from the γ transition probability balance at each level of the decay scheme, using a normalization factor N = 0.0670 (7) (See Section 5.3). The $I_{\beta-}$(g.s. + 9.2 keV) = 0.022 (7) and $I_{\beta-}$(58.6keV) < 0.33 are experimental values from a β^- Kurie plot (1975Ho14). Measured and recommended β^- transition probabilities are given in Table 2.

Table 2. Measured and recommended β^- transition probabilities (%)

Level energy/keV	1975Ho14	Adopted value
0	0.022 (7)	0.022 (7)
58.6	< 0.33	< 0.33
77.7	< 0.33	0.43 (2)
84.2		29 (18)
101.4		41 (16)
102.3		13 (8)
174.2		1.36 (24)
183.5		12.2 (15)
218.2		0.31 (23)
247.3		2.7 (4)
318		0.00078 (5)
320.2		0.066 (2)
351.8		0.0032 (2)

The values of *lg ft* and average β^- energies have been calculated with the program LOGFT.

2.2 g-Ray Transitions

The γ-ray transition probabilities were calculated using the γ-ray emission intensities and the relevant internal conversion coefficients.

Multipolarities and mixing ratios of γ-ray transitions are from 1975Ho14 and 2001Br31.

The internal conversion coefficients (ICC) and their associated uncertainties for γ-ray transitions have been obtained using the BrIcc computer program, which uses the “Frozen Orbital” approximation (2002Ba85). The mixing ratios of the 18- and 63-keV gamma transitions have asymmetric uncertainties, δ = 0.14 (+12 -4) and 0.52 (+20 -32) respectively. The ICC of the 84.214 keV γ-ray has been taken from a measurement of 1975Ho14 because it has an anomalous conversion coefficient. Experimental and theoretical conversion coefficients are compared in Table 3.

Table 3. Comparison of theoretical and measured conversion coefficients

E_γ (keV)	Multipolarity	α(theory)	α(exp.)	
			1960As02	1975Ho14
18.07	M1+E2	α_T = 757		α_{M3} > 9
25.64	E1	α_T = 4.37, α_L = 3.26, α_M = 0.84	α_T = 4.8 10	α_{L3} = 1.6 3, α_M = 0.96 9
58.57	E2	α_T = 155.5, α_L = 113.6, α_M = 31.3		α_L = 115.9, α_M = 29.9 30
63.86	M1+E2	α_T = 34 16, α_L = 25, α_M = 7		α_{L1} = 9.1 16
68.5	E2	α_T = 73.3, α_L = 53.5, α_M = 14.8		α_L = 57 11
81.228	M1(+E2)	α_T = 8.1, α_L = 6.1, α_M = 1.5		α_{L1} = 4.7 8, α_M = 1.3 3
82.087	M1(+E2)	α_T = 7.9, α_L = 5.9, α_M = 1.4		α_{L1+L3} = 5.7 11, α_M = 1.6 4
84.214	E1	α_T = 0.19, α_L = 0.14	α_T = 2.8 4	α_T = 2.50 25, α_M = 0.57 10
99.278	M1+E2	α_T = 6, α_L = 4.4, α_M = 1.1		α_M = 1.13 14, α_N = 0.35 10
135.664	M1(+E2)	α_T = 8, α_K = 6.1, α_L = 1.4		α_K = 6.5 11, α_L = 1.1 3
145.94	M1+E2	α_T = 5.1, α_K = 3.4, α_L = 1.3		α_K = 3.6 8, α_L = 0.8 3
163.101	M1(+E2)	α_T = 4.9, α_K = 3.9, α_L = 0.78		α_K = 4.1 5, α_L = 0.6 1
217.94	E1	α_T = 0.079, α_K = 0.062, α_L = 0.01		α_K < 0.12, α_L < 0.09
311	M1+E2	α_T = 0.6, α_K = 0.5, α_L = 0.1		α_L = 0.11 3, α_M = 0.04 1
410.64	E2	α_T = 0.0548, α_K = 0.0344 5		

3. Atomic data

Atomic fluorescence yields (ω_K, ϖ_L, ϖ_M, η_{KL} and η_{LM}) are from Schönfeld (1996Sc06).

The X-ray and Auger electron emission probabilities have been deduced from γ-ray and conversion electron data by using the computer code RADLST. Measured and calculated X-ray emission probabilities are compared in Table 4.

Table 4. Comparison of the calculated and measured X-ray emission probabilities

	1973Br12	1999Ch12	Recommended (deduced)
$K_{\alpha1}$	0.69 (8)	0.64 (4)	0.59 (7)
$K_{\alpha2}$	0.40 (5)	0.376 (24)	0.37 (4)
K_{β}	0.332 (25)	0.310 (14)	0.28 (3)

The deduced KX-ray emission probabilities agree with the measured values of 1999Ch12 and 1973Br12, thus confirming the completeness of the decay scheme.

4. Electron Emissions.

The conversion electron emission probabilities have been deduced from γ-ray transition data using theoretical internal conversion coefficients.

5. Photon Emissions

5.1 g-ray energy values

Measurements of γ-ray energy values from ^{231}Th β^- decay are listed in Table 5. The recommended values are taken from the measurements of 1975Ho14 and 1979Bo30, except as noted in Table 5.

It should be noticed that some uncertain weak γ-rays: 26.55, 29.30, 32.73, 33.32, 38.90, 41.55, 42.22, 45.34, 85.80, 97.55, 106.85, 173.0, 224.1 and 237.8 keV, were observed only by 1977Ba72. These γ-rays have not been considered in the present evaluation.

Table 5. Measured and recommended γ-ray energies for ^{231}Th

1973Br12	1973Te06	1975Ho14	1977Ba72	1979Bo30	Recommended
					9.2[a]
					10.25[a]
		17.2	17.21		17.2
		18.07	18.05		18.07
(25.65)		25.64 (2)	25.64 (5)		25.64 (2)
42.80 (6)		42.86 (7)	42.22 (5)		42.86 (7)
44.1 (3)		44.08 (17)	45.34 (5)		44.08 (17)
58.47 (5)		58.57 (2)	58.54 (5)	58.5700 (24)	58.5700 (24)[b]
63.7 (2)		63.86 (3)	63.65 (5)		63.86 (3)
		68.5 (1)	68.55		68.5 (1)
72.66 (6)	72.74 (5)	72.78 (2)	72.70 (5)	72.7510 (25)	72.7510 (25)[b]
			76		77.69[c]
81.18 (5)	81.20 (6)	81.24 (2)	81.16 (5)	81.2280 (14)	81.2280 (14)[b]
82.02 (6)	82.06 (7)	82.11 (2)	82.02 (5)	82.0870 (14)	82.0870 (14)[b]

(84.17)	84.20	84.21 (2)	84.16 (5)	84.2140 (13)	84.2140 (13)^b
89.94 (5)	89.95 (4)	89.95 (2)	89.94 (5)		89.95 (2)
93.0 (1)	92.91 (10)	93.02 (4)			93.02 (4)
99.30 (5)	99.33 (5)	99.28 (2)	99.33 (5)	99.278 (3)	99.278 (3)^b
102.30 (5)	102.32 (4)	102.27 (2)	102.23 (5)	102.2700 (13)	102.2700 (13)^b
105.73 (10)	105.74 (10)	105.81 (3)			105.81 (3)
106.58 (10)	106.66 (8)	106.61 (3)	106.65 (10)		106.61 (3)
115.5 (2)		115.63 (3)	115.83 (10)		115.63 (3)
116.91 (5)		116.82 (2)	116.80 (10)		116.82 (2)
125.10 (5)		124.93 (2)	125.00 (10)	124.914 (17)	124.914 (17)^b
134.14 (8)		134.03 (2)	134.00 (5)		134.03 (2)
135.77 (6)		135.68 (2)	135.66 (5)	135.664 (11)	135.664 (11)^b
136.78 (20)		136.75 (7)			136.75 (7)
		140.54 (4)			140.54 (4)
145.15 (30)		145.06 (4)			145.06 (4)
146.00 (7)		145.94 (2)	145.90 (5)		145.94 (2)
163.16 (6)		163.12 (2)	163.15 (5)	163.101 (4)	163.101 (4)^b
164.94 (10)		165.00 (5)	164.70 (10)		165.00 (5)
169.58 (10)		169.66 (3)			169.66 (3)
174.19 (8)		174.15 (2)	174.1 (10)		174.15 (2)
					177.66
183.47 (7)		183.50 (2)	183.4 (10)	183.480 (25)	183.480 (25)^b
188.77 (20)		188.76 (2)	188.7 (10)		188.76 (2)
218.00 (7)		217.94 (3)	218.0 (5)		217.94 (3)
236.17 (7)		236.01 (3)	236.l (10)		236.01 (3)
240.4 (2)		240.27 (5)			240.27 (5)
242.6 (1)		242.50 (4)			242.50 (4)
249.8 (3)		249.60 (7)	249.8		249.60 (7)
250.5 (3)		250.45 (7)			250.45 (7)
267.80 (7)		267.62 (8)	267.8		267.62 (8)
		274.10 (10)			274.10 (10)
308.9 (3)		308.78 (7)			308.78 (7)
311.0 (1)		311.00 (5)	312.3 (25)		311.00 (5)
318.0 (4)		317.87 (8)			317.87 (8)
320.2 (3)		320.15 (8)			320.15 (8)
		351.80 (10)			351.80 (10)

a: Expected but as yet unobserved; b: from 1979Bo30 curved cryst. ; c: from 1999Ch12.

5.2 Relative g-ray intensities

Experimental γ-ray intensities from ^{231}Th β^- decay are listed in Table 6. The recommended values are from a LWM average of values reported in 1999Ch12, 1983BaZZ, 1975Ho14, 1973Te06, and 1973Br12.

1977Ba72 observed some uncertain weak γ-rays with measured relative γ-ray intensities different from those given in other measurements. These relative intensities may not be accurate and thus have not been considered here.

Table 6 Measured and evaluated relative γ-ray intensities for ^{231}Th

E_γ (keV)	I_γ								
	1953 Fr37	1971 Ko48	1973 Br12	1973 Te06	1975 Ho14	1977 Ba72	1983 BaZZ	1999 Ch12	LWM	Evaluation
(9.2)										7.44[a]
(10.25)										11.0[a]
17.2										680 (230)[b]
18.07					≤ 5.1					310 (110)[b]
25.64	170	119 (25)	202 (20)		228 (15)	331.92 (56)	230 (16)	210 (10)	217 (7)	207 (10)
42.86			0.87 (10)		0.89 (6)	0.469 (19)		0.89 (2)	0.89 (2)	0.89 (2)
44.08			0.06 (4)		0.011 (3)	0.527 (20)			0.011 (3)	0.011 (3)
58.5700		8.4 (6)	7.2 (7)		7.4 (3)	8.748 (82)	6.8 (6)	6.8 (2)	6.98 (16)	7.17 (22)
63.86	< 40		0.68 (14)		0.35 (3)			0.29 (5)	0.35 (3)	0.35 (3)
68.5					0.088 (22)			0.088 (4)	0.088 (2)	0.088 (2)
72.7510		4.4 (4)	4.0 (4)	3.8 (2)	3.86 (23)	4.046 (59)	7.8 (8)	3.8 (1)	3.88 (24)	3.88 (24)
77.69								0.063 (10)	0.063 (10)	0.063 (10)
81.2280		1.03 (3)	14.2 (14)	13.5 (9)	13.7 (8)	11.69 (10)	13.2 (5)	13.5 (5)	13.5 (3)	13.5 (3)
82.0870		21.5 (13)	7.2 (7)	6.8 (4)	6.2 (5)	4.675 (67)	6.0 (3)	6.0 (3)	6.24 (17)	6.24 (17)
84.2140	100	100	100	100	100	100	100	100	100	100
89.95		13.9 (13)	15.3 (15)	15.3 (8)	14.5 (9)	13.25 (12)		15.0 (5)	15.0 (4)	15.0 (4)
93.02			0.50 (5)	0.9 (2)	0.69 (8)			0.71 (8)	0.60 (4)	0.60 (4)
99.278		1.03 (10)	2.1 (2)	2.2 (2)	1.85 (11)	1.555 (43)		2.0 (1)	2.05 (8)	2.05 (8)
102.2700		4.6 (4)	6.7 (7)	6.8 (4)	6.3 (5)	5.424 (82)	6.5 (3)	6.6 (2)	6.58 (14)	6.58 (14)
105.81	6 (5)		0.14 (2)	0.13 (8)	0.11 (1)			0.12 (1)	0.118 (7)	0.118 (7)
106.61		3.04 (25)	0.34 (4)	0.33 (10)	0.262 (15)	0.482 (25)		0.264 (11)	0.267 (9)	0.267 (9)
115.63			0.04 (1)		0.015 (3)	0.267 (20)		0.015 (4)	0.0164 (23)	0.0164 (23)
116.82			0.39 (4)		0.318 (20)	0.367 (21)		0.34 (2)	0.336 (13)	0.336 (13)
124.914	2		0.95 (9)		0.86 (5)	1.014 (43)	0.89 (12)	0.88 (2)	0.88 (2)	0.88 (2)
134.03			0.42 (5)		0.37 (2)	0.562 (24)	0.29 (14)	0.38 (1)	0.38 (1)	0.38 (1)
135.664			1.3 (1)		1.20 (8)	1.704 (28)	1.30 (23)	1.17 (4)	1.19 (3)	1.19 (3)
136.75			0.09 (3)		0.065 (3)			0.067 (3)	0.066 (2)	0.066 (2)
140.54					0.011 (1)			0.011 (1)	0.011 (1)	0.011 (1)
145.06			0.12 (3)		0.089 (6)			0.084 (6)	0.087 (4)	0.087 (4)
145.94			0.58 (6)		0.49 (3)	0.571 (25)		0.47 (2)	0.484 (16)	0.484 (16)
163.101	1.8		2.6 (3)		2.38 (14)	2.754 (64)		2.30 (8)	2.33 (7)	2.33 (7)
165.00			0.06 (3)		0.060 (6)	0.200 (11)		0.051 (2)	0.052 (2)	0.052 (2)
169.66			0.03 (1)		0.0185 (15)			0.021 (1)	0.021 (1)	0.021 (1)
174.15			0.31 (3)		0.278 (17)	0.704 (21)		0.26 (1)	0.268 (8)	0.268 (8)
177.66[×]								0.00095 (20)	0.00095 (20)	0.00095 (20)
183.480			0.57 (6)		0.506 (20)	1.005 (26)		0.49 (2)	0.50 (1)	0.50 (1)
188.76			0.08 (1)		0.049 (3)	0.084 (8)		0.049 (1)	0.050 (4)	0.050 (4)
217.94	0.3		0.67 (7)		0.62 (5)	0.960 (29)	0.57 (2)	0.60 (1)	0.60 (1)	0.60 (1)
236.01	0.1		0.18 (2)		0.14 (1)	1.465 (28)		0.138 (5)	0.140 (4)	0.140 (4)
240.27			0.0050 (5)		0.0043 (5)			0.0040 (5)	0.0043 (6)	0.0043 (6)

E_γ (keV)	I_γ								
	1953 Fr37	1971 Ko48	1973 Br12	1973 Te06	1975 Ho14	1977 Ba72	1983 BaZZ	1999 Ch12	LWM	Evaluation
242.50			0.0130 (6)		0.013 (1)			0.011 (1)	0.0123 (6)	0.0123 (6)
249.60			0.010 (2)		0.012 (1)			0.012 (1)	0.012 (1)	0.012 (1)
250.45			0.011 (2)		0.010 (1)			0.010 (1)	0.010 (1)	0.010 (1)
267.62			0.0230 (6)		0.018 (2)			0.019 (1)	0.021 (2)	0.021 (2)
274.10					0.00046 (15)			0.0006 (2)	0.0005 (2)	0.0005 (2)
308.78			0.008 (1)		0.0060 (6)			0.0053 (2)	0.0054 (2)	0.0054 (2)
311.00			0.054 (5)		0.045 (3)			0.046 (2)	0.047 (2)	0.047 (2)
317.87			0.0020 (2)		0.00123 (15)			0.0013 (2)	0.0015 (2)	0.0015 (2)
320.15			0.0035 (3)		0.0017 (2)			0.0020 (2)	0.0022 (4)	0.0022 (4)
351.80					0.0011 (2)			0.0010 (2)	0.0010 (2)	0.0010 (2)

a: I(γ+ce), from γ-ray transition intensity balance;

b: I(γ+ce), from ce measurements(1975Ho14);

c: adjusted value from intensity balance;

×: not placed in level scheme.

5.3 Absolute values g-ray emission probabilities

Measurements of the absolute emission probability of the 84.21keV γ-ray from ^{231}Th β^- decay and the LWM results are listed in Table 7. The recommended absolute γ-ray emission probability of the 84.21keV γ-ray is from the LWM calculation, and has been used here to produce a recommended normalization factor N = 0.0670 (7).

Table 7 Measured and recommended absolute γ-ray emission probability of 84.21keV for ^{231}Th

P_g (84.21 keV) (%)	References	measurement method
7.2 (1)	1960As02	
7.9 (5)	1971Ko48	Ge(Li)
7.0 (3)	1973Br12	Ge(Li)
6.5 (4)	1975Ho14	Ge(Li)
6.6 (3)	1982Va04	Si(Li), weighted average of 3 sources
6.52 (13)	1983BaZZ	
7.25 (41)	1983Ch06	Ge(Li), Replaced by 1999Ch12
6.84 (10)	1984He12	Ge detector, weighted average of 5 measurements
6.60 (25)	1999Ch12	LEPS,secular equilibrium with ^{235}U
6.71 (10)	1986LoZT	CRP evaluation in 1986
6.89 (31)		LWM of all measurements
6.71 (7)		LWM(except 1960As03,1971Ko48),χ^2=1.07
6.70 (7)		LWM (except 1960As03, 1971Ko48. 1973Br12),χ^2=1.1
6.70 (7)		**recommended value**

The recommended absolute γ-ray emission probabilities are the relative values evaluated in Table 6 multiplied by 0.0670 (7).

6. References

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^{232}Th – Comments on evaluation of decay data by A. Arinc

This evaluation was completed in September 2008 and has a literature cut off date of April 2008. The weighted mean was applied to determine recommended values throughout the evaluation where the data were in statistical agreement. Where the data were not in statistical agreement, the Limitation of Relative Statistical Weights (LRSW) was used.

1. Decay Scheme

The nuclide ^{232}Th disintegrates by alpha emission to two excited levels and to the ground state of ^{228}Ra. The spin, parity, half-life of first excited state, multipolarities and level energies of ^{228}Ra are based on the mass-chain evaluation of A. Artna-Cohen (1997Ar08).

Spontaneous fission and cluster decay of $^{24\text{-}26}$Ne have been observed by R. Bonetti (1995Bo18) with a partial half-life of 1.22 10^{21} years for the spontaneous fission and a partial half-life greater than 5.04 10^{21} years for the cluster decay. However, these decay modes were not taken into account in this evaluation.

2. Nuclear data

The Q(a) value of 4081.6 (14) keV is taken from the evaluation of Audi *et al.* (2003Au03). The effective Q-value calculated from decay scheme data is 4070 (70) keV.

The experimental half-life values are given in table 1.

Table 1. Experimental half-life values of ^{232}Th

Reference	**Half-life (10^{10} years)**	**Comments**
1963Le21	1.401 (7)	
1960Fa07	1.410 (14)	
1956Ma43	1.45 (5)	Rejected by Chauvenet's criterion
1956Pi42	1.39 (3)	
1956Se17	1.42 (7)	
1938Ko01	1.39 (3)	
Recommended value	**1.402 (6)**	

The value of R. Macklin (1956Ma43) was excluded from the data analysis by Chauvenet's criterion. The data set is consistent and the recommended value, which is the weighted average of 5 remaining values, is 1.402 (6) 10^{10} years. The reduced chi-square value is 0.18 which is smaller than the critical value 3.32.

2.1 Alpha Transitions and emissions

The alpha transition and emission energies have been determined from the Q-value and level energies. Published alpha emission energies are given in table 2.

Table 2. Published alpha emission energies (keV)

Transition	$a_{0,0}$	$a_{0,1}$	$a_{0,2}$
1954Philbert[1]	4014 (20)	3939 (20)	
1957Ha08[2]	4012.3 (50)		
1961Ko11[2]	4013.6 (50)[4]	3950 (8)	3825 (10)
1962Ko12[2]	4013.4 (50)		
1989Sa01	4012.3 (14)	3947.2 (20)	
Mean experimental emission values	4012.4 (14)	3947.3 (20)	3825 (10)
Calculated values[3]	4011.2 (14)	3948.5 (14)	3810.0 (14)
Recommended Values	**4011.2 (14)**	**3948.5 (14)**	**3810.0 (14)**

[1] The values were adjusted by the evaluator for changes in the calibration energy.
[2] The values were adjusted as suggested by A. Rytz (1991Ry01)
[3] Calculated from alpha transition energies taking into account the recoil of the alpha particle
[4] For the $a_{0,0}$ transition, the value from 1961Ko11 was not taken into account as the same author published an updated value in 1962Ko12

Alpha hindrance factors were calculated using the ALPHAD computer program. A summary of the adopted level, alpha transition and emission values is presented in table 3.

Table 3. Adopted level, alpha particle transition and emission energies

Transition	**Level Energy (keV)**	**Alpha Transition Energy (keV)**	**Alpha Emission Energy (keV)**	**HF**
$a_{0,0}$	0.0	4081.6 (14)	4011.2 (14)	1.000
$a_{0,1}$	63.823 (20)	4017.8 (14)	3948.5 (14)	1.02 (7)
$a_{0,2}$	204.68 (3)	3876.9 (14)	3810.0 (14)	16 (5)

2.2 Gamma Transitions and Internal Conversion Coefficients

The recommended $\gamma_{1,0}$ transition energy of 63.811 (10) keV was calculated by taking the weighted mean of 63.81 (7) keV (1973Ta25), 63.81 (1) keV (1983Mi30) and 63.84 (6) keV (1989Sa01). The recommended $\gamma_{2,1}$ transition energy of 140.880 (10) keV was calculated by taking the weighted mean of 140.88 (1) keV (1983Mi30) and 140.83 (15) keV (1989Sa01).

Internal conversion coefficients were calculated using the BrIcc code (T.Kibédi, 2005KiZW), which uses interpolated values of Band *et al.* (2002Ba85).

The γ-ray transition energies, multipolarities and electron internal conversion coefficients are presented in table 4.

Table 4. Energies, multipolarities and electron internal conversion coefficients for gamma transitions

Transition	**Transition Energy (keV)**	**Multipolarity**	a_T	a_K	a_L	a_M
$g_{1,0}$	63.811 (10)	E2	80.4 (12)	-	59.1 (9)	16.05 (23)
$g_{2,1}$	140.880 (10)	E2	2.26 (4)	0.283 (4)	1.450 (21)	0.394 (6)

3. Alpha particle emissions

The alpha particle emission intensities were deduced from the decay scheme and can be viewed in table 5.

Table 5. Alpha particle emission energies and probabilities

Transition	Emission Energy (keV)	Emission intensity (%)
$a_{0,0}$	4012.4 (14)	78.9 (13)
$a_{0,1}$	3947.3 (20)	21.0 (13)
$a_{0,2}$	3810.0 (14)	0.068 (20)

The values calculated using the balancing of the decay scheme are in good agreement with the experimental values (table 6) but the former values have been used as they are more precise.

Table 6: Reported values on alpha particle emission intensities

Reference	$a_{0,0}$	$a_{0,1}$	$a_{0,2}$	Comments
1952Du12		24 (3)		See note 1)
1956Al30		22 (2)		See note 1)
1959Ko58		23 (3)	0.20 (8)	See note 2)
1961Ko11	77	23	0.2	No uncertainties. See note 2)
1983Mi30	77 (3)	23 (2)	0.066 (7)	See 3)
1989Sa01	100	33 (5)		

Notes:

1) The values found in the publications of D. Dunlavey (1952Du12) and G. Albouy (1956Al30) represent the percentage of conversion electron accompanying alpha decays ($a_{0,1}$ and $a_{0,2}$).
2) The values published by G. Kocharov in 1959Ko58 and 1961Ko11 appear to be from the same experiment.
3) The values from T. Mitsugashira (1983Mi30) are deduced by the author from the gamma emission probabilities measured by the author.

4. Gamma-ray emissions

The published data for the gamma-ray emissions can be viewed in table 7.

Table 7: Experimental data on gamma-ray emission probabilities

Reference	Absolute values (%) 63 keV	140 keV	Ratio of 140 keV/63 keV
1982Sa36	0.29[1] (2)		
1983Mi30	0.24 (3)	0.018 (2)	0.075 (13)
1983Ro23	0.247[2] (15)		0.102 (9)
1989Sa01			0.055 (10)

[1]Value recalculated using the new DDEP recommended value for $\gamma_{1,0}$(84 keV) of ^{228}Th decay.
[2]Value recalculated using the new DDEP recommended value for $\gamma_{2,0}$(238 keV) of ^{212}Pb decay.

The recommended 63 keV emission intensity of 0.259 (15) % was calculated by taking the weighted mean of 0.29 (2) % (1982Sa36), 0.24 (3) % (1983Mi30) and 0.247 (15) % (1983Ro23).
The recommended ratio 140 keV/63 keV of 0.080 (22) was calculated by taking the weighted mean of 0.075 (13) (1983Mi30), 0.102 (9) (1983Ro23) and 0.055 (10) (1989Sa01). The spread in the results is

quite significant and the reduced chi-square is larger than the critical chi-square. This may be due to the low probability of the gamma combined with the low specific activity of ^{232}Th. The recommended emission probability for the 140 keV line, calculated from the above ratio and the 63 keV emission probability, is 0.021 (6) %.

Transition	**Recommended Values**	**Gamma-ray emission intensity (%)**	a_T
$g_{1,0}$	63.811 (10)	0.259 (15)	80.4 (12)
$g_{2,1}$	140.880 (10)	0.021 (6)	2.26 (4)

5. Atomic data

The values of ω_K, ω_L and n_{KL} relative probabilities of the X-ray and Auger emissions are from Schönfeld and Janßen (1996Sc06).

The energies and relative emission probabilities of the X-ray and Auger electrons have been calculated by using the computer code EMISSION.

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^{233}Th– Comments on evaluation of decay data
by V.P.Chechev and N.K.Kuzmenko

This evaluation was done originally in 2004 and then updated and revised in January 2009 with a literature cut-off by the same date.

1. DECAY SCHEME

The decay scheme is based on 2005Si15. Some gamma-ray transitions were not observed directly in ^{233}Th decay but have been adopted from ^{237}Np α-decay. There are no precise measurements of beta transitions from the decay of ^{233}Th available. Data on gamma-ray emission probabilities have been taken mainly from measurements in 2008De31.

Several unplaced gamma rays were observed. These gamma rays carry ≤ 3 % of the total intensity of all the gamma rays placed in the decay scheme.

2. NUCLEAR DATA

Q^{-} value is from 2003Au03.

The recommended half-life of ^{233}Th is based on the experimental results given in Table 1.

Table 1. Experimental values of ^{233}Th half-life (in minutes)

Reference	Author(s)	Original value	Re-estimated	Measurement method
1952Ru10	Rutledge et al.	23,6 (6)		β-counting
1955Je26	Jenkins	22,12 (5) [a]	22,12 (7)	β-counting, good purification of the thorium sample
1957Dr46	Dropesky and Langer	22,4 (1)		β-counting
1969HoZY	Hoekstra	22,3 (1)		Gamma-ray counting
1989Ab05	Abzouzi et al.	22,30 (2) [b]	22,30 (10)	Gamma-ray counting
1998Us01	Usman et al.	21,83 (4) [c]	21,83 (10)	Gamma-ray counting
2008De31	DeVries and Griffin	21,99 (5) [d]	21,99 (9)	Liquid scintillation counting, multiple purifications of the thorium sample

[a] Original value was deduced as the mean value from two experiments with the same result of 22,12 (7) min. As these experiments were correlated the evaluators used the value of 22,12 (7) min.

[b] Uncertainty may include only statistical errors. The evaluators have taken into account the contribution of possible systematic errors associated with the gamma-ray counting method (see below).

[c] Possible systematic errors associated to the gamma-ray counting method may have been caused by the use of a different shape of pulser and gamma-ray peaks, and by contamination of the gamma-ray spectrum with ^{233}Pa and other radionuclides. Based on data scattering in three experiments for the strongest 459 keV and 669 keV gamma ray peaks (with a half-life ranging from 21,748 to 21,945 min) the evaluators have estimated the overall uncertainty of 0.10 min, which includes possible systematic errors.

[d] Authors reported only statistical errors ≤ (0,2 – 0,3) %. Assuming possible systematic errors of the same order of magnitude (~ 0,3 %), the evaluators have estimated an overall uncertainty of 0,09 min.

The value from 1952Ru10 has been omitted because it is an outlier. The unweighted mean of the 6 remaining values from Table 1 is 22,16 (9), the weighted mean is 22,15, the internal uncertainty is 0,037, the external uncertainty is 0,082. The LWEIGHT computer program recommended the weighted mean and its external uncertainty. Therefore, the recommended value of ^{233}Th half-life is 22,15 (8) minutes.

2.1. Beta-transitions

The energies of β^- transitions have been obtained from the Q^- value and the ^{233}Pa level energies given in Table 2, taken mainly from 2005Si15. The adopted level energies include also available data from ^{237}Np alpha-decay. The energies of the levels ”5”, ”10” and “12” have been obtained directly from the energies of the $\gamma_{5,0}$ (94,65 keV), $\gamma_{10,0}$ (237,86 keV) and $\gamma_{12,0}$ (447,762 keV) gamma rays, respectively.

The comparison of measured and recommended energies of β^- transitions is given in Table 3.

The emission probabilities of β^- transitions have been deduced from the P(γ+ce) balance at each level of ^{233}Pa. The accurate combine β^- intensity of the $\beta_{0,0}$ and $\beta_{0,1}$ transitions is 84,0 (5) %, using 100 % for the total intensity of the beta decay from ^{233}Th.

Table 2. ^{233}Pa levels populated in ^{233}Th decay

Level	Energy (keV)	Spin and Parity	Half-life	Probabilities of β^--transitions (%)
0	0	$3/2^-$	26,98 (2) d	34 (6)
1	6,65 (5)	$1/2^-$		50 (6)
2	57,10 (2)	$7/2^-$		-
3	70,49 (10)	$5/2^-$		-
4	86,477 (10)	$5/2^+$		-
5	94,65 (5)	$3/2^+$		10,4 (4)
6	103,8 (1)	$7/2^+$		-
7	169,159 (10)	$1/2^+$		0,692 (12)
8	201,62 (5)	$3/2^+$		0,074 (8)
9	212,34 (5)	$5/2^+$		-
10	237,86 (6)	$5/2^+$		-
11	257,30 (15)	$5/2^-$		0,60 (3)
12	447,762 (20)	$3/2^-$		0,821 (14)
13	454,40 (7)	$3/2^+$		0,217 (13)
14	553,88 (6)	$1/2^+$, $3/2^+$		1,23 (3)
15	585,50 (5)	$3/2^+$		0,15 (3)
16	669,9 (5)	$(3/2^-)$		0,0174 (22)
17	764,55 (6)	$1/2^+$, $3/2^+$		1,19 (3)
18	811,6 (2)	$(3/2^+)$		0,385 (4)
19	984,8 (5)	$(3/2^+)$		0,205 (2)
20	1018,7 (5)	(3/2)		0,0434 (9)

Table 3. Measured and recommended energies of β^- -transitions

	1957Dr46	1957Fr55	Recommended
$\beta_{0,0}$	1230 (10)	1245 (3)	1243,1 (14)
$\beta_{0,5}$		1158	1148,4 (14)
$\beta_{0,7}$		1073	1073,9 (14)
$\beta_{0,11}$		880	985,8 (14)
$\beta_{0,12}$		790	795,3 (14)
$\beta_{0,13}$			788,7 (14)
$\beta_{0,14}$			689,2 (14)
$\beta_{0,15}$			657,6 (14)
$\beta_{0,16}$		580	573,2 (14)
$\beta_{0,17}$			478,5 (14)
$\beta_{0,18}$			431,5 (14)

2.2. Gamma Transitions and Internal Conversion Coefficients

The recommended energies of gamma-ray transitions are virtually the same as the gamma-ray energies because nuclear recoil is negligible for 233Pa..

The gamma-ray transition probabilities [P(γ+ce)] have been obtained using the gamma-ray emission probabilities and total conversion coefficients (ICC). The ICC have been interpolated using the BrIcc package with the so called "*Frozen Orbital*" approximation (2008Ki07). The uncertainties in the ICC for pure multipolarities have been taken as 2 %.

P(γ+ce)(8,22 keV) has been obtained from the intensity imbalance at the level "4" (86,477 keV) assuming negligible beta transition probability to this level [P($\beta_{0,4}$) = 0]. The obtained value of P(γ+ce)(8,22 keV)=12,3 (4) % differs from ≈ 19 % estimated in 2005Si15 using the intensity of N conversion electrons measured in 1976JeZU. It should be noted that the E2/M1mixing ratio for the 8,22 keV gamma ray transition has not been measured. However, the experimental P_{ce} (N2) ≈ P_{ce} (N3) indicates a large contribution of E2 multipolarity for this transition.

The ICC for the anomalous E1 gamma-ray transition $\gamma_{4,0}$ (86,477 keV) has been taken from 1988Wo01. The value of the total internal conversion coefficient of 1,43 (8) measured in 1988Wo01 agrees well with the theoretical assessment of 1,49 (18) (which includes the effect of nuclear penetration) obtained in 2008Go10 for this anomalous E1 gamma-ray transition.

The conversion electron data of 1988Wo01 indicate that the gamma-transition $\gamma_{4,2}$ (29,37 keV) also may be an anomalous E1. However, the evaluators have been adopted (following 2005Si15) the theoretical ICC for this transition since the detector efficiency was not completely reliable for energies lower than 50 keV, as pointed out in 1988Wo01.

Multipolarities and E2/M1 mixing ratios have been adopted from conversion electron measurements of 1972SeZI, 1976JeZU, and from data on ^{237}Np alpha-decay (see 2005Si15).

3. ATOMIC DATA

The atomic data (fluorescence yields, X-ray energies and relative probabilities, and Auger electrons energies and relative probabilities) have been deduced by using the SAISINUC software (2002Be).

4. ELECTRON EMISSIONS

The energies of the conversion electrons have been obtained from the gamma-ray transition energies and the electron binding energies.

The absolute emission probabilities of conversion electrons have been obtained using the recommended P_γ and ICC.

The absolute emission probabilities of K- and L- Auger electrons have been deduced from the emission probabilities of KX- and LX- rays measured in 2008De31. Their values, given in Table 4, are compared to the results of calculations using the evaluated $P_{\gamma,}$ ICC with the EMISSION computer program.

Table 4. Absolute emission probabilities of K- and L- Auger electrons from the decay of ^{233}Th

	Calculated using recommended $P_{\gamma\,,}$ ICC (EMISSION code)	Deduced from absolute intensities of LX-, KX- rays measured in 2008De31	Recommended
e_{AL} (Pa)	6,71 (26)	8,6 (10)	8,6 (10)
e_{AK} (Pa)	0,037 (6)	0,041 (5)	0,041 (5)
KLL	0,022 (4)	0,024 (3)	0,024 (3)
KLX	0,013 (2)	0,014 (2)	0,014 (2)
KXY	0,0020 (3)	0,0021 (3)	0,0021 (3)

β^- average energies have been obtained using the LOGFT computer program.

5. PHOTON EMISSIONS

5.1. X-Ray Emissions

The recommended absolute emission probabilities of Pa KX- and LX- rays are from the measurements of 2008De31, which include a contribution from possible systematic errors in the uncertainties of photon intensities (see section 5.2).

In Tables 5 and 6, a comparison of measured and calculated emission probabilities for specific groups of Pa KX- and LX- rays is given. The calculated values have been obtained with the EMISSION computer program using the adopted atomic data for Pa and the recommended total absolute emission probabilities of K- and L- conversion electrons from ^{233}Th→^{233}Pa decay.

Table 5. Experimental and calculated values of absolute Pa KX- ray emission probabilities in the decay of ^{233}Th

	Energy (keV)	1969HoZY (measured)	2008De31 (measured)	Calculated	Recommended
$K\alpha_2$	92,288	0,54 (7)	0,39 (1)	0,357 (20)	0,39 (1)
$K\alpha_1$	95,869	1,01 (7)	0,615 (10)	0,57 (4)	0,615 (13)
$K\beta'_1$	107,60-109,07	0,28	0,235 (5)	0,206 (12)	0,235 (6)
$K\beta'_2$	111,40-112,38	0,09	0,079 (3)	0,070 (5)	0,079 (3)

Table 6. Experimental and calculated values of absolute Pa LX- ray emission probabilities in the decay of ^{233}Th

	Energy (keV)	2008De31 (measured)	Calculated	Recommended
Ll	11,366	0,14 (2)	0,151 (5)	0,14 (2)
Lα	13,122 – 13,291	2,84 (32)	2,48 (7)	2,84 (32)
Lη	14,946	4,3 (5)	0,0626 (20)	4,3 (5)
Lβ	15,3 – 16,7		3,07 (8)	
Lγ	19,9 – 21,6	0,95 (11)	0,706 (17)	0,95 (11)

5. 2. Gamma-Ray Emissions

The energies of the gamma-rays $\gamma_{7,5}$ (74 keV), $\gamma_{9,6}$ (109 keV), $\gamma_{8,4}$ (115 keV), $\gamma_{11,6}$ (153 keV), $\gamma_{17,15}$ (179 keV), $\gamma_{10,2}$ (181 keV), $\gamma_{11,3}$ (187 keV), $\gamma_{8,1}$ (195 keV), $\gamma_{17,14}$ (211 keV), $\gamma_{13,10}$ (216 keV), $\gamma_{12,8}$ (246 keV), $\gamma_{11,1}$ (251 keV), $\gamma_{13,8}$ (253 keV), $\gamma_{13,7}$ (285 keV), $\gamma_{15,10}$ (348 keV), $\gamma_{12,4}$ (361 keV), $\gamma_{13,4}$ (368 keV), $\gamma_{12,3}$ (377 keV), $\gamma_{14,4}$ (467 keV), $\gamma_{17,10}$ (527 keV), $\gamma_{17,9}$ (552 keV), $\gamma_{7,8}$ (563 keV), $\gamma_{17,7}$ (595 keV), $\gamma_{18,9}$ (599 keV), $\gamma_{18,7}$ (642 keV), $\gamma_{16,0}$ (670 keV), $\gamma_{17,4}$ (678 keV), $\gamma_{18,6}$ (708 keV), $\gamma_{18,5}$ (717 keV), $\gamma_{18,4}$ (725 keV), $\gamma_{18,3}$ (741 keV), $\gamma_{17,1}$ (758 keV), $\gamma_{19,8}$ (783 keV), $\gamma_{18,1}$ (805 keV), $\gamma_{20,7}$ (849 keV), $\gamma_{19,4}$ (898 keV), $\gamma_{20,3}$ (948 keV), $\gamma_{19,1}$ (978 keV) have been deduced from the adopted ^{233}Pa level energies (Table 2).

The energies of the gamma-rays $\gamma_{7,1}$ (162 keV), $\gamma_{7,0}$ (169 keV), $\gamma_{12,11}$ (190 keV), $\gamma_{13,5}$ (360 keV), $\gamma_{12,1}$ (441 keV), $\gamma_{12,0}$ (448 keV), $\gamma_{14,5}$ (459 keV), $\gamma_{15,5}$ (491 keV), $\gamma_{17,5}$ (670 keV) are from precise measurements performed with a crystal spectrometer (1979Bo30).

The following gamma-rays, $\gamma_{6,2}$ (46 keV), $\gamma_{3,0}$ (70 keV), $\gamma_{8,4}$ (115 keV), $\gamma_{10,6}$ (134 keV), $\gamma_{9,3}$ (141 keV), $\gamma_{9,2}$ (155 keV), $\gamma_{10,2}$ (181 keV), $\gamma_{9,0}$ (212 keV), $\gamma_{10,0}$ (238 keV) have not been observed in ^{233}Th decay. These gamma-rays have been adopted from the decay scheme on the basis of the available data on ^{237}Np α-decay.

In Table 7 various experimental energies for a number of prominent gamma-rays in the decay of ^{233}Th are compared with evaluated results.

The recommended energies of the remaining gamma-rays are from 1969HoZY, 1972SeZI, 1972Vo08 following the evaluation by 2005Si15. See also 1968Br25, 1968Da24, 1969Va06, 1970Se06 and 1972De67.

Table 7. Experimental and evaluated gamma-ray energies in the decay of ^{233}Th

	1976Sk01	1979Bo30	1979Go12	1988Wo01 (Ge detector)	1988Wo01 (LEPS detector)	Evaluated (recommended)
$\gamma_{4,2}$	29,373 (10)		29,374 (20)	29,5 (17)	29,18 (21)	29,373 (10)
$\gamma_{6,2}$	46,534 (40)		46,53 (6)	46,7 (11)	46,28 (18)	46,53 (4)
$\gamma_{2,0}$	57,15 (4)	57,11 (5)	57,104 (20)	57,15 (80)	56,88 (17)	57,10 (2)
$\gamma_{3,0}$						70,49 (10) [a, b]
$\gamma_{4,0}$	86,503 (20)	86,48 (6)	86,477 (10)	86,50 (48)	86,26 (14)	86,477 (10)
$\gamma_{5,1}$	88,04 (16)		87,988 (30)			87,99 (3)
$\gamma_{5,0}$	94,66 (5)		94,638 (50)			94,65 (5)
$\gamma_{8,4}$	115,40 (35)		115,40 (35)			115,14 (5)[a]
$\gamma_{9,5}$	117,681 (30)		117,702 (20)	117,72 (50)	117,41 (15)	117,692 (20)
$\gamma_{8,3}$	131,043 (30)		131,101 (25)	131,09 (52)	130,62 (15)	131,101 (25)
$\gamma_{10,6}$	134,23 (4)		134,285 (20)	134,27 (53)		134,285 (20)
$\gamma_{9,3}$			141,74 (10)			141,74 (10)
$\gamma_{10,5}$	143,208 (25)		143,249 (20)	143,27 (56)	142,96 (16)	143,230 (20)
$\gamma_{10,4}$	151,375 (35)		151,414 (20)	151,42 (60)	151,06 (17)	151,409 (20)
$\gamma_{9,2}$	155,22 (4)		155,239 (20)	155,28 (63)		155,239 (20)
$\gamma_{7,1}$	162,50 (6)	162,504 (12)	162,41 (8)	162,45 (68)		162,504 (12)
$\gamma_{7,0}$	169,17 (5)	169,162 (10)	169,156 (20)	169,18 (73)		169,159 (10)
$\gamma_{11,4}$	170,63 (8)		170,59 (6)			170,60 (6)
$\gamma_{10,2}$	180,80 (8)		180,81 (10)	180,87 (85)		180,76 (3) [a]
$\gamma_{11,3}$	186,8 (5)		186,86 (35)			186,80 (18) [a]
$\gamma_{12,11}$		190,552 (14)				190,552 (14)
$\gamma_{8,0}$	201,72 (5)		201,62 (5)	201,8 (11)		201,62 (5)
$\gamma_{9,0}$	212,415 (25)	212,4 (12)	212,290 (50)			212,34 (5) [a]
$\gamma_{10,0}$	238,04 (4)		237,862 (60)	238,0 (14)		237,86 (6)
$\gamma_{13,5}$		359,745 (40)				359,74 (4)
$\gamma_{12,1}$		440,943 (40)				440,94 (4)

[a] deduced from level energies
[b] observed by 1969HoXY (71,0 keV) and 1974HeYW (70,75 (10) keV)

The gamma-ray transitions with energies (keV) of 80, 105,147, 211, 242, 310, 383, 409, 418, 454, 465, 474, 497, 505, 513, 517, 532, 554, 555, 579, 583, 681, 690, 698, 704, 728, 745, 752, 767, 774, 784, 832, 847, 871, 874, 919, 935, 942, 943, 955, 961, 963, 968, 994, 1001, 1007, 1011, 1026, 1092, 1132, 1139, 1144 and 1201 have not been placed in the ^{233}Th decay scheme.

The gamma-ray transitions $\gamma_{7,1}$ (162 keV) and $\gamma_{11,5}$ (162 keV), $\gamma_{16,0}$ (670 keV) and $\gamma_{17,5}$ (670 keV) are doublets, and have been placed twice in the decay scheme; their intensities have been suitably divided (2005Si15).

The absolute gamma-ray emission probabilities have been adopted from 2008De31. In 2008De31 absolute photon intensities were measured using multiple purifications of stock solutions of ^{233}Th produced by the ^{232}Th(n,γ) reaction. The measurement consisted of liquid scintillation counting (LSC) and γ-ray spectroscopy with HPGe detectors. As the authors of 2008De31 quoted only statistical uncertainties for their intensity values, the evaluators have considered an additional contribution from possible systematic errors when estimating the overall uncertainties in the absolute photon intensities. This contribution was estimated on the basis of data scattering for LSC measurements and detection efficiency uncertainties for γ-ray spectroscopy discussed in 2008De31 and 2008De10. The estimations of detection uncertainties (~ 11 % for ≤ 20 keV, ~ 1 % for 29 keV, and ~ 0,7 % for energies ≥ 50 keV) have been adopted from 2008De31, 2008De10 and combined with the statistical uncertainties. In particular, the systematic uncertainty due to the absolute LSC measurements of the effective number of disintegrations in 2008De31 has been estimated as ~ 1 % on the basis of measured data scattering, and it has been used here.

P(γ)(6,65 keV) has been deduced from the absolute intensity of N1-conversion electrons of 9 (1) per 100 decays measured in 1976JeZU using the theoretical conversion coefficient α(N1) = 545 (11) for an M1 multipolarity.

The recommended absolute gamma-ray emission probability for $\gamma_{2,0}$(57,1 keV) (0,0498 (15) %) agrees well with 0,057 (11) % but is much more precise. The latter was deduced from the absolute intensity of L-conversion electrons measured in 1976JeZU and the theoretical ICC (see 2005Si15).

In Table 8 the relative gamma-ray emission probabilities measured in 2008De31 (scaling to 100 for the 57,1-keV γ-ray) are compared to the early experimental results reported without uncertainties. Such a comparison shows that the intensities in 2008De31 for the major transitions are ~ (10-30) % lower than results in 1969HoZY, 1972SeZI. This may be due to the use of not sufficiently purified ^{233}Th samples in the early measurements.

Table 8. Measured relative gamma-ray emission probabilities in the decay of ^{233}Th

	Energy (keV)	2008De31	1969HoZY, 1972SeZI (see 2005Si15)
$\gamma_{1,0}$	6,65 (5)	--	29,6
$\gamma_{4,2}$	29,373 (10)	$4,34 (5)\cdot10^3$	$4,6\cdot10^3$
$\gamma_{2,0}$	57,10 (2)	100	100
$\gamma_{3,1}$	63,92 (6)	--	1,5
$\gamma_{3,0}$	70,49 (10)	--	1,5
$\gamma_{7,5}$	74,51 (5)	80,4 (9)	96
$\gamma_{4,0}$	86,477 (10)	$3,68 (4)\cdot10^3$	$5,0\cdot10^3$
$\gamma_{5,1}$	87,99 (3)	340 (4)	333
$\gamma_{5,0}$	94,66 (5)	$1,55 (2)\cdot10^3$	$1,5\cdot10^3$
$\gamma_{9,6}$	108,5 (1)	--	1,1
$\gamma_{8,4}$	115,14 (5)	0,6 (13)	4,1
$\gamma_{9,5}$	117,692 (20)	5,8 (6)	2,8
$\gamma_{8,3}$	131,101 (25)	101 (2)	122

	Energy (keV)	2008De31	1969HoZY, 1972SeZI (see 2005Si15)
$\gamma_{10,6}$	134,285 (20)	3,6 (9)	4,1
$\gamma_{10,5}$	143,230 (20)	22,8 (15)	26
$\gamma_{10,4}$	151,409 (20)	13,4 (8)	17
$\gamma_{11,6}$	153,49 (18)	81,4 (9)	122
$\gamma_{9,2}$	155,239 (20)	4,6 (1)	1,7
$\gamma_{7,1}$	162,504 (12)	335 (4)	278
$\gamma_{11,5}$	162,504	--	315
$\gamma_{7,0}$	169,162 (10)	502 (6)	630
$\gamma_{11,4}$	170,60 (6)	101 (2)	241
$\gamma_{17,15}$	179,05 (8)	55,6 (7)	70
$\gamma_{10,2}$	180,76 (3)	2,2 (6)	1,3
$\gamma_{11,3}$	186,80 (18)	41,8 (13)	63
$\gamma_{12,11}$	190,552 (14)	172 (2)	241
$\gamma_{8,1}$	194,97 (7)	214 (3)	296
$\gamma_{8,0}$	201,62 (5)	44,2 (18)	57
$\gamma_{17,14}$	210,67 (8)	35,6 (18)	65
$\gamma_{-1,4}$	211,3 (2)	40 (2)	35
$\gamma_{9,0}$	212,34 (5)	13 (1)	2,8
$\gamma_{13,10}$	216,54 (8)	26 (3)	28
$\gamma_{18,15}$	226,1 (2)	34 (2)	43
$\gamma_{10,0}$	237,86 (2)	3,8 (8)	3,9
$\gamma_{12,8}$	246,14 (6)	8,2 (14)	--
$\gamma_{11,1}$	250,65 (16)	9,4 (7)	8,7
$\gamma_{13,8}$	252,78 (9)	13,2 (7)	22
$\gamma_{11,0}$	257,30 (15)	105 (2)	126
$\gamma_{12,7}$	278,7 (4)	9,4 (11)	14
$\gamma_{13,7}$	285,24 (7)	31 (2)	39
$\gamma_{15,10}$	347,64 (6)	29 (2)	22
$\gamma_{13,5}$	359,74 (4)	174 (2)	222
$\gamma_{12,4}$	361,285 (22)	43,6 (9)	70
$\gamma_{13,4}$	367,92 (7)	7,4 (15)	8,7
$\gamma_{12,3}$	377,27 (11)	55 (2)	70
$\gamma_{19,15}$	398,8 (5)	22,2 (15)	26
$\gamma_{-1,8}$	408,8 (5)	1 (1)	7,0

	Energy (keV)	2008De31	1969HoZY, 1972SeZI (see 2005Si15)
$\gamma_{16,11}$	412,5 (5)	16,6 (3)	24
$\gamma_{-1,9}$	418,4 (5)	18,2 (18)	22
$\gamma_{19,14}$	430,9 (4)	35,6 (7)	42
$\gamma_{20,15}$	433,2 (4)	23,4 (8)	28
$\gamma_{12,1}$	440,94 (4)	382 (4)	426
$\gamma_{12,0}$	447,762 (20)	208 (3)	278
$\gamma_{14,5}$	459,222 (7)	1,98 (2) $\cdot 10^3$	2,6$\cdot 10^3$
$\gamma_{14,4}$	467,40 (6)	28,8 (9)	33
$\gamma_{-1,12}$	473,9 (5)	6,6 (12)	6,5
$\gamma_{15,5}$	490,80 (6)	215 (4)	315
$\gamma_{-1,13}$	497,1 (4)	25,6 (8)	39
$\gamma_{15,4}$	499,02 (4)	315 (3)	389
$\gamma_{-1,14}$	505,5 (6)	11,0 (6)	9,1
$\gamma_{-1,15}$	513,4 (4)	26,6 (10)	37
$\gamma_{-1,16}$	517,0 (4)	9,2 (1)	13
$\gamma_{17,10}$	526,69 (6)	92,6 (19)	12
$\gamma_{-1,17}$	531,8 (4)	14 (2)	7,8
$\gamma_{17,9}$	552,21 (8)	33 (1)	44
$\gamma_{-1,18}$	554,9 (5)	6,2 (6)	6,5
$\gamma_{17,8}$	562,93 (8)	109 (2)	130
$\gamma_{18,10}$	573,7 (4)	66,4 (14)	78
$\gamma_{17,7}$	595,39 (6)	236 (20)	296
$\gamma_{18,9}$	599,3 (2)	58,8 (12)	87
$\gamma_{18,8}$	610,0 (3)	113 (2)	157
$\gamma_{18,7}$	642,4 (2)	40,4 (8)	52
$\gamma_{16,1}$	663,3 (5)	7,4 (10)	4,4
$\gamma_{17,5}$	669,901 (16)	1,00 (3)$\cdot 10^3$	1,3$\cdot 10^3$
$\gamma_{17,4}$	678,04 (10)	129 (2)	161
$\gamma_{-1,22}$	681,2 (6)	28,6 (8)	30
$\gamma_{-1,23}$	698,5 (6)	21,2 (1)	22
$\gamma_{-1,24}$	703,7 (6)	18,2 (1)	20
$\gamma_{18,6}$	707,8 (3)	18,2 (1)	22
$\gamma_{18,5}$	717,0 (2)	84,2 (17)	104
$\gamma_{18,4}$	725,1 (2)	126 (2)	161

	Energy (keV)	2008De31	1969HoZY, 1972SeZI (see 2005Si15)
$\gamma_{18,3}$	741,1 (2)	47,2 (9)	57
$\gamma_{-1,27}$	744,9 (5)	10,6 (4)	13
$\gamma_{-1,28}$	751,6 (6)	4,6 (6)	4,4
$\gamma_{17,1}$	757,90 (7)	64,8 (13)	78
$\gamma_{17,0}$	764,55 (6)	178 (2)	222
$\gamma_{-1,30}$	774,0 (4)	21,6 (12)	26
$\gamma_{19,8}$	783,2 (5)	11,2 (7)	11
$\gamma_{-1,31}$	784,2 (5)	4,4 (6)	9,1
$\gamma_{18,1}$	805,0 (2)	42,8 (13)	57
$\gamma_{20,9}$	806,4 (5)	24,6 (14)	24
$\gamma_{18,0}$	811,6 (2)	12,0 (5)	14
$\gamma_{19,7}$	815,9 (4)	39 (2)	52
$\gamma_{20,8}$	817,0 (6)	19 (1)	30
$\gamma_{20,7}$	849,5 (5)	7,8 (5)	8,7
$\gamma_{-1,34}$	870,7 (7)	6,2 (5)	3,9
$\gamma_{-1,35}$	874,0 (5)	24,0 (8)	11
$\gamma_{19,6}$	880,9 (5)	19,4 (8)	14
$\gamma_{19,5}$	890,1 (5)	210 (8)	259
$\gamma_{19,4}$	898,3 (5)	4,4	6,1
$\gamma_{-1,37}$	935,2 (7)	73,8 (15)	91
$\gamma_{-1,38}$	941,9 (8)	9,6 (1)	14
$\gamma_{20,3}$	948,3 (5)	12,0 (7)	14
$\gamma_{-1,40}$	955 (1)	0,4 (5)	10
$\gamma_{-1,41}$	960,8 (8)	8,2 (3)	13
$\gamma_{-1,42}$	962,8 (9)	3,0 (1)	2,6
$\gamma_{-1,43}$	968,2 (9)	16,6 (7)	20
$\gamma_{19,1}$	978,2 (5)	11,6 (7)	14
$\gamma_{19,0}$	984,8 (5)	20,4 (6)	2,6
$\gamma_{-1,44}$	994 (1)	1,2 (2)	1,7
$\gamma_{-1,45}$	1001 (1)	1,6 (4)	2,2
$\gamma_{-1,46}$	1007 (1)	2,8 (4)	5,2
$\gamma_{-1,47}$	1011 (1)	3,8 (4)	7,4

6. CONSISTENCY OF RECOMMENDED DATA

The most accurate Q value, Q(M), is taken from the atomic mass adjustment table of Audi et al. (2003Au03). Comparison of Q(eff)(deduced as the sum of average energies per disintegration ($\sum E_i \times P_i$) for all emissions accompanying 233Th β- decay) with the tabulated decay energy Q(M) allows to check a consistency of the recommended decay-scheme parameters obtained in this evaluation.

Here E_i and P_i are the evaluated energies and emission probabilities of the i-th alpha particle, beta particle, gamma ray, X-ray, etc.. Consistency (percentage deviation) is determined by {[Q(M)– Q(eff))]/ Q(M)} ×100. "Percentage deviations above 5 % would be regarded as high and imply a poorly defined decay scheme; a value of less than 5 % indicates the construction of a reasonably consistent decay scheme" (quoted from the article by A.L. Nichols in Appl. Rad. Isotopes 55 (2001) 23-70).

For the above ^{233}Th decay data evaluation we have Q(M) = 1243,1 (14) keV and Q(eff) = 1247 (2) keV, i.e. consistency is better than 1 %.

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^{234}Th – Comments on Evaluation of Decay Data
by A. Luca

This evaluation was completed in May 2009. The literature available by December 31st, 2008 was included.

1. Evaluation Procedures

The Limitation of Relative Statistical Weight (LWM) method was applied for averaging numbers throughout this evaluation; this method was implemented by using the computer code LWEIGHT, ver. 4 (designed for Excel, MS Office). The uncertainty assigned to an average value in this evaluation is never lower than the lowest uncertainty of any of the experimental input values.

2. Decay Scheme

^{234}Th decays 100 % by beta minus particle emissions, mainly to ^{234}Pa^{m} - the 1.159 min. half-life metastable state of ^{234}Pa (the first experimentally established case of nuclear isomerism, by O. Hahn, in 1921). The decay scheme was studied by many authors, since early '60s (1961Ge13, 1962Br05, 1963Bj02, 1964Ab04, 1965Fo12 and 1973Go40). The first recommended values for the main ^{234}Th nuclear decay data were published in the evaluation of Coursol et al., in 1990 (1990Co08); other important evaluation can be found in 1998Ad08. In the present evaluation, the spin, parity, energy and half-life values of the ^{234}Pa excited levels, and the multipolarities of the γ-ray transitions, have been adopted from the most recent A=234 ENSDF mass-chain evaluation, published by E. Browne and J.K. Tuli (2007Br04). The very important low energy and intensity isomeric transition (maximum energy of less than 10 keV) from ^{234}Pa^{m} to the first excited level of ^{234}Pa (explaining the 73.92 keV gamma-ray transition to the ^{234}Pa ground state), was not observed yet, probably because the conversion lines are obscured by intense Auger M and Coster-Kronig electrons (according to Godart and Gizon, 1973); as a consequence, the energies of all the ^{234}Pa excited levels decaying to ^{234}Pa^{m} are known to be upheld 10 keV at most with a systematic uncertainty (usually considered as "x" keV, in 2007Br04 and other evaluations; in the present evaluation, this quantity is not written in the decay scheme, but it should be added to the energy of the excited levels, respectively subtracted from the reported beta transitions energies). A more detailed decay scheme of ^{234}Th can be found in 2007Br04. The decay of ^{234}Pa^{m} (by alpha-particle emission and isomeric transition) is not studied in this evaluation.

3. Nuclear Data

The adopted beta decay energy value $Q(\beta^-)$=272 (10) keV, is based on the energy measurements of Godart and Gizon (1973Go40): 198.5 (15) keV for the maximum energy of the beta minus particle emissions and 73.92 (2) keV for the isomeric transition; an uncertainty of 10 keV was assigned to the result, according to the above-mentioned considerations. The adopted value of $Q(\beta^-)$ is in agreement with the value from 2003Audi03: 273.1 (32) keV (based on some older energy measurements of the beta minus particle emissions). The value adopted by this evaluation is also in good agreement with the effective $Q(\beta^-)$ value of 273 keV (with an uncertainty of 11 keV), calculated from the decay scheme data, by using the SAISINUC software.

3.1. Half-life

In the literature, only a few measured ^{234}Th half-life ($T_{1/2}$) values are reported; these measurements are very old (the most recent is from 1948), so new half-life measurements are needed to improve the quality of the evaluation. The half-life values and their uncertainties are presented in Table 1; the value recommended by Curie et al. (1931), with an estimated uncertainty added by the evaluator, was also included. The set of data is consistent and the recommended value, 24.10 days, with an uncertainty of 0.03 day, is the weighted average (LWM, χ^2_ν=3.78) of the four input values. The references are expressed as NSR (Nuclear Science References) type keynumbers:

Table 1 : ^{234}Th Half-life values

$T_{1/2}$ (days)	Uncertainty of $T_{1/2}$ (days)	Reference
23.8	0.7	1920Ki01
24.5	0.5	1931Cu01
24.1	0.2	1939Sa11
24.101	0.025	1948Kn23

3.2. Beta transitions and emissions

In the literature, the most complete reference reporting measurements of energy and emission intensities for ^{234}Th beta minus transitions is 1973Go40.
For this evaluation, the beta transitions energies were calculated from Q(β-) and the energies of the decay scheme levels; the high energy uncertainty (10 keV) is explained by the possible low energy and intensity isomeric transition (as described above, in section 2, Decay Scheme). The intensities of the beta branches were deduced from γ-ray transition intensity balance at each level, with the exception of the main branch; its intensity was deduced from the normalization condition of the beta emissions (the sum of the all the beta transitions intensities must be 100 %). The existence of the weakest beta decay branch (95.8 keV) is questionable (2007Br04). The energy and intensity values of the beta transitions, as well as their Log ft values are shown in Table 2.

Table 2: ^{234}Th β^- Energies and Emission Probabilities

$E_{\beta-}$ (keV)	Uncertainty $E_{\beta-}$ (keV)	Transition intensity (%)	Transition intensity (%), from 1973Go40	Log ft
85	10	1.6 (6)	1.3 (7)	7.0
95	10	0.016 (5)	-	9.1
105	10	6.5 (7)	5.4 (10)	6.7
106	10	14.1 (12)	20.7 (10)	6.3
198	10	77.8 (15)	72.5 (20)	6.4

3.3. γ- transitions: γ rays and internal conversion electrons

Many measurements of the γ-ray energies and emission intensities following the ^{234}Th decay were published by different authors: 1973Go40, 1973Sa33, 1973Ta25, 1978Ch06, 1982Mo30, 1990Sc09, 1993Su37, 2004Ab03 and 2006Al28. The interest for high quality data of photon emission probabilities is justified especially in the field of environmental radioactivity monitoring. Table 3 presents measured values of the 63.30 (2) keV γ-ray emission probability following the decay of ^{234}Th. The set of data is consistent and the recommended value, 3.75 (8) %, is the weighted average (LWM, χ^2_ν=3.32) of the five input values. The references are expressed as NSR type keynumbers.

Table 3 : Absolute Emission Intensity Results (in %) for the 63.30-keV γ ray.

Gamma-ray emission probability	Uncertainty of the gamma-ray emission probability	Reference
3.3	0.3	1973Go40
4.05	0.20	1982Mo30
3.6	0.2	1990Sc09
3.99	0.20	1993Su37
3.73	0.07	2004Ab03
3.75	**0.08**	**Adopted**

Using this evaluated value and the relative photon intensity values from the measurements of Chu and Scharff-Goldhaber (1978), the corresponding absolute gamma-ray emission probabilities and their uncertainties were computed for all the γ rays and are given below in Table 4. The relative photon intensities measured by Chu and Scharff-Goldhaber were preferred to those of Godart and Gizon (1973), mainly because in this case the U KX-rays contributions were resolved from the gamma-ray peaks situated in the (90-115) keV energy range of the spectra; no other references reporting relative photon intensities measurements were found in the literature.

The intensity balance for level 3 (103.42 keV) was used to compute the emission probability for the 73.85 keV photons, but the obtained value was negative (-0.011 %); as the placement of this transition in the level scheme is uncertain (2007Br04), this low probability photon emission was not considered in this evaluation. Other possible gamma-ray transitions neither confirmed nor placed in the level scheme (proposed / observed only by some authors) are: 57.75 keV, 87.02 keV, 92.00 keV, 103.71 keV, 108.00 keV, 132.9 keV and 184.8 keV.

The internal conversion coefficients were computed with the program BrIcc, version 2.2/2008, using the “Frozen Orbitals” approximation. A difficult case is the computation of the ICC for the 112.81 keV gamma-ray transition, because this energy is too close to the K-shell binding energy for protactinium (112.6 keV) and the software can not be used directly for this purpose. Following Browne and Tuli (2007), a limit on α(K) (≤ 0.29) has been obtained from extrapolation of α(K)’s for energies higher than 113.6 keV; however, this procedure introduced a large uncertainty of the total ICC value (see Table 4).

Table 4: ^{234}Th γ-ray Energies and Absolute Emission Probabilities

E_γ (keV)	Uncertainty E_γ (keV)	Absolute Emission Probability (%)	Uncertainty of absolute emission probability (%)	Total ICC (α_T)
20.01	0.02	0.005 1	0.002 1	240 (70)
29.50	0.02	0.001 23	0.000 14	4390 (70)
62.88	0.02	0.016 4	0.002 8	25 (5)
63.30	0.02	3.75	0.08	0.405 (6)
73.92	0.02	0.013 3	0.001 4	10.6 (4)
83.31	0.05	0.061	0.005	0.196 (3)
92.38	0.01	2.18	0.19	5.27 (8)
92.80	0.02	2.15	0.19	0.1472 (21)
103.35	0.10	0.003 2	0.001 0	3.81 (6)
112.81	0.05	0.215	0.022	0.23 (14)

4. Atomic data

The K-shell fluorescence yield (ω_K), the mean L-shell fluorescence yield (ϖ_L) and the mean number of vacancies in the L-shell produced by one vacancy in the K-shell (η_{KL}) were determined using the computer program EMISSION v3.10, 28-Jan-2003: 0.970 (4), 0.488 (18) and 0.795 (5) respectively.

4.1. Auger electrons and X-rays

The relative probability values of the K Auger electron emissions (KLL, KLX, KXY) normalized to the KLL value, were computed using the same EMISSION computer program. The total K Auger electron emission probability (absolute) and the emission probability of the L Auger electrons were also calculated. The energy ranges for K and L Auger electrons were filled-in by the SAISINUC program, version 2008 April.
The relative probability (normalized to $K_{\alpha1}$ X-rays emission) and the absolute emission probability values of the different groups of K and L X-rays were determined using the same EMISSION program. The energy range values of the K and L X-rays are from the tables linked to SAISINUC. Neither measurements of X-ray energies nor of emission probabilities were found in the literature, in order to compare them with the results of this evaluation.

5. Main production mode

The main production mode of ^{234}Th is by alpha-particle decay of the ^{238}U nuclei (^{234}Th is the daughter of ^{238}U), present in important quantities in many natural ores.

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^{231}Pa – Comments on evaluation of decay data

A. Arinc

Evaluation completed: February 2010
Literature cut-off date: June 2009

Evaluation procedure

Weighted mean analyses were applied to determine recommended values throughout the evaluation when the data were in statistical agreement. When the data were not in statistical agreement, the Limitation of Relative Statistical Weights (LRSW) was used. Uncertainties were expanded to match the minimum input uncertainty where appropriate.

1. Decay scheme

^{231}Pa disintegrates by alpha emission to various excited levels and the ground state of ^{227}Ac. The spin, parity, half-life of first excited state, multipolarities, mixing ratios and level energies of ^{227}Ac are based on the mass-chain evaluation of Browne (2001Br31).

A lack of experimental data for low-energy gamma transitions and imprecise alpha spectrometry measurements has adversely affected the construction of the decay scheme. The strongest transition of the decay scheme $\gamma_{1,0}$ at 27.370 (10) keV has a transition probability with an uncertainty of 12 %. Further measurements are required in order to build a more reliable decay scheme.

2. Nuclear data

The Q(α) value of 5149.9 (8) keV is taken from the evaluation of Audi et al (2003Au03). The Q-value calculated with Saisinuc is 5100 (120) keV.

% Deviation = [Q(Audi *et al.*) – Q(calculated) / Q(Audi *et al.*)] × 100

= [5149.9 (8) – 5100 (120) / 5149.9 (8)] x 100
= [(49.9 ± 120.0) / (5149.9 ± 0.8)] x 100 = (1.0 ± 2.3) %

The experimental half-life values used for calculating the mean are given in Table 1. The half-life value of 32 000 (3 200) years from Van Grosse (1932Grosse) was omitted from the analysis due to its inaccuracy. The published values from 1969Ro33 and 1961Ki05 were adjusted by 2001Br31 to take into account the change in the adopted decay scheme.
The AveTool computer code was used to calculate the average using three statistical methods: Limitation of Relative Statistical Weights (LRSW), Normalised Residual Methods (NRM) and the Rajeval Technique (RT).

Table 1: Experimental half-life values of ^{231}Pa.

Reference	Half-life (years)	Comments
1949Va02	34 300 (300)	
1961Ki05	32 643 (260)	
1968Br04	32 340 (115)	
1969Ro33	32 765 (110)	
LRSW	32 670 (260)	
NRM	32 705 (93)	reduced-χ^2 = 2.40
RT	32 718 (97)	reduced-χ^2 = 1.09
Recommended value	**32 670 (260)**	

The data set is discrepant with a reduced-χ^2 = 12.84 on the LRSW which is larger than the critical reduced-χ^2 = 3.78 (99 % confidence level). Although the value from 1949Va02 is not in good agreement with the other three values it was not excluded by Chauvenet's criterion. The published uncertainty of 300 years of 1949Va02 was adjusted to 800 years by NRM and to 1300 years by RT, while the published uncertainty of 115 years of 1968Br04 was adjusted to 400 years by RT. The recommended value is the LRSW mean of 32 670 (260) years. This value was chosen as it includes the two most precise values.

Overall the half-life data set is unsatisfactory and there is a strong need for new half-life measurements.

3. Atomic data

The values of ω_K, ω_L, n_{KL} and relative probabilities of the X-ray and Auger emissions were derived from Schönfeld and Janßen (1996Sc06).

The energies and relative emission probabilities of the X-ray and Auger electrons have been calculated using the computer code EMISSION. A summary of the results is given in Tables 2 and 3. The calculated L X-ray and K X-ray subshell ratios were in good agreement with the published data from De Pinho (1974De11).

Table 2: Calculated L X-ray emission energies and probabilities.

L X-ray	Energy (keV)	Calculated value
Ll	10.87	1.10 (4)
Lα	12.50 – 12.65	18.7 (7)
Lη	14.08	0.303 (19)
Lβ	14.60 – 16.63	19.7 (7)
Lγ	17.81 – 18.92	4.45 (16)
LX total		44.3 (13)

Table 3: Calculated K X-ray emission energies and probabilities.

K X-ray	Energy (keV)	Calculated value
$K\alpha_2$	87.768	0.715 (23)
$K\alpha_1$	90.885	1.16 (4)
$K\beta_1$’	102.10 – 103.46	0.410 (15)
$K\beta_2$’	105.68 – 106.56	0.136 (6)
KX total		2.42 (8)

4. Alpha particles

4.1 Alpha particle energies

The alpha transition energies have been calculated from the Q(α) value (2003Au03), and the level energies were adopted from Browne (2001Br31) and are given in Table 4.

Adopted alpha emission energies have been calculated from the transition energies taking into account the recoil energy of the daughter nucleus. The theoretically calculated values were compared to the published data where available (Table 5). The data from 1961Ba42, 1968Ba25 and 1976BaZZ are from the same main author (Baranov). Experimental alpha emission energies were taken from the compilation of 1991Ry01 when available; otherwise primarily from 1976BaZZ and then from 1961Ba42.

Alpha hindrance factors were calculated using the ALPHAD computer program. The radius parameter of r_0 (^{227}Ac) = 1.5323 (14) was calculated as the average of r_0 (^{226}Ra) = 1.5331 (13), r_0 (^{226}Th) = 1.531 (5), r_0 (^{228}Th) = 1.5289 (5) and r_0 (^{228}Ra) = 1.5361 (22) from 1998Ak04. A summary of the adopted levels and theoretical and experimental alpha emission values is presented in Table 6.

Table 4: Adopted nuclear levels of ^{227}Ac.

Nuclear level number	Nuclear level energy (keV)	Spin and parity	Half-life
0	0.0	3/2-	21.772 (3) a
1	27.37 (1)	3/2+	38.3 (3) ns
2	29.98 (1)	5/2-	
3	46.35 (1)	5/2+	
4	74.14 (1)	(7/2)-	
5	84.55 (1)	(7/2)+	
6	109.94 (2)	(9/2)+	
7	126.86 (2)	(9/2)-	
8	160 (2)		
9	187.32 (3)	(11/2+)	
10	198.71 (4)	(11/2-)	
11	210.78 (5)	(13/2+)	
12	271.29 (6)	(13/2-)	
13	273.14 (3)	(5/2)-	
14	304.73 (5)	(5/2+)	
15	330.04 (1)	3/2-	<70 ps
16	354.50 (4)	1/2-	
17	387.23 (2)	7/2-	

Nuclear level number	Nuclear level energy (keV)	Spin and parity	Half-life
18	425.59 (3)	5/2+	
19	435.19 (2)	(1/2)+	
20	437.96 (4)	(5/2-)	
21	469.24 (6)	(9/2+)	
22	501.28 (7)	(3/2-,5/2-)	
23	537.0 (1)	(3/2+)	
24	562.8 (1)	(3/2+,5/2+)	
25	656.4 (3)	(7/2+)	

Table 5: Experimental alpha emission energies (keV).

Transition	1961Ba42[1]	1966Ba04	1968Ba25[2]	1976BaZZ	1991Ry01
$\alpha_{0,0}$	5058.9 (21)	5058.5 (15)	5057.5 (10)	5058.1 (10)	5058.6 (15)
$\alpha_{0,1}$	5032.0 (21)	-	5030.8	-	-
$\alpha_{0,2}$	5029.9 (21)	-	5028.3	-	5028.4 (10)
$\alpha_{0,3}$	5012.7 (20)	5013.5 (15)	5012.7	5013.3 (10)	5013.8 (14)
$\alpha_{0,4}$	4985.5 (20)	-	4985.8 (10)	4986.4 (10)	-
$\alpha_{0,5}$	4974.8 (20)	-	-	-	-
$\alpha_{0,6}$	4951.2 (20)	4951.0 (15)	4950.3 (10)	4950.9 (10)	4951.3 (14)
$\alpha_{0,7}$	4933.8 (21)	-	-	-	-
$\alpha_{0,8}$	4900.0 (21)	-	-	-	-
$\alpha_{0,9}$	-	-	-	-	-
$\alpha_{0,10}$	-	-	-	-	-
$\alpha_{0,11}$	4852.2 (21)	-	-	-	-
$\alpha_{0,12}$	4794.3 (22)	-	-	-	-
$\alpha_{0,13}$	-	-	-	-	-
$\alpha_{0,14}$	-	-	-	-	-
$\alpha_{0,15}$	4736.4 (23)	4733.5 (15)		4736.1 (10)	4736.0 (8)
$\alpha_{0,16}$	4712.0 (24)	-	-	-	-
$\alpha_{0,17}$	4679.7 (24)	-	-	-	-
$\alpha_{0,18}$	4642.2 (25)	-	-	-	-
$\alpha_{0,19}$	-	-	-	-	-
$\alpha_{0,20}$	4631 (3)	-	-	-	-
$\alpha_{0,21}$	4598 (3)	-	-	-	-
$\alpha_{0,22}$	4565 (3)	-	-	-	-
$\alpha_{0,23}$	-	-	-	-	-
$\alpha_{0,24}$	4506 (3)	-	-	-	-
$\alpha_{0,25}$	-	-	-	-	-

[1] Published value was adjusted to recommended values by 1991Ry01 and 4986.4 (10) keV by 1976BaZZ due to changes in calibration energy.
[2] Additional values, which were not placed in the decay scheme, were reported at 5026.6 keV (population of 32-keV energy level of ^{227}Ac) and at 5009.0 keV (population of 49-keV energy level of ^{227}Ac).

Table 6: Adopted levels, theoretical and experimental alpha particle emission energies and hindrance factors.

Transition	Level energy (keV)	Theoretical alpha emission energy[1] (keV)	Experimental alpha emission energy (keV)	HF
$\alpha_{0,0}$	0.0	5060.7 (8)	5058.6 (15)	250
$\alpha_{0,1}$	27.37 (1)	5033.8 (8)	5032.0 (21)	707
$\alpha_{0,2}$	29.98 (1)	5031.2 (8)	5028.4 (10)	95
$\alpha_{0,3}$	46.35 (1)	5015.1 (8)	5013.8 (14)	59.5
$\alpha_{0,4}$	74.14 (1)	4987.8 (8)	4986.4 (10)	629
$\alpha_{0,5}$	84.55 (1)	4977.6 (8)	4974.8 (20)	2 160
$\alpha_{0,6}$	109.94 (2)	4952.6 (8)	4951.3 (14)	26.5
$\alpha_{0,7}$	126.86 (2)	4936.0 (8)	4933.8 (21)	160
$\alpha_{0,8}$	160 (2)	4903.4 (22)	4900.0 (21)	141 000
$\alpha_{0,9}$	187.32 (3)	4876.6 (8)	-	-
$\alpha_{0,10}$	198.71 (4)	4865.4 (8)	-	-
$\alpha_{0,11}$	210.78 (5)	4853.5 (8)	4852.2 (21)	94
$\alpha_{0,12}$	271.29 (6)	4794.1 (8)	4794.3 (22)	1 300
$\alpha_{0,13}$	273.14 (3)	4792.3 (8)	-	-
$\alpha_{0,14}$	304.73 (5)	4761.2 (8)	-	9 600
$\alpha_{0,15}$	330.04 (1)	4736.3 (8)	4736.0 (8)	2.46
$\alpha_{0,16}$	354.50 (4)	4712.3 (8)	4712.0 (24)	11.7
$\alpha_{0,17}$	387.23 (2)	4680.1 (8)	4679.7 (24)	4.6
$\alpha_{0,18}$	425.59 (3)	4642.5 (8)	4642.2 (25)	56
$\alpha_{0,19}$	435.19 (2)	4633.0 (8)	-	75.8
$\alpha_{0,20}$	437.96 (4)	4630.3 (8)	4631 (3)	47
$\alpha_{0,21}$	469.24 (6)	4599.6 (8)	4598 (3)	146
$\alpha_{0,22}$	501.28 (7)	4568.1 (8)	4565 (3)	160
$\alpha_{0,23}$	537.0 (1)	4533.0 (8)	-	930
$\alpha_{0,24}$	562.8 (1)	4507.6 (8)	4506 (3)	126
$\alpha_{0,25}$	656.4 (3)	4415.6 (9)	-	43

[1] Calculated from alpha transition energy, taking into account the recoil energy of the daughter nucleus.

4.2 Alpha particle emission probabilities

The alpha emission probabilities have been determined from published data measurements when available; otherwise they are calculated from the balance of the decay scheme. All available experimental measurements were derived from magnetic spectrometers (1956Hu96, 1961Ba42 and 1976BaZZ). Data from Baranov (1961Ba42 and 1976BaZZ) and Hummel (1956Hu96) are in good agreement, with the exception of the $\alpha_{0,15}$ emission. For the recommended alpha emission probabilities, the evaluator has used values with uncertainties when available, adjusting the uncertainty as necessary. Otherwise the average of the values from Baranov (1961Ba42) and Hummel (1956Hu96) was used, with the uncertainty being estimated on the basis of the decay scheme and individual values.

The theoretical emission probabilities were calculated from the P(γ+ce) balances using the GTOL software. There are large uncertainties associated with the theoretical calculations at the lower energy levels (see Table 7). These large uncertainties arise as a consequence of the incomplete decay scheme, which in turn is due to the difficulties experienced in measuring low-energy gamma transitions.

There is a discrepancy between the alpha particle and gamma ray feeding and the gamma ray depopulating the first excited state. This is very probably due to the dominant $\gamma_{1,0}$ transition for which the emission probability and ICC value are not very well known.

Weak alpha particle emissions to levels 14, 19, 23 and 25 were expected, but not observed experimentally. These emissions were added to the decay scheme.

Table 7: Alpha particle emission energies, published and recommended probabilities.

Transition	Adopted emission energy (keV)	1961Ba42	1956Hu96	1976BaZZ[1]	Calculated[2] emission probability	Adopted emission probability
$\alpha_{0,0}$	5060.7 (8)	11.0	10	11.7 (1)	11 (8)	11.7 (5)
$\alpha_{0,1}$	5033.8 (8)	~ 2.5	} 23	-	10 (8)	2.8 (3)
$\alpha_{0,2}$	5031.2 (8)	≤ 20.0		-	16 (4)	20 (2)
$\alpha_{0,3}$	5015.1 (8)	25.4	24	25.3 (2)	26 (5)	25.3 (5)
$\alpha_{0,4}$	4987.8 (8)	1.4	} 2.3	1.60 (5)	0.97 (20)	1.60 (20)
$\alpha_{0,5}$	4977.6 (8)	0.4			-1 (4)	0.4 (1)
$\alpha_{0,6}$	4952.6 (8)	22.8	22	22.5 (2)	21.4 (14)	22.5 (5)
$\alpha_{0,7}$	4936.0 (8)	3.0	2.8		2.51 (12)	2.9 (3)
$\alpha_{0,8}$	4903.4 (22)	0.002	-	-	0	0.002 (1)
$\alpha_{0,9}$	4876.6 (8)	-	-	-	-0.46 (16)	-
$\alpha_{0,10}$	4865.4 (8)	-	-	-	0.012 (10)	-
$\alpha_{0,11}$	4853.5 (8)	1.4	1.4	-	1.41 (15)	1.40 (15)
$\alpha_{0,12}$	4794.1 (8)	0.04	-	-	0.066 (8)	0.040 (15)
$\alpha_{0,13}$	4792.3 (8)	-	-	-	0.00 (5)	-
$\alpha_{0,14}$	4761.2 (8)	-	-	-	0.003 2 (9)	0.003 2 (9)
$\alpha_{0,15}$	4736.3 (8)	8.4	11	8.35 (8)	9.1 (5)	8.4 (4)
$\alpha_{0,16}$	4712.3 (8)	~ 1	1.4	-	1.20 (22)	1.20 (22)
$\alpha_{0,17}$	4680.1 (8)	1.5	2.1	-	1.8 (4)	1.8 (3)
$\alpha_{0,18}$	4642.5 (8)	~ 0.1	-	-	0.080 (6)	0.080 (6)
$\alpha_{0,19}$	4633.0 (8)	-	-	-	0.050 4 (11)	0.050 4 (11)
$\alpha_{0,20}$	4630.3 (8)	~ 0.1	-	-	0.078 (21)	0.078 (21)
$\alpha_{0,21}$	4599.6 (8)	0.015	-	-	0.003 65 (22)	0.015 (7)
$\alpha_{0,22}$	4568.1 (8)	0.008	-	-	0.001 5 (5)	0.008 (4)
$\alpha_{0,23}$	4533.0 (8)	-	-	-	0.000 76 (20)	0.000 76 (20)
$\alpha_{0,24}$	4507.6 (8)	0.003	-	-	0.003 6 (3)	0.003 6 (3)
$\alpha_{0,25}$	4415.6 (9)	-	-	-	0.002 1 (5)	0.002 1 (5)

[1]Authors have reported only type A uncertainties.
[2]Emission probabilities calculated from balance of the decay scheme.

5. Gamma rays

5.1 Gamma-ray transitions and internal conversion coefficients

All gamma-ray transition energies were calculated from the differences in level energies as adopted from Browne (2001Br31).

Theoretical internal conversion coefficients (ICCs) were calculated using the BrIcc code (Kibédi et al., 2008Ki07) with the “frozen orbital” approximation, which uses interpolated values of Band et al. (2002Ba85).

The agreement between theoretical and measured ICC values was poor for $\gamma_{1,0}$ – under these circumstances, the experimental ICC data was adopted.

ICCs for some low-energy gamma transitions

$\gamma_{3,2}$: 16.370 (14) keV

The transition energy for this gamma ray is within 1 keV of the L3 shell binding energy of 15.971 keV. Since the model may be inaccurate close to the binding energy, the BrIcc code cannot be used to calculate theoretical ICCs. Therefore, the theoretical ICCs were calculated by Kibédi using the RAINE code, resulting in a value of 5.06 (7) for the L3 shell conversion and a total conversion coefficient of 8.58 (12) for this transition.

$\gamma_{1,0}$: 27.370 (10) keV

Disagreement between theoretically derived and experimentally measured data has been observed for this low-energy E1 transition (Table 8).

Table 8: Experimental and calculated values of α_L for the $\gamma_{1,0}$ transition of 27.370 (10) keV and E1 multipolarity.

Reference	α_L	Comments
1960As02	2.8 (3)	
1961Ba42	3.6 (4)	
1970De19	3.0 (3)	Not used - same author as 1974De11
1974De11	3.7 (3)	
Experimental mean	3.3 (4)	Weighted mean of 3 values
BrIcc code	2.66 (4)	

Asaro et al. suggest that the disagreement observed for this E1 transition can be explained by a small M2 contribution (1960As02). Assuming a multipolarity of E1+M2, the mixing ratio that agrees with the recommended value of α_L = 3.3 (4) is δ= 0.007.

$\gamma_{2,0}$: 29.980 (10) keV

The mixing ratio of 0.22 (2) from the evaluation of Browne (2001Br31) was derived from the measurements of De Pinho (1974De11). De Pinho derives the mixing ratio from an experimental value of α_L = 220 (20); the author suggests that a value of δ^2 from approximately 0.042 to 0.053 can explain the experimental α_L coefficients observed. Changing the mixing ratio value within the limits indicated above varies the $\gamma_{2,0}$ transition probability significantly from 24.4 to 27.6. More precise measurements are necessary to clarify the decay scheme at this level.

Summary of ICCs

A summary of the ICCs for the low-energy gamma-ray transitions is given in Table 9.

Table 9: Energies, multipolarities and internal conversion coefficients for low-energy gamma-ray transitions. Data within square parentheses [] are unconfirmed.

Transition	Transition energy (keV)	Multipolarity	Mixing ratio	α_T	α_L	α_M
$\gamma_{3,2}$	16.370 (14)	[E1]	-	8.58 (12)	5.06 (7)	2.68 (4)
$\gamma_{3,1}$	18.980 (14)	[M1]	-	113.2 (16)	2.35 (4)	82.7 (12)
$\gamma_{11,9}$	23.46 (6)	[M1]	-	241 (4)	182 (3)	44.1 (7)
$\gamma_{16,15}$	24.46 (4)	[M1]	-	214 (4)	161.3 (24)	39.0 (6)
$\gamma_{6,5}$	25.390 (22)	[M1]	-	191 (3)	144.6 (21)	34.9 (5)
$\gamma_{1,0}$	27.370 (10)	E1 [+M2]	[0.007]	4.5 (6)	3.3 (4)	0.87 (13)
$\gamma_{2,0}$	29.980 (10)	M1+E2	0.22 (2)	270 (30)	202 (21)	52 (6)
$\gamma_{6,4}$	35.800 (22)	[E1]	-	1.746 (25)	1.313 (19)	0.327 (5)
$\gamma_{5,3}$	38.200 (14)	M1+E2	0.18 (5)	89 (19)	66 (14)	17 (4)
$\gamma_{4,2}$	44.160 (14)	[M1]	-	37.4 (6)	28.3 (4)	6.79 (10)
$\gamma_{3,0}$	46.350 (10)	[E1]	-	0.879 (13)	0.663 (10)	0.1634 (23)
$\gamma_{20,17}$	50.73 (5)	[M1]	-	24.9 (4)	18.8 (3)	4.52 (7)
$\gamma_{7,4}$	52.720 (22)	[M1]	-	22.2 (4)	16.81 (24)	4.03 (6)
$\gamma_{5,2}$	54.570 (14)	[E1]	-	0.569 (8)	0.430 (6)	0.1053 (15)
$\gamma_{15,13}$	56.90 (3)	[M1+E2]	[0.41 (7)]	37 (6)	28 (5)	7.1 (12)
$\gamma_{5,1}$	57.180 (14)	E2	-	148.1 (21)	108.6 (16)	29.6 (5)
$\gamma_{17,15}$	57.190 (22)	E2	-	148.0 (21)	108.5 (16)	29.6 (5)
$\gamma_{9,7}$	60.46 (4)	[E1]	-	0.433 (7)	0.327 (5)	0.0800 (12)
$\gamma_{6,3}$	63.590 (22)	E2	-	88.8 (13)	65.1 (10)	17.8 (3)
$\gamma_{10,7}$	71.85 (5)	[M1]	-	8.98 (13)	6.79 (10)	1.630 (23)
$\gamma_{12,10}$	72.58 (7)	[M1]	-	8.71 (13)	6.59 (10)	1.582 (23)
$\gamma_{4,0}$	74.140 (10)	[E2]	-	42.6 (6)	31.2 (5)	8.53 (12)
$\gamma_{9,6}$	77.38 (4)	[M1]	-	7.23 (11)	5.47 (8)	1.313 (19)
$\gamma_{7,2}$	96.880 (22)	E2	-	12.02 (17)	8.81 (13)	2.41 (4)
$\gamma_{11,6}$	100.84 (5)	[E2]	-	9.97 (15)	7.30 (11)	2.00 (3)
$\gamma_{9,5}$	102.77 (3)	[E2]	-	9.12 (13)	6.69 (10)	1.83 (3)

5.2 Gamma-ray emission energies

There are a total of 9 sets of measurements for the gamma-ray emission energies. The recommended values were calculated from the differences in level energies as adopted from Browne (2001Br31) and were compared to the experimental values calculated from the weighted means (calculated with LWEIGHT4 code) of Lange (1969La04), De Pinho (1970De19), Leang (1970Le11), Börner (1979Bo30) and Teoh (1979Te02). The measurements from Falk-Vairant (1953Fa08), Foucher (1960Fo05), Baranov (1961Ba42) and Abou-Leila (1963Ab04) were not taken into account as they either do not have uncertainties, or are imprecise (uncertainties of a few keV). Experimental results and recommended values can be seen in Table 1 of Appendix 1.

Unplaced gamma rays

Below 45 keV

In the region 30-45 keV, various authors have reported 7 unplaced gamma rays. See Table 10 below for the reported energies.

Table 10: Experimental gamma-ray emission energies for unplaced gamma rays below 45 keV.

Reference	1961Ba42	1969La04	1970De19	1979Te02
Energy (keV)		30.7 (5)	31.00 (5)	30.87 (4)
			31.54 (4)	31.55 (5)
	34.0			
		39.6 (5)	39.57 (4)	39.73 (3)
			39.97 (2)	40.00 (3)
			42.48 (5)	42.41 (4)
			43.05 (5)	43.08 (4)

Baranov (1961Ba42), De Pinho (1970De19), Teoh (1970Te02) and Banham (1983Banham) have reported gamma-ray emission probabilities for these energies.

De Pinho et al. mention in their later paper (1974De19) that the six transitions reported in their earlier paper (1970De19) were not confirmed by later measurements and were the result of X-ray summing effects.

The evaluator has decided not to include these 7 transitions in the final table of evaluated gamma rays because their genuine existence is questionable.

Above 45 keV

With the exception of the 59.4 keV and 512.2 keV gamma-ray emissions reported by Lange (1969La04), the 318.1 keV gamma ray reported by Leang (1970Le11) and the 536.6 keV gamma ray reported by Teoh (1979Te02), the other unplaced gamma rays have been listed in the table.

The unplaced gamma-ray transition at 56.78 (4) keV detected by De Pinho (1970De19) and Teoh (1979Te02) was placed in the decay scheme based on the energy difference that constitutes the $\gamma_{15,13}$ transition. The energy for $\gamma_{15,13}$ calculated from the difference in level energies is 56.90 (3) keV which is in good agreement with the experimental value. If this gamma transition was absent, the balance of the decay scheme at level 13 would result in an alpha emission ($\alpha_{0,13}$) with an intensity of 0.19 (4) %; since weaker alpha emissions were detected in this region, it seems unlikely such an emission could be missed, which lends support to the placement of $\gamma_{15,13}$. With a transition from level 3/2- to level 5/2- and assuming a probability for $\alpha_{0,13}$ = 0, a multipolarity M1+E2 with a mixing ratio of δ = 0.41 (7) has been tentatively deduced.

5.3 Gamma-ray emission probabilities

There are a total of 9 sets of measurements for the gamma-ray emission probabilities. Four of the authors (1970De19, 1970Le11, 1979Te02 and 1983Banham) have measured over a wide energy range. Two of the publications are from the same authors (1970De19 and 1974De11); the later publication was favoured for emissions reported in both papers. Values were first normalised such that the intensity of the 283.7 keV peak was set to be 100. The scaling factor used for the two data sets from De Pinho et al. was derived from their most recent publication.

The recommended values are the weighted mean of De Pinho (1970De19, 1974De11), Leang (1970Le11), Teoh (1979Te02), Aničin (1982An02) and Banham (1983Banham, 1984BAYS). The measurements from Foucher (1960Fo05), Baranov (1961Ba42) and Lange (1969La04) were not taken into account as they have no reported uncertainties. The experimental results and recommended values can be seen in Table 2 of Appendix 1.

Normalisation factor

Two experimental values were reported:
0.016 49 (27) from Banham (1984BAYS)
0.016 (2) from Leang (1970Le11)

The theoretical value obtained from the balance of the decay scheme to the ground state is 0.016 3 (14), which is in good agreement with the experimental values. As the theoretical normalisation factor is strongly influenced by the dominant $\gamma_{1,0}$ transition for which the theoretical and experimental ICC values do not agree, the evaluator has decided to use the experimental normalisation factor of 0.016 5 (3) derived from Banham (1984BAYS).

Low-energy gamma-ray emission probabilities

The emission probabilities for many of the gamma-ray transitions of 25 keV and below were either missing or imprecise, and had to be calculated using the balance of the decay scheme.

$\gamma_{3,2}$: 16.370 (14) keV

One measured value of $I\gamma_{3,2}$ =13.4 (5) from Banham (1984BAYS) is available and was adopted as the recommended value. De Pinho (1974De11) has measured a transition ratio between Iγ+ce(19 keV)/ Iγ+ce(16.4 keV) ≈ 18 (5). Calculating the same ratio with the evaluated data gives 20.1 (15) which is in good agreement with the value of De Pinho et al.

$\gamma_{3,1}$: 18.980 (14) keV

The lack of coherent experimental data reported for this transition, due to the intense L X-rays observed in this part of the spectrum, made it impossible to calculate a weighted mean. This transition was calculated from the balance of the decay scheme at level 3. The resulting relative emission probability is $I\gamma_{3,1}$ = 22.2 (16).

$\gamma_{11,9}$: 23.46 (6) keV

No values have been reported for this transition, and the emission probability has been calculated from the balance of the decay scheme to level 11. The resulting gamma-ray emission probability is $I\gamma_{11,9}$ = 0.288 (35).

$\gamma_{16,15}$: 24.46 (4) keV

Two measurements are available for this gamma ray: 0.7 (3) from Teoh (1979Te02), and ~ 0.59 from De Pinho (1970De19). Neither of these values is very precise, and therefore the evaluator decided to evaluate this gamma-ray emission probability by means of the balance of the decay scheme to level 16. The resulting relative emission probability is $I\gamma_{16,15}$ = 0.30 (6).

$\gamma_{6,5}$: 25.390 (22) keV

There are four reported measurements for this transition. The measurements are not in very good agreement and fall into two ranges. Measurements of 7.6 (12) from De Pinho (1974De11) and 6.9 (10) from Teoh (1979Te02) contrast with the equivalent data from Leang (1970Le11) and Banham (1984BAYS) of 18.75 and 16.5 (9), respectively. The evaluator has decided to calculate the gamma-ray emission probability using the mean value of the balance of the decay scheme to levels 5 and 6 to give $I\gamma_{6,5}$ = 5.8 (4). This value is in agreement with the lower set of values from De Pinho and Teoh.

Multiple placement - doublets

The gamma-ray transitions $\gamma_{15,1}$ (302.7 keV) and $\gamma_{17,5}$ (302.7 keV), $\gamma_{5,1}$ (52.7 keV) and $\gamma_{17,15}$ (52.7 keV) have been placed twice in the decay scheme; their individual emission probabilities have been suitably divided as follows.

$\gamma_{15,1}$ and $\gamma_{17,5}$: 302.7 keV

The combined evaluated relative probability for this gamma ray is 149.4 (12). Two authors have reported values for the separated doublet and the agreement between authors is poor:

Transition	1979Te02	1982An02
$\gamma_{15,1}$	100 (10)	138 (20)
$\gamma_{17,5}$	40 (5)	10.6 (26)

Only $\gamma_{15,1}$ is observed in the decay of ^{227}Ra, so using the ratios between this transition and $\gamma_{15,0}$, $\gamma_{15,2}$ and $\gamma_{15,3}$ the expected transition probability for the doublet in the ^{231}Pa decay was calculated:

^{27}Ra transition	Calculated $\gamma_{15,1}$ in ^{231}Pa decay
$\gamma_{15,0}$	132 (16)
$\gamma_{15,2}$	137 (16)
$\gamma_{15,3}$	141 (16)
Unweighted mean	137 (16)

The recommended emission probability for $\gamma_{15,1}$ is 137 (16), and therefore the calculated $\gamma_{17,5}$ probability is 13 (6).

These values are in good agreement with the value of $\gamma_{15,1}$=138 (20) and $\gamma_{17,5}$=10.6 (26) from Aničin (1982An02).

$\gamma_{5,1}$ and $\gamma_{17,15}$: 57.2 keV

The combined evaluated relative probability for this gamma ray is 2.16 (14). One author (1979Te02) has reported values for the separated doublet. The calculated values using the balance of the decay scheme at level 17 are as follows:

Transitions	1979Te02	Calculated
$\gamma_{5,1}$	1.58 (16)	1.88 (19)
$\gamma_{17,15}$	0.96 (10)	0.28 (13)

The agreement between the calculated and measured values is poor for $I\gamma_{17,15}$. The evaluator has decided to adopt the calculated values.

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Appendix 1: Experimental and recommended gamma-ray emission energies and probabilities.

Table 1. Experimental and recommended gamma-ray emission energies (keV).

	1969La04	1970De17	1970Le11	1979Bo30 [a]	1979Te02	Calculated from experimental data	Recommended values
$\gamma_{3,2}$	-	16.5 (1)	-	-	-	16.5 (1)	16.370 (14)
$\gamma_{3,1}$	-	18.88 [b]	-	-	-	18.88	18.980 (14)
$\gamma_{11,9}$	-	-	-	-	-	-	23.46 (6)
$\gamma_{16,15}$	-	24.5 (1)	-	-	24.6 (5)	24.50 (10)	24.46 (4)
$\gamma_{6,5}$	25.3 (5)	25.54 (6)	25.2 (2)	-	25.36 (8)	25.46 (6)	25.390 (22)
$\gamma_{1,0}$	27.3 (5)	27.35 (2)	27.3 (2)	-	27.38 (2)	27.365 (20)	27.370 (10)
$\gamma_{2,0}$	29.8 (5)	29.95 (2)	29.9 (2)	-	30.01 (3)	29.968 (20)	29.980 (10)
$\gamma_{6,4}$	35.6 (5)	35.82 (3)	35.8 (3)	-	35.86 (4)	35.834 (30)	35.800 (22)
$\gamma_{5,3}$	38.0 (5)	38.20 (2)	38.1 (2)	-	38.19 (2)	38.194 (20)	38.200 (14)
$\gamma_{4,2}$	43.9 (5)	44.16 (2)	44.1 (2)	-	44.13 (2)	44.145 (20)	44.160 (14)
$\gamma_{3,0}$	46.1 (5)	46.37 (2)	46.2 (2)	-	46.32 (2)	46.344 (20)	46.350 (10)
$\gamma_{20,17}$	-	50.98 (5)	-	-	50.68 (6)	50.83 (15)	50.73 (5)
$\gamma_{7,4}$	52.4 (5)	52.74 (2)	52.6 (2)	-	52.66 (3)	52.658 (30)	52.720 (22)
$\gamma_{5,2}$	54.8 (5)	54.61 (2)	54.5 (2)	-	54.56 (3)	54.594 (20)	54.570 (14)
$\gamma_{15,13}$	-	56.76 (4)		-	56.79 (4)	56.78 (4)	56.90 (3)
$\gamma_{5,1}$	-	57.19 (3)	57.0 (2)	-	57.19 (3)	57.188 (30)	57.180 (14)
$\gamma_{17,15}$	-	57.19 (3)	57.0 (2)	-	57.19 (3)	57.188 (30)	57.190 (22)
$\gamma_{9,7}$	-	60.50 (3)	60.2 (3)	-	60.47 (8)	60.494 (30)	60.46 (4)
$\gamma_{6,3}$	63.3 (5)	63.67 (3)	63.5 (2)	-	63.60 (4)	63.642 (30)	63.590 (22)
$\gamma_{-1,1}$	-	70.50 (5)	-	-	70.45 (8)	70.49 (5)	70.49 (5) [c]

	1969La04	1970De17	1970Le11	1979Bo30 [a]	1979Te02	Calculated from experimental data	Recommended values
$\gamma_{10,7}$	-	71.9 (1)	-	-	71.9 (1)	71.9 (1)	71.85 (5)
$\gamma_{12,10}$	-	72.5 (1)	-	-	72.78 (8)	72.67 (14)	72.58 (7)
$\gamma_{4,0}$	-	74.18 (4)	74.1 (3)	-	74.08 (6)	74.15 (4)	74.140 (10)
$\gamma_{9,6}$	77.1 (5)	77.36 (3)	77.2 (2)	-	77.30 (4)	77.336 (30)	77.38 (4)
$\gamma_{7,2}$	-	96.88 (3)	96.7 (2)	-	96.80 (3)	96.838 (30)	96.880 (22)
$\gamma_{11,6}$	-	100.92 (4)	100.5 (5)	-	100.77 (4)	100.84 (5)	100.84 (5)
$\gamma_{9,5}$	102.5 (5)	-	102.5 (4)	-	102.6 (5)	102.5 (4)	102.77 (3)
$\gamma_{10,4}$	-	124.6 (1)	124.4 (5)	-	124.56 (8)	124.57 (8)	124.57 (4)
$\gamma_{12,7}$	-	144.5 (1)	144.4 (5)	-	144.33 (8)	144.40 (8)	144.43 (6)
$\gamma_{13,4}$	-	199 (1)	198.7 (6)	-	198.89 (10)	198.89 (10)	199.00 (3)
$\gamma_{14,4}$	-	-	-	-	230.0 (10)	230.0 (10)	230.59 (5)
$\gamma_{-1,2}$	-	242.2 (1)	-	-	242.16 (8)	242.18 (8)	242.18 (8) [c]
$\gamma_{13,2}$	243.0 (5)	243.0 (1)	242.9 (4)	-	243.15 (9)	243.08 (9)	243.16 (3)
$\gamma_{15,5}$	-	245.4 (1)	245.3 (5)	-	245.77 (9)	245.60 (13)	245.490 (14)
$\gamma_{13,1}$	-	246.0 (2)	-	-	246.05 (9)	246.04 (9)	245.77 (3)
$\gamma_{15,4}$	256.1 (5)	255.78 (7)	255.9 (3)	-	255.76 (8)	255.78 (7)	255.900 (14)
$\gamma_{14,3}$	-	258.4 (1)	-	-	258.54 (15)	258.44 (10)	258.38 (5)
$\gamma_{17,7}$	260.2 (5)	260.14 (8)	260.2 (3)	-	260.23 (8)	260.19 (8)	260.37 (3)
$\gamma_{13,0}$	273.5 (5)	273.08 (9)	273.2 (3)	273.237 (117)	273.15 (9)	273.14 (9)	273.14 (3)
$\gamma_{17,6}$	277.7 (5)	276.99 (9)	277.2 (3)	277.322 (15)	277.10 (9)	277.19 (7)	277.29 (3)
$\gamma_{15,3}$	283.9 (5)	283.56 (6)	283.7 (3)	283.690 (16)	283.65 (5)	283.679 (16)	283.690 (14)

	1969La04	1970De17	1970Le11	1979Bo30 [a]	1979Te02	Calculated from experimental data	Recommended values
$\gamma_{-1,3}$	-	286.55 (10)	-	-	286.60 (10)	286.58 (10)	286.58 (10) [c]
$\gamma_{15,2}$	300.5 (5)	299.94 (6)	300.1 (2)	300.069 (12)	300.02 (5)	300.062 (15)	300.060 (14)
$\gamma_{15,1}$	303.2 (5)	302.52 (6)	302.7 (2)	302.669 (11)	302.65 (5)	302.664 (15)	302.670 (14)
$\gamma_{17,5}$	303.2 (5)	302.52 (6)	302.7 (2)	302.669 (11)	302.65 (5)	302.664 (15)	302.680 (22)
$\gamma_{-1,4}$	-	310.0 (1)	-	-	310.0 (5)	310.0 (1)	310.0 (1) [c]
$\gamma_{17,4}$	313.0 (5)	312.88 (8)	312.9 (3)	-	312.94 (5)	312.92 (5)	313.090 (22)
$\gamma_{16,1}$	-	327.02 (10)	327.2 (4)	327.130 (188)	327.26 (10)	327.14 (10)	327.13 (4)
$\gamma_{15,0}$	330.2 (5)	329.89 (6)	330.0 (2)	330.057 (18)	330.06 (5)	330.045 (22)	330.040 (10)
$\gamma_{17,3}$	341.0 (5)	340.61 (7)	340.8 (2)	-	340.77 (6)	340.71 (6)	340.880 (22)
$\gamma_{18,4}$	-	351.4 (1)	-	-	351.6 (1)	351.50 (10)	351.45 (3)
$\gamma_{16,0}$	-	354.38 (8)	354.6 (2)	354.474 (76)	354.57 (8)	354.48 (8)	354.50 (4)
$\gamma_{17,2}$	356.6 (5)	356.96 (7)	357.2 (2)	-	357.21 (6)	357.10 (7)	357.250 (22)
$\gamma_{17,1}$	-	359.25 (10)	358.6 (4)	-	359.57 (10)	359.39 (15)	359.860 (22)
$\gamma_{20,4}$	364.2 (5)	363.74 (10)	363.9 (4)	-	363.93 (10)	363.84 (10)	363.82 (4)
$\gamma_{-1,5}$	-	374.9 (1)	374.9 (4)	-	375.01 (10)	374.95 (10)	374.95 (10) [c]
$\gamma_{18,3}$	379.5 (5)	379.09 (8)	379.2 (3)	-	379.41 (6)	379.29 (9)	379.24 (3)
$\gamma_{21,5}$	-	384.7 (1)	384.8 (3)	-	384.7 (1)	384.71 (10)	384.69 (6)
$\gamma_{17,0}$	-	387.0 (1)	-	-	-	387.0 (1)	387.230 (20)
$\gamma_{20,3}$	392.5 (5)	391.5 (1)	391.7 (3)	-	391.67 (9)	391.61 (9)	391.61 (4)
$\gamma_{18,2}$	-	395.5 (1)	395.7 (4)	-	395.49 (10)	395.50 (10)	395.61 (3)
$\gamma_{18,1}$	398.4 (5)	398.10 (8)	398.1 (3)	-	398.19 (9)	398.14 (8)	398.22 (3)

	1969La04	1970De17	1970Le11	1979Bo30 [a]	1979Te02	Calculated from experimental data	Recommended values
$\gamma_{19,1}$	408.1 (5)	407.71 (6)	407.7 (3)	407.829 (31)	407.80 (5)	407.802 (31)	407.820 (22)
$\gamma_{20,1}$	410.5 (5)	410.5 (1)	410.3 (10)	-	410.1 (1)	410.30 (12)	410.59 (4)
$\gamma_{22,4}$	-	-	-	-	427.0 (10)	427.0 (10)	427.14 (7)
$\gamma_{19,0}$	-	435.1 (1)	434.9 (8)	-	435.0 (1)	435.05 (10)	435.190 (20)
$\gamma_{20,0}$	437.9 (5)	437.9 (1)	437.9 (8)	-	438.10 (9)	438.01 (9)	437.96 (4)
$\gamma_{-1,6}$	-	438.7 (1)	-	-	438.8 (2)	438.72 (10)	438.72 (10) [c]
$\gamma_{24,4}$	487.2 (5)	486.7 (3)	486.6 (10)	486.827 (27)	486.8 (10)	486.826 (27)	488.66 (10)
$\gamma_{23,3}$	-	491.0 (6)	491 (2)	-	491.0 (10)	491.0 (6)	490.65 (10)
$\gamma_{22,0}$	-	501.6 (5)	501 (1)	-	501.0 (10)	501.4 (5)	501.28 (7)
$\gamma_{23,1}$	-	509 (1)	510 (1)	-	510.0 (10)	509.7 (10)	509.63 (10)
$\gamma_{24,3}$	516.2 (5)	516.2 (6)	516 (1)	-	516.1 (10)	516.2 (5)	516.45 (10)
$\gamma_{24,1}$	-	535.3 (7)	535 (1)	-	-	535.2 (7)	535.43 (10)
$\gamma_{25,6}$	-	546.6 (7)	546 (1)	-	546.6 (10)	546.5 (7)	546.5 (3)
$\gamma_{25,5}$	-	572.1 (8)	571 (2)	-	571.0 (10)	571.6 (8)	571.9 (3)
$\gamma_{25,4}$	-	-	583 (2)	-	-	583 (2)	582.3 (3)
$\gamma_{25,3}$	-	-	609 (2)	-	-	609 (2)	610.1 (3)

a) Uncertainty on energy calibration of detectors was added to published data
b) Obtained from private communication.
c) Unplaced gamma.

Table 2. Experimental and recommended relative gamma-ray emission probabilities.

	E_γ(keV)	P_γ^{rel}					
		1970De19 [a]	**1970Le11**	**1974De11** [a]	**1979Te02**	**1984BAYS** [b]	**Recommended values**
$\gamma_{3,2}$	16.370 (14)	-	-	-	-	13.4 (5)	13.4 (5)
$\gamma_{3,1}$	18.980 (14)	-	-	-	-	76.7 (15)	22.2 (16) [c]
$\gamma_{11,9}$	23.46 (6)	-	-	-	-	-	0.29 (4) [c]
$\gamma_{16,15}$	24.46 (4)	~ 0.59	-	-	0.7 (3)	-	0.30 (6) [c]
$\gamma_{6,5}$	25.390 (22)	~ 5.9	~ 18.75	7.6 (12)	6.9 (10)	16.5 (9)	5.8 (4) [c]
$\gamma_{1,0}$	27.370 (10)	588 (28)	440 (130)	588 (28)	640 (50)	673 (13)	655 (22)
$\gamma_{2,0}$	29.980 (10)	5.8 (5)	6.3 (19)	5.88 (24)	6.5 (5)	5.63 (30)	5.87 (24)
$\gamma_{6,4}$	35.800 (22)	1.00 (12)	0.94 (31)	1.15 (9)	0.94 (5)	-	0.99 (6)
$\gamma_{5,3}$	38.200 (14)	9.4 (9)	6.3 (19)	8.6 (6)	9.4 (5)	8.59 (33)	8.8 (4)
$\gamma_{4,2}$	44.160 (14)	3.8 (4)	2.8 (9)	3.41 (24)	3.77 (40)	2.7 (5)	3.36 (24)
$\gamma_{3,0}$	46.350 (10)	13.18 (12)	8.1 (25)	11.1 (5)	12.97 (64)	10.6 (7)	11.5 (6)
$\gamma_{20,17}$	50.73 (5)	0.09 (4)	-	0.12 (3)	0.3 (1)	-	0.14 (5)
$\gamma_{7,4}$	52.720 (22)	5.4 (5)	3.8 (13)	4.41 (22)	4.85 (34)	5.4 (6)	4.60 (22)
$\gamma_{5,2}$	54.570 (14)	5.1 (5)	3.8 (13)	4.12 (19)	4.33 (35)	4.44 (32)	4.22 (19)
$\gamma_{15,13}$	56.90 (3)	0.35 (6)	-	0.31 (5)	0.27 (4)	-	0.29 (4)
$\gamma_{5,1}$	57.180 (14)	} 2.47 (24)	} 1.9 (6)	} 1.94 (11)	1.58 (16)	} 2.34 (15)	} 2.16 (14)
$\gamma_{17,15}$	57.190 (22)				0.96 (10)		
$\gamma_{9,7}$	60.46 (4)	0.41 (6)	0.19 (13)	0.36 (4)	0.3 (1)	0.29 (5)	0.32 (4)
$\gamma_{6,3}$	63.590 (22)	3.2 (3)	1.9 (6)	2.82 (21)	2.7 (3)	2.70 (9)	2.70 (9)
$\gamma_{-1,1}$	70.49 (5)	0.41 (6)	-	0.29 (6)	0.6 (2)	0.30 (5)	0.31 (5)
$\gamma_{10,7}$	71.85 (5)	0.12 (6)	-	0.12 (4)	0.1 (1)	-	0.12 (4)

	E_γ(keV)	P_γ^{rel}						
		1970De19 [a]	1970Le11	1974De11 [a]	1979Te02	1982An02	1984BAYS [b]	Recommended values
$\gamma_{12,10}$	72.58 (7)	0.24 (12)	-	0.18 (4)	0.2 (1)	-	-	0.18 (4)
$\gamma_{4,0}$	74.140 (10)	1.59 (18)	1.25 (44)	1.41 (12)	1.24 (20)	-	1.35 (5)	1.35 (5)
$\gamma_{9,6}$	77.38 (4)	4.3 (5)	2.5 (6)	3.53 (24)	4.31 (20)	-	3.45 (7)	3.67 (25)
$\gamma_{7,2}$	96.880 (22)	5.6 (6)	4.1 (9)	5.5 (4)	5.62 (28)	-	5.00 (10)	5.08 (14)
$\gamma_{11,6}$	100.84 (5)	2.0 (3)	0.75 (31)	1.35 (12)	1.66 (25)	-	1.38 (4)	1.37 (5)
$\gamma_{9,5}$	102.77 (3)	~ 1.2	2.8 (9)	1.35 (24)	<0.8	-	0.9 (2)	1.13 (25)
$\gamma_{10,4}$	124.57 (4)	0.29 (12)	0.13 (6)	-	0.29 (9)	0.23 (13)	0.259 (24)	0.261 (24)
$\gamma_{12,7}$	144.43 (6)	0.76 (24)	0.25 (13)	-	0.64 (30)	0.70 (6)	0.69 (5)	0.70 (5)
$\gamma_{13,4}$	199.00 (3)	0.35 (12)	0.06 (3)	-	0.23 (10)	0.28 (5)	0.246 (29)	0.18 (7)
$\gamma_{14,4}$	230.59 (5)	-	-	-	0.10 (5)	-	-	0.10 (5)
$\gamma_{-1,2}$	242.18 (8)	0.53 (6)	-	-	0.5 (2)	0.44 (8)	0.70 (4)	0.60 (6)
$\gamma_{13,2}$	243.16 (3)	2.18 (18)	2.5 (6)	-	2.97 (24)	2.51 (43)	1.87 (4)	2.2 (3)
$\gamma_{15,5}$	245.490 (14)	0.47 (6)	0.44 (13)	-	0.48 (12)	0.44 (8)	0.382 (31)	0.41 (3)
$\gamma_{13,1}$	245.77 (3)	-	-	-	0.7 (2)	0.70 (20)	-	0.70 (20)
$\gamma_{15,4}$	255.900 (14)	6.4 (4)	8.1 (13)	-	6.34 (41)	7.00 (48)	6.41 (6)	6.42 (6)
$\gamma_{14,3}$	258.38 (5)	0.15 (4)	-	-	0.15 (5)	0.13 (4)	0.06 (2)	0.093 (24)
$\gamma_{17,7}$	260.37 (3)	10.9 (6)	11.3 (19)	-	11.39 (57)	11.03 (14)	10.97 (10)	11.00 (10)
$\gamma_{13,0}$	273.14 (3)	3.65 (18)	4.4 (9)	-	3.48 (24)	3.48 (18)	3.50 (4)	3.51 (4)
$\gamma_{17,6}$	277.29 (3)	4.24 (24)	5.0 (9)	-	3.88 (25)	4.59 (58)	4.12 (5)	4.12 (5)

	E_γ(keV)	P_γ^{rel}						
		1970De19 [a]	1970Le11	1974De11 [a]	1979Te02	1982An02	1984BAYS [b]	Recommended values
$\gamma_{15,3}$	283.690 (14)	100.0	100.0	100.0	100.0	100.0	100.0 (8)	100.0
$\gamma_{-1,3}$	286.58 (10)	0.59 (6)	-	-	0.8 (3)	0.68 (10)	0.632 (30)	0.63 (3)
$\gamma_{15,2}$	300.060 (14)	144 (8)	144 (13)		149.6 (75)	143.2 (55)	146.3 (13)	146.2 (13)
$\gamma_{15,1}$	302.670 (14)	} 148 (8)	} 144 (13)	} 294 (8)	100 (10)	138 (20)	} 149.6 (12)	} 149.4 (12)
$\gamma_{17,5}$	302.680 (22)				40 (5)	10.6 (26)		
$\gamma_{-1,4}$	310.0 (1)	0.088 (29)	-	-	0.07 (3)	0.03 (2)	0.058 (12)	0.056 (12)
$\gamma_{17,4}$	313.090 (22)	6.0 (4)	6.9 (13)	-	7.05 (56)	5.93 (17)	5.97 (5)	5.98 (5)
$\gamma_{16,1}$	327.13 (4)	1.88 (12)	2.5 (13)	-	2.27 (28)	2.19 (44)	2.22 (4)	2.19 (5)
$\gamma_{15,0}$	330.040 (10)	82.4 (41)	81 (13)	82.4 (29)	81.9 (65)	82.1 (12)	82.4 (7)	82.3 (7)
$\gamma_{17,3}$	340.880 (22)	10.5 (5)	10.0 (25)	-	10.9 (13)	10.62 (16)	10.80 (9)	10.75 (9)
$\gamma_{18,4}$	351.45 (3)	0.224 (24)	-	-	0.15 (6)	0.44 (7)	0.102 (4)	0.17 (7)
$\gamma_{16,0}$	354.50 (4)	6.00 (35)	6.3 (13)	-	5.07 (56)	5.92 (16)	5.81 (6)	5.83 (6)
$\gamma_{17,2}$	357.250 (22)	10.9 (6)	9.4 (19)	-	9.67 (82)	10.35 (46)	10.14 (9)	10.16 (9)
$\gamma_{17,1}$	359.860 (22)	0.57 (5)	0.38 (19)	-	0.41 (18)	0.42 (8)	0.512 (14)	0.512 (14)
$\gamma_{20,4}$	363.82 (4)	0.47 (4)	0.38 (19)	-	0.42 (15)	0.45 (5)	0.488 (14)	0.483 (14)
$\gamma_{-1,5}$	374.95 (10)	0.294 (24)	0.19 (6)	-	0.24 (10)	0.21 (3)	0.282 (15)	0.270 (16)
$\gamma_{18,3}$	379.24 (3)	3.12 (24)	2.5 (9)	-	2.89 (23)	2.96 (10)	3.03 (4)	3.02 (4)
$\gamma_{21,5}$	384.69 (6)	0.259 (24)	0.13 (6)	-	0.18 (4)	0.18 (5)	0.221 (12)	0.221 (13)
$\gamma_{17,0}$	387.230 (20)	0.029 (12)	-	-	-	0.01 (1)	0.018 (6)	0.018 (6)

	E_γ(keV)	P_γ^{rel}					
		1970De19 [a]	1970Le11	1979Te02	1982An02	1984BAYS [b]	Recommended values
$\gamma_{20,3}$	391.61 (4)	0.43 (4)	0.31 (13)	0.52 (8)	0.35 (5)	0.408 (11)	0.408 (11)
$\gamma_{18,2}$	395.61 (3)	0.165 (18)	0.06 (3)	0.11 (2)	0.12 (2)	0.148 (10)	0.137 (13)
$\gamma_{18,1}$	398.22 (3)	0.59 (5)	0.44 (19)	0.49 (9)	0.49 (12)	0.574 (14)	0.572 (14)
$\gamma_{19,1}$	407.820 (22)	2.29 (18)	1.3 (6)	2.13 (18)	2.07 (16)	2.156 (24)	2.160 (24)
$\gamma_{20,1}$	410.59 (4)	0.118 (12)	0.06 (3)	0.19 (4)	0.21 (6)	0.099 (11)	0.109 (13)
$\gamma_{22,4}$	427.14 (7)	-	-	0.04 (2)	-	-	0.04 (2)
$\gamma_{19,0}$	435.190 (20)	0.212 (24)	0.125 (60)	0.12 (3)	0.18 (1)	0.177 (10)	0.178 (10)
$\gamma_{20,0}$	437.96 (4)	0.259 (24)	0.25 (13)	0.20 (6)	0.28 (3)	0.283 (16)	0.273 (16)
$\gamma_{-1,6}$	438.72 (10)	0.094 (24)	-	0.07 (2)	-	-	0.080 (20)
$\gamma_{24,4}$	488.66 (10)	0.112 (24)	0.063 (30)	0.15 (5)	0.10 (3)	0.091 (9)	0.100 (10)
$\gamma_{23,3}$	490.65 (10)	0.0294	0.006	< 0.04	0.04 (2)	0.023 (6)	0.024 (6)
$\gamma_{22,0}$	501.28 (7)	0.035 (12)	0.0125	0.05 (2)	0.07 (7)	0.053 (11)	0.046 (11)
$\gamma_{23,1}$	509.63 (10)	0.018 (6)	0.031	0.05 (2)	0.10 (4)	-	0.022 (10)
$\gamma_{24,3}$	516.45 (10)	0.082 (18)	0.050	0.06 (2)	0.06 (2)	0.093 (9)	0.083 (9)
$\gamma_{24,1}$	535.43 (10)	0.029 (12)	0.031	0.05 (2)	0.04 (2)	0.038 (7)	0.037 (6)
$\gamma_{25,6}$	546.5 (3)	0.035 (12)	0.025	0.04 (2)	0.06 (2)	0.056 (8)	0.050 (8)
$\gamma_{25,5}$	571.9 (3)	0.029 (12)	0.019	0.04 (2)	0.02 (2)	-	0.029 (12)
$\gamma_{25,4}$	582.3 (3)	-	0.019	-	0.26 (1)	-	0.019 (10) [d]
$\gamma_{25,3}$	610.1 (3)	-	0.031	-	0.43 (2)	-	0.031 (20) [d]

a) Same author for both publications - data from (1974De11) used when available.
b) Data originally published as 1983Banham, then as private communication (1984BAYS) within 1986LoZT.
c) Calculated from balance of decay scheme.
d) Values taken from 1970Le11; uncertainties were evaluated.

^{233}Pa - Comments on evaluation of decay data by V. P. Chechev and K. N. Kuzmenko

This evaluation was done originally in September 2004, corrected in December 2004 and in March 2006, and then updated in April 2009 with a literature cut-off by the same date.

1 Decay Scheme

The decay scheme is based on the experimental results of Kouassi et al. (1990Ko41) and NDS evaluations of 1990Ak02 and 2005Si15. In addition to the nuclear transitions well studied (1990Ak02), Singh and Tuli (2005Si15) list a large number of weak transitions and γ rays from unpublished work of de Bettencourt (1985DeZR), defining them as tentative. Latter ones have not been considered in this evaluation. The list of the tentative gamma rays is given in section 5.2.1. These gamma rays carry ≤ 1,2 % of the total intensity of all the gamma rays placed in the decay scheme.

2 Nuclear Data

Q^- value is from 2003Au03.

The recommended half-life of ^{233}Pa is based on the experimental results given in Table 1.

Table 1. Experimental values of ^{233}Pa half-life (in days)

Reference	Author(s)	Value	Measurement method
1941Gr03	Grosse et al.	27,4 (4)	β-counting
1956Mc60	Mc Isaac and Freiling	27,0 (1)	4πγ ionization chamber (4 $T_{1/2}$) and β proportional counter (2 $T_{1/2}$)
1957Wr37	Wright et al.	26,95 (6)	Gamma ionization chamber and β proportional counter (2 $T_{1/2}$)
1986Jo07	Jones et al.	26,967 (2)	Gamma ionization chamber (11 $T_{1/2}$)
1999Popov	Popov and Timofeev	26,9 (1)	Ge(Li) γ-ray spectrometer
2000Us01	Usman and MacMahon	27,02 (3)	HPGe gamma-ray spectrometer (8 gamma lines, 5 $T_{1/2}$)

The weighted mean of the six values from Table 1 of 26,967 (2) is dominated by the very accurate value from 1986Jo07. The LWEIGHT computer program uses a limitation of relative statistical weights (LRSW method), and increased the uncertainty of 1986Jo07 from 0,002 to 0,025 to give a weighted mean of 26,984 (18). The evaluation technique from 2000Ch01 also uses the LRSW method and some additional criteria to give the same value of 26,984 (18).The Rajeval data evaluation technique (1992Ra08) uses different criteria to adjust the uncertainties, and has increased the uncertainties of 1986Jo07 and 2000Us01 to give the same value of 26,984 (18).

Huang et al. (2005Hu06) used the analogous procedures for their statistical analysis, and adopted the mean of the normalized residuals and Rajeval technique to give the value for the ^{233}Pa half-life of 26,971 (13) d. However, they did not take into account the measurement of Popov and Timofeev (1999).

Thus, taking into account the accuracy of most of the available measurements, the best estimate of the ^{233}Pa half-life is believed to be a recommended value of 26,98 (2) days.

2.1 b- Transitions

The energies of β^- transitions have been obtained from the Q^- value and the ^{233}U level energies given in Table 2 from 2005Si15.

Table 2. ^{233}U levels populated in ^{233}Pa β^--decay

Level	Energy (keV)	Spin and Parity	Half-life	Probability of β^- transitions (%)
0	0,0	$5/2^+$	1,592 (2) × 10^5 a	6,3 (23)
1	40,350 (4)	$7/2^+$	0,11 (8) ns	0,3 (19)
2	92,16 (4)	$9/2^+$		
3	298,810 (4)	$5/2^-$		0,12 (5)
4	301,94 (9)	$5/2^-$		0,010 (2)
5	311,904 (4)	$3/2^+$	0,120 (15) ns	26,6 (32)
6	320,83 (4)	$7/2^-$		0,020 (3)
7	340,477 (4)	$5/2^+$	52 (10) ps	25,9 (32)
8	380,43 (8)	$7/2^+$		0,020 (3)
9	398,496 (4)	$1/2^+$	55 (20) ps	15,4 (8)
10	415,758 (4)	$3/2^+$	≤ 30 ps	25,4 (16)
11	456,114 (6)	$5/2^+$		0,0011 (2)

The recommended probabilities of β^--transitions have been deduced from the P(γ+ce) balance at each level of ^{233}U.

The accurate sum of intensities of β^--transitions to the ground and first excited states $[P(\beta_{0,0})+P(\beta_{0,1})]\times100$ has been deduced as (100 % – $\Sigma P_{i,j}$ (γ+ce)(j=0,1,2)), where the latter value includes only the intensities of the gamma-ray transitions feeding the ground state and the 40,3- and 92,2-keV levels. The 92,2-keV level ($9/2^+$) cannot be fed directly in the β^- decay of ^{233}Pa ground state ($3/2^-$). This forbiddenness allows the accurate combine β^- intensity of the $\beta_{0,0}$ and $\beta_{0,1}$ transitions to be evaluated as 100 % – 93,4 (22) % = 6,6 (22) % to be compared with a value of 8,8 (14) % as measured by Browne et al. (1989Br24) and deduced from the decay scheme in 1990Ko41 (6,9 (15) %) and in 2005Hu06 (7,4 (6) %), respectively.

Measured and recommended β^--transition energies and probabilities are given in Tables 3 and 4, respectively.

Table 3. Measured and recommended energies of β^- transitions (keV)

	1954Br37	1955On05	1960Un01	1963Bj03	Recommended
$\beta_{0,10}$	140 (14)	145 (10)	155 (7)	154 (5)	154,3 (20)
$\beta_{0,9}$			175 (8)		171,5 (20)
$\beta_{0,5}$	256 (4)	257 (5)	250 (5)	254 (5)	258,2 (20)
$\beta_{0,0}$	568 (5)	568 (5)		578 (10)	570,1 (20)

Table 4. Measured and evaluated probabilities (%) of β^- transitions

	1954Br37	1955On05	1963Bj03	Evaluated
$\beta_{0,10}$	50	37	32	25,4 (16)
$\beta_{0,5}$	45	58	56	26,6 (32)
$\beta_{0,0}$	5	5	12	6,3 (23)

2.2 Gamma-Ray Transitions and Internal Conversion Coefficients

The recommended energies of gamma-ray transitions are virtually the same as the gamma-ray energies because nuclear recoil is negligible.

The gamma-ray transition probabilities have been obtained from the gamma-ray emission probabilities and the total internal conversion coefficients (ICCs). Multipolarities of gamma-ray transitions have been taken from 2005Si15. The ICCs have been interpolated using the BrIcc package with the so called "*Frozen Orbital*" approximation (2008Ki07). The relative uncertainties of α_K, α_L, α_M, α_T for pure multipolarities have been taken as 2 %.

E2 admixtures for M1+E2 gamma-ray transitions in ^{233}Pa decay were determined in a whole number of measurements (see Table 5).

For the ICC evaluation the E2 admixture of 0,0166 from 1962Sc03 has been used for the gamma ray of 17,2-keV ($\gamma_{10,9}$). The best set of E2/M1 mixing ratios obtained by Krane (1986Kr10) from the angular correlation measurements has been used to determine the ICCs for the gamma rays of 28,6-keV ($\gamma_{7,5}$), 75,3-keV ($\gamma_{10,7}$), 86,6-keV ($\gamma_{9,5}$), and 103,9-keV($\gamma_{10,5}$), respectively. This set agrees mainly with the conversion electron data from 1961Al19, 1962Sc03, 1963Bi03, 1966Ze02, 1973Va33, 1985DeZR, 1988Wo01, and 1990Pe16 (Table 5). Use of the BrIcc package for correction of the above conversion electron data does not change this conclusion.

The evaluators have adopted the value of 0,54 (4) from 1962Sc03 for the 40,3-keV gamma ray ($\gamma_{1,0}$) E2 admixture that coincides with the values obtained by Zender (1966Ze02) and Krane (1986Kr10). This ratio produces a better P(γ+ce) balance for the 40,3-keV level ("1"). If the smaller value of 0,3 reported by Albridge et al. (1961 Al19) and Bisgard et al. (1963 Bi03) was used, the intensity of the β^- transition to the level "1" would have been negative (2006Ch39).

The ICC values measured by Browne et al. (1989Br24) have been adopted for the most intense, predominantly M1, 300,1- ($\gamma_{7,1}$), 311,9- ($\gamma_{5,0}$), and 340,5-keV ($\gamma_{7,0}$) transitions affected by nuclear penetration effects.

The E2/M1 mixing ratio $\delta \approx 0,62$ has been taken from 2005Si15 for the gamma ray of 51,8-keV ($\gamma_{2,1}$).

Table 5. Experimental and recommended E2 γ-ray admixtures

Eγ (keV)	1961 Al19	1962 Sc03	1963 Bi03	1966 Ze02	1986 Kr10	1973 Va33	1985 DeZR	1988 Wo01	1990 Pe16	Recommended admixture & δ
28,6	0,030 (5)	0,0102 (8)	0,02 (1)	0,024 (2)	0,0244 (15)	0,02	0,019 (2)	0,03 (1)	0,022 (3)	0,0244 (15) δ 0,158 (10)
40,3	0,30 (10)	0,54 (4)	0,31 (2)	0,54 (5)	0,54 (8)	0,43	0,46 (5)			0,54 (4) δ 1,08 (12)
75,3	0,01 (1)	< 0,0005	0	< 0,005	0,022 (16)	0	0,008 (4)	0		0,022 (16) δ 0,15 (8)
86,6	0,020 (5)	< 0,002	0,01 (1)	< 0,006	0,0031 (3)	0,01	0,0049 (7)	0,046 (27)		0,0031 (3) δ 0,056 (5)
103,9	0,04 (1)	< 0,03	0,01 (1)	0,020 (15)	0,010 (14)	0,01	0,022 (2)	0,073 (9)		0,010 (14) δ 0,1 (1)
300,1	0,12 (10)	0,03	0	0	0,006 (2)	0	0,025 (3)	0		0,006 (2) δ 0,08 (3)
311,9	< 0,02	< 0,03	0	< 0,016	0,010 (1)	0	0,063 (6)	0		0,010 (1) δ 0,10 (1)
415,8	0,82 (7)	0,96 (4)	0,78 (11)	0,76 (8)		0,84				0,83 (7) δ 2,2 (9)

[a] Weighted average of 1961Al19, 1962Sc03, 1963Bi03, and 1966Ze02.

3 Atomic Data

The atomic data are from Schönfeld (1996Sc06).

4 Electron Emissions

The energies of the conversion electrons have been obtained from the gamma transition energies and the electron binding energies.

The emission probabilities of the conversion electrons have been deduced using evaluated P_γ and ICC values.

The absolute emission probabilities of K Auger electrons have been deduced using the $P(ce_K)$ values and the adopted ω_K given in section 3.

The absolute emission probabilities of L Auger electrons have been deduced using the $P(ce_K)$ and $P(ce_L)$ values and the adopted ϖ_L, n_{KL} given in section 3.

β^- average energies have been calculated using the LOGFT computer program.

5 Photon emissions

5.1 X-ray emissions

The absolute emission probabilities of U KX-rays have been deduced using the adopted value of ω_K (U) and the total evaluated absolute emission probability of K conversion electrons in the ^{233}Pa→^{233}U decay. In Table 6 the deduced values are compared to measured results. The total absolute U KX-ray emission probability of 30,7 (9) % agrees with the experimental values of 29,3 (28) % from 2008De10 and 30,0 (4) % from 2004Sh07.

The absolute emission probabilities of U LX-rays have been calculated with the EMISSION computer program using the adopted values of ϖ_L (U), ω_K (U), n_{KL} (U) and the evaluated absolute emission probabilities of L_1, L_2, L_3-, and K- conversion electrons in ^{233}Pa β^--decay.

As authors of 2008De10 quote only statistical uncertainties for their intensity values, the evaluators have considered additionally a contribution of possible systematic errors to obtain the overall uncertainties in the absolute photon intensities. This contribution was estimated on the basis of detection efficiency uncertainties for γ-ray spectroscopy discussed in 2008De10: 1 % for U KX-ray emission probabilities and 20 % for U LX-ray emission probabilities.

Table 6. Experimental and recommended (calculated) absolute U KX- ray emission probabilities in decay of ^{233}Pa

	Energy (keV)	1979 Ge08	1984Va28	1990Ko41	2000 Smith	2000Sc04	2002Lu01	2004Sh07	2008De10	Recom-mended (calculated)
$K\alpha_2$	94,666	8,8 (5)	8,8 (4)	8,3 (4)		8,78 (10)	8,77 (9)	8,78 (10)	8,50 (14)	9,10 (26)
$K\alpha_1$	98,440	14,4 (8)	14,3 (5)	13,4 (7)	14,3 (3)	14,4 (4)	14,17 (14)	14,22 (17)	14,02 (24)	14,6 (4)
$K\beta_3$	110,421	} 5,2 (3)	1,78 (9)	1,60 (8)	1,89 (4)	1,90 (5)	1,708 (25)	1,708 (38)	1,694 (31)	} 5,25 (18)
$K\beta_1$	111,298		3,27 (15)	3,11 (15)			3,35 (5)	3,34 (8)	3,24 (6)	
$K\beta_5$	111,964			0,15 (1)			0,1230 (17)	0,1239 (28)	0,139 (18)	
$K\beta_2$	114,407 (11)	} 1,74 (8)	} 1,71 (8)	0,52 (7)	} 1,73 (8)	} 1,59 (9)	1,293 (23)	1,34 (5)	} 1,317 (21)	} 1,49 (10)
$K\beta_4$	115,012			0,78 (7)			0,0380 (6)	0,0388 (13)		
$KO_{2,3}$	115,377			} 0,39 (2)		0,332 (10)	} 0,391 (9)	} 0,399 (18)	} 0,406 (11)	} 0,31 (7)
$KP_{2,3}$	115,580									

Table 7. Experimental and recommended (calculated) absolute U XL- ray emission probabilities in decay of ^{233}Pa

	Energy (keV)	2000Sc04	2004Sh07	2008De10	Recommended (calculated)
Ll	11,62	1,18 (7)	0,78 (11)	1,19 (25)	1,05 (4)
Lα	13,93	15,7 (7)	12,7 (13)	21,5 (43)	16,9 (6)
Lβ	15,73-17,45			16,9 (34)	18,1 (6)
$L\gamma_1$	20,17-20,84			3,2 (6)	2,25 (13)

5.2 Gamma-ray emissions

The energies of gamma rays have been taken from 1990Ko41 (see also 2005Si15) except for $\gamma_{10,9}$(17,26 keV) and $\gamma_{2,0}$(92,16 keV) which were deduced from the adopted ^{233}U levels. A comparison of the recommended γ-ray energies with early experimental results is given in Table 8.

In Table 9 the experimental and recommended absolute gamma ray emission probabilities (Pγ) are presented. All the values given in Table 8 given in Table 9 are absolute measurement results (per 100 disintegrations).

The original values from 1973Va33 and 1990Ko41 have been renormalized by the evaluators to $P\gamma_{2,0}$ (311,9 keV) = 38,3 (5). Values given in the last column are weighted averages (LRSW) of individual results taking into account the LRSW procedure and sometimes increasing the uncertainty to cover the most precise input value (2006Ch39).
$P\gamma_{10,9}$(17,26 keV) = 0,0041 has been deduced from the value of Pce(M1) = 0,0054 (1962Sc03) and the ICC value of α_{M1} = 132,3 (1993Ba60) calculated for this conversion line using an E2/M1 admixture of 0,016 (δ=0,13) from 1990Ak02.

$P\gamma_{2,1}$(51,8 keV) and $P\gamma_{2,0}$ (92,2 keV) have been obtained from the P(γ+ce) balance at the 92,2-keV level and the ratio $P\gamma_{2,1}/P\gamma_{2,0}$ = 0,21 (4) taken from 1990Ak02.

The contribution of 1 % estimated on the basis of detection efficiency uncertainty for γ-ray spectroscopy discussed in 2008De10 has been added to the overall uncertainties for the recommended γ-ray emission probabilities.

Table 8. Experimental and recommended gamma-ray energies in decay of ^{233}Pa, in keV

	1952Br84	1961Al19	1967Br20	1968Ma13	1971Vo02	1972De67	1973Va33	1988Wo01	1990Ko41	Recommended
$\gamma_{10,9}$						17,2 (1)				17,262 (6)
$\gamma_{7,5}$	28,67 (2)					28,6 (1)		28,375 (5)	28,559 (10)	28,559 (10)
$\gamma_{1,0}$	40,47 (10)	40,35 (1)				40,5 (1)			40,349 (5)	40,349 (5)
$\gamma_{7,3}$		41,65 (2)							41,663 (10)	41,663 (10)
$\gamma_{10,7}$	75,4 (2)	75,28 (1)				75,27 (3)		75,354 (4)	75,269 (10)	75,269 (10)
$\gamma_{9,5}$	87,0 (3)	86,59 (1)				86,58 (3)		86,814 (3)	86,595 (10)	86,595 (5)
$\gamma_{2,0}$							92,0 (5)		92,1 (5)	92,16 (4)
$\gamma_{10,5}$		103,86 (2)						103,971 (9)	103,860 (10)	103,860 (10)
$\gamma_{6,2}$									228,57 (5)	228,57 (5)
$\gamma_{7,2}$			248,3 (3)	248,69 (24)			248,0 (2)		248,38 (4)	248,38 (4)
$\gamma_{3,1}$							258,292)		258,45 (2)	258,45 (2)
$\gamma_{5,1}$		271,62 (23)			271,48 (8)				271,555 (10)	271,555 (10)
$\gamma_{6,1}$									280,61 (5)	280,61 (5)
$\gamma_{8,2}$									288,42 (10)	288,42 (10)
$\gamma_{3,0}$									298,81 (2)	298,81 (2)
$\gamma_{7,1}$		300,20 (24)						300,34 (2)	300,129 (5)	300,129 (5)
$\gamma_{4,0}$									301,99 (10)	301,99 (10)
$\gamma_{5,0}$		311,91 (13)						312,17 (12)	311,904 (5)	311,904 (5)

	1952Br84	1961Al19	1967Br20	1968Ma13	1971Vo02	1972De67	1973Va33	1988Wo01	1990Ko41	Recommended
$\gamma_{6,0}$									320,73 (10)	320,73 (10)
$\gamma_{7,0}$		340,51 (18)						340,81 (3)	340,476 (5)	340,476 (5)
$\gamma_{10,1}$		375,35 (32)			375,45 (4)				375,404 (5)	375,404 (5)
$\gamma_{8,0}$									380,28 (10)	380,28 (10)
$\gamma_{9,0}$		398,57 (40)			398,62 (8)				398,492 (5)	398,492 (5)
$\gamma_{10,0}$		415,87 (42)			415,76 (4)				415,764 (5)	415,764 (5)
$\gamma_{11,0}$									455,96 (10)	455,96 (10)

Table 9. Experimental and recommended absolute gamma-ray emission probabilities (%) in decay of ^{233}Pa, in %.

Eγ (keV)	1973Va33	1978Poenitz	1979Ge08	1984Va27	1985DeZR	1988Wo01	1990Ko41	2000Wo01	2000Sc04	2002Lu01 2000Lu01	2004Sh07	2006Ha53	2008De10	Recommended
17,2														
28,56	0,069 (8)			0,15 (1)	0,096 (35)	0,068 (9)	0,074 (8)			0,034 (10)	0,019 (2)			0,071 (8) [a]
40,35	0,039 (8)						0,024 (4)	0,0215 (16)		0,028 (4)	0,032 (4)			0,024 (2)
41,66	0,013 (4)						0,014 (3)							0,014 (3)
75,27	1,25 (8)		1,39 (8)	1,30 (4)		1,25 (9)	1,25 (9)	1,401 (25)	1,38 (4)	1,270 (8)				1,30 (3)
86,60	1,87 (23)		1,97 (12)			1,87 (25)	1,93 (11)			2,61 (23)				1,99 (10)
92,1	< 0,004						< 0,002							0,002 (1)
103,86	0,73 (8)		0,87 (3)	0,87 (3)		0,73 (9)	0,847 (60)	0,853 (8)	0,844 (17)	0,855 (6)	0,825 (25)			0,853 (6)
228,57					0,0058 (8)		0,0042 (7)							0,0042 (7)

Eγ (keV)	1973Va33	1978Poenitz	1979Ge08	1984Va27	1985DeZR	1988Wo01	1990Ko41	2000Wo01	2000Sc04	2002Lu01 2000Lu01	2004Sh07	2006Ha53	2008De10	Recommended
248,38	0,0039 (12)		0,059 (2)	0,06 (1)			0,058 (4)	0,0607 (12)	0,0618 (11)	0,057 (6)				0,0609 (11)
258,45	0,0039 (16)				0,031 (4)		0,027 (2)		0,0274 (6)					0,0274 (6)
271,56	0,30 (3)		0,33 (1)	0,32 (1)			0,334 (17)	0,3227 (29)	0,323 (4)	0,323 (5)	0,290 (56)			0,323 (3)
280,61					0,0116 (13)		0,011 (2)							0,011 (2)
288,42					0,0164 (5)		0,016 (3)							0,016 (3)
298,81	0,035						0,085 (7)			0,147 (29)				0,12 (5)
300,13	6,57 (31)		6,62 (10)	6,64 (6)		6,57 (46)	6,76 (7)	6,66 (6)	6,55 (7)	6,39 (6)			6,47 (8)	6,60 (21)
301,99					0,027 (4)		0,010 (2)							0,010 (2)
311,90		38,6 (15)	38,6 (5)	38,65 (39)				38,7 (4)	38,5 (4)	37,80 (23)	37,5 (24)	41,6 (9)	38,08 (51)	38,3 (5)
320,73					0,039 (12)		0,0051 (4)							0,0051 (4)
340,48	4,47 (46)		4,47 (6)	4,52 (5)		4,48 (51)		4,52 (4)	4,50 (5)	4,41 (3)	4,36 (44)		4,436 (56)	4,47 (3)
375,40			0,68 (1)	0,69 (1)				0,690 (6)	0,686 (7)	0,687 (6)	0,58 (8)			0,684 (7)
380,28					0,0039 (8)		0,0037 (9)							0,0037 (9)
398,49			1,39 (2)	1,43 (2)				1,407 (11)	1,406 (15)	1,39 (1)	1,33 (10)			1,408 (14)
415,76			1,74 (2)	1,74 (2)				1,771 (14)	1,765 (18)	1,740 (7)	1,59 (10)		1,724 (23)	1,747 (7)
455,96							0,0011 (2)							0,0011 (2)

[a] Weighted average of the values from 1988Wo01 and 1990Ko41 (see discussion in 2006Ch39).

5.2.1 Tentative gamma-ray

This section is given only for information on measurements done in the thesis of 1985DeZR. These results require confirmation and do not consider for evaluation (as well as by Singh and Tuli in Nucl. Data Sheets (2005Si05)).

Energy (keV)	Pγ (%)	Level energy (keV)
18,7 (2)	0,023 (8)	320,83
18,7 (2)	0,023 (8)	330,67
19,7 (2)	0,046 (15)	340,478
22,0 (3)		320,83
23,9 (2)	0,0031 (12)	344,56 ?
24,7 (2)	0,0031 (12)	571,36 ?
28,7 (1)		330,67
31,9 (2)	0,0023 (8)	330,67
35,3 (2)	0,0015 (4)	432,81 ?
35,8 (2)	0,0019 (8)	380,48
38,5 (2)	0,0032 (12)	340,478
38,5 (2)	0,0031 (12)	392,25 ?
39,9 (3)		380,48
40,4 (1)		432,81 ?
40,4 (1)		494,75 ?
40,7 (3)		456,113
40,7 (3)		496,65 ?
41,7 (1)	< 0,019	432,81 ?
42,7 (2)	0,0019 (8)	344,56 ?
45,8 (2)	≈ 0,0004	344,56 ?
46,7 (2)	≈ 0,0008	391,09 ?
47,7 (2)	≈ 0,0008	392,25 ?
48,8 (2)	≈ 0,0008	393,33 ?
48,8 (2)	≈ 0,0008	475,69 ?
49,7 (2)	≈ 0,0008	380,48
51,8 (2)	0,0012 (4)	353,71 ?
51,8 (2)	0,0012 (4)	392,25 ?
52,5 (2)	≈ 0,0008	393,33 ?
52,5 (2)	≈ 0,0008	432,81 ?
53,2 (2)	0,0012 (4)	397,71 ?
55,0 (2)	≈ 0,0008	353,71 ?
58,0 (2)	0,0012 (4)	398,495
59,2 (2)	≈ 0,0008	563,00 ?
59,6 (2)	0,0008 (8)	380,48
60,6 (2)	≈ 0,008	391,09 ?
60,6 (2)	≈ 0,008	414,37 ?
60,6 (2)	≈ 0,008	441,20 ?
61,6	≈ 0,0008	392,25 ?
61,6	≈ 0,0008	494,75 ?
63,2 (2)	≈ 0,0004	155,35 ?
63,2 (2)	≈ 0,0004	454,29 ?
63,6 (2)	≈ 0,0008	496,65 ?
65,5 (2)	0,0027 (8)	410,13 ?
66,4 (2)	0,0019 (8)	570,27 ?
67,5 (2)	0,0019 (8)	571,36 ?
68,5 (2)	0,0027 (8)	380,48

Energy (keV)	Pγ (%)	Level energy (keV)
69,6 (2)	0,0046 (12)	410,13 ?
70,3 (2)	0,0027 (8)	391,09 ?
71,3 (2)	0,0039 (12)	392,25 ?
71,3 (2)	0,0039 (12)	565,90 ?
74,0 (2)	0,0035 (8)	414,37 ?
74,4 (2)		229,79 ?
75,3 (1)		456,113
75,3 (1)		473,04 ?
77,0 (2)	0,0019 (8)	388,68 ?
77,0 (2)	0,0019 (8)	397,71 ?
77,9 (2)	≈ 0,0012	475,69 ?
78,4 (2)	0,0077 (19)	380,48
79,1 (3)	≈ 0,0008	432,81 ?
80,8 (2)	0,0015 (4)	473,04 ?
81,8 (2)	0,0015 (4)	380,48
81,8 (2)	0,0015 (4)	393,33 ?
81,8 (2)	0,0015 (4)	473,04 ?
82,5 (2)	0,0015 (4)	427,08 ?
84,8 (2)	< 0,0131	475,69 ?
85,2	< 0,0131	315,06 ?
85,2	< 0,0131	415,758
86,6 (1)		388,68 ?
86,6 (1)		427,08 ?
87,5 (3)		441,20 ?
89,0 (3)	< 0,0147	391,09 ?
89,3 (3)	< 0,0147	410,13 ?
90,0 (2)	0,0012 (4)	388,68 ?
91,0 (2)	0,0012 (4)	546,83
91,5 (2)	0,0012 (4)	393,33 ?
92,2 (2)	0,0035 (12)	391,09 ?
92,5 (2)		432,81 ?
92,7 (2)	0,0012 (8)	473,04 ?
93,0 (2)	< 0,0015	565,90 ?
93,5 (2)	< 0,0015	414,37 ?
94,5 (3)		393,33 ?
94,5 (3)		570,27 ?
95,3 (3)		475,69 ?
95,3 (3)		571,36 ?
96,7 (2)	0,0040 (12)	441,20 ?
97,0 (2)	0,0050 (12)	494,75 ?
98,0 (2)		410,13 ?
100,6 (2)	0,0031 (12)	454,29 ?
102,1 (2)	0,0019 (4)	432,81 ?
102,5 (2)	0,0023 (8)	414,37 ?
102,5 (2)	0,0023 (8)	494,75 ?
103,8 (1)		494,75 ?
104,5 (3)		496,65 ?

Energy (keV)	Pγ (%)	Level energy (keV)
105,7 (3)	≈ 0,0008	496,65 ?
106,3 (2)	0,0008	427,08 ?
106,3 (2)	0,0008	503,90 ?
108,1 (2)	0,0012 (4)	410,13 ?
110,0 (3)		565,90 ?
111,5 (3)		410,12 ?
112,1 (3)		432,81 ?
112,4 (3)		414/37 ?
113,0 (3)	0,0035 (12)	503,90 ?
114,9 (3)		155,35 ?
115,3 (3)		427,08 ?
115,3 (3)		456,113
116,5 (3)	0,0058 (8)	496,65 ?
116,9 (1)	0,0058 (8)	415,758
119,6 (2)	≈ 0,0008	473,04 ?
122,0 (2)	0,0015 (4)	475,69 ?
125,1 (3)	0,0015 (4)	427,08 ?
125,1 (3)	0,0015 (4)	456,113
128,3 (2)	0,0012 (4)	427,08 ?
130,0 (2)	0,0012 (4)	571,36 ?
131,0 (2)	0,0015 (4)	475,69 ?
131,0 (2)	0,0015 (4)	546,83
132,9 (2)	0,0012 (4)	565,90 ?
135,2 (3)	0,0023 (8)	456,113
135,2 (3)	0,0023 (8)	475,69 ?
135,8 (2)	0,0015 (4)	563,00 ?
136,5 (2)	0,0019 (8)	546,83
139,3 (2)	0,0023 (8)	441,20 ?
139,3 (2)	0,0023 (8)	454,29 ?
142,7 (2)	0,0023 (8)	496,65 ?
143,1 (2)	0,0015 (4)	570,27 ?
144,4 (2)	0,0035 (8)	456,113
144,4 (2)	0,0035 (8)	571,36 ?
148,5 (2)	0,0027 (8)	546,83
150,5 (2)	0,0023 (8)	503,90 ?
153,7 (2)	0,0039 (8)	546,83
154,7 (2)	0,0023 (4)	475,69 ?
154,7 (2)	0,0023 (4)	546,83
156,1 (2)	0,0023 (8)	496,65 ?
157,0 (2)	0,0027 (8)	571,36 ?
157,9 (2)	0,0023 (8)	473,04 ?
159,1 (2)	0,0039 (8)	503,90 ?
160,0 (2)	0,0031 (8)	570,27 ?
161,2 (2)	0,0027 (8)	571,36 ?
162,4 (2)	0,0023 (8)	392,25 ?
163,3 (2)	0,0023 (8)	503,90 ?
166,6 (3)	0,0012 (4)	546,83
168,0 (2)	0,0031 (8)	397,71 ?
170,6 (2)	0,0050 (8)	563,00 ?
172,8 (2)	0,0027 (8)	503,90 ?
173,7 (2)	0,0042 (12)	475,69 ?
173,7 (2)	0,0042 (12)	565,90 ?

Energy (keV)	Pγ (%)	Level energy (keV)
174,7 (2)	0,0042 (12)	565,90 ?
175,2 (2)	0,0012 (4)	330,67
178,0 (2)	0,0027 (8)	570,27 ?
178,0 (2)	0,0027 (8)	571,36 ?
180,1 (2)	0,0027 (8)	571,36 ?
182,7 (2)	0,0027 (8)	571,36 ?
183,3 (3)	0,0012 (4)	503,90 ?
184,8 (2)	0,0031 (8)	496,65 ?
185,7 (3)	0,0035 (8)	565,90 ?
198,5 (2)	0,0031 (8)	353,71 ?
202,1 (2)	0,0031 (8)	503,90 ?
202,1 (2)	0,0031 (8)	546,83
205,3 (2)	0,0031 (8)	503,90 ?
206,4 (2)	0,0027 (8)	546,83
209,2 (2)	0,0023 (8)	563,00 ?
215,8 (2)	0,0027 (8)	546,83
217,8 (2)	0,0031 (8)	571,36 ?
224,4 (2)	0,0023 (8)	454,29 ?
225,2 (2)	0,0046 (12)	380,48
225,2 (2)	0,0046 (12)	565,90 ?
226,1 (2)	0,0027 (8)	546,83
226,1 (2)	0,0027 (8)	570,27 ?
226,8 (2)	0,0031 (8)	571,36 ?
232,1 (2)	0,0027 (8)	563,00 ?
235,0 (2)	0,0012 (4)	546,83
236,0 (2)	0,0023 (8)	391,09 ?
238,5 (2)	0,0054 (12)	330,67
239,8 (2)	0,0031 (8)	570,27 ?
242,3 (2)	0,0027 (8)	397,71 ?
242,3 (2)	0,0027 (8)	563,00 ?
243,4 (2)	0,0023 (8)	473,04 ?
244,6 (2)	0,0027 (8)	546,83
248,1 (1)		546,83
249,6 (2)	0,0031 (8)	570,27 ?
250,4 (2)	0,0031 (8)	571,36 ?
252,3 (2)	0,0039 (8)	344,56 ?
261,4 (2)	0,0039 (12)	302,00
261,4 (2)	0,0039 (12)	353,71 ?
264,4 (2)	0,0035 (8)	563,00 ?
268,1 (2)	0,0031 (8)	570,27 ?
269,3 (2)	0,0031 (8)	571,36 ?
271,4 (1)		570,27 ?
272,8 (3)	0,0039 (8)	571,36 ?
290,1 (1)	0,0035 (8)	330,67
298,7 (2)		391,09 ?
298,7 (2)		454,29 ?
300,0 (1)		392,25 ?
304,0 (2)	0,0046 (12)	344,56 ?
305,4 (2)	0,0050 (12)	397,71 ?
313,5 (2)	0,0139 (23)	353,71 ?
317,6 (3)	0,0023 (8)	473,04 ?
330,5 (3)	0,0023 (4)	330,67

Energy (keV)	Pγ (%)	Level energy (keV)
335,9 (3)	0,0027 (8)	565,90 ?
339,5 (5)		380,48
339,5 (5)		494,75 ?
340,5 (1)		432,81 ?
341,4 (5)		496,65 ?
344,5 (3)	0,0015 (4)	344,56 ?
351,8 (3)	0,0046 (8)	392,25 ?
363,9 (3)	0,0035 (8)	456,113
374,0 (3)	0,0073 (19)	414,37 ?
386,8 (3)	0,0031 (8)	427,08 ?
393,3 (3)	0,0050 (12)	393,33 ?
400,5 (3)	0,0031 (8)	441,20 ?
402,9 (2)	0,0023 (8)	494,75 ?
404,5 (3)	0,0035 (8)	496,65 ?
410,0 (3)	0,0069 (12)	410,13 ?
414,3 (3)	0,0054 (19)	414,37 ?

Energy (keV)	Pγ (%)	Level energy (keV)
415,764 (5)		456,113
427,0 (3)	0,0019 (8)	427,08 ?
432,8 (3)	≈ 0,0008	432,81 ?
435,1 (3)	0,0012 (4)	475,69 ?
441,1 (3)	0,0019 (8)	441,20 ?
454,2 (3)	0,0012 (8)	494,75 ?
454,2 (3)	0,0012 (8)	546,83
463,6 (3)	≈ 0,0008	503,90 ?
471,1 (3)	0,0012 (4)	563,00 ?
473,8 (3)	0,0019 (8)	565,90 ?
475,6 (3)	0,0019 (8)	475,69 ?
478,0 (3)	0,0012 (4)	570,27 ?
496,9 (3)	0,0012 (8)	496,65 ?
503,7 (3)	0,0012 (4)	503,90 ?
506,3 (3)	0,0012 (8)	546,83

6. Consistency

The most accurate Q value, Q(M), is taken from the atomic mass adjustment table of Audi et al. (2003Au03). Comparison of Q(eff) (deduced as the sum of average energies per disintegration ($\sum E_i \times P_i$) for all emissions accompanying ^{233}Pa β^- decay) with the tabulated decay energy Q(M) allows to check a consistency of the recommended decay-scheme parameters obtained in this evaluation.

Here E_i and P_i are the evaluated energies and emission probabilities of the i-th alpha particle, beta particle, gamma-ray, X-ray, etc. Consistency (percentage deviation) is determined by $\{[Q(M)–Q(eff))]/Q(M)\}\times 100$. "Percentage deviations above 5 % would be regarded as high and imply a poorly defined decay scheme; a value of less than 5 % indicates the construction of a reasonably consistent decay scheme" (quoted from the article by A.L. Nichols in Appl. Rad. Isotopes 55 (2001) 23-70).

For the above ^{233}Pa decay data evaluation we have Q(M) = 570,1 (20) keV and Q(eff) = 572 (20) keV, i.e. consistency is 0,35 %.

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^{234}Pa-Comments on evaluation of decay data

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This evaluation was completed in 2009. Literature available by January 2009 was included.

1 Decay Scheme

^{234}Pa disintegrates 100 % by β^- emissions to levels in ^{234}U. ^{234}Pa ground state has $J^\pi = 4^+$ (2007Br04).

The β^- decay scheme of ^{234}Pa is based on the measurement results of 1986Ar05. 28 observed γ-rays were not placed in the current decay scheme. These gamma rays carry about 3.2 % of the total intensity of all the gamma rays placed in the decay scheme.

The Q(β^-) value of 2195 (4) keV adopted from 2003Au03 is not in good agreement with the effective Q(β^-) value of 2336 (70) keV, calculated by the evaluators from average radiation energies using the RADLST computer program. The total intensity ΣI(β^-) deduced by the evaluators from intensity balance at each level is about 110 %.

These results suggest that the γ-ray intensity balance for some levels may be incomplete and the decay scheme has some inconsistency. Further measurements are strongly needed to determine the γ transitions and the decay scheme with greater precision.

2 Nuclear Data

The Q(β-) value is from the mass adjustment in 2003Au03.

Level energies, have been obtained from a least-squares fit to γ-ray energies (GTOL computer code). Spin and parities are from 2007Br04.

The measured and recommended ^{234}Pa half-life values are listed in Table 1.

Table 1: Measured half-life values of ^{234}Pa and recommended value

$T_{1/2}$ (h)	References	Comments
6.7	1931Cu01	Not used
6.658 (12)	1954Zi02	
6.75 (3)	1962Bj01	
6.704 (46)		Unweighted mean
6.671 (11)		Weighted mean
6.704 (46)		LWEIGHT weighted mean, χ^2= 4.7
6.70 (5)		**Recommended value**

The weighted average for this data set of the 2 discrepant experimental values is dominated by the accurate value of 1954Zi02. The LWEIGHT computer program, which uses a Limitation of Relative Statistical Weights (LRSW method), has increased the 1954Zi02 uncertainty from 0.012 to 0.030 and used a weighted mean and an external uncertainty for recommended average.

Thus, the adopted value of the ^{234}Pa half-life is 6.70 (5) hours.

2.1 β^- transitions

The maximum energies of the β^- transitions in the decay of ^{234}Pa have been deduced from the Q(β-) value (2003Au03) and the ^{234}U level energies (Table 2), obtained from a least-squares fit to recommended γ-ray energies (GTOL computer code).

Table 2: ^{234}U levels populated in ^{234}Pa β^- decay

Level energy (keV)	Spin & parity	Half-life	β^- transition probabilities (%)
0.0	0+	2.455 (6) × 10^5 a	
43.481 (15)	2+	0.252 (7) ns	
143.375 (21)	4+		< 5
296.075 (24)	6+		
497.05 (4)	8+		
786.295 (15)	1-		
809.92 (8)	0+	< 0.1 ns	
849.265 (23)	3-		< 0.8
851.73 (5)	2+	> 1.74 ps	
926.744 (21)	2+	1.38 (17) ps	
947.59 (5)	4+		< 0.8
962.55 (3)	5-		< 0.4
968.45 (3)	3+		< 2.5
989.444 (20)	2-	0.76 (4) ns	< 3.1
1023.795 (24)	3-		< 5
1023.92 (3)	4+		1.5 (13)
1069.297 (22)	4-		< 8
1085.07 (10)	2+		
1090.89 (4)	5+		0.69 (20)
1096.12 (9)	6+		
1125.29 (5)	7-		
1126.65 (3)	2+		
1127.535 (25)	5-		1.9 (10)
1165.41 (4)	3+		
1172.03 (3)	6+		
1194.761 (23)	6-		< 1.5
1214.70 (5)	4+		0.30 (12)
1237.24 (3)	1-		
1261.77 (3)	7+		
1274.32 (9)	(5+)		
1277.45 (3)	7-		
1312.20 (9)	3-		0.109 (18)
1341.33 (8)	(6+)		
1421.252 (24)	6-	33.5 (20) μs	
1447.89 (10)	5-		0.11 (3)
1456.54 (7)	(2-)		
1486.17 (12)	(3-)		0.117 (25)
1496.14 (3)	3+		< 2.7
1502.38 (8)	3,4+		0.25 (4)
1533.37 (5)	(4-)		0.21 (4)
1537.25 (3)	4+		< 0.9
1543.71 (5)	4+		0.10 (9)
1548.10 (8)	(5)		0.078 (20)
1552.554 (24)	5+	2.20 (25) ns	19.6 (18)
1581.67 (10)	(5-)		0.05 (3)
1588.84 (3)	5+		< 0.7
1619.46 (9)	(6+)		0.035 (20)
1649.99 (12)	(6-)		0.18 (4)

Level energy (keV)	Spin & parity	Half-life	β^- transition probabilities (%)
1653.35 (7)	(3+)		0.95 (13)
1693.42 (3)	5-		6.9 (8)
1722.89 (4)	3-		8.4 (9)
1723.424 (24)	4+		36 (5)
1737.42 (7)	3+		1.16 (14)
1738.18 (6)	(3+)		0.78 (19)
1761.86 (6)	(4-)		2.8 (4)
1770.79 (9)	(3+)		0.129 (17)
1782.58 (3)	5+		8 (3)
1784.19 (13)	4+		0.061 (11)
1793.05 (6)	4+		0.41 (8)
1811.62 (6)	4+		1.43 (15)
1843.88 (17)	3,4,5-		0.17 (3)
1863.08 (15)	(5+)		0.029 (7)
1881.75 (7)	4+		0.25 (3)
1916.28 (9)	3,4+		0.21 (3)
1927.51 (7)	4+		0.22 (4)
1940.52 (9)	4+		0.35 (5)
1958.75 (4)	3-		0.44 (19)
1968.84 (10)	4+,5		0.044 (12)
1981.22 (7)	4+		0.59 (8)
2000.45 (13)	(4+)		0.122 (16)
2019.82 (13)	4+		0.112 (16)
2033.54 (5)	3+,4+		0.90 (15)
2037.06 (17)	4+,5		0.055 (8)
2066.24 (10)			0.140 (24)
2068.82 (11)	3,4,5+		0.40 (7)
2101.42 (9)	5+		0.064 (11)
2115.71 (11)	4+		0.21 (3)
2144.04 (9)	3+,4+		0.42 (5)

Table 3: Measured and evaluated β^- energies (keV) and probabilities (%) in the ^{234}Pa decay

1956On07		1959De30		1968Bj06		**Evaluated**	
$E_{\beta-}$	$P_{\beta-}$	$E_{\beta-}$	$P_{\beta-}$	$E_{\beta-}$	$P_{\beta-}$	$E_{\beta-}$	$\mathbf{P_{\beta-}}$
155	28	141 (10)	35.5			158 (4)	**0.055 (8)**
		274 (10)	21.4	280 (70)	12	279 (4)	**0.21 (3)**
320 (20)	32					313 (4)	**0.25 (3)**
		363 (10)	10.3			383 (4)	**1.43 (15)**
		477 (10)	16.0			472 (4)	**36 (5)**
530 (20)	27			550 (100)	63	545 (4)	**0.18 (4)**
		576 (10)	13.2			576 (4)	**0.035 (20)**
				790 (100)	19	747 (4)	**0.11 (3)**
		1042 (20)	3.6			1067 (4)	**1.9 (10)**
1130 (50)	13					1126 (4)	< 8
				1190 (100)	5	1171 (4)	< 5
				1510 (200)	≤ 1	**1346 (4)**	< 0.8

The adopted β^- transition probabilities and the associated uncertainties were deduced from the γ transition probability balance at each ^{234}U level.
The values of *logft* and average β^- energies have been calculated with the LOGFT computer program.

2.2 γ Transitions

The γ-ray transition probabilities were deduced using the γ-ray emission intensities and the relevant internal conversion coefficients.
Multipolarities and mixing ratios of γ-ray transitions are from 1967Wa26, 1968Bj06 and 2007Br04.
The internal conversion coefficient (ICC) (and its associated uncertainty) for γ-ray transitions have been interpolated from theoretical values based on the “Frozen Orbital” approximation (2002Ba85) using the BrIcc computer program (2008Ki07).

3. Atomic data

Atomic fluorescence yields (ω_K, ϖ_L, ϖ_M, η_{KL} and η_{LM}) are from Schönfeld (1996Sc06).
The X-ray and Auger electron emission probabilities have been deduced from γ-ray and conversion electron data by using the RADLST computer code.
The deduced total KX-ray emission probability is 35.7 (12) %. Measured KX-ray emission probability is 50.9 % (from I(KX-ray)/I_γ(131keV γ-ray) = 2.8 in 1967Wa26). The 30 % deviation suggests a problem with the decay scheme.

4. Electron Emissions.

The conversion electron emission probabilities have been deduced from γ-ray transition data using theoretical internal conversion coefficients.

5. Photon Emissions

5.1 γ-ray energies

Measured results for the energies of γ-rays from ^{234}Pa are listed in Table 4. The recommended values are taken from the precise measurements of 2000Ni13, 1986Ar05 and 1972Sa06, except as noted in the table.

Table 4: Measured and recommended γ-ray energy values from ^{234}Pa β^-decay

1968Bj06	1968Go20	1972Sa06	1975Ar24	1986Ar05	2000Ni13	Recommended
34.30 (4)						34.30 (4)
						41.82 (11)[a]
43.40 (5)				43.49 (2)		43.49 (2)
45.19 (5)				45.45 (5)		45.45 (5)
				54.96 (10)		54.96 (10)
				55.45 (5)		55.45 (5)
58.20 (6)				58.2 (1)		58.20 (6)
				59.19 (5)		59.19 (5)
63.40 (7)			63.0 (5)	62.70 (1)		62.70 (1)
67.10 (7)				67.25 (10)		67.25 (10)
69.90 (7)				69.46 (5)		69.46 (5)
				75.0 (3)[a]		75.0 (3)[a]
79.69 (8)			80.5 (5)	79.84 (2)		79.84 (2)
				97.17 (10)		97.17 (10)
99.67 (10)				99.86 (2)		99.86 (2)
				100.89 (2)		100.89 (2)
103.41 (11)				103.77 (2)		103.77 (2)

1968Bj06	1968Go20	1972Sa06	1975Ar24	1986Ar05	2000Ni13	Recommended
				106.68 (5)		106.68 (5)
125.20 (13)			125.3 (2)	125.46 (1)		125.46 (1)
131.00 (13)			131.28 (10)	131.30 (1)		131.30 (1)
134.37 (14)				134.61 (2)		134.61 (2)
			137.7 (5)	137.23 (5)		137.23 (5)
139.97 (14)			140.3 (2)	140.15 (2)		140.15 (2)
				140.91 (3)		140.91 (3)
144.35 (15)			143.6 (5)	143.78 (2)		143.78 (2)
~ 150.2				149.88 (3)		149.88 (3)
152.46 (16)			153.0 (2)	152.71 (2)		152.71 (2)
159.10 (16)			159.2 (3)	159.48 (2)		159.48 (2)
				164.94 (5)		164.94 (5)
			166.3 (10)	165.61 (5)		165.61 (5)
170.77 (18)			170.6 (3)	170.85 (2)		170.85 (2)
			174.6 (8)	174.55 (3)		174.55 (3)
				179.80 (8)		179.80 (8)
185.95 (19)			186.2 (5)	186.15 (2)		186.15 (2)
193.4 (2)			193.5 (5)	193.73 (3)		193.73 (3)
196.4 (2)			196.5 (10)	196.80 (5)		196.80 (5)
199.7 (2)				199.95 (5)		199.95 (5)
200.6 (2)			200.9 (3)	200.97 (3)		200.97 (3)
202.9 (2)			202.9 (3)	203.12 (3)		203.12 (3)
219.60 (22)			220.8 (5)	220.00 (8)		220.00 (8)
				221.15 (10)		221.15 (10)
				221.83 (10)		221.83 (10)
226.15 (23)			226.87 (10)	226.50 (3)		226.50 (3)
227.00 (23)				227.25 (3)		227.25 (3)
				232.21 (3)		232.21 (3)
						233.6 (2)[b]
				235.11 (3)		235.11 (3)
						235.9 (3)[b]
				240.2 (1)		240.2 (1)
245.00 (25)			245.2 (3)	245.37 (2)		245.37 (2)
						247.79 (7)[b]
248.80 (25)			249.1 (3)	249.22 (1)		249.22 (1)
				257.2 (1)		257.2 (1)
			267.1 (8)	267.12 (5)		267.12 (5)
271.85 (27)			272.1 (3)	272.28 (5)		272.28 (5)
				275.04 (10)		275.04 (10)
			277.9 (8)	278.3 (1)		278.3 (1)
293.5 (3)			293.7 (2)	293.79 (5)		293.79 (5)
				295.91 (8)		295.91 (8)
				298.7 (2)		298.7 (2)
			309.6 (8)	308.6 (2)		308.6 (2)
				310.2 (1)		310.2 (1)
						310.52 (10)[b]
312.5 (3)				313.5 (1)		313.5 (1)
316.8 (3)			316.3 (8)	316.7 (1)		316.7 (1)
			320.7 (8)	320.4 (1)		320.4 (1)
328.3 (3)			330.3 (5)	330.40 (5)		330.40 (5)

1968Bj06	1968Go20	1972Sa06	1975Ar24	1986Ar05	2000Ni13	Recommended
330.6 (3)				331.4 (1)		331.4 (1)
				340.2 (1)		340.2 (1)
				343.8 (2)		343.8 (2)
351.6 (4)			351.8 (3)	351.9 (1)		351.9 (1)
				357.9 (1)		357.9 (1)
				360.6 (3)		360.6 (3)
				365.0 (3)		365.0 (3)
369.3 (4)			369.6 (3)	369.50 (5)		369.50 (5)
371.8 (4)			372.2 (3)	372.0 (1)		372.0 (1)
				379.1 (1)		379.1 (1)
				385.4 (1)		385.4 (1)
						387.94 (6)[b]
				394.1 (1)		394.1 (1)
				397.7 (3)		397.7 (3)
				401.8 (2)		401.8 (2)
			409.8 (5)	409.8 (1)		409.8 (1)
				416.1 (1)		416.1 (1)
				425.3 (2)		425.3 (2)
427.0 (4)			426.8 (5)	426.95 (5)		426.95 (5)
						427.4 (4)[b]
			432.6 (5)	433.1 (1)		433.1 (1)
			446.9 (5)	446.6 (1)		446.6 (1)
						450.93 (4)[b]
				452.4 (3)		452.4 (3)
458.6 (5)			458.6 (3)	458.68 (5)		458.68 (5)
			461.8 (10)	461.5 (1)		461.5 (1)
				464.2 (1)		464.2 (1)
468.0 (5)			467.5 (10)	468.0 (1)		468.0 (1)
			472.1 (10)	472.3 (1)		472.3 (1)
474.0 (5)			473.5 (10)	474.2 (2)		474.2 (2)
			478.7 (10)	478.6 (1)		478.6 (1)
			480.5 (8)	481.0 (1)		481.0 (1)
			498.9 (10)	498.0 (1)		498.0 (1)
				502.0 (1)		502.0 (1)
506.0 (5)			506.8 (5)	506.75 (5)		506.75 (5)
513.6 (5)			513.7 (5)	513.4 (1)		513.4 (1)
			520.2 (5)	519.6 (1)		519.6 (1)
521.0 (5)			521.0 (5)	521.4 (1)		521.4 (1)
527.6 (5)			528.0 (5)	527.9 (1)		527.9 (1)
				529.1 (3)		529.1 (3)
			533.2 (10)	534.1 (1)		534.1 (1)
			537.1 (10)	537.2 (1)		537.2 (1)
				543.8 (1)		543.8 (1)
				553.7 (1)		553.7 (1)
			557 (1)	558.0 (2)		558.0 (2)
				559.2 (2)		559.2 (2)
				562.8 (3)		562.8 (3)
565.1 (6)			566.3 (10)	565.2 (1)		565.2 (1)
568.7 (6)				568.9 (2)		568.9 (2)
569.5 (6)			569.26 (10)	569.5 (1)		569.5 (1)

1968Bj06	1968Go20	1972Sa06	1975Ar24	1986Ar05	2000Ni13	Recommended
574.0 (6)				575.5 (1)		575.5 (1)
				584.1 (1)		584.1 (1)
			586.1 (8)	586.3 (1)		586.3 (1)
				590.3 (10)		590.3 (10)
				595.4 (2)		595.4 (2)
			596.5 (5)	596.9 (1)		596.9 (1)
			602.7 (5)	602.6 (1)		602.6 (1)
				604.6 (3)		604.6 (3)
612.0 (6)			611.4 (10)	612.0 (1)		612.0 (1)
			616.2 (5)	617.0 (2)		617.0 (2)
				619.0 (2)		619.0 (2)
623.8 (6)			623.6 (5)	624.2 (1)		624.2 (1)
629.1 (6)			627.5 (5)	628.1 (1)		628.1 (1)
			630.6 (10)	629.4 (1)		629.4 (1)
				632.6 (2)		632.6 (2)
			634.5 (10)	634.3 (2)		634.3 (2)
			643.2 (10)	643.2 (2)		643.2 (2)$^{\times}$
646.0 (7)			646.2 (10)	646.5 (1)		646.5 (1)
653.7 (7)			653.2 (8)	653.7 (1)		653.7 (1)
			655.0 (8)	655.2 (2)		655.2 (2)
657.0 (7)			658.0 (5)	657.4 (1)		657.4 (1)
			660.6 (10)	659.8 (1)		659.8 (1)$^{\times}$
			664.6 (10)	663.9 (1)		663.9 (1)
667.0 (7)			666.7 (6)	666.5 (1)		666.5 (1)
			669.8 (5)	669.7 (1)		669.7 (1)
				675.1 (1)		675.1 (1)
			683.3 (8)	683.9 (2)		683.9 (2)
687.0 (7)			685.5 (10)	685.1 (2)		685.1 (2)
692.8 (7)			692.5 (5)	692.6 (1)		692.6 (1)
699.0 (7)			699.1 (3)	699.03 (5)		699.03 (5)
706.8 (7)			706.0 (2)	705.9 (1)		705.9 (1)
						708.3 (2)^{b}
			711.2 (8)	711.5 (1)		711.5 (1)$^{\times}$
				713.7 (1)		713.7 (1)
				716.5 (2)		716.5 (2)
				727.8 (2)		727.8 (2)
				730.9 (2)		730.9 (2)
732.9 (7)			733.0 (2)	733.39 (5)		733.39 (5)
737.5 (7)			738.4 (5)	738.0 (1)		738.0 (1)
~ 743.4	742.8 (6)	742.814 (22)	742.67 (20)	742.81 (3)	742.813 (5)	742.813 (5)
			746.5 (15)	745.9 (1)		745.9 (1)
				748.1 (3)		748.1 (3)
756.6 (8)			754.8 (6)	755.0 (1)		755.0 (1)
				758.9 (1)		758.9 (1)
			760 (1)	761.0 (2)		761.0 (2)
				764.8 (2)		764.8 (2)
767.0 (8)	765.0 (7)	766.358 (20)	865.7 (8)	766.4 (2)		766.4 (2)
			768.7 (10)	769.1 (1)		769.1 (1)
				772.4 (2)		772.4 (2)
			777.9 (10)	778.6 (2)		778.6 (2)$^{\times}$

1968Bj06	1968Go20	1972Sa06	1975Ar24	1986Ar05	2000Ni13	Recommended
~ 780.9			780.5 (6)	780.4 (2)		780.4 (2)
			783.1 (10)	783.4 (1)		783.4 (1)
~ 787.0	786.3 (5)	786.272 (22)	786.2 (6)	786.27 (3)		786.27 (3)
			793.6 (10)	792.8 (3)		792.8 (3)
				794.9 (2)		794.9 (2)
797.2 (8)			796.2 (5)	796.1 (1)		796.1 (1)
						799.7 (2)[b]
				802.3 (2)		802.3 (2)
804.2 (8)			804.5 (10)	804.1 (1)		804.1 (1)
806.8 (8)			805.5 (5)	805.8 (5)		805.8 (5)
808.0 (8)				808.4 (3)		808.4 (3)
810.0 (8)				810.0 (7)		810.0 (7)
			812.5 (15)	811.5 (1)		811.5 (1)
				814.2 (1)		814.2 (1)
~ 820.2			819.4 (5)	819.2 (1)		819.2 (1)
824.0 (8)			824.7 (5)	824.2 (2)		824.2 (2)[×]
826.3 (8)				825.1 (2)		825.1 (2)
				829.3 (2)		829.3 (2)
832.4 (24)			831.1 (5)	831.5 (1)		831.5 (1)
			841.9 (10)	839.5 (1)		839.5 (1)
~ 845.4			844.1 (10)	844.1 (1)		844.1 (1)
				846.1 (2)		846.1 (2)[×]
				848.9 (2)		848.9 (2)
				851.8 (1)		851.8 (1)
				857.7 (2)		857.7 (2)
				863.2 (2)		863.2 (2)
				869.7 (1)		869.7 (1)
872.0 (26)			872.9 (10)	874.0 (3)		874.0 (3)
876.4 (26)			876.7 (7)	876.0 (1)		876.0 (1)
880.2 (27)	880.0 (7)	880.514 (36)	880.6 (5)	880.5 (1)		880.5 (1)
883.0 (27)	883.0 (6)	883.237 (33)	883.5 (5)	883.24 (4)		883.24 (4)
				890.1 (4)		890.1 (4)
899.3 (27)			898.6 (5)	898.67 (5)		898.67 (5)
905.2 (28)			904.2 (10)	904.2 (1)		904.2 (1)
				916.5 (2)		916.5 (2)
				918.4 (1)		918.4 (1)
				920.5 (2)		920.5 (2)[×]
926 (3)			924.6 (10)	925.0 (1)		925.0 (1)
						926.0 (2)[a]
927.1 (28)			926.7 (5)	926.7 (1)		926.7 (1)
				935.8 (2)		935.8 (2)
				942.0 (3)		942.0 (3)
946.3 (28)	945.8 (3)	946.002 (28)	945.78 (10)	946.00 (3)		946.00 (3)
949.6 (28)				947.7 (2)		947.7 (2)
				952.7 (1)		952.7 (1)
			959 (1)	960.0 (1)		960.0 (1)
966.4 (29)			965.9 (10)	965.8 (1)		965.8 (1)
				975.1 (1)		975.1 (1)
			978.8 (10)	978.2 (3)		978.2 (3)
980.8 (29)			980.5 (5)	980.3 (1)		980.3 (1)

1968Bj06	1968Go20	1972Sa06	1975Ar24	1986Ar05	2000Ni13	Recommended
				981.6 (3)		981.6 (3)
984.5 (29)			983.4 (10)	984.2 (1)		984.2 (1)
				989.5 (1)		989.5 (1)
				992.0 (2)		992.0 (2)$^{\times}$
				994.6 (3)		994.6 (3)
				997.7 (3)		997.7 (3)
				1009.9 (3)		1009.9 (3)
				1019.5 (4)		1019.5 (4)
				1021.8 (2)		1021.8 (2)
1023.1 (30)			1022.7 (8)	1023.6 (2)		1023.6 (2)$^{\times}$
				1025.3 (2)		1025.3 (2)$^{\times}$
1028.6 (30)			1028.1 (8)	1028.7 (1)		1028.7 (1)
				1032.8 (2)		1032.8 (2)
				1035.9 (2)		1035.9 (2)$^{\times}$
				1037.9 (2)		1037.9 (2)
				1041.1 (2)		1041.1 (2)
1044.9 (31)				1044.4 (2)		1044.4 (2)
				1051.4 (2)		1051.4 (2)
				1057.8 (3)		1057.8 (3)
				1065.1 (1)		1065.1 (1)
1073 (3)			1074.4 (10)	1073.6 (2)		1073.6 (2)
1084 (3)			1082.5 (6)	1083.2 (1)		1083.2 (1)
				1085.3 (3)		1085.3 (3)
			1108.5 (6)	1106.9 (2)		1106.9 (2)
				1110.6 (1)		1110.6 (1)
1121.9 (33)			1122.3 (6)	1121.7 (1)		1121.7 (1)
				1125.2 (1)		1125.2 (1)
1126.8 (33)			1126.0 (6)	1126.8 (1)		1126.8 (1)
				1151.4 (3)		1151.4 (3)
			1153.1 (6)	1153.5 (3)		1153.5 (3)
			1171.3 (8)	1171.3 (1)		1171.3 (1)
				1173.1 (1)		1173.1 (1)
				1182.1 (2)		1182.1 (2)
		1193.767 (30)		1194.0 (2)		1194.0 (2)
1217 (4)			1217.5 (8)	1217.3 (1)		1217.3 (1)
				1220.4 (2)		1220.4 (2)$^{\times}$
1239 (4)				1237.3 (3)		1237.3 (3)
			1240.9 (8)	1241.2 (1)		1241.2 (1)
				1247.8 (2)		1247.8 (2)
				1252.6 (2)		1252.6 (2)
				1256.5 (1)		1256.5 (1)
			1277.1 (8)	1277.7 (2)		1277.7 (2)
1292 (4)			1292.8 (8)	1292.8 (1)		1292.8 (1)
				1296.4 (2)		1296.4 (2)$^{\times}$
				1301.2 (2)		1301.2 (2)$^{\times}$
				1327.0 (2)		1327.0 (2)$^{\times}$
				1342.9 (2)		1342.9 (2)
			1353.0 (6)	1352.9 (1)		1352.9 (1)
1354 (4)				1354.6 (2)		1354.6 (2)
			1358.4 (10)	1359.0 (1)		1359.0 (1)

1968Bj06	1968Go20	1972Sa06	1975Ar24	1986Ar05	2000Ni13	Recommended
				1389.6 (2)		1389.6 (2)
1394 (4)			1394.1 (5)	1393.9 (1)		1393.9 (1)
			1399.7 (10)	1397.5 (2)		1397.5 (2)
				1400.3 (1)		1400.3 (1)
				1409.1 (2)		1409.1 (2)
				1414.4 (2)		1414.4 (2)
			1427 (1)	1426.9 (1)		1426.9 (1)
				1442.8 (2)		1442.8 (2)
1446 (4)			1446.1 (8)	1445.4 (1)		1445.4 (1)
1453 (4)			1452.6 (15)	1452.7 (1)		1452.7 (1)
				1458.9 (1)		1458.9 (1)
				1475.8 (2)		1475.8 (2)
				1485.4 (2)		1485.4 (2)
				1488.0 (2)		1488.0 (2)
1493 (4)			1493.7 (10)	1493.6 (1)		1493.6 (1)
				1496.0 (2)		1496.0 (2)
				1500.0 (2)		1500.0 (2)
				1507.3 (2)		1507.3 (2)$^{\times}$
				1510.1 (2)		1510.1 (2)
1516 (5)				1515.6 (2)		1515.6 (2)
				1520.7 (2)		1520.7 (2)$^{\times}$
				1538.8 (2)		1538.8 (2)$^{\times}$
~1552			1549.2 (10)	1550.1 (1)		1550.1 (1)
				1567.0 (2)		1567.0 (2)
			1580.1 (10)	1579.9 (1)		1579.9 (1)
			1585.4 (10)	1585.9 (1)		1585.9 (1)
1595 (5)			1593.8 (8)	1594.0 (1)		1594.0 (1)
				1618.3 (2)		1618.3 (2)
			1628 (1)	1627.3 (1)		1627.3 (1)
			1638.2 (10)	1638.1 (1)		1638.1 (1)
1640 (5)				1640.5 (3)		1640.5 (3)
				1644.9 (2)		1644.9 (2)
1653 (5)				1650.2 (2)		1650.2 (2)
				1655.7 (1)		1655.7 (1)$^{\times}$
				1664.8 (3)		1664.8 (3)$^{\times}$
			1668.5 (8)	1668.4 (1)		1668.4 (1)
1671 (5)				1672.8 (1)		1672.8 (1)
				1679.5 (1)		1679.5 (1)
1688 (5)			1686.3 (10)	1685.7 (1)		1685.7 (1)
			1694.0 (8)	1693.8 (2)		1693.8 (2)
1695 (5)				1695.0 (3)		1695.0 (3)
				1700.5 (2)		1700.5 (2)
				1719.7 (2)		1719.7 (2)
				1723.2 (2)		1723.2 (2)
				1727.8 (2)		1727.8 (2)
1736 (5)			1737.9 (10)	1737.7 (2)		1737.7 (2)
				1741.1 (2)		1741.1 (2)
				1743.2 (2)		1743.2 (2)$^{\times}$
				1750.0 (1)		1750.0 (1)
1756 (5)				1757.5 (1)		1757.5 (1)$^{\times}$

1968Bj06	1968Go20	1972Sa06	1975Ar24	1986Ar05	2000Ni13	Recommended
			1768.4 (15)	1768.0 (3)		1768.0 (3)
				1770.8 (2)		1770.8 (2)
1775 (5)			1772.2 (15)	1773.0 (2)		1773.0 (2)
				1783.7 (2)		1783.7 (2)
			1796.9 (10)	1797.1 (1)		1797.1 (1)
1802 (5)				1805.8 (3)		1805.8 (3)
				1815.3 (3)		1815.3 (3)
				1819.8 (3)		1819.8 (3)
				1825.1 (3)		1825.1 (3)
1828 (5)				1830.8 (3)		1830.8 (3)[×]
			1838.20 (8)	1838.0 (2)		1838.0 (2)
1849 (6)			1850 (1)	1849.8 (2)		1849.8 (2)[×]
			1872.8 (10)	1872.8 (2)		1872.8 (2)
				1884.1 (3)		1884.1 (3)
			1891.1 (10)	1890.1 (2)		1890.1 (2)
				1893.4 (3)		1893.4 (3)
			1897.5 (10)	1896.7 (2)		1896.7 (2)
1905 (6)				1915.5 (3)		1915.5 (3)
			1926.5 (6)	1925.4 (2)		1925.4 (2)
				1927.9 (4)		1927.9 (4)[×]
				1935.2 (4)		1935.2 (4)[×]
1940 (6)			1937.8 (10)	1937.7 (3)		1937.7 (3)
				1958.0 (4)		1958.0 (4)
				1971.2 (4)		1971.2 (4)
				1977.4 (4)		1977.4 (4)
				1989.6 (4)		1989.6 (4)
				2072.2 (4)		2072.2 (4)

a: Expected but as yet unobserved, energy from level scheme.

b: Expected but as yet unobserved, energy from adopted gammas.

×: Not placed in level scheme.

5.2 Relative values of the γ-ray intensities

Measured results for the relative γ-ray intensities from ^{234}Pa are listed in table 5. The recommended values are from the measurements of 1986Ar05, except as noted in the footnotes of the table.

The values from 1975Ar24 were superseded by the same group in 1986Ar05. The uncertainties of 1968Bj06 are large (~ 20-30 %), and not listed in table. Some γ-ray intensities from 1990Sc09 are also not listed in table because these intensities contain the contributions from ^{234}Pa^{m} decay.

Table 5: Measured and recommended relative γ-ray intensities in decay of ^{234}Pa

E_γ/keV	I_γ							
	1967Wa09	1968Bj06[!]	1975Ar24	1986Ar05	1990Sc09[!]	2006Al28[!]	LWEIGHT	Recommended
34.30								0.0036[f]
41.82[a]								0.27 (7)[d]
43.49		0.123		0.12 (3)				0.12 (3)
45.45		0.009		0.026 (8)				0.026 (8)
54.96[b]				~ 0.009				~ 0.009
54.96[b]								~ 0.009
55.45				0.026 (8)				0.026 (8)
58.20		0.0026		< 0.009				0.0026 (8)

E_γ/keV	I_γ							
	1967Wa09	1968Bj06[!]	1975Ar24	1986Ar05	1990Sc09[!]	2006Al28[!]	LWEIGHT	Recommended
59.19				0.031 (10)				0.031 (10)
62.70	3.2	2.45	3.6	1.5 (4)				1.5 (4)
67.25				0.035 (10)				0.035 (10)
69.46				0.017 (7)				0.017 (7)
75.0[a]								0.030 (6)[d]
79.84		0.11		0.06 (2)				0.06 (2)
97.17				0.23 (8)				0.23 (8)
99.86		4.64		3.1 (5)				3.1 (5)
100.89				0.12 (2)				0.12 (2)
103.77		0.114		0.23 (3)				0.23 (3)
106.68				0.035 (10)				0.035 (10)
125.46	1.2	0.79	0.61	0.76 (9)				0.76 (9)
131.30	18	17.5	17.5	17.5	17.5	17.5		17.5
134.61		0.13		0.11 (2)				0.11 (2)
137.23				0.026 (8)				0.026 (8)
140.15	0.9			0.49 (5)				0.49 (5)
140.91				0.30 (3)				0.30 (3)
143.78	0.2		0.32	0.31 (3)				0.31 (3)
149.88				0.07 (2)				0.07 (2)
152.71	6	5.25	5.78	5.8 (4)	5.08 (19)		5.2 (2)	5.8 (4)
159.48	0.6	0.44	0.61	0.63 (7)				0.63 (7)
164.94				0.05 (2)				0.05 (2)
165.61				0.07 (2)				0.07 (2)
170.85	0.4	0.44	0.55	0.49 (5)				0.49 (5)
174.55			0.21	0.16 (2)				0.16 (2)
179.80				0.043 (15)				0.043 (15)
186.15	1.8	1.5	2.02	1.71 (10)				1.71 (10)
193.73	0.5	0.6	0.51	0.48 (6)				0.48 (6)
196.80		< 0.44	0.06	0.07 (2)				0.07 (2)
199.95				0.07 (2)				0.07 (2)
200.97		0.9	0.96	0.87 (9)				0.87 (9)
203.12	2.1		1.14	1.19 (10)				1.19 (10)
220.00	0.4		0.1	0.14 (2)				0.14 (2)
221.15				0.05 (2)				0.05 (2)
221.83				0.07 (2)				0.07 (2)
226.50	10	5.6	10.1	4.1 (3)	10.25 (15)			4.7 (3)[#]
227.25		5.25		5.6 (3)				5.6 (3)
232.21				0.17 (2)				0.17 (2)
233.6[a]								~ 0.018[d]
235.11				0.11 (2)				0.11 (2)
235.9[a]								0.0044 (25)[e]
240.2				0.05 (2)				0.05 (2)
245.37	0.8	0.9	0.66	0.73 (8)				0.73 (8)
247.79[a]								3.6 (3)E-4[e]
249.22	2.5	2.19	2.45	2.4 (3)	2.14 (10)		2.2 (1)	2.4 (3)
257.2				0.05 (2)				0.05 (2)
267.12			0.15	0.17 (2)				0.17 (2)
272.28	1	0.9	0.88	1.05 (10)	1.1 (1)		1.08 (7)	1.05 (10)

E_γ/keV	I_γ							
	1967Wa09	1968Bj06[!]	1975Ar24	1986Ar05	1990Sc09[!]	2006Al28[!]	LWEIGHT	Recommended
275.04				0.09 (2)				0.09 (2)
278.3			0.06	0.04 (1)				0.04 (1)
293.79	3.7		3.4	2.9 (2)	3.0 (1)		2.98 (9)	2.9 (2)
295.91				0.14 (2)				0.14 (2)
298.7				0.013 (5)				0.013 (5)
308.6				0.020 (5)				0.020 (5)
310.2				0.07 (1)				0.07 (1)
310.52[a]								1.30 (14)E-4[e]
313.5				0.10 (1)				0.10 (1)
316.7			0.11	0.10 (1)				0.10 (1)
320.4				0.050 (6)				0.050 (6)
330.4[b]	1.1		0.75	0.75 (5)				0.75 (5)
330.4[b]								
331.4				0.07 (1)				0.07 (1)
340.2				0.039 (8)				0.039 (8)
343.8				0.033 (7)				0.033 (7)
351.9	0.5	0.6	0.53	0.40 (3)				0.40 (3)
357.9				0.035 (10)				0.035 (10)
360.6				0.017 (6)				0.017 (6)
365.0[b]				0.017 (6)				0.017 (6)
365.0[b]								
369.50	3.5	2.63	2.49	2.40 (15)	2.69 (10)		2.60 (8)	2.40 (15)
372.0	1	0.96	1.23	1.18 (8)	1.41 (10)		1.27 (6)	1.18 (8)
379.1				0.04 (1)				0.04 (1)
385.4				0.04 (1)				0.04 (1)
387.94[a]								6.9 (4)E-4[e]
394.1				0.09 (1)				0.09 (1)
397.7				0.026 (6)				0.026 (6)
401.8[×]				0.035 (10)				0.035 (10)
409.8	0.4		0.48	0.33 (3)				0.33 (3)
416.1	0.1			0.035 (10)				0.035 (10)
425.3[×]				0.035 (10)				0.035 (10)
426.95	0.8		0.47	0.44 (3)				0.44 (3)
427.4[a]								3.0 (8)E-5[e]
433.1			0.05	0.09 (1)				0.09 (1)
446.6[b]			0.11	0.11 (1)				0.11 (1)
446.6[b]								
450.93[a]								3.8 (18)E-3[e]
452.4				0.026 (8)				0.026 (8)
458.68	1.3		1.26	1.10 (6)	1.22 (10)		1.13 (5)	1.10 (6)
461.5[b]				0.033 (10)				0.033 (10)
461.5[b]								
464.2				0.03 (1)				0.03 (1)
468.0				0.21 (2)				0.21 (2)
472.3			0.21	0.35 (2)				0.35 (2)
474.2				0.035 (10)				0.035 (10)
478.6[b]			0.26	0.12 (1)				0.12 (1)
478.6[b]								
481.0	0.4		0.42	0.30 (2)				0.30 (2)

E_γ/keV	I_γ							
	1967Wa09	1968Bj06[!]	1975Ar24	1986Ar05	1990Sc09[!]	2006Al28[!]	LWEIGHT	Recommended
498.0[b]			0.09	0.06 (1)				0.06 (1)
498.0[b]								
502.0				0.026 (8)				0.026 (8)
506.75	1.5		1.4	1.25 (8)	2.14 (12)		1.7 (5)	1.25 (8)
513.4[c]	1.3		1.3	1.10 (7)				~ 0.73
513.4[c]								~ 0.37
519.6				0.38 (3)				0.38 (3)
521.4	1.1	0.9	0.81	0.72 (5)				0.72 (5)
527.9		0.6	0.61	0.38 (3)				0.38 (3)
529.1[b]	0.3			0.09 (3)				0.09 (3)
529.1[b]								
534.1				0.08 (1)				0.08 (1)
537.2			0.14	0.08 (1)				0.08 (1)
543.8				0.13 (2)				0.13 (2)
553.7				0.043 (15)				0.043 (15)
558.0[b]				0.09 (2)				0.09 (2)
558.0[b]								
559.2				0.07 (2)				0.07 (2)
562.8				0.035 (10)				0.035 (10)
565.2[b]		0.9		1.00 (6)				1.00 (6)
565.2[b]								
568.9		2.63		3.5 (4)				3.5 (4)
569.5	14.5	8.75	12.1	8.0 (8)	12.42 (16)	12.9 (38)		8.9 (8)[~]
575.5				0.026 (8)				0.026 (8)
584.1				0.17 (2)				0.17 (2)
586.3			0.09	0.07 (1)				0.07 (1)
590.3				0.035 (10)				0.035 (10)
595.4				0.09 (2)				0.09 (2)
596.9[b]			0.31	0.19 (2)				0.19 (2)
596.9[b]								
602.6	0.4		0.76	0.52 (3)				0.52 (3)
604.6				0.05 (2)				0.05 (2)
612.0		0.6	0.61	0.37 (3)				0.37 (3)
617.0[b]				0.05 (2)				0.05 (2)
617.0[b]								
619.0				0.035 (10)				0.035 (10)
624.2		0.35	0.54	0.34 (3)				0.34 (3)
628.1				0.23 (4)				0.23 (4)
629.4		0.35		0.34 (5)				0.34 (5)
632.6				0.035 (10)				0.035 (10)
634.3[b]				0.13 (2)				0.13 (2)
634.3[b]								
643.2[×]				0.026 (8)				0.026 (8)
646.5		0.9	0.19	0.11 (1)				0.11 (1)
653.7[b]		0.44	0.58	0.45 (6)				0.45 (6)
653.7[b]								
655.2	0.7			0.13 (2)				0.13 (2)
657.4	0.7	0.9		0.38 (3)				0.38 (3)
659.8[×]				0.26 (2)				0.26 (2)

E_γ/keV	I_γ							
	1967Wa09	1968Bj06[!]	1975Ar24	1986Ar05	1990Sc09[!]	2006Al28[!]	LWEIGHT	Recommended
663.9			0.9	0.52 (7)				0.52 (7)
666.5	2.2		1.49	1.13 (7)	0.92 (9)		1.05 (6)	1.13 (7)
669.7[c]	2.0		1.14	0.96 (5)	1.04 (10)		0.98 (5)	0.96 (5)
669.7[c]								< 0.0005
675.1				0.097 (10)				0.097 (10)
683.9				0.15 (3)				0.15 (3)
685.1[b]			0.24	0.14 (3)				0.14 (3)
685.1[b]								
692.6	1.3	1.5	1.4	1.20 (7)				1.20 (7)
699.03[b]	4.1	3.5	4.16	3.5 (2)	3.61 (10)		3.59 (9)	3.5 (2)
699.03[b]								
705.9	2.9	3.1	2.14	2.2 (1)				2.2 (1)
708.3[a]								0.022 (8)[e]
711.5[×]			0.18	0.15 (2)				0.15 (2)
713.7[b]				0.14 (2)				0.14 (2)
713.7[b]								
716.5				0.030 (8)				0.030 (8)
727.8				0.11 (1)				0.11 (1)
730.9				0.61 (8)				0.61 (8)
733.39	9.2	7	7.5	6.7 (4)	7.04 (11)		7.02 (11)	6.7 (4)
738.0		1.75	1.14	1.12 (7)	1.29 (11)		1.17 (6)	1.12 (7)
742.813	2.5		2.0	2.0 (1)				2.0 (1)
745.9			0.11	0.31 (3)				0.31 (3)
748.1				0.10 (2)				0.10 (2)
755.0[b]	0.6		1.4	1.18 (6)	1.29 (11)		1.21 (5)	1.18 (6)
755.0[b]								
758.9				0.24 (2)				0.24 (2)
761.0				0.07 (2)				0.07 (2)
764.8				0.19 (4)				0.19 (4)
766.4	0.4	0.26		0.25 (4)				0.25 (4)
769.1				0.18 (1)				0.18 (1)
772.4				0.07 (2)				0.07 (2)
778.6[×]				0.044 (8)				0.044 (8)
780.4	0.7		0.88	0.87 (4)				0.87 (4)
783.4			0.44	0.29 (3)				0.29 (3)
786.272	1		1.4	1.16 (6)				1.16 (6)
792.8				0.043 (10)				0.043 (10)
794.9				0.65 (8)				0.65 (8)
796.1	3.8		2.9	2.5 (2)	3.31 (15)		2.9 (4)	2.5 (2)
799.7[a]								
802.3				0.030 (8)				0.030 (8)
804.1			0.35	0.6 (2)				0.6 (2)
805.8	3	2.9	2.71	2.45 (15)				2.45 (15)
808.4				0.035 (10)				0.035 (10)
810.0								0.19 (6)[f]
811.5				0.12 (1)				0.12 (1)
814.2				0.30 (2)				0.30 (2)
819.2	2.8		2.01	1.83 (10)	2.26 (9)		2.05 (22)	1.83 (10)
824.2[×]			3.23	1.2 (1)				1.2 (1)

E_γ/keV	I_γ							
	1967Wa09	1968Bj06[!]	1975Ar24	1986Ar05	1990Sc09[!]	2006Al28[!]	LWEIGHT	Recommended
825.1	4.3			1.83 (10)	4.16 (11)			1.83 (10)
829.3				0.35 (10)				0.35 (10)
831.5	5.3		4.46	4.0 (2)	4.77 (9)	3.8 (23)	4.38 (28)	4.0 (2)
839.5				0.030 (7)				0.030 (7)
844.1	0.4		0.44	0.41 (3)				0.41 (3)
846.1[×]				0.05 (1)				0.05 (1)
848.9				0.026 (7)				0.026 (7)
851.8				0.07 (2)				0.07 (2)
857.7				0.035 (7)				0.035 (7)
863.2				0.07 (2)				0.07 (2)
869.7				0.19 (2)				0.19 (2)
874.0				0.035 (7)				0.035 (7)
876.0	7		3.19	2.45 (2)	2.57 (8)		2.46 (2)	2.45 (2)
880.52[c]	18		11.64	10.1 (6)	12.97 (12)		11.6 (15)	4.1 (4)
880.52[c]								6.0 (5)
883.24	4		10.85	9.3 (6)				9.3 (6)
890.1				0.026 (7)				0.026 (7)
898.67	4.3	3.6	3.15	3.15 (20)	3.61 (8)		3.55 (8)	3.15 (20)
904.2	0.5		0.41	0.33 (2)				0.33 (2)
916.5				0.023 (6)				0.023 (6)
918.4				0.096 (10)				0.096 (10)
920.5[×]				0.028 (7)				0.028 (7)
925.0		8.8		7.6 (5)	8.69 (11)		8.64 (11)	7.6 (5)
926.0[a]								1.7 (12)[g]
926.7	22	8.75	14.7	8.7 (5)				7.0 (9)[g]
935.8				0.064 (7)				0.064 (7)
942.0				0.044 (7)				0.044 (7)
946.00	19	13.1	16.1	13.0 (8)				13.0 (8)
947.7				1.57 (15)	1.90 (9)		1.81 (8)	1.57 (15)
952.7				0.08 (1)				0.08 (1)
960.0	0..2		0.09	0.07 (1)				0.07 (1)
965.8	0.4	0.7	0.09	0.46 (3)				0.46 (3)
975.1				0.026 (7)				0.026 (7)
978.2				0.087 (20)				0.087 (20)
980.3[c]	3.8		~ 2.6	1.92 (10)	2.75 (9)			~ 2.6[h]
980.3[c]			~ 1.7					~ 1.7[h]
981.6				0.7 (2)				0.7 (2)
984.2	1.5		1.49	1.57 (15)	1.84 (8)		1.78 (7)	1.57 (15)
989.5				0.10 (1)				0.10 (1)
992.0[×]				0.08 (2)				0.08 (2)
994.6				0.06 (2)				0.06 (2)
997.7				0.044 (10)				0.044 (10)
1009.9[b]				0.064 (10)				0.064 (10)
1009.9[b]								
1019.5				0.026 (7)				0.026 (7)
1021.8	0.4			0.14 (3)				0.14 (3)
1023.6[×]				0.06 (2)				0.06 (2)
1025.3[×]				0.05 (2)				0.05 (2)
1028.7	0.8	0.8	0.44	0.55 (3)				0.55 (3)

E_γ/keV	I_γ							
	1967Wa09	1968Bj06[!]	1975Ar24	1986Ar05	1990Sc09[!]	2006Al28[!]	LWEIGHT	Recommended
1032.8				0.017 (4)				0.017 (4)
1035.9[×]				0.025 (9)				0.025 (9)
1037.9				0.017 (6)				0.017 (6)
1041.1				0.031 (10)				0.031 (10)
1044.4		0.44		~ 0.030				~ 0.030
1051.4				0.06 (1)				0.06 (1)
1057.8				~ 0.017				~ 0.017
1065.1				0.026 (7)				0.026 (7)
1073.6		0.21	0.17	0.10 (1)				0.10 (1)
1083.2	0.6	0.7		0.49 (3)				0.49 (3)
1085.3				0.026 (7)				0.026 (7)
1106.9				0.08 (1)				0.08 (1)
1110.6				0.06 (1)				0.06 (1)
1121.7	0.4		0.44	0.24 (3)				0.24 (3)
1125.2	0.8			0.35 (7)				0.35 (7)
1126.8				0.29 (3)				0.29 (3)
1151.4[b]				0.031 (9)				0.031 (9)
1151.4[b]								
1153.5				0.044 (7)				0.044 (7)
1171.3				0.087 (10)				0.087 (10)
1173.1				0.044 (7)				0.044 (7)
1182.1				~ 0.009				~ 0.009
1193.77				0.020 (5)				0.020 (5)
1217.3		0.9	0.32	0.21 (2)				0.21 (2)
1220.4[×]				0.06 (1)				0.06 (1)
1237.3				< 0.009				< 0.009
1241.2				0.22 (2)				0.22 (2)
1247.8				0.021 (5)				0.021 (5)
1252.6				0.017 (7)				0.017 (7)
1256.5				0.057 (6)				0.057 (6)
1277.7			0.24	0.043 (7)				0.043 (7)
1292.8	0.6	0.7	0.45	0.45 (3)	0.55 (6)		0.47 (3)	0.45 (3)
1296.4[×]				0.028 (6)				0.028 (6)
1301.2[×]				0.017 (4)				0.017 (4)
1327.0[×]				0.017 (4)				0.017 (4)
1342.9				0.012 (4)				0.012 (4)
1352.9	1.7	1.84	1.10	1.12 (5)	1.17 (5)		1.15 (4)	1.12 (5)
1354.6				0.13 (3)				0.13 (3)
1359.0			0.11	0.15 (2)				0.15 (2)
1389.6				0.07 (2)				0.07 (2)
1393.9	2.8	2.2	2.1	2.0 (1)	2.39 (6)		2.2 (2)	2.0 (1)
1397.5				0.08 (2)				0.08 (2)
1400.3				0.17 (2)				0.17 (2)
1409.1				0.043 (8)				0.043 (8)
1414.4				< 0.0026				< 0.0026
1426.9			0.17	0.16 (2)				0.16 (2)
1442.8				0.030 (6)				0.030 (6)
1445.4	0.3			0.31 (3)				0.31 (3)
1452.7	0.9	1	0.7	0.78 (5)	0.74 (6)		0.76 (4)	0.78 (5)

E_γ/keV	I_γ							
	1967Wa09	1968Bj06[!]	1975Ar24	1986Ar05	1990Sc09[!]	2006Al28[!]	LWEIGHT	Recommended
1458.9				0.09 (2)				0.09 (2)
1475.8				0.008 (3)				0.008 (3)
1485.4				0.029 (6)				0.029 (6)
1488.0				0.013 (5)				0.013 (5)
1493.6		0.26	0.17	0.10 (1)				0.10 (1)
1496.0				0.035 (8)				0.035 (8)
1500.0				0.011 (3)				0.011 (3)
1507.3[×]				0.019 (4)				0.019 (4)
1510.1				< 0.009				< 0.009
1515.6		0.35		0.07 (1)				0.07 (1)
1520.7[×]				~ 0.009				~ 0.009
1538.8[×]				0.013 (3)				0.013 (3)
1550.1			0.09	0.07 (1)				0.07 (1)
1567.0				0.011 (2)				0.011 (2)
1579.9			0.15	0.07 (2)				0.07 (2)
1585.9	0.3		0.26	0.14 (1)				0.14 (1)
1594.0	0.8	0.6	0.46	0.30 (2)				0.30 (2)
1618.3				0.009 (3)				0.009 (3)
1627.3			0.09	0.073 (8)				0.073 (8)
1638.1	0.3		0.19	0.20 (1)				0.20 (1)
1640.5		0.6		0.010 (3)				0.010 (3)
1644.9				0.010 (3)				0.010 (3)
1650.2				< 0.005				< 0.005
1655.7[×]				0.025 (3)				0.025 (3)
1664.8[×]				0.017 (6)				0.017 (6)
1668.41	1		0.33	0.74 (5)	0.74 (5)			0.74 (5)
1672.8				0.033 (10)				0.033 (10)
1679.5				0.074 (16)				0.074 (16)
1685.7				0.30 (2)				0.30 (2)
1693.8			0.80	0.67 (7)				0.67 (7)
1695.0	1.1	1.4		0.26 (6)				0.26 (6)
1700.5				0.10 (1)				0.10 (1)
1719.7				0.017 (5)				0.017 (5)
1723.2				0.015 (3)				0.015 (3)
1727.8				0.019 (4)				0.019 (4)
1737.7		0.19	0.07	0.072 (8)				0.072 (8)
1741.1				0.047 (6)				0.047 (6)
1743.2[×]				0.032 (7)				0.032 (7)
1750.0				0.062 (7)				0.062 (7)
1757.5[×]				0.023 (5)				0.023 (5)
1768.0	0.2		0.05	0.019 (4)				0.019 (4)
1770.8				0.065 (15)				0.065 (15)
1773.0				0.065 (15)				0.065 (15)
1783.7				0.024 (6)				0.024 (6)
1797.1	0.3		0.19	0.23 (2)				0.23 (2)
1805.8				0.005 (2)				0.005 (2)
1815.3				0.009 (3)				0.009 (3)
1819.8				0.004 (1)				0.004 (1)
1825.1				0.009 (3)				0.009 (3)

E_γ/keV	I_γ							
	1967Wa09	1968Bj06!	1975Ar24	1986Ar05	1990Sc09!	2006Al28!	LWEIGHT	Recommended
1830.8×				0.004 (1)				0.004 (1)
1838.0b			0.08	0.040 (9)				0.040 (9)
1838.0b								
1849.8×		0.044		0.027 (6)				0.027 (6)
1872.8				0.034 (8)				0.034 (8)
1884.1				0.015 (4)				0.015 (4)
1890.1	0.4			0.14 (1)				0.14 (1)
1893.4				~ 0.006				~ 0.006
1896.7				0.10 (2)				0.10 (2)
1915.5				0.019 (4)				0.019 (4)
1925.4	0.6		0.28	0.29 (4)	0.31 (3)		0.30 (2)	0.29 (4)
1927.9×				0.052 (10)				0.052 (10)
1935.2×				~ 0.009				~ 0.009
1937.7			0.04	0.04 (1)				0.04 (1)
1958.0				0.0096 (25				0.0096 (25)
1971.2				~ 0.0026				~ 0.0026
1977.4				0.016 (4)				0.016 (4)
1989.6				0.007 (3)				0.007 (3)
2072.2				0.004 (2)				0.004 (2)

!: Normalized to I(γ131.3) = 17.5.

#: From I(γ227.25) = 5.6 (3) in 1986Ar05 and I(γ226.5+γ227.25) = 10.25 (15) in 1990Sc09.

~: From I(γ568.9) = 3.5 (4) in 1986Ar05 and I(γ569.5+568.9) = 12.42 (16) in 1990Sc09.

a: Expected but as unobserved yet.

b: Multiply placed, intensity not divided.

c: Multiply placed, intensity suitably divided.

d: I(γ+ce), from γ-ray transition intensity balance.

e: From adopted γ branching.

f: From I(γ+ce), from ce measurements(1968Bj06).

g: From Iγ(926+926.7) = 8.7 (5) and Iγ(926.7)/ Iγ(883.2) = 0.75 (8) in ^{238}Pu α decay.

h: From γγ coincidence measurements(1968Bj06).

×: Not placed in level scheme.

5.3 Absolute values of the γ-ray emission probabilities

There is no measured absolute γ-ray emission probability in the ^{234}Pa β^- decay. The normalization factor N for translation of the relative intensities to the absolute emission probabilities has been obtained from the relation of ΣI(γ+ce)(g.s.) + ΣI(γ+ce)(43.5keV level) = 100 %, excluding the 43.5-keV transition and supposing no β^- feeding to the above-mentioned two states. N = 1.04 (9).

The recommended absolute γ-ray emission probabilities (photons per 100 disintegrations) are the relative values recommended in table 5 multiplied by 1.04 (9).

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$^{234}Pa^{m}$-Comments on evaluation of the decay data

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This evaluation was completed in 2009. Literature available by January 2009 was included.

1 Decay Scheme

$^{234}Pa^{m}$ disintegrates 99.85 (1) % by β^- emissions to levels in ^{234}U and also 0.15 (1) % through IT decay to ^{234}Pa. $^{234}Pa^{m}$ isomer state has $J^{\pi} = (0)^-$ (2007Br04).

Measured and recommended branching ratios for $^{234}Pa^{m}$ IT decay are listed in Table 1.

Table 1: Measured and recommended branching ratio for $^{234}Pa^{m}$ IT decay.

IT (%)	References	Comments
0.150 (25)	1938Fe02	
0.12	1945Br05	Not used
0.63	1954Zi02	Not used
0.18 (2)	1960Fo15	
0.13 (3)	1963Bj02	Deduced by comparing $I_{ce's}$, $I_{\gamma's}$, and β- disintegration rates from $^{234}Pa^{g}$ following $^{234}Pa^{m}$ decay
0.15 (5)	1973Go40	
0.19 (6)		
0.19 (5)	1978Ch06	Deduced from measured I_{γ}(73.9 keV)
0.157 (14)	1990Sc09	Deduced from measured P_{γ}(131 keV)
0.126 (16)	2006Al28	Deduced from measured P_{γ}(131 keV)
0.151 (8)		LWEIGHT
0.15 (1)		Adopted

Statistical processing was performed with the LWEIGHT computer program.

Our recommended IT decay branching ratio is I_{IT} = 0.15 (1) % which taken from LWEIGHT result. Thus, $I_{\beta-}$= 99.85 (1) %.

The $^{234}Pa^{m}$ β^- decay scheme was built based mainly on measurement results from 1963Bj02, 1967Wa09 and 1975Ar23. 16 γ-rays were not placed in the current decay scheme. The total photon intensity of these γ transitions is about 0.018 %.

The adopted Q(β^-) value of 2269(4) + x keV has been obtained from Q(β^-) = 2195 (4) keV for ^{234}Pa β^- decay (2003Au03), the energy of γ-ray transition 73.92 keV and the estimate of isomeric transition energy x < 10 keV deduced from the limit on experimental detection (1973Go40) in ^{234}Th β^- decay. The adopted Q(β^-) is in certain agreement with the effective Q(β^-) value of 2259.7 (24) keV, calculated by the evaluators from average radiation energies using the RADLST computer program. This agreement supports the completeness and correctness of the decay scheme.

2 Nuclear Data

The Q(β^-) value is from the mass adjustment in 2003Au03 and the energies of γ-ray transitions in $^{234}Pa^{m}$ IT decay (see above).

Level energies, have been obtained from a least-squares fit to γ-ray energies (GTOL computer code). Spin and parities are from 2007Br04.
The measured and recommended $^{234}Pa^{m}$ half-life values are listed in Table 2.

Table 2: Measured half-life values of $^{234}Pa^{m}$ and recommended value

$T_{1/2}$ (min)	References	Comments
1.175 (3)	1951Ba83	
1.25 (10)	1956On07	
1.14 (1)	1963Bj02	
1.183 (37)	1969SaZR	
1.175	1969DeZX	Not used
1.159 (16)	2004Wo02	Evaluated value
1.187 (23)		Unweighted mean
1.159 (11)		LWEIGHT weighted mean,χ^2=2.54
1.159 (11)		Recommended value

The weighted average of 1.15946 for this data set of the 4 values is dominated by the accurate value of 1951Ba83. The LWEIGHT computer program, which uses a Limitation of Relative Statistical Weights (LRSW method), has increased the 1951Ba83 uncertainty from 0.003 to 0.0096 and used a weighted mean and an external uncertainty for recommended average.

Thus, the adopted value of the $^{234}Pa^{m}$ half-life is 1.159 (11) minute.

2.1 β^- transitions

The maximum energies of the β^- transitions in the decay of $^{234}Pa^{m}$ have been deduced from the Q(β-) value (2003Au03), and the level energies which given in Tables 3 and 4.

Table 3: ^{234}Pa levels populated in $^{234}Pa^{m}$ IT decay

Level energy (keV)	Spin & parity	Half-life
0.0	4+	6.70 (5) h
73.92 (2)	(3+)	
73.92+x	(0-)	1.159 (11) min

Table 4: ^{234}U levels populated in $^{234}Pa^{m}$ β^- decay

Level energy (keV)	Spin & parity	Half-life	β^- transition probabilities (%)
0.0	0+	2.455 (6)×10^5 a	97.599 (24)
43.428 (14)	2+	0.252 (7) ns	
143.279 (24)	4+		
786.243 (14)	1-		0.049 (3)
809.786 (23)	0+	< 0.1 ns	0.945 (12)
849.18 (7)	3-		
851.56 (4)	2+	> 1.74 ps	
926.659 (20)	2+	1.38 (17) ps	
989.359 (19)	2-	0.76 (4) ns	
1044.469 (15)	0+		1.006 (13)
1085.04 (4)	2+		

Level energy (keV)	Spin & parity	Half-life	β^- transition probabilities (%)
1126.32 (4)	2+		
1174.2 (4)	(1,2+)		0.004 6 (3)
1237.23 (3)	1-		0.012 1 (11)
1435.05 (5)	1-		0.009 2 (11)
1457.40 (8)	(2-)		
1500.8 (3)	(1)		0.013 1 (6)
1553.62 (6)	(1)		0.032 0 (6)
1570.53 (4)	1+		0.002 31 (19)
1591.64 (7)	(1)		0.024 9 (5)
1601.68 (4)	1+		0.001 27 (23)
1666.77 (5)	(1-)		0.006 1 (3)
1693.7? (6)	(1-)		0.002 4 (3)
1781.19 (8)	(0+,1)		0.035 7 (18)
1796.4 (6)	(1)		0.002 1 (3)
1808.97 (7)	(1-)		0.014 6 (7)
1863.11 (7)	(1)		0.003 11 (19)
1874.86 (8)	(1)		0.025 8 (3)
1911.04 (5)	(1-)		0.045 2 (8)
1936.68 (7)	(1)		0.010 8 (3)
1970.0 (5)	(1-)		0.003 89 (22)

The adopted β^- transition probabilities and the associated uncertainties were deduced from the γ transition probability balance at each level of the decay scheme.

The values of *logft* and average β^- energies have been calculated with the program LOGFT.

2.2 γ Transitions

The γ-ray transition probabilities were deduced using the γ-ray emission intensities and the relevant internal conversion coefficients.

Multipolarities and mixing ratios of γ-ray transitions are from 1963Bj02 and 2007Br04.

The internal conversion coefficient (ICC) (and its associated uncertainty) for γ-ray transitions have been interpolated from theoretical values based on the "Frozen Orbital" approximation (2002Ba85) using the BrIcc computer program (2008Ki07).

3. Atomic data

Atomic fluorescence yields (ω_K,ϖ_L, ϖ_M, η_{KL} and η_{LM}) are from Schönfeld (1996Sc06).

The X-ray and Auger electron emission probabilities have been deduced from γ-ray and conversion electron data by using the computer code RADLST.

The deduced total KX-ray emission probability of 0.67 ± 0.01 %, is in agreement with the measured value of 0.72 (1963Bj02), thus confirming the completeness of the decay scheme.

4. Electron Emissions.

The conversion electron emission probabilities have been deduced from γ-ray transition data using theoretical internal conversion coefficients.

5. Photon Emissions

5.1 γ-ray energies

Measured results for the energies of γ-rays from $^{234}Pa^m$ decay are listed in Table 5. The recommended values were obtained mainly from measurements of 2004Br43, 2000Ni13, 1975Ar23, 1972Sa06 and 1967Wa09 using the LWEIGHT computer program, except as noted in the table.

Table 5: Measured and recommended γ-ray energy values from $^{234}Pa^m$ decay

1963Bj02	1967Wa09	1972Sa06	1975Ar23	2000Ni13	2004Br43	LWEIGHT	Recommended
							< 10[#]
							41.82[a]
43.5							43.49 (2)[b]
							62.70 (1)[a]
							73.92 (2)[#]
							99.86 (2)[ab]
							135.32 (8)[a]
							137.23 (5)[a]
			140.1 (10)				140.1 (10)
							166.5 (1)[a]
	185.2 (5)		184.7 (5)			185.0 (4)	185.0 (4)
			193.4 (8)				193.4 (8)
							197.91 (15)[a]
			199.9 (10)				199.9 (10)
			203.3 (8)				203.3 (8)
			209.9 (4)				209.9 (4)
							233.6 (2)[a]
							235.9 (3)[ab]
236 (1)							236 (1)
			243.5 (8)				243.5 (8)[×]
			247.7 (8)				247.7 (8)
255 (5)	258.0 (5)		258.26 (3)	258.227 (3)		258.227 (3)	258.227 (3)
			275.5 (8)				275.5 (8)
			299.0 (10)				299.0 (10)
			311.0 (10)				311.0 (10)
							316.7 (1)[a]
			338.1 (8)				338.1 (8)
							340.2 (1)[a]
			357.5 (10)				357.5 (10)
			362.8 (10)				362.8 (10)
			387.6 (8)				387.6 (8)
							427.4 (2)[a]
							445.91 (10)[a]
	451.4 (6)		450.97 (10)			450.98 (10)	450.98 (10)
			453.58 (10)				453.58 (10)
			456.7 (10)				456.7 (10)
			468.43 (10)				468.43 (10)
			475.74 (10)				475.74 (10)

1963Bj02	1967Wa09	1972Sa06	1975Ar23	2000Ni13	2004Br43	LWEIGHT	Recommended
							485.44 (7)[a]
			507.5 (10)				507.5 (10)
			509.2 (8)				509.2 (8)
							516.60 (6)[a]
							526.02 (10)[a]
			543.98 (10)				543.98 (10)
							557.24 (6)[a]
			557.3 (10)				557.3 (10)[×]
			572.0 (10)				572.0 (10)
							581.19 (10)[a]
			624.6 (10)				624.6 (10)
			647.7 (8)				647.7 (8)[×]
			649.0 (10)				649.0 (10)
			655.3 (10)				655.3 (10)
			670.8 (10)				670.8 (10)
			673.9 (10)				673.9 (10)
			683.4 (10)				683.4 (10)
			691.0 (3)				691.0 (3)
			695.5 (10)				695.5 (10)
			699.02 (10)				699.02 (10)
			702.0 (1)				702.0 (1)
			705.94 (12)				705.94 (12)
			708.2 (10)				708.2 (10)
							719.01 (7)[a]
			732.5 (10)				732.5 (10)
			740.10 (8)				740.10 (8)
746 (5)	742.7 (6)	742.814 (22)	742.77 (8)	742.813 (5)		742.813 (5)	742.813 (5)
							750.12 (6)[a]
			760.3 (10)				760.3 (10)[×]
							760.53 (15)[a]
765	766.5 (6)	766.358 (20)	766.42 (10)			766.361 (20)	766.361 (20)
			781.75 (10)				781.75 (10)
							783.4 (1)[a]
	786.3 (8)	786.272 (22)	786.28 (10)			786.272 (22)	786.272 (22)
790 (5)							791.94 (5)[b]
806			805.75 (10)				805.75 (10)
			808.2 (1)				808.2 (1)
811							810.0 (7)[b]
			818.2 (5)				818.2 (5)
	825.5 (2)		825.6 (5)			825.5 (2)	825.5 (2)
			844.1 (8)				844.1 (8)
	852.1 (12)		851.58 (10)			851.6 (1)	851.6 (1)
			866.8 (10)				866.8 (10)
		880.514 (36)	880.9 (5)			880.52 (4)	880.52 (4)
		883.237 (33)	883.22 (10)			883.24 (3)	883.24 (3)

1963Bj02	1967Wa09	1972Sa06	1975Ar23	2000Ni13	2004Br43	LWEIGHT	Recommended
			887.29 (10)				887.29 (10)$^{\times}$
			921.72 (10)				921.72 (10)
			926.61 (10)				926.61 (10)
			936.3 (10)				936.3 (10)
			941.96 (10)				941.96 (10)
		946.002 (28)	945.94 (2)			945.961 (16)	945.961 (16)
			960.0 (10)				960.0 (10)
			996.1 (20)				996.1 (20)
1001	1001.3 (5)	1001.025 (22)	1000.99 (10)		1001.03 (3)	1001.026 (18)	1001.026 (18)
1045			1041.70 (10)				1041.70 (10)
			1059.4 (8)				1059.4 (8)
			1061.86 (10)				1061.86 (10)
			1081.9 (10)				1081.9 (10)
			1084.25 (10)				1084.25 (10)
			1120.6 (8)				1120.6 (8)
	1125.2 (8)		1124.93 (10)			1124.93 (10)	1124.93 (10)
1160			1174.2 (10)				1174.2 (10)
	1194.2 (6)	1193.767 (30)	1193.73 (12)			1193.77 (3)	1193.77 (3)
			1220.37 (10)				1220.37 (10)$^{\times}$
	1238.0 (7)		1237.26 (10)			1237.28 (10)	1237.28 (10)
			1353.0 (15)				1353.0 (15)$^{\times}$
	1392 (2)		1392.7 (10)			1392.6 (9)	1392.6 (9)
	1414.7 (10)		1413.88 (10)			1413.89 (10)	1413.89 (10)
1440	1435.5 (8)		1434.14 (10)			1434.16 (10)	1434.16 (10)
			1458.5 (15)				1458.5 (15)
			1501 (2)				1501 (2)
	1510.9 (7)		1510.21 (10)			1510.22 (10)	1510.22 (10)
	1528.2 (12)		1527.27 (10)			1527.28 (10)	1527.28 (10)
			1550.0 (10)				1550.0 (10)
	1554.7 (8)		1553.75 (10)			1553.77 (10)	1553.77 (10)
			1558.4 (10)				1558.4 (10)
	1570.6 (12)		1570.67 (10)			1570.67 (10)	1570.67 (10)
	1593.4 (7)		1593.8 (10)			1593.5 (6)	1593.5 (6)
			1601.8 (15)				1601.8 (15)
			1667.6 (10)				1667.6 (10)
			1694.1 (10)				1694.1 (10)
			1720.5 (15)				1720.5 (15)$^{\times}$
			1732.2 (15)				1732.2 (15)$^{\times}$
	1738.5 (7)		1737.75 (10)			1737.77 (10)	1737.77 (10)
1750	1759 (2)		1759.81 (10)			1759.81 (10)	1759.81 (10)
	1765.5 (6)		1765.44 (10)			1765.44 (10)	1765.44 (10)
	1796.5 (20)		1796.2 (10)			1796.3 (9)	1796.3 (9)
	1809.4 (7)		1809.04 (10)			1809.05 (10)	1809.05 (10)
			1819.69 (10)				1819.69 (10)
	1831.9 (10)		1831.36 (10)			1831.37 (10)	1831.37 (10)

1963Bj02	1967Wa09	1972Sa06	1975Ar23	2000Ni13	2004Br43	LWEIGHT	Recommended
			1863.09 (10)				1863.09 (10)
	1868.6 (8)		1867.69 (10)			1867.7 (1)	1867.7 (1)
	1876.3 (8)		1874.88 (10)			1874.9 (1)	1874.9 (1)
	1893.5 (8)		1893.51 (11)			1893.51 (11)	1893.51 (11)
	1911.5 (7)		1911.19 (11)			1911.20 (11)	1911.20 (11)
			1926.5 (10)				1926.5 (10)
	1937.5 (7)		1937.04 (13)			1937.01 (13)	1937.01 (13)
	1970.4 (10)		1970.0 (15)			1970.3 (8)	1970.3 (8)
					2022.24 (12)		2022.24 (12)[×]
					2041.23 (13)		2041.23 (13)[×]
					2065.80 (13)		2065.80 (13)[×]
					2093.19 (38)		2093.19 (38)[×]
					2102.14 (15)		2102.14 (15)[×]
					2136.69 (14)		2136.69 (14)[×]

#: IT decay, energy from 1973Go40.

a: Expected but as yet unobserved, energy from adopted gammas.

b: Energy from ^{238}Pu α decay.

×: Not placed in level scheme.

5.2 Relative values of the γ-ray intensities

Measurements of the relative γ-ray intensities from $^{234}Pa^{m}$ are listed in table 6. The recommended values have been obtained with the LWEIGHT computer program using measurement results from 2006Al28, 2004Br43, 2000Ni13, 1992Si17, 1990Sc09, 1986Mo09, 1975Ar23 1971GuZQ and 1967Wa09.

As the measured results of 1990Sc09 and 1971GuZQ contained the contributions from $^{234}Pa^{g}$ β^- decay, these contributions had to be estimated and removed from the values cited in 2007Br04. Also the measurement results of 1963Bj02 have been rejected and not listed in table as the associated uncertainties are not given.

Table 6: Measured and recommended relative γ-ray intensities from $^{234}Pa^{m}$ decay

E_γ/keV	I_γ										
	1967Wa09	1971GuZQ	1975Ar23	1986Mo09	1990Sc09	1992Si17	2000Ni13	2004Br43!	2006Al28!	LWEIGHT	Recommended
< 10											17.7 (12)[#]
41.82[a]											1.61 (8)[b]
43.49											166.8 (4)[b]
62.70[a]											0.15 (4)[d]
73.92											1.53 (12)[#]
99.86[a]											0.96 (7)[b]
135.32[a]											0.000 50 (6)[d]
137.23[a]											0.0057 (21)[d]
140.1			< 0.15								< 0.15
166.5[a]											0.000 028 (6)[d]
185.0	0.2 (1)		0.203 (17)							0.203 (17)	0.203 (17)
193.4			0.085 (17)								0.085 (17)
197.91[a]											0.003 2 (7)[d]

E_γ/keV	I_γ										
	1967Wa09	1971GuZQ	1975Ar23	1986Mo09	1990Sc09	1992Si17	2000Ni13	2004Br43!	2006Al28!	LWEIGHT	Recommended
199.9			0.068 (14)								0.068 (14)
203.3			0.122 (24)		0.145 (12)[c]					0.14 (1)	0.14 (1)
209.9			0.156 (17)								0.156 (17)
233.6[a]			0.059 (12)								≈ 0.1[e]
235.9[a]											0.010 (4)[d]
236											8.7 (9)[f]
243.5[×]			0.059 (10)								0.059 (10)
247.7			0.114 (26)								0.114 (26)
258.227	6.7 (17)	8.82 (24)	9.66 (39)		8.70 (4)	8.6 (6)	9.08 (24)		8.46 (33)	8.72 (4)	8.72 (4)
275.5			0.037 (7)								0.037 (7)
299.0			0.076 (15)								0.076 (15)
311.0			0.061 (12)								0.061 (12)
316.7[a]											0.022 (5)[d]
338.1			0.134 (27)								0.134 (27)
340.2[a]											0.008 5 (25)[d]
357.5			0.095 (20)								0.095 (20)
362.8			0.081 (17)								0.081 (17)
387.6[&]			0.170 (17)								0.115 (17)
387.6[&]											0.056 (4)[d]
427.4[a]											0.002 4 (6)d
445.91[a]											0.003 6 (8)[d]
450.98	0.42 (10)	0.42 (5)	0.356 (34)		0.358 (19)	0.39 (8)				0.366 (15)	0.366 (15)
453.58		0.254 (24)	0.288 (34)		0.23 (2)	0.31 (6)				0.251 (14)	0.251 (14)
456.7			0.085 (17)								0.085 (17)
468.43		0.204 (41)[c]	0.280 (27)		0.237 (16)[c]				0.19 (10)c	0.243 (13)	0.243 (13)
475.74		0.209 (42)	0.339 (34)		0.274 (18)	0.34 (9)				0.280 (15)	0.280 (15)
485.44[a]											0.002 2 (2)[d]
507.5			0.187 (17)								0.187 (17)
509.2			0.254 (34)								0.254 (34)
516.60[a]											0.001 44 (19)[d]
526.02[a]											0.001 06 (14)[d]
543.98		0.40 (8)[c]	0.441 (51)		0.404 (19)[c]	0.46 (6)			0.32 (21)c	0.412 (17)	0.412 (17)
557.24[a]											0.000 98 (13)[d]
557.3[×]			0.085 (19)								0.085 (19)
572.0			0.103 (20)								0.103 (20)
581.19[a]											0.009 4 (11)[d]
624.6			0.170 (17)								0.013 7 (14)[d]
647.7[×]			0.187 (17)								0.187 (17)
649.0[&]			0.127 (25)								0.007 (1)
649.0[&]											0.12 (3)
655.3			0.164 (17)								0.164 (17)
670.8			0.044 (10)								0.044 (10)
673.9			0.076 (15)								0.076 (15)
683.4			0.068 (14)								0.068 (14)

E_γ/keV	I_γ										
	1967Wa09	1971GuZQ	1975Ar23	1986Mo09	1990Sc09	1992Si17	2000Ni13	2004Br43!	2006Al28!	LWEIGHT	Recommended
691.0		1.09 (6)	0.932 (85)		1.073 (23)	0.92 (10)				1.06 (2)	1.06 (2)
695.5			0.187 (17)			0.28 (6)				0.194 (16)	0.194 (16)
699.02		0.70 (7)	0.095 (19)		0.68 (3)					0.68 (3)	0.68 (3)
702.0		0.85 (8)	0.915 (85)		0.846 (20)	0.93 (10)			0.67 (34)	0.852 (17)	0.852 (17)
705.94		0.72 (7)[c]	0.481 (51)		0.656 (16)[c]	0.47 (12)				0.61 (6)	0.61 (6)
708.2			< 0.085								< 0.085
719.01[a]											0.003 02 (24)[d]
732.5			0.154 (17)								0.154 (17)
740.10		1.33 (12)	1.20 (12)		1.41 (3)	1.26 (12)				1.39 (3)	1.39 (3)
742.813	13.3 (17)	11.12 (24)[c]	9.59 (39)	11.3 (7)	10.93 (8)[c]	10.4 (5)	12.27 (23)c			11.13 (28)	11.13 (28)
750.12[a]											0.002 02 (27)[d]
760.3[×]			0.187 (17)								0.187 (17)
760.53[a]											0.000 5 (1)[d]
766.361	36.7 (67)	37.8 (4)[c]	35.1 (14)	39.91 (84)	38.36 (25)[c]	37.6 (11)			35.7 (16)	38.2 (2)	38.2 (2)
781.75		0.845 (85)	0.898 (85)		0.93 (2)	0.86 (12)				0.923 (19)	0.923 (19)
783.4[a]											0.004 6 (8)[d]
786.272	5 (1)	6.41 (12)[c]	5.80 (22)	6.36 (46)	6.37 (6)[c]	5.97 (33)				6.33 (5)	6.33 (5)
791.94											0.001 17 (15)[d]
805.75		0.718 (38)[c]	0.509 (51)		0.820 (15)[c]	0.49 (15)				0.73 (9)	0.73 (9)
808.2		0.34 (4)[c]	0.356 (34)		0.303 (30)[c]	0.39 (10)				0.332 (19)	0.332 (19)
810.0											85[g]
818.2			0.119 (34)								0.119 (34)
825.5	0.42 (25)	0.489 (25)[c]	0.168 (34)		0.547 (14)[c]					0.46 (9)	0.17 (4)
844.1			0.129 (27)								0.129 (27)
851.6	0.67 (25)	0.879 (48)[c]	0.746 (68)		0.820 (17)[c]	0.83 (9)				0.822 (16)	0.822 (16)
866.8		0.145 (24)	0.127 (26)							0.137 (18)	0.137 (18)
880.52		0.438 (9)[c]	0.458 (51)		0.468 (4)[c]	0.52 (16)				0.463 (4)	0.463 (4)
883.24		0.428 (13)[c]	0.424 (34)		0.453 (4)[c]	0.50 (16)			0.38 (10)	0.450 (4)	0.450 (4)
887.29[×]		0.761 (36)	0.882 (85)		0.846 (15)	0.90 (12)				0.836 (14)	0.836 (14)
921.72		1.51 (7)	1.41 (14)		1.51 (2)	1.40 (15)			1.34 (45)	1.506 (19)	1.506 (19)
926.61		0.215 (11)[c]	0.148 (15)		0.213 (3)[c]					0.202 (18)	0.148 (15)
936.3		0.091 (23)	0.22 (5)							0.12 (2)	0.12 (2)
941.96		0.282 (24)[c]	0.356 (34)		0.289 (12)[c]	0.33 (6)				0.295 (10)	0.295 (10)
945.961		1.33 (3)[c]	1.19 (12)	1.27 (15)	1.242 (11)[c]	1.25 (37)			1.18 (31)	1.252 (10)	1.252 (10)
960.0			0.102 (34)								0.102 (34)
996.1		0.90 (5)	0.492 (85)			0.51 (10)				0.7 (2)	0.7 (2)
1001.026	100	100	100	100	100	100	100	100	100		100
1041.70		0.111 (22)	0.170 (17)		0.137 (11)					0.141 (9)	0.141 (9)
1059.4			0.131 (26)								0.131 (26)
1061.86		0.290 (24)	0.237 (17)		0.274 (15)	0.25 (10)				0.264 (10)	0.264 (10)
1081.9			0.107 (22)								0.107 (22)
1084.25			0.058 (10)		0.136 (11)[c]					0.10 (4)	0.10 (4)
1120.6			0.204 (17)								0.204 (17)
1124.93[&]	0.50 (17)	0.495 (21)[c]	0.475 (51)		0.436 (14)[c]	0.48 (8)				0.456 (11)	0.046 (1)

E_γ/keV	I_γ									
	1967Wa09	1971GuZQ	1975Ar23	1986Mo09	1990Sc09	1992Si17	2000Ni13	2004Br43!	2006Al28!	LWEIGHT	Recommended
1124.93[&]											0.41 (1)
1174.2			0.227 (22)								0.227 (22)
1193.77	1.33 (33)	1.615 (36)[c]	1.525 (85)		1.606 (16)[c]	1.58 (14)			1.67 (78)	1.605 (15)	1.605 (15)
1220.37[×]		0.106 (23)	0.119 (34)		0.107 (11)					0.108 (10)	0.108 (10)
1237.28	0.50 (17)	0.592 (24)	0.610 (68)		0.632 (12)	0.58 (13)				0.623 (11)	0.623 (11)
1353.0[×]		0.271 (27)	0.075 (15)		0.226 (10)					0.18 (6)	0.18 (6)
1392.6	0.50 (25)	0.447 (48)	0.187 (17)		0.465 (5)					0.34 (12)	0.34 (12)
1413.89	0.2 (1)	0.279 (17)	0.254 (17)		0.274 (12)					0.270 (9)	0.270 (9)
1434.16	1.17 (33)	1.09 (6)	0.99 (10)		1.156 (15)	1.12 (17)				1.149 (15)	1.149 (15)
1458.5			0.220 (51)								0.22 (5)
1501			0.153								0.153
1510.22	1.83 (33)	1.57 (4)	1.54 (10)		1.538 (19)	1.59 (15)				1.545 (17)	1.545 (17)
1527.28	0.33 (10)	0.263 (16)	0.254 (34)		0.286 (11)					0.277 (9)	0.277 (9)
1550.0		0.153 (11)[c]	0.220 (17)		0.151 (9)[c]					0.162 (17)	0.162 (17)
1553.77	1.0 (2)	0.990 (24)	1.068 (85)		0.966 (16)	1.07 (18)				0.976 (13)	0.976 (13)
1558.4		0.085 (12)	0.090 (19)							0.086 (10)	0.086 (10)
1570.67	0.10 (4)	0.127 (19)	0.146 (34)		0.131 (11)					0.130 (9)	0.130 (9)
1593.5	1.33 (33)	0.284 (3)[c]	0.458 (51)		0.253 (9)[c]	0.45 (19)				0.278 (13)	0.278 (13)
1601.8			0.056 (25)								0.056 (25)
1667.6		0.145 (12)	0.098 (21)		0.143 (9)					0.139 (7)	0.139 (7)
1694.1		0.044 (4)[c]	0.054 (10)		0.044 (3)[c]					0.0445 (23)	0.0445 (23)
1720.5[×]			0.039 (17)								0.039 (17)
1732.2[×]			0.220 (34)								0.220 (34)
1737.77	3.0 (4)	2.545 (24)[c]	2.41 (10)		2.51 (3)[c]	2.45 (25)				2.528 (18)	2.528 (18)
1759.81[×]	0.33 (17)	0.174 (7)	0.271 (34)		0.167 (7)					0.173 (5)	0.173 (5)
1765.44	1.17 (33)	0.918 (24)	1.04 (10)		1.037 (15)	1.01 (25)				0.99 (6)	0.99 (6)
1796.3	0.10 (7)	0.036 (6)[c]	0.037 (7)							0.037 (5)	0.037 (5)
1809.05	0.4 (1)	0.447 (12)	0.508 (51)		0.441 (9)	0.46 (9)				0.444 (7)	0.444 (7)
1819.69		0.103 (7)[c]	0.141 (31)		0.106 (8)					0.105 (5)	0.105 (5)
1831.37	2.33 (33)	2.114 (24)	1.90 (7)		2.05 (3)	2.09 (21)				2.077 (18)	2.077 (18)
1863.09		0.139 (11)	0.144 (29)		0.143 (6)					0.142 (5)	0.142 (5)
1867.7	1.33 (33)	1.105 (11)	0.90 (9)		1.097 (16)	1.15 (17)				1.101 (9)	1.101 (9)
1874.9	1.17 (33)	0.942 (24)	0.932 (85)		0.977 (15)	0.97 (14)				0.967 (13)	0.967 (13)
1893.51	0.33 (10)	0.256 (11)[c]	0.254 (17)		0.260 (8)[c]	0.26 (7)				0.258 (6)	0.258 (6)
1911.20	0.83 (17)	0.737 (12)	0.627 (68)		0.751 (12)	0.74 (11)				0.742 (8)	0.742 (8)
1926.5		0.057 (5)[c]	0.053 (10)		0.049 (5)[c]					0.053 (4)	0.053 (4)
1937.0	0.4 (1)	0.336 (7)[c]	0.356 (34)		0.335 (8)[c]	0.38 (9)				0.336 (5)	0.336 (5)
1970.3	0.033 (33)	0.0483 (36)	0.066 (14)							0.049 (4)	0.049 (4)
2022.24[×]								0.022 (2)			0.022 (2)
2041.23[×]								0.013 (1)			0.013 (1)
2065.80[×]								0.008 4 (12)			0.008 4 (12)
2093.19[×]								0.002 4 (7)			0.002 4 (7)
2102.14[×]								0.007 2 (10)			0.007 2 (10)
2136.69[×]								0.008 4 (5)			0.008 4 (5)

#: I(γ+ce), from IT decay.

a: Expected but as yet unobserved.

b: From γ-ray transition intensity balance.

c: Removed the contributions from $^{234}Pa^g$ β^- decay.

d: Deduced from adopted γ branching in 2007Br04.

e: I(γ+ce), from I(γ+ce)(γ234)/ I(γ1042) ≈ 0.7 in ^{234}Np ε decay.

f: I(γ+ce), from measured $I_{ce}(K)$ = 70.

g: I(γ+ce), from $I_{ce}(810)$/ I(γ1001) = 0.51 / 0.6 in 1963Bj02.

&: Multiply placed, intensity suitably divided.

×: Not placed in level scheme.

5.3 Absolute values of the γ-ray emission probabilities

Measurements of the absolute γ-ray emission probability of 1001.026 keV per 100 disintegrations of $^{234}Pa^m$ β^--decay and three weighted average results are listed in Table 7.

It should be noted that the uncertainties quoted in 1990Sc09, 1986Mo09, and 1971GuZQ are questionable (perhaps, only statistical errors were included) when compared with the data of 1992Si17 who used a purified $^{234}Pa^m$ source. Thus 2 % systematic uncertainty was added by the evaluators to those measurement results.

Table 7: Measured and recommended absolute emission probability of the 1001.026 keV γ-ray per 100 disintegrations of $^{234}Pa^m$ β^- decay

P_γ (1001.026 keV) (%)	References	Comments
0.59 (10)	1963Bj02	scintillation spectrometers
0.828 (18)	1971GuZQ	
0.92	1982Mo30	Not used
0.834 (21)	1986Mo09	Ge(Li)
0.839 (20)	1990Sc09	HPGe
0.818 (30)	1992Ja17	
0.788 (43)	1992Li05	
0.845 (21)	1992Si17	HPGe, 0.844 104 with another method
0.910 (25)	1993Su37	
0.924 (17)	1999An40	HPGe
0.861 (15)	2003Yu06	n-type Ge detector
0.923 (30)	2006Al28	HPGe, from extended sample
0.835 (11)	1998Ad08	Evaluation
0.835 (4)	1999Nz01	Evaluation
0.862 (13)		Average of all measurements with LWEIGHT program, χ^2 = 3.7
0.856 (12)		Average of all measurements with Normalised residuals method
0.848 (8)		Average of all measurements with Rajput and MacMahon method
0.848 (8)		**Recommended value**

The recommended value of the absolute γ-ray emission probability of the 1001.026 keV γ-ray is obtained with the method of averaging discrepant data of Rajput and MacMahon (1992Ra08) and adopted as the normalization factor N, with N = 0.008 48 (8) × 0.998 5 (1).

Thus, the recommended absolute γ-ray emission probabilities are the relative values recommended in Table 6 multiplied by 0.008 47 (8).

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^{232}U - Comments on Evaluation of Decay Data by Andy Pearce

This evaluation was completed in August 2008 drawing in part on the mass-chain evaluation of Artna-Cohen[1]. Some references not in the NSR database were identified by cross-referencing with the evaluation of Nichols[2]. The literature available up until January 2008 was included.

1 Decay Scheme

The decay scheme (nuclear level energies, half lives and spins of ^{228}Th) are based upon the adopted levels and gammas from Artna-Cohen[1].

2 Nuclear Data

Uranium-232 decays primarily by alpha decay to excited states in ^{228}Th. A small branching of exotic decay via ^{24}Ne emission and a smaller branching of spontaneous fission have been reported[3-5]. The Q-value for alpha decay is taken from Audi, Wapstra and Thibault[6-7]. The alpha decay branching is reported as essentially 100 %.

Seven published values of the half life were found in literature from which three independent values with uncertainties were used for analysis. The value of 1964Ch05[8] determined by calorimetry has been adjusted taking into account the Q-values of Audi, Wapstra and Thibault[6-7]. The authors of 1979Ag04[9] measured the half life by two methods and both are stated here, although an arithmetic mean of the two has been used in analysis. Similarly the authors of 1964Ch05[8] performed measurements by two methods and an arithmetic mean is taken for subsequent analysis. Sufficient experimental details were published in 1964Ch05 to allow the values to be recalculated using, for example, current values of Q, however doing so has no significant effect on the data. The adopted value has been determined by a LRSW weighted mean of the values from 1954Se26[10], 1964Ch05[8] and 1979Ag04[9]. Overall the data are not consistent, however no valid reason could be found to exclude or prefer any of the three values. The discrepancies probably reflect the difficulties in measuring half lives of the order of several decades, and the uncertainty of the adopted value is large. The available data are presented in table 1.

There have been several publications on the spontaneous fission/cluster decay of ^{232}U[3-5] suggesting that ^{24}Ne cluster decay has been misidentified in earlier work as spontaneous fission. This leads to significantly lower values for branching to spontaneous fission than in previous evaluations. The value quoted here for spontaneous fission is that from 1990Bo16[4] and that for cluster decay is a weighted mean of the values from 1985Ba18[3] and 1990Bo16[4]. The earlier data from Jaffey and Hirsh[10] has not been published in open literature. Analysis of their data in the light of recent work would appear to confirm the cluster decay branching ratio at approximately 2×10^{-10} per 100 decays. The available data are presented in table 2.

Table 1. Measured half lives of alpha decay of ^{232}U. The reports 1949Go01 and 1949Ja01 were not used in analysis as they were presented without uncertainties.

Reference	**Value (days)**	**Uncertainty (days)**	**Method**
1949Go01[11]	10 957	-	Ingrowth from ^{232}Pa
1949Ja01[12]	25 567	-	Ingrowth from ^{236}Pu
1954Se26	26 880	370	Isotope dilution mass spec and proportional counting
1964Ch05 [A]	26 080	110	Calorimetry
1964Ch05 [B]	26 330	110	Alpha counting
1964Ch05 [mean]	26 130	110	-
1979Ag04 [A]	25 200	150	Isotope dilution mass spec and LS/proportional counting
1979Ag04 [B]	25 170	140	Relative activity vs. ^{233}U
1979Ag04 [mean]	25 090	140	-
1986Ag01	25 170	140	Relative activity vs. ^{233}U; same data as half of 1979Ag01, republished
LRSW/expanded	25 800	390	-
Median (all values)	25 600	400	
Adopted	**25 800**	**400**	**LWM/expanded**

Table 2. Branching ratios for cluster decay and spontaneous fission, calculated where necessary from the partial decay constants using the recommended half life. The cluster decay value of Jaffey and Hirsh has been calculated by doubling the spontaneous fission value (in cluster decay one fragment will be detected compared with two in spontaneous fission).

Reference	**Spontaneous Fission (%)**	**Cluster Decay (^{24}Ne) (%)**
2000Bo46	2.8 (6) $\times 10^{-12}$	-
1990Bo16	$<10^{-12}$	8.7 (8) $\times 10^{-10}$
1985Ba18	-	2.0 (5) $\times 10^{-10}$
Jaffey & Hirsh (unpublished)	9 (3) $\times 10^{-11}$	1.8 (12) $\times 10^{-10}$
Adopted	**2.8 (6) ´ 10^{-12}**	**5 (3) ´ 10^{-10}**

2.1 Alpha-particleTransitions

The energies of the alpha-particle transitions have been determined from the Q-value and the adopted levels from Artna-Cohen[1]. Alpha-particle hindrance factors were calculated using ALPHAD[13]. The values so obtained are presented in table 3.

Table 3. Adopted level and alpha-particle transition energies

Transition	**Level Energy (keV)**	**Transition Energy (keV)**	**Alpha-particle Emission Energy (keV)**	**HF**
a_{0}	0	5413.63 (9)	5320.24 (9)	1
a_{58}	57.759 (4)	5355.87 (9)	5263.48 (9)	1.04 (3)
a_{187}	186.823 (4)	5226.81 (9)	5136.64 (9)	16.4 (4)
a_{328}	328.003 (4)	5085.63 (9)	4997.90 (9)	112.0 (24)
a_{378}	378.179 (10)	5035.45 (9)	4948.59 (9)	6490 (80)
a_{396}	396.078 (5)	5017.55 (9)	4931.00 (9)	5270 (50)
a_{519}	519.192 (6)	4894.44 (9)	4810.01 (9)	710 (50)
a_{831}	831.823 (10)	4581.81 (9)	4502.77 (9)	10.6 (8)
a_{874}	874.473 (18)	4539.16 (9)	4460.86 (9)	33 (9)

2.2 Gamma-ray Transitions and Internal Conversion Coefficients

Gamma-ray transition energies (Table 5) are calculated from the differences in level energies from Artna-Cohen[1]. Transition energies calculated from the level scheme are compared with those derived from measured values in table 6. No precise measurements have been reported for the energy of the 831 keV E0 transition.

Table 5. Recommended gamma-ray emission energies, rescaled to be compatible with the values of 1971He23. Values from 1971He23 have been recalculated based on improved calibration standards from 2000He14. The uncertainties of the recalculated values have been increased to be not less than those in the original publication.

Nominal energy (keV)	**57**	**129**	**141**	**191**	**209**	**270**	**328**
1971He23	57.78 (6)	129.1 (1)	-	-	-	270.2 (5)	-
1973Ta25	57.78 (6)	-	-	-	-	-	-
1977Ku15	57.77 (6)	129.07 (6)	-	-	-	270.2 (2)	-
1979Bo30	-	129.070 (16)	-	-	209.238 (21)	270.235 (21)	328.004 (11)
1979He10	57.752 (13)	129.065 (3)	-	-	-	270.245 (7)	-
1987Da28	57.758 (7)	129.067 (7)	141.02 (3)	191.353 (11)	209.254 (7)	270.245 (8)	328.004 (7)
1995Ba42	57.75 (2)	129.05 (2)	140.99 (2)	191.34 (2)	209.25 (2)	270.24 (2)	328.02 (4)
LWEIGHT4	57.757 (6)	129.0655 (27)	140.999 (17)	191.351 (9)	209.252 (6)	270.2441 (13)	328.004 (6)
Adopted	57.752 (13)	129.065 (3)	140.999 (20)	191.351 (11)	209.252 (6)	270.245 (7)	328.004 (7)
Comments	From 1979He10	From 1979He10	LWEIGHT, uncert inc.	LWEIGHT, uncert inc.	LWEIGHT	From 1979He10	LWEIGHT

Table 5 (Cont.)

Nominal energy (keV)	**332**	**338**	**478**	**503**	**546**	**773**	**817**
1971He23	-	338.3 (4)	-	-	-	-	-
1973Ta25	-	-	-	-	-	-	-
1977Ku15	332.3 (3)	338.1 (2)	-	503.6 (3)	-	773.4 (5)	817 (1)
1979Bo30	-	338.321(10)	-	-	-	-	-
1979He10	332.371 (6)	338.320 (5)	-	503.819(23)	-	-	-
1987Da28	332.37 (5)	338.324 (7)	478.34 (5)	503.83 (5)	546.48 (5)	774.1 (2)	816.7 (1)
1995Ba42	332.36 (2)	338.31 (2)	478.45 (4)	503.69 (20)	546.45 (2)	774.06 (10)	816.49 (12)
LWEIGHT4	332.370 (6)	338.3209 (37)	478.41 (5)	503.818 (21)	546.454 (19)	774.05 (9)	816.62 (7)
Adopted	332.371 (6)	338.320 (5)	478.41 (5)	503.819 (23)	546.454 (21)	774.05 (9)	816.62 (7)
Comments	From 1979He10	From 1979He10	LWEIGHT	From 1979He10	LWEIGHT, uncert. inc.	LWEIGHT, uncert inc.	LWEIGHT, uncert inc.

Table 6. Recommended gamma-ray transition energies and internal conversion coefficients. Measured transition energies are those obtained from gamma-ray emission energies via the recoil correction, whereas derived transition energies are those determined from the level scheme.

Measured Energy (keV)	Transition Energy (keV)		Multi-polarity from ENSDF	Conversion Coefficients			
	Measured	Derived		a_K	a_L	a_{M+}	a_T
57.752 (13)	57.752 (13)	57.759 (4)	E2	-	112.2 (16)	41.1 (5)	153.2 (22)
129.065 (3)	129.065 (3)	129.064 (6)	E2	0.264 (4)	2.54 (4)	0.933 (41)	3.74 (6)
140.999 (20)	140.999 (20)	141.013 (12)	E1	0.1689 (24)	0.0362 (5)	0.01169 (14)	0.217 (3)
191.351 (11)	191.350 (11)	191.356 (11)	E2	0.1710 (24)	0.443 (7)	0.162 (7)	0.776 (11)
209.252 (6)	209.252 (6)	209.255 (7)	E1	0.0672 (10)	0.01333 (19)	0.00429 (5)	0.0848 (12)
270.245 (7)	270.245 (7)	270.244 (6)	E1	0.0376 (6)	0.00716 (10)	0.002297 (25)	0.0470 (7)
328.004 (7)	328.005 (7)	328.003 (4)	E1	0.0245 (4)	0.00455 (7)	0.001458 (16)	0.0305 (5)
332.371 (6)	332.372 (6)	332.369 (7)	E1	0.0238 (4)	0.00441 (7)	0.001414 (16)	0.0297 (5)
338.320 (5)	338.321 (5)	338.319 (7)	E1	0.0229 (4)	0.00424 (6)	0.001358 (16)	0.0285 (4)
478.41 (5)	478.41 (5)	478.395 (18)	E1	0.01118 (16)	0.0198 (3)	0.000631 (7)	0.01379 (20)
503.819 (23)	503.820 (23)	503.820 (11)	E1	0.01009 (15)	0.001775 (25)	0.000565 (6)	0.01243 (18)
546.454 (21)	546.455 (21)	546.470 (18)	E1	0.00861 (12)	0.001500 (21)	0.000478 (5)	0.01058 (15)
774.05 (9)	774.05 (9)	774.064 (11)	E2	0.01204 (17)	0.00333 (5)	0.001199 (13)	0.01649 (23)
816.62 (7)	816.62 (7)	816.714 (18)	M1+E2 (d=1)	0.028 (18)	0.006 (3)	0.0019 (7)	0.036 (21)
-	-	831.823 (10)	E0	-	-	-	-

Internal conversion coefficients have been determined using the BrIcc code[14], using the gamma-ray multipolarities and mixing ratios from the evaluation of Artna-Cohen[1]. No mixing ratio could be found in literature for the 817 keV transition and a mixing ratio of 1 has been assumed. Measured and adopted conversion coefficients are compared in table 9.

Table 9. Comparison of available measured conversion coefficients with the values calculated with the BrIcc code. Adopted values are from the BrIcc code in all cases.

Energy (keV)	BrIcc		1971He23[25]		1982Ma52[35]	
	a_K	a_L	a_K	a_L	a_K	a_L
57.752 (13)	-	112.2 (16)	-	117 (3)	-	85 (5)
129.065 (3)	0.264 (4)	2.54 (4)	0.23 (1)	2.45 (8)		2.74 (12)
140.999 (20)	0.1689 (24)	0.0362 (5)	0.11 (5)	-	-	-
191.350 (11)	0.1710 (24)	0.443 (7)	0.20 (2)	-	-	-
209.252 (6)	0.0672 (10)	0.01333 (19)	0.058 (1)	-	-	-
270.245 (7)	0.0376 (6)	0.00716 (10)	0.025 (3)	-	0.042 (3)	-
338.320 (5)	0.0229 (4)	0.00424 (6)	0.008 (1)	-	0.030 (2)	

3 Atomic Data

All values of atomic data (ω_K, ω_L, n_{KL}, relative probabilities of the X-ray and Auger emissions) were derived from Schönfeld and Janßen[15].

4 Alpha-particle Emissions

The alpha-particle emission probabilities were calculated from the balance of the gamma-ray decay scheme using GTOL[16]. The adopted emission probabilities of the three strongest transitions a_{0}, a_{58} & a_{187} are in good agreement with a weighted mean of the available measured data[17-21], and those of a_{328} & a_{831} are in agreement with the measured values of 1964Le17[19]. However, there are significant unexplained differences between the recommended values and the values measured by Baranov[21] for the emission probabilities of a_{328}, a_{381} and a_{396}. Further measurements of the weak alpha-particle and gamma-ray transitions would be necessary to fully resolve these issues.

Table 4. Alpha-particle emission probabilities. Note the value quoted in the table may not match the published value exactly, as the values have been adjusted to a common scale (by dividing by the probability of the most intense emission) to take into account undetected alpha-particle emissions.

Trans.	**Alpha-particle emissions per 100 decays**							**Adopted values (%)**
	1955As28	**1955Go32**	**1963Le17**	**1965Be15**	**1966Ba49**	**LWEIGHT**	**GTOL**	
a_{0}	68 (1)	68.0	-	67.8 (7)	68.6 (6)	68.0 (4)	69.1 (6)	69.1 (6)
a_{58}	32 (1)	34.1	-	32.2 (3)	31.2 (4)	31.7 (7)	30.6 (6)	30.6 (6)
a_{187}	0.32 (3)	-	-	0.30 (9)	0.28 (2)	0.294 (23)	0.325 (6)	0.325 (6)
a_{328}	-	-	6 (2) $\times 10^{-3}$	-	2.9 (2) $\times 10^{-4}$	6 (2) $\times 10^{-3}$	6.22 (9) $\times 10^{-3}$	6.22 (9) $\times 10^{-3}$
a_{378}	-	-	-	-	1.7 (3) $\times 10^{-4}$	1.7 (4) $\times 10^{-4}$	5.1 (6) $\times 10^{-5}$	5.1 (6) $\times 10^{-5}$
a_{396}	-	-	-	-	2.1 (3) $\times 10^{-4}$	2.1 (4) $\times 10^{-4}$	4.8 (4) $\times 10^{-5}$	4.8 (4) $\times 10^{-5}$
a_{519}	-	-	-	-	-	-	5.4 (4) $\times 10^{-5}$	5.4 (4) $\times 10^{-5}$
a_{831}	-	-	2.4 (7) $\times 10^{-5}$	-	-	2.4 (7) $\times 10^{-5}$	2.14 (16) $\times 10^{-5}$	2.14 (16) $\times 10^{-5}$
a_{874}	-	-	-	-	-	-	3.3 (9) $\times 10^{-6}$	3.3 (9) $\times 10^{-6}$

5 Electron Emissions

Auger and conversion electron emissions per 100 decays were calculated from the gamma-ray data and conversion coefficients according to the method of Schönfeld and Janßen[22] using version 3.10 of the code EMISSION.

6 Photon Emissions

6.1 X-ray Emissions

The X-ray intensities per 100 decays have been calculated from the gamma-ray data and conversion coefficients using version 3.10 of the code EMISSION.

6.2 Gamma-ray Emissions

The gamma-ray emission energies have been taken from 1979He10[23] where possible, in which precise measurements were made by measuring energy differences against accepted calibration standards. Only the directly measured values have been taken as the decay scheme used to derive further values was incomplete. These values have been adjusted to reflect the updated calibration standards given in 2000He14[24]. Where gamma-ray lines are not present in 1979He10, weighted means of the values in 1971He23[25], 1973Ta25[26], 1977Ku15[27], 1979Bo30[28], 1987Da28[29] and 1995Ba42[30] were taken. The values in these publications were first rescaled by a least-squares fit to be compatible with 1979He10. In most cases the energy shift incurred by doing so was very small.

Relative gamma-ray emission probabilities were determined by a weighted mean of values in 1966Ah02[31], 1977Ku15[27], 1984Ge07[32] and Banham & McChrohon[33]. Data for many of the less intense gamma-ray emissions have only been reported in 1977Ku15. In determining means, values were normalised to the 129 keV gamma-ray transition rather than the most intense 60 keV transition due to the experimental difficulties in measuring gamma-ray emissions below 100 keV. There were three absolute emission probability measurements, two by 1984Ge07[32] and one by Banham & McChrohon[34]. The reference value of the normalisation factor was determined from the weighted mean of the absolute values of the 129 keV line and is 6.86 (7) $\times 10^{-4}$ per 100 decays. The normalisation factor was also calculated with the code GABS[34] and by balance of the feeding to the 1st excited state and the figures thus obtained were 7.0 (3) $\times 10^{-4}$ per 100 decays and 7.08 (16) $\times 10^{-4}$ per 100 decays respectively. These values are statistically compatible with the reference value.

The intensity of the 831 keV E0 transition is given by 1963Le17 as 2 (1) $\times 10^{-6}$ per 100 decays. The 831 keV transition is E0, thus, it emits only electrons.

Table 7. Relative gamma-ray emission probabilities, normalised to 100 emissions for the 129 keV line. Note one additional significant figure is quoted in columns 2-6 over that which would normally be quoted; this is intentional to allow statistics to be calculated. The 817 keV line is quoted by 1977Ku15 as ~0.0011; the uncertainty assumed is a relative uncertainty of ±100 % at 3s, giving a relative emission probability of 0.0011 ± 0.0004.

Energy (keV)	**Gamma-ray emissions per 100 emissions at 129 keV**				
	1966Ah02	**1977Ku15**	**1984Ge07**	**Banham 1986**	**Adopted**
57.752 (13)	256 (26)	298.9 (118)	291.5 (65)	292.5 (42)	292 (4)
129.065 (3)	100	100	100	100	100
140.999 (20)	-	0.00453 (189)	-	-	0.0045 (19)
191.351 (11)	-	0.0453 (40)	-	-	0.0453 (40)
209.252 (6)	-	0.0155 (38)	-	-	0.0155 (38)
270.245 (7)	4.62 (90)	4.264 (198)	-	4.660 (68)	4.62 (9)
328.004 (7)	4.10 (88)	3.774 (161)	-	4.168 (62)	4.12 (9)
332.371 (6)	-	0.0717 (44)	-	-	0.0717 (44)
338.320 (5)	-	0.05396 (249)	-	-	0.0540 (25)
478.41 (5)	-	0.00208 (80)	-	-	0.0021 (8)
503.819 (23)	-	0.02113 (130)	-	-	0.0211 (13)
546.454 (21)	-	0.00147 (91)	-	-	0.0015 (9)
774.05 (9)	-	0.00679 (115)	-	-	0.0068 (12)
816.62 (7)	-	~0.0011	-	-	0.0011 (4)
831.823 (10)	-	E0	-	-	E0

Table 8. Recommended gamma-ray emission probabilities.

Energy (keV)	**Multipolarity**	**Gamma-ray Emission Probability per 100 decays**
57.752 (13)	E2	0.200 (4)
129.065 (3)	E2	0.0686 (7)
140.999 (20)	E1	3.1 (13) × 10^{-6}
191.351 (11)	E2	3.1 (3) × 10^{-5}
209.252 (6)	E1	1.1 (3) × 10^{-5}
270.245 (7)	E1	0.00317 (7)
328.004 (7)	E1	0.00283 (7)
332.371 (6)	E1	4.9 (3) × 10^{-5}
338.320 (5)	E1	3.70 (18) × 10^{-5}
478.41 (5)	E1	1.4 (6) × 10^{-6}
503.819 (23)	E1	1.45 (9) × 10^{-5}
546.454 (21)	E1	1.0 (6) × 10^{-6}
774.05 (9)	E2	4.7 (8) × 10^{-6}
816.62 (7)	M1+E2 (d=1)	8 (3) × 10^{-7}
831.823 (10)	E0	0 [TI 2 (1) × 10^{-6}]

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^{233}U - Comments on evaluation of decay data by G. Mukherjee

Evaluated: June 2011

This evaluation was completed in June 2011, and the literature available at this date has been included here. ^{233}U is usually produced by n-capture on ^{232}Th and subsequent beta-decays of ^{233}Th and ^{233}Pa. That is ^{232}Th(n,γ) → ^{233}Th → ^{233}Pa → ^{233}U. The samples used in various measurements were several years (~20 years) old and generally enriched to 99.9%. The impurities may come from ^{232}U ($T_{1/2}$ = 70 y) produced by the ^{233}U(n,2n) reaction during the ^{232}Th target irradiation in the reactor. However, radiochemical separation was performed before measurements in almost all of the published reports.

Decay Scheme

^{233}U is part of the 4n+1 series of the Neptunium decay chain which disintegrates almost entirely by alpha decay to about 50 excited levels including the ground state of ^{229}Th. A very small amount (6 x 10^{-11} %) disintegrates by spontaneous fission. The level energy of the isomeric $3/2^+$ 1st excited state has been taken from the recent highly precise measurement of Beck et al. (2007Be16). Many investigations were carried out of this unusually low nuclear excited state. In a recent work (2011), Campbell et al. (2011Ca17) explored the possibility of optical excitation of this nuclear state and produced laser-cooled crystals of triply charged ^{229}Th in a linear Paul trap. A new value of nuclear electric quadrupole moment Q = 3.11(16) eb was deduced by them.

The decay scheme is reasonably complete and consistent. Its overall consistency is verified by the comparison between Q_{calc} (4908.5 ± 1.2 keV) deduced from the evaluated average energies of all emissions, and Q_{alpha} (4893 ± 2 keV) from the atomic mass evaluation of Audi et al. (2003Au03). The percentage deviation between Q_{calc} and Q_{alpha} is 0.4 ± 0.6 %. There are, however, 44 unplaced gamma rays observed in this decay scheme. The level energies, spins, parities along with the multipolarities and mixing ratios of the γ-rays presented in this evaluation are from 2008Br17.

Nuclear Data

The Q value (4908.5 ± 1.2 keV) is from the atomic mass evaluation of Audi et al. (2003Au03). The experimental half-life values of ^{233}U are given in Table 1.

Table 1: Experimental values of ^{233}U half-life

Reference	$T_{1/2}$ Values (10^5 y)	Comments
1949Hy02	1.62 (1)	Not used for averaging
1959Do63	1.626 (8)	Not used for averaging
1961Po10	1.615 (9)	Not used for averaging
1967Ih01	1.621 (3)	Not used for averaging
1968Ke15	1.553 (10)	Not used for averaging
1968Oe02	1.560 (3)	Not used for averaging
1974Ja08	1.5911 (15)	
1976Va02	1.5925 (13)	Revised uncertainty from 1989Ho24
1979Ge11	1.5937 (17)	Revised uncertainty from 1989Ho24
1980Ag04	1.5885 (28)	Revised uncertainty from 1989Ho24
2009Po15	1.5867 (14)	
Recommended value	**1.591 (2)**	**LWEIGHT Reduced χ^2 = 3.5**

The evaluator has chosen to take into account the recommendations of N.E. Holden (1989Ho24) to assign uncertainties. The last five values were used in the analysis. The computer program LWEIGHT (v3) has been used to calculate the weighted mean of the chosen experimental values which yields a mean of (1.591 ± 0.002) x 10^5 y with a reduced chi-squared of 3.5.

Table 2: Spontaneous fission half-life of ^{233}U

Reference	$T_{1/2}$ Values (10^{17} y)	Comments
1952Se67	> 2.7	
1966Al23	1.2(3)	No mention of correction for ^{232}U. Small admixture (0.03%) of ^{232}U may account for the discrepancy with other measurements.
1981Vo02	>2.7	
Recommended value	**> 2.7**	**Selected value**

Two of the measurements quote the limits of spontaneous fission half-life of ^{233}U. The other measurement (1966Al23) quotes a value outside this limit. But since the details of corrections are not mentioned and a small admixture of ^{232}U is enough to account for the discrepancy with the other values, thus a recommended value is selected as > 2.7 x 10^{17} y as also mentioned in 1989Ho24.

Experimental results of the ratio of α-decay half-life and partial half-life of ^{24}Ne cluster decay are given in Table 3, i.e. $T_{1/2}$ (α) / $T_{1/2}$ (^{24}Ne) = BF of ^{24}Ne cluster decay.

Table 3: $T_{1/2}$ (α) / $T_{1/2}$ (^{24}Ne) published results

Reference	BF (^{24}Ne cluster decay)	Comments
1986Ba65	≤ 9.5 x 10^{-13}	
1985Al28	≤ 7 x 10^{-12}	
1991Pr02	7.2 (7) x 10^{-13}	Using track-recording phosphate glass detector
Recommended value	**7.2 (7) x 10^{-13}**	**Selected value**

The evaluator has adopted the value given by Price et al. (1991Pr02) to recommend a ^{24}Ne cluster branch of (7.2 ± 0.7) x 10^{-13}. Both of the other measurements give only upper limits, and the adopted value is beneath these limits. Assuming the α-decay branching is 100%, this gives a ^{24}Ne cluster branching of (7.2 ± 0.7) x 10^{-11} %.

The experimental half-life values of ^{229}Th are given in Table 4. The first measurements available in the literature are by 1947Ha02 and 1947En03 who reported values of 7 x 10^3 y and 5 x 10^3 y, respectively, without reporting any uncertainty or giving details of the measurements. These values have been excluded from the averaging procedure.

The measurement of 1950Ha52 was an indirect method done in 1950. A known amount of ^{233}U was allowed to decay for a measured period of time and then the activity of the daughter ^{229}Th was determined. They used a half-life of 1.62 x 10^5 y for ^{233}U, which is about 2% greater than the presently adopted value (see Table 1). Consequently, an additional uncertainty of 2% has been added by the evaluator to this value. Still there remains a discrepancy of about 5% which may be due to an underestimation of the effect of impurities. Considering these, the experimental value of (7.880 ± 0.120) x 10^3 y reported in 1989Go19 has been recommended by the evaluator.

Table 4: Experimental values of ^{229}Th half-life

Reference	$T_{1/2}$ Values (10^3 y)	Comments
1947Ha02	7	Not used
1947En03	5	Not used
1950Ha52	7.340 (0.217)	Indirect method. 2% greater $T_{1/2}$ used for ^{233}U. Modified uncertainty.
1989Go19	7.880 (0.120)	Isotope dilution mass spectrometry.
Recommended value	**7.880 (0.120)**	**Value reported in 1989Go19**

α-particle Transitions

The energies of the α-particle transitions have been calculated from the Q_α (2003Au03) and level energies. The level energies of ^{225}Ra, as deduced in 2008Br17, have been adopted. The energy of the alpha particles can be deduced from these calculated alpha transition energies considering the recoil effect. A comparison of the deduced and adopted alpha particle energies is given in Table 5 along with the adopted values of the level energies, their spin and parities, the half-lives of the levels and the emission probabilities of the alpha particles.

Table 5: Levels of ^{229}Th populated by α-decay of ^{233}U

Level No.	Level Energy (keV)	Spin & Parity	Half-life	Measured energy of α-particle (keV)	Deduced energy of α-particle (keV)	Emission probability of α (%)
0	0.	$5/2^+$	7.88 (12) 10^3 y	4824.2 (12)	4824.2 (12)	84.3 (6)
1	0.0076 (5)	$(3/2^+)$				
2	20.2 (8)	$(7/2^-)$		4804	4804.4 (12)	
3	29.1927 (5)	$(5/2^+)$		4796 (2)	4795.5 (12)	0.28
4	42.4349 (2)	$7/2^+$	0.172 (6) ns	4783.5 (12)	4782.5 (12)	13 (2)
5	67.8 (7)			4758 (2)	4757.6 (2)	0.016
6	71.8260 (5)	$(7/2^+)$		4754 (2)	4753.6 (2)	0.163
7	75.1(10)	$(9/2^-)$		4751 (2)	4750.4 (2)	0.01
8	97.13595(24)	$9/2^+$	0.147 (12) ns	4729 (2)	4728.8 (2)	1.61
9	125.4385 (10)	$(9/2^+)$		4701 (2)	4700.9 (2)	0.06
10	140.9 (8)	$(11/2^-)$		4687 (2)	4685.8 (2)	0.0028
11	146.3569 (14)	$(5/2^-)$		4681	4680.4	0.01
12	148.1730 (22)	$(7/2^-)$		4678.6	4678.6	
13	163.2542	$11/2^+$		4664.2	4663.8	0.042
14	164.5317 (4)	$(3/2^-)$		4662.5	4662.5	
15	173.4837(22)	$(9/2^-)$		4656 (2)	4653.7 (2)	~ 0.005
16	189.99 (3)			4641 (2)	4637.5 (2)	0.003
17	195.7194 (16)	$(11/2^+)$		4634 (2)	4631.9	0.01
18	212.382 (20)	$(5/2^+)$		4615 (2)	4615.5 (2)	0.004
19	217.1597 (3)	$(5/2^-)$		4611 (2)	4610.8 (2)	0.006
20	235.1266 (11)	$(5/2^-,7/2^-)$		4593.1	4593.1	
21	237.366 (5)	$(7/2^-)$		4590 (2)	4590.9 (2)	0.007
22	241.546 (19)	$13/2^+$		4586.8	4586.8	
23	255.957 (15)	$(3/2^+,5/2^+, 7/2^+)$		4572 (2)	4572.7 (2)	
24	261.964 (4)	$(1/2^+)$		4565 (2)	4566.7 (2)	0.0023
25	272.84 (3)	$(13/2^+)$				
26	287.895 (4)	$(7/2^-)$		4538 (2)	4540.6(2)	0.004
27	288.491 (14)	$(3/2^+)$				
28	302.989 (4)	$(7/2^+)$				

Level No.	Level Energy (keV)	Spin & Parity	Half-life	Measured energy of α-particle (keV)	Deduced energy of α-particle (keV)	Emission probability of α (%)
29	317.1731 (7)	$(5/2^+)$		4513 (2)	4512.5 (2)	0.018
30	320.5483 (7)	$(5/2^+)$		4507 (2)	4509.2 (2)	0.012
31	327.8 (3)	$(15/2^+)$		4503 (2)	4502.1 (2)	0.001
32	347.800 (20)	$(5/2^+)$		4483 (2)	4482.4 (2)	0.0014
33	359.6044 (20)	$(7/2^+)$				
34	365.8136 (15)	$(7/2^+)$		4465 (2)	4464.7 (2)	0.003
35	374.815 (4)	$(7/2)^+$		4457 (2)	4455.9 (2)	0.0028
36	382.54 (5)	$(7/2^-,9/2, 11/2^+)$		4448.3	4448.3	
37	425.877 (10)	$(9/2^+)$		4411 (2)	4410.9 (2)	0.0004
38	428.04 (8)	$(5/2^+)$		4404 (2)	4403.5 (2)	0.0003
39	436.951 (15)	$(7/2^-)$		4394.8	4394.8	
40	465.426 (9)	$(5/2^-,7/2, 9/2^+)$		4366.8	4366.8	
41	478.649 (8)	$(7/2^+, 9/2^+)$		4353.8	4353.8	
42	513.479 (10)	$(5/2^+,7/2, 9/2^+)$		4319.6	4319.6	
43	526.516 (9)	(5/2,7/2)		4309 (2)	4308.7 (2)	0.0009
44	536.08 (8)	$(1/2^-)$		4297.4	4297.4	
45	569.2721 (12)	$(3/2,5/2^+)$		4264.7	4264.7	
46	585.237 (10)	$(5/2^+,7/2, 9/2^+)$		4249.0	4249.0	
47	605.165 (10)	$(5/2,7/2)^+$		4229.5	4229.5	
48	620.837 (16)	$(5/2^+,7/2)$		4214.1	4214.1	
49	637.384 (18)	$(5/2^+,7/2, 9/2^+)$		4197.8	4197.8	
50	656.89 (4)	$(5/2^+,7/2, 9/2^+)$		4178.6	4178.6	
51	664.98 (7)	(1/2, 3/2, 5/2)		4170.7	4170.7	
52	749.849 (20)	$(5/2^+,7/2, 9/2^+)$		4087.3	4087.3	0.0000144 (21)

The α-transition energies of a few intense alpha decays of ^{233}U have been calculated from the Q-value and the adopted level energies. The alpha particle energies deduced from these calculated transition energies (taking in to account the recoil energy of the alpha) are tabulated in Table 6. This table also shows the energy and the transition probability of the most intense α-particles from the ^{233}U decay known from direct measurements.

Table 6: Energy and probability of the intense α-particles from the decay of ^{233}U.

Level	Level Energy (keV)	Energy of α-particle (keV)			Probability of α-transition (%)		
		Deduced (2008Br17)	1984Ah06	1984Gl03	Adopted	1984Ah06	1984Gl03
0	0.	4824.2(12)	4824	4824	84.3(6)	82.7(3)	84.5
4	42.4349 (2)	4782.6(12)	4783	4784	13.2(2)	14.9(2)	13.2
8	97.13595(24)	4728.8(12)	4729	4729	1.61	1.85(5)	1.6

γ Transitions

The gamma-ray transitions in ^{229}Th following the ^{233}U decay are presented in section 2.2 along with the multipolarity of the gamma rays and the internal conversion coefficients. The ENSDF evaluation has been done in 1989 (1989Ak03) by Y.A Akovali and recently by E. Browne and J.K. Tuli (2008Br17). All the reported data previous to that date have been taken into account in the latest evaluation. New and precise measurements of gamma-rays have been recently done by V. Barci et al. (2003Ba78). The gamma ray energies and intensities measured in this and two other experiments are given in Table 7. The gamma transition energies, intensities and the multipolarities of the transitions are from 2008Br17.

The energy of the first excited state has been recommended to be 7.6(5) eV from the recent measurement in 2007Be16. This excited state is the energetically lowest level ever known in nuclei. In the measurement of 2007Be16, they have used a micro calorimeter with a very high energy resolution of FWHM ~ 26 eV. They were able to resolve very close γ-ray doublets of 29 keV and 42 keV, and thus obtained an energy of 7.6 eV *0.5* for the $3/2^+$ state in ^{229}Th. This result has greater implication in the internal conversion decay of this level. This value (7.6 eV) for the excited state of this level indicates that the internal-conversion decay is energetically allowed since it is greater than 6.3 eV, the ionization energy of an isolated thorium atom. The previous recommended value of the energy of the first excited state in ^{229}Th was <= 0.010 keV (1989Ak03). Later on this was modified to be -1(4) eV (1990Re03) and subsequently to 3.5 (1.0) eV (1994He08) by Reich and Helmer respectively. The weighted mean of the values reported in 1994He08 and 2007Be16 is 5.5 (0.71) eV and the Lweighted mean is 5.5 (2.0) eV. However, since the value reported in 2007Be16 has been measured with much better precision the evaluator has adopted this value of 7.6(5) eV as the recommended value for the energy of the 1[st] excited state in ^{229}Th.

Table-7: Measured energy and intensity of γ-rays in ^{229}Th from the decay of ^{233}U

	2003Ba78		1976Kr03		1996Ko29	
	Energy (keV)	Intensity	Energy (keV)	Intensity[*]	Energy (keV)	Intensity[§]
$\gamma_{1,0}$	0.0034[a]	>2100[c]				
$\gamma_{4,3}$	13.244	2.4[d] (7)				
$\gamma_{2,0}$	20.25					
$\gamma_{21,18}$	25.02(5)	0.10(4)				
$\gamma_{15,12}$ $\gamma_{5,4}$	25.311(4)	2.11(12) <0.004	25.30(6)	2.4	25.24(1)	4.5(2)
$\gamma_{8,6}$						
$\gamma_{15,11}$	27.119	<0.002			27.4(2)	4.8(3)
$\gamma_{9,8}$	28.288	0.036[d] (9)				
$\gamma_{3,1}$	29.1867(11)	7.8(10)				
$\gamma_{3,0}$	29.190	2.7[d] (5)	29.16(6)	12.0	29.12(1)	267(20)
$\gamma_{6,4}$	29.382	0.80[d] (14)				
[b]	31.449(13)	0.24(4)			31.39(1)	5.7(8)
$\gamma_{13,17}$	32.453	0.016[d] (3)				
$\gamma_{27,23}$	32.57(3)	0.018[e] (6)	32.2(2)		32.51(1)	32.6(12)
$\gamma_{30,26}$	32.73(5)	0.97(12)				
[b]	36.516(23)	0.14(3)				
[b]	36.95(3)	0.12(3)				
$\gamma_{13,9}$	37.823(16)	0.25(4)	37.8(1)	0.5	37.77(2)	7.0(1)
[b]	42.005(19)	0.34(4)			41.96(2)	10.7(23)
$\gamma_{4,1}$	42.431	0.18[d] (5)	42.44(2)	62(5)	42.38(1)	2308(19)
$\gamma_{4,0}$	42.4344(11)	72(4)				
$\gamma_{10,8}$	43.69(3)	0.042(14)				

	2003Ba78		1976Kr03		1996Ko29	
	Energy (keV)	Intensity	Energy (keV)	Intensity*	Energy (keV)	Intensity§
$\gamma_{32,28}$	44.813(21)	0.028[e] (9)			44.76(3)	2.8(6)
$\gamma_{22,17}$	45.855	0.0091[d] (16)				
$\gamma_{26,21}$	51.0(3)	0.03(1)	50.6			
$\gamma_{19,14}$	52.607(25)	0.10(3)	52.6			
$\gamma_{9,6}$	53.6104(17)	3.47(8)	53.59(5)	4.1(3)	52.60(3)	3.0(1)
b					53.18(1)	14.0(1)
$\gamma_{8,4}$	54.7040(11)	16.8(8)	54.69(2)	15.0(10)	53.56(1)	131(2)
$\gamma_{7,2}$					54.65(1)	650(5)
b					57.72(1)	67.0(1)
$\gamma_{21,15}$	63.79(6)	0.029(11)	63.88(15)	0.03	63.8(2)	11(2)
$\gamma_{10,7}$	65.62(5)	0.05(1)	65.7			
$\gamma_{28,21}$						
$\gamma_{13,8}$	66.116(3)	1.02(6)	66.11(4)	0.87(5)	66.07(1)	41(1)
$\gamma_{8,3}$	67.943(7)	0.320(23)	67.98(5)	0.2	67.89(1)	14(1)
$\gamma_{19,12}$	68.85(6)	0.100(23)			68.80(3)	4.0(1)
$\gamma_{17,9}$	70.281(5)	0.58(4)	70.33(5)	0.59	70.23(1)	25.5(13)
$\gamma_{35,28}$		1.81[d] (14)				
$\gamma_{6,1}$	71.8133(16)	1.16[d] (12)	71.84(2)	2.9(15)	71.76(1)	127(1)
$\gamma_{6,0}$						
$\gamma_{21,14}$	72.825	<0.03			72.74(1)	33(2)
$\gamma_{11,6}$	74.550(6)	1.49(8)	74.59(5)	1.6(8)	74.49(1)	64(2)
$\gamma_{15,8}$	76.335(10)	0.30(3)	76.41(8)	0.52(3)	76.28(1)	14.5(15)
$\gamma_{12,6}$		<0.02				
$\gamma_{39,33}$	77.142(8)	0.43(4)			77.08(1)	15(1)
$\gamma_{25,17}$						
$\gamma_{22,13}$	78.21(5)	0.044(7)	78.20(1)	0.1	78.10(10)	1.5(3)
$\gamma_{9,4}$	83.000(13)	0.197(22)	83.08(5)	0.14	82.93(2)	8(1)
$\gamma_{30,20}$	85.16(5)	0.12(4)	84.75(2)	0.07	85.2(2)	4.1(1)
$\gamma_{31,22}$		0.038(3)				
$\gamma_{35,27}$	86.3(3)	0.099(23)			86.3(3)	6.0(1)
$\gamma_{20,12}$						
$\gamma_{18,9}$	87.30(15)	0.088(22)			87.25(4)	4.8
$\gamma_{20,11}$	88.7(2)	0.229(23)			88.7(2)	10.0(1)
$\gamma_{21,12}$	89.39(7)	0.26(3)				
$\gamma_{21,11}$	90.999(11)	0.31(4)	91.0(5)	0.20(5)	90.97(2)	8.7(12)
$\gamma_{13,6}$	91.433	0.041[d] (7)				
$\gamma_{32,23}$	92.23(12)	0.033(12)				
$\gamma_{16,8}$	92.85(3)	0.26(3)				
$\gamma_{9,3}$	96.232(4)	1.70(9)	96.28(1)	3.0(5)	96.14(1)	63.5(28)
b	96.69(7)	0.190(25)				
$\gamma_{8,0}$	97.1376(11)	20.3(10)	97.14(2)	22.0(11)	97.03(1)	846(14)
$\gamma_{24,14}$	97.37(4)	2.0(6)				
$\gamma_{17,8}$	98.565	0.097[d] (16)			98.37(2)	5.6(8)
$\gamma_{29,19}$	99.95(15)	0.019(6)	100.03(15)	0.05	100.1(2)	1.6(6)
$\gamma_{15,6}$	101.73(3)	0.069(15)	101.75(1)	0.07	101.62(5)	2.0(1)
$\gamma_{30,19}$	103.84(18)	0.063(19)			103.69(10)	1.3(5)
$\gamma_{21,9}$	111.927(7)	0.40(3)	112.0(1)	0.45	111.98(3)	13.1(5)
$\gamma_{26,15}$	114.2(2)	0.183(23)	114.4		114.2(2)	8.0(1)
$\gamma_{22,9}$	116.3(2))	0.0047(9)			116.3(2)	5.5(10)

	2003Ba78		1976Kr03		1996Ko29	
	Energy (keV)	Intensity	Energy (keV)	Intensity*	Energy (keV)	Intensity§
$\gamma_{39,30}$		0.121(23)				
$\gamma_{11,3}$	117.1575(19)	2.87(14)	117.16(2)	2.60(13)	117.23(2)	96.6(11)
$\gamma_{12,3}$	118.9625(17)	3.63(18)	118.98(2)	3.7(2)	119.04(1)	123.6(14)
$\gamma_{13,4}$	120.8129(19)	2.82(15)	120.82(5)	3.10(15)	120.88(1)	109.8(13)
$\gamma_{10,2}$						
$\gamma_{17,6}$	123.881(5)	0.72(5)	123.93(5)	0.73(4)	123.96(1)	23.9(4)
$\gamma_{38,28}$	125.04(23)	0.010(3)	125.4(1)	0.07	125.51(9)	1.8(2)
$\gamma_{9,0}$	125.41(4)	0.051(10)				
$\gamma_{28,15}$	129.514	~ 0.06	129.4(1)	0.1	129.13(1)	7.8(1)
$\gamma_{15,4}$	131.24(10)	0.0174(22)	131.05(15)	0.03	131.21(8)	0.7(2)
$\gamma_{31,17}$	132.1	0.0035[d] (7)				
$\gamma_{14,3}$	135.3394(24)	1.97(10)	135.34(5)	2.30(12)	135.39(1)	82.4(10)
$\gamma_{35,20}$	139.3(3)				139.3(3)	0.9(1)
$\gamma_{38,27}$		0.0206(23)	139.72(8)	0.1		
$\gamma_{26,12}$	139.720(3)	0.090(18)			139.87(4)	4.393)
$\gamma_{27,11}$	141.95(10)	0.0090(15)	141.6		141.8(2)	0.8(2)
$\gamma_{33,19}$	142.69(1)	0.034(5)			142.69(11)	1.5(2)
$\gamma_{22,8}$	144.426(14)	0.30(3)	144.7(5)	0.9(3)	144.41(3)	13.5(6)
$\gamma_{19,6}$	145.342(3)	1.73(7)	145.37(1)	1.5(2)	145.40(1)	67(1)
$\gamma_{11,1}$	146.3462(16)	6.5(3)	146.34(5)	6.40(32)	146.39(1)	238(3)
$\gamma_{25,9}$	146.9(5)	0.116(10)				
$\gamma_{12,0}$	148.179(10)	0.397(20)	148.14(5)	0.42	148.21(1)	13.9(3)
b	149.691(24)	0.095(6)	149.86(1)	0.13	149.69(2)	3.6(2)
$\gamma_{29,14}$	152.62(10)	0.011(3)	152.6			
$\gamma_{17,4}$		0.037(3)				
$\gamma_{15,2}$	153.13(5)		153.2(2)	0.14	153.19(4)	2.2(1)
$\gamma_{34,18}$						
$\gamma_{28,12}$	154.846(22)	0.143(8)	154.85(1)	0.17	154.90(2)	6.1(2)
$\gamma_{30,14}$	156.15(5)	0.036(3)	156.1(15)	0.07	156.25(6)	1.6(2)
$\gamma_{26,9}$	162.48(3)	0.054(5)	162.6(1)	0.24	162.41(3)	2.3(2)
$\gamma_{40,28}$						
b	163.72(3)	0.117(6)				
$\gamma_{31,13}$	164.5	0.261(5)	164.54(3)	6.2(4)	164.55(1)	256(3)
$\gamma_{14,1}$	164.534(16)	6.0(3)				
$\gamma_{21,6}$	165.581(19)	0.407(23)	165.6(1)	0.45	165.64(2)	15.3(4)
$\gamma_{43,33}$	167.10(7)	0.0165(14)				
$\gamma_{29,12}$	169.10(9)	0.041(6)	168.96(1)	0.1	169.06(4)	2.4(2)
$\gamma_{29,11}$	170.82(3)	0.100(6)	170.84(5)	0.2	170.84(2)	5.2(2)
$\gamma_{30,12}$	172.34(10)	0.0228(22)	172.42(12)	0.03	172.46(11)	0.8(2)
$\gamma_{30,11}$	174.209(18)	0.170(9)	174.17(5)	0.28	174.21(1)	8.1(2)
b	176.12(5)	0.016(5)			176.03(11)	0.7(2)
$\gamma_{50,41}$	177.94(16)				177.78(32)	0.2(2)
$\gamma_{28,9}$		0.0066(13)				
$\gamma_{37,22}$	184.1(3)	0.022(5)	184.4(1)	0.14	184.1(3)	0.9(2)
$\gamma_{33,15}$	185.83(11)	0.0078(21)			185.71(9)	1.9(3)
b	187.12(3)	0.032(4)	187.96(2)	2.0(1)	187.97(1)	79.9(12)
$\gamma_{29,3}$	187.953(16)	1.87(9)				
$\gamma_{37,21}$	188.65(6)	0.025(4)				
$\gamma_{34,15}$	192.29(6)	0.036(4)	192.13(8)	0.07	192.25(4)	1.3(1)
b	198.60(1)	0.0038(13)				

	2003Ba78		1976Kr03		1996Ko29	
	Energy (keV)	Intensity	Energy (keV)	Intensity*	Energy (keV)	Intensity§
[b]		0.0038(13)	200.7(1)	0.001		
$\gamma_{28,8}$	205.90(15)	0.0228(24)	206.2(2)	0.1	205.72(6)	1.0(1)
$\gamma_{43,30}$						
[b]	207.25(9)	0.032(5)				
$\gamma_{21,3}$	208.164(16)	2.29(11)	208.18(5)	2.40(12)	208.22(1)	100(2)
$\gamma_{36,15}$	209.08(8)	0.019(3)				
$\gamma_{38,19}$	210.90(8)	0.0137(24)				
$\gamma_{18,0}$	212.332(19)	0.130(7)	212.36(5)	0.1	212.39(2)	5.6(2)
[b]	214.98(11)	0.0058(16)				
$\gamma_{26,6}$	216.053(17)	0.62(3)	216.1(2)	0.8	216.08(1)	26.4(5)
$\gamma_{19,1}$	217.119(16)	3.28(16)	217.15(5)	3.5(2)	217.18(1)	144.6(2)
$\gamma_{34,12}$	217.8(2)	<0.003			217.8(2)	3(1)
$\gamma_{34,11}$	219.421(18)	0.118(6)	219.42(1)	0.17	219.46(3)	5.1(1)
$\gamma_{30,8}$	223.39(6)	0.024(3)	223.45(1)	0.03	223.37(3)	1.1(1)
$\gamma_{39,18}$	224.39(19)	0.0013(4)	224.8(1)	0.028	224.25(22)	0.3(2)
$\gamma_{23,3}$	226.2(2)	0.070(23)			226.2(2)	0.3(1)
$\gamma_{37,17}$	230.11(3)	0.071(5)	230.11(5)	0.08	230.18(1)	2.5(2)
[b]	230.97(9)	0.0086(22)				
[b]			236.3(1)	0.01		
[b]	237.51(10)	0.0051(17)			237.44(15)	0.5(2)
$\gamma_{34,9}$	240.388(8)	0.413(22)	240.35(5)	0.31(2)	240.37(2)	13.8(7)
$\gamma_{36,10}$	240.90(4)					
[b]	244.50(6)	0.038(5)	245.33(3)	3.8(2)	245.36(1)	158.6(26)
$\gamma_{29,6}$	245.337(16)	3.57(18)				
$\gamma_{45,30}$	248.710(16)		248.71(4)	1.5(8)	248.73(1)	62.2(5)
$\gamma_{30,6}$		1.40(7)				
$\gamma_{23,0}$	255.89(3)	0.0393(25)	255.93(5)	0.03		
$\gamma_{27,3}$	259.268(19)	0.155(8)	259.36(5)	0.21	259.32(1)	6.8(2)
$\gamma_{28,4}$	260.52(3)	0.102(6)			260.54(2)	4.2(2)
$\gamma_{24,1}$	261.944(18)	0.278(14)	261.92(5)	0.32	261.95(1)	12.5(3)
$\gamma_{34,8}$	268.680(18)	0.246(12)	268.67(5)	0.26(2)	268.66(3)	10.5(2)
$\gamma_{39,14}$	272.40(9)	0.071(4)	272.36(5)	0.12	272.39(2)	3.1(1)
$\gamma_{28,3}$	273.74(5)	0.0155(17)				
$\gamma_{29,4}$	274.717(17)	0.420(22)	274.71(4)	0.48(6)	274.71(1)	18.2(4)
$\gamma_{30,4}$	278.070(20)	1.13(6)	278.10(4)	1.20(6)	278.08(1)	48.2(9)
[b]	284.23(8)	0.0089(16)	284.25(15)	0.01	284.49(14)	0.3(1)
[b]	287.32(14)	0.015(7)				
$\gamma_{29,3}$	288.037(25)	0.91(5)	288.01(4)	0.90(5)	288.03(1)	39.1(9)
$\gamma_{47,29}$						
$\gamma_{27,1}$	288.50(3)	0.117(14)				
[b]	290.62(3)	0.109(7)				
$\gamma_{43,20}$	291.353(16)	0.62[e] (25)	291.34(3)	5.5(3)	291.38(1)	230(4)
$\gamma_{30,3}$		4.63(25)				
$\gamma_{40,15}$	291.93(4)	0.102(15)				
$\gamma_{34,6}$	294.006(24)	0.122(7)	293.94(1)	0.17		
$\gamma_{35,6}$	302.978(19)		302.96(5)	0.09	302.95(2)	3.5(1)
$\gamma_{28,0}$		0.078(4)				
$\gamma_{45,24}$	307.29(16)	0.0050(14)			307.68(19)	0.3(1)
$\gamma_{43,19}$	309.58(12)	0.083(5)	309.49(1)	0.1	309.48(3)	4.0(1)
$\gamma_{36,6}$	310.71(5)	0.038(3)				
$\gamma_{39,9}$	311.9(3)	0.063(4)			311.76(3)	2.8(5)

	2003Ba78		1976Kr03		1996Ko29	
	Energy (keV)	Intensity	Energy (keV)	Intensity*	Energy (keV)	Intensity§
$\gamma_{45,23}$	313.45(18)	0.0056(11)				
$\gamma_{41,13}$	315.39(13)	0.0100(15)				
b	316.30(4)	0.094(7)				
$\gamma_{29,0}$ $\gamma_{33,4}$	317.191(16)	7.1(4) 0.27(11)	317.15(2)	8.0	317.18(1)	330(7)
$\gamma_{30,0}$	320.560(16)	2.78(14)	320.53(3)	3.0(2)	320.52(4)	122(3)
$\gamma_{34,4}$	323.396(16)	0.77(4)	323.37(4)	0.87(6)	323.39(4)	33.7(7)
$\gamma_{37,8}$	328.53(12)	0.080(4)	328.74(5)	0.066	328.64(6)	3.2(1)
b	335.68(8)	0.0081(19)				
$\gamma_{34,3}$	336.631(16)	0.58(3)	336.60(4)	0.59(3)	336.63(1)	24.4(5)
$\gamma_{39,8}$	339.2(6)	0.0025(16)			340.20(5)	0.4(1)
$\gamma_{37,6}$	354.082(20)	0.060(4)	354.05(5)	0.062	354.03(1)	2.4(1)
$\gamma_{33,0}$	359.38(19)	0.0049(15)			359.38(4)	0.2(1)
$\gamma_{47,22}$	364.01(12)	0.0064(16)				
$\gamma_{34,0}$	365.820(16)	0.77(4)	365.79(3)	0.87(5)	365.76(1)	33.2(8)
$\gamma_{44,14}$	371.26(23)	0.0014(7)			371.35(9)	0.05(1)
$\gamma_{35,0}$	374.7(3)	0.0038(20)			374.72(20)	0.05
$\gamma_{41,8}$	381.54(15)	0.0039(13)			381.32(6)	0.14(1)
$\gamma_{37,4}$	383.482(21)	0.096(5)	383.43(1)	0.1	383.42(1)	4.1(1)
$\gamma_{42,9}$	387.76(12)	0.0012(3)			387.96(12)	0.03(8)
$\gamma_{40,6}$	393.64(5)	0.0130(12)	393.59(1)	0.017	393.60(1)	0.56(4)
$\gamma_{37,3}$	396.64(13)	0.0044(10)	396.7(1)	0.008	396.62(3)	0.15(3)
$\gamma_{49,20}$	402.36(9)	0.0072(14)	402.4(2)	0.008	402.22(1)	0.27(4)
$\gamma_{45,14}$	404.33(19)	0.0013(4)			404.40(5)	0.08(1)
$\gamma_{41,6}$	406.58(16)	0.0015(4)	406.7(3)	0.005	406.58(5)	0.07(1)
$\gamma_{42,8}$	416.24(3)	0.0120(10)	416.4(2)	0.014	416.32(1)	0.46(4)
$\gamma_{40,4}$ $\gamma_{45,11}$	423.09(14)	0.00052(14)			423.09(14)	0.022(6)
$\gamma_{49,18}$	425.33(12)	0.00080(14)			425.53(9)	0.034(6)
$\gamma_{41,4}$ $\gamma_{40,3}$	436.20(12)	0.0035(9)	436.6(4)	0.036	436.23(2)	0.2(1)
$\gamma_{42,6}$	441.53(17)				441.53(17)	0.031(9)
$\gamma_{41,3}$	449.46(7)	0.0064(8)	449.5(2)	0.01	449.53(2)	0.3(1)
$\gamma_{43,6}$	455.13(11)	0.00117(21)			455.66(8)	0.05(9)
$\gamma_{47,12}$	456.87(16)	0.00044(21)			456.87(16)	0.019(9)
$\gamma_{46,9}$	459.74(6)	0.0076(11)	459.8(2)	0.008	459.81(1)	0.31(3)
$\gamma_{40,0}$	465.37(12)	0.00047(23)			465.37(12)	0.02(1)
$\gamma_{42,4}$	471.05(4)	0.0185(18)	471.0(2)	0.02	471.06(1)	0.64(6)
b	473.51(18)	0.0030(15)				
$\gamma_{48,11}$	474.41(8)	0.00077(11)			474.41(8)	0.033(5)
$\gamma_{41,0}$	478.64(4)	0.0148(12)	478.6(2)	0.02	478.64(1)	0.64(5)
$\gamma_{43,4}$	484.8(3)	0.0023(10)	484.1(2)	0.004	484.33(3)	0.09(3)
$\gamma_{51,14}$	500.44(23)	0.00070(23)			500.39(9)	0.03(1)
$\gamma_{42,0}$ $\gamma_{46,6}$	513.23(13)	0.0165(21)			513.19(5)	0.31(10)
$\gamma_{52,20}$	514.72(13)	0.0112(18)	514.0(5)		514.88(11)	0.46(2)
$\gamma_{48,8}$	523.59(24)	0.00094(24)			523.69(6)	0.04(1)
$\gamma_{50,9}$	531.54(8)	0.00070(23)			531.54(8)	0.03(1)
$\gamma_{47,6}$	533.53(5)	0.00117(23)			533.53(5)	0.05(1)
$\gamma_{44,1}$	536.44(12)	0.00047(23)	537.6(5)		536.44(12)	0.02(1)

	2003Ba78		1976Kr03		1996Ko29	
	Energy (keV)	Intensity	Energy (keV)	Intensity*	Energy (keV)	Intensity§
$\gamma_{49,8}$	540.68(13)	0.00164(23)	540.3(2)	0.005	540.49(6)	0.07(1)
$\gamma_{46,4}$	542.41(13)	0.00047(23)			542.41(13)	0.02(1)
b			545.1(3)	0.0023		
$\gamma_{50,8}$	559.87(18)	~ 0.00023			559.87(18)	0.01(1)
$\gamma_{47,4}$	562.95(24)	0.0014(7)	562.8(5)		562.60(4)	0.06(1)
$\gamma_{45,0}$	569.31(16)	0.0039(15)	569.4(2)	0.0036	569.19(2)	0.1(1)
$\gamma_{47,3}$	576.09(20)	0.0009(4)				
$\gamma_{48,4}$	578.61(17)	0.0034(11)	578.5(2)	0.0049	578.42(2)	0.15(1)
$\gamma_{50,6}$ $\gamma_{46,0}$	584.94(16)	~ 0.00023			584.94(16)	0.04(1)
$\gamma_{48,3}$	591.6(3)	0.00070(23)			591.64(7)	0.03(1)
$\gamma_{47,0}$	605.22(13)	0.0048(9)			605.16(1)	0.15(1)
$\gamma_{49,3}$	608.15(5)	0.00047(23)			608.15(8)	0.02(1)
$\gamma_{50,4}$	614.60(20)	0.00070(23)			614.43(7)	0.03(1)
$\gamma_{48,0}$	620.63(23)	0.0015(6)	620.9(2)	0.0022	620.82(3)	0.62(4)
$\gamma_{50,3}$	627.70(8)	0.00047(23)			627.70(8)	0.02(1)
b	633.51(12)	0.00069(23)			633.51(12)	0.03(1)
$\gamma_{49,0}$	637.25(10)	~ 0.00023			637.25(10)	0.01(1)
$\gamma_{52,8}$	652.79(19)	~ 0.00023			652.79(19)	0.01(1)
$\gamma_{50,0}$	657.30(17)	0.0040(10)	657.0(2)	0.0028	656.88(2)	0.08(4)
$\gamma_{51,0}$	665.03(10)	~ 0.00023			665.03(10)	0.01(1)
b	702.7(3)	0.0011(5)			703.46(18)	0.01(1)
$\gamma_{52,4}$	707.4(3)	0.0020(9)	707.5(2)	0.0027	707.41(2)	0.08(3)
b			710.8(5)			
b	714.3(3)	0.00047(23)			714.28(6)	0.02(1)
$\gamma_{52,3}$	720.62(11)	0.00047(23)			720.62(11)	0.02(1)
b	721.88(14)	0.0040(11)				
$\gamma_{52,0}$	749.8(4)	0.00047(23)			749.80(9)	0.02(1)
b	765.82(20)	0.00014(7)			765.82(20)	0.006(3)
b			826.3(5)			
b	843.35(10)	0.00016(5)			843.35(18)	0.007(2)
b			867.9(4)	0.002		
b			920.0(10)			
b	927.1(3)	0.0014(7)				
b	932.6(3)	0.0014(7)				
b			1003.0(10)	0.008		
b			1055.0(10)			
b	1109.8(5)	0.0008(3)				
b			1119.0(10)	0.008		

* Uncertainty in intensity is 10% unless otherwise stated.
§ Relative γ-intensity normalized to 100 for 208.2 keV
a Deduced value, not observed.
b unplaced gamma rays.
c Total intensity limit required for intensity balance
d Calculated from strong coupling rotational model
3 Calculated from intensity balance

γ-ray intensity normalization: The normalization of gamma rays to a scale per 100 alpha decays uses the measured intensity (Iγ = 0.00229%) for the 208.178 keV ($\gamma_{21,3}$) gamma ray, as reported in 1984Re05.

Atomic Data

ω_K : 0.969(4)
ω_L : 0.476(18)
η_{KL} : 0.797(5)

The fluorescence yields were obtained from 1996Sc06. The energies of the K-Auger electrons were obtained from 1998ScZM, where as the energies and the yield of Th X-rays were obtained from 1999ScZX.The X-ray and Auger electron emission probabilities have been calculated using the computer program EMISSION (V3.10, 28-Jan-2003) described in 2000Sc47. The energies of the internal conversion electrons have been deduced using gamma-ray energies and electron binding energies from 1977La19 and 1996FiZX. Absolute conversion electron emission probabilities have been calculated by using gamma-ray internal conversion coefficients and absolute emission probabilities.

Electron Emission

The energies of the conversion electrons have been obtained from the gamma transition energies and the electron binding energies. The number of K- and L- Auger electrons per 100 disintegrations has been deduced using the evaluated XK- and XL- emission probabilities.

X-ray Emission

The adopted Th X-ray energies and absolute intensities are given in Table 8 along with measured values reported in 1976Kr03 and 1979Ce04. The KX-ray deduced relative emission probabilities are also given in Table 8.

Table 8: Energies and intensities of Th X-rays

	Energy (keV) adopted	Energy (keV) 1976Kr03	Energy (keV) 1979Ce04	Energy (keV) 2003Ba78	Rel. Prob. deduced	Photons per 100 disint. deduced
XLl	11.1177	11.12		11.11		0.00936 (21)
XLα	12.8085 – 12.967	12.97		12.95		0.00418 (12)
XLη	14.509			14.51		7.87E-5 (26)
XLβ_6		14.97		15.03		
XLβ_2		15.64		15.61		
XLβ_4	14.972 – 17.1383					0.00402 (10)
XLβ_1		16.20		16.18		
XLβ_9		17.08		17.05		
XLγ_5		18.37		18.35		
XLγ_1		18.98		18.95		
XL$\gamma_{2,}$	18.3633 – 19.5043					0.000830 (22)
XLγ_3,		19.50		19.52		
XLγ_6						
XLγ_4		20.27		20.25		
XKα_2	89.954	89.94	89.96	89.96	61.82	0.00700 (18)
XKα_1	93.351	93.34	93.35	93.35	100.	0.01133(28)
XKβ_3	104.819		104.83			
XKβ_1	105.604	105.59	105.5		35.58346	0.00403 (12)
XK$\beta_5^{//}$	106.239		106.16			
XKβ_2	108.509	108.67	108.69			
XKβ_4	108.955		108.49		11.99162	0.00136 (5)
XK$O_{2,3}$	109.442					

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^{234}U - Comments on evaluation of decay data by V. Chisté and M.M. Bé

This evaluation was completed in 2005. Literature available by September 2005 was included.

1 Decay Scheme

^{234}U disintegrates by alpha emission to excited and ground state levels of ^{230}Th. Spin and half-lives of excited states are from the mass-chain evaluation of Y.A. Akovali (1993Ak02 to A = 230, and 1994Ak05 to A = 234).

2 Nuclear Data

The Q value is from atomic mass evaluation of Audi et al. (2003Au03).

The experimental ^{234}U half-life values (in years) are given in Table 1:

Table 1: Experimental values of ^{234}U half-life.

Reference	Original value (10^5 a)	Revised Value by Holden (1981HoZI and 1989Ho24)	Comments
Nier (1939Ni03)	2.70 (27)		**Not used**.
Chamberlain (1946Ch02)	2.29 (14)		**Not used**. Measurements of relative abundance of ^{234}U and ^{238}U.
Chamberlain (1946Ch02)	2.35 (14)		**Not used**. Measurements of α-activity of ^{234}U.
Baldinger (1949Ba41)	2.33 (10)		**Not used**.
Goldin (1949Go18)	2.67 (4)		**Not used**.
Kienberger (1949Ki26)	2.552 (8)		**Not used**. Superseded 1952Ki19
Fleming (1952Fl20)	2.475 (16)	2.475 (24)	**Not used**. Uncertainty increased for missing details.
Kienberger (1952Ki19)	2.520 (8)		**Not used**.
White (1965Wh05)	2.47 (3)		**Not used**.
Meadows (1970MeZN)	2.439 (14)	2.439 (18)	**Not used**. Uncertainty increased for missing details.
de Bievre (1972DeYN)	2.446 (7)	2.450 (9) *	Revised by author (see 1989Ho24)
Lounsbury (1972LoZL)	2.444 (6)	2.458 (13) *	Revised by author (see 1989Ho24)
Geidel'man (1980Ge13)	2.4604 (45)	2.459 (9) *	4πα - x coincidence. Revised uncertainty for missing details.
	2.4570 (45)		Liquid scintillator. Revised uncertainty for missing details.
Poenitz (1983 and 1985 Poenitz)	2.457 (5)		**Not used**.
Davideenam (1984Davideenam)	2.457 (5)		**Not used**. Evaluated value.
Recommended value		**2.455 (6)**	reduced $\chi^2 = 0.28$

The first six and less precise values (1940's) were omitted from analysis. For remaining values, the evaluators have chosen to take into account the recommendations given by N.E. Holden (1989Ho24), thus the only three experimental values (*) with associated uncertainties used to the weighted average are 1972DeYN, 1972LoZL and 1980Ge13. For the data in 1980Ge13, the evaluators have chosen to use the average value of 2.459 (9) 10^5 a, calculated from two experimental values given in the paper to produce a single DDEP value from each laboratory. A weighted average has been calculated using LWEIGHT computer program (version 3). However, the treatment of uncertainties in 1989Ho24 ("… when detailed information on the uncertainties was available in each of these experiments, the standard deviation for the experiment was combined with one third of the systematic error to provide the uncertainty quoted in the table: $\sigma_{tot} = \sigma_{statistical} + 1/3\ \sigma_{systematic}$") seemed more realistic, so the evaluators recommend a half-life of *2.455 10^5 a* with a final uncertainty of

0.006 10^5 a. The reduced χ^2 value is 0.28.

The experimental ^{230}Th half-life values (in years) are given in Table 2:

Table 2: Experimental values of ^{230}Th half-life.

Reference	Value (a)	Uncertainty (a)
M. Curie (1930Cu02)	82 300	2 469
E.K. Hyde (1949Hy03)	80 000	3 000
R.W. Attree (1961Attree)	75 200	1 600
J.W. Meadows (1980Me10)	75 381	295
Recommend value	**75 500**	**500**

The recommended value is the weighted average (calculated with LWEIGHT computer program) of *75.5 10^3 a* with an external uncertainty of *0.5 10^3 a*. The reduced χ^2 value is 3.3.

The evaluated spontaneous fission partial half-life of ^{234}U is based on the experimental results given in Table 3.

Table 3: Experimental values of ^{234}U spontaneous fission half-life (in 10^{16} years).

Reference	Value	Uncertainty	Comments
A. Ghiorso (1952Gh27)	2	1	**Not used**.
H.R. von Gunten (1981Vo02)	1.42	0.08	
S. Wang (1987Sh27)	1.90	0.15	
Recommend value	1.5	0.2	reduced χ^2 = 5.12

The evaluators have not use the value given in 1952Gh27, as recommended in 1989Ho24. Evaluators' recommended value is the weighted average of the two remaining values: *1.5 10^{16} a* with an external uncertainty of *0.2 10^{16} a*. The reduced χ^2 value is 5.12.
This value produces a spontaneous fission branching of 1.6 (2) 10^{-9} %.

2.1 α Transitions

The energies of the α-particle transitions given in Section 2.1 have been calculated from the Q_α (2003Au03) and level energies deduced by the evaluators from a least-squares fit to γ-ray energies.

2.2 γ Transitions

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

For the 634-keV γ-ray (E0 transition), $P_{(\gamma+ce)}$ = 1.4 (7) 10^{-5} % has been deduced from decay scheme balance.

Multipolarities of γ-ray transitions in decay of ^{230}Th are from 1993Ak02:

53-keV γ-ray:	E2	581-keV γ-ray:	E2
120-keV γ-ray:	E2	624-keV γ-ray:	E0 + E2 + M1
454-keV γ-ray:	E1	634-keV γ-ray:	E0
503-keV γ-ray:	[E2]	677-keV γ-ray:	[E2]
508-keV γ-ray:	E1		

The internal conversion coefficients (ICC's) have been calculated using the Icc99v3a computer program (GETICC dialog), which uses interpolated values from new tables of Band et al (2002Ba85). The evaluators have used a fractional uncertainty of 3 % for all conversion coefficients.

3 Atomic Data

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

4 α Emissions

α-particle energies are from Q_α (2003Au03) and level energies (see section 2.1). For the $\alpha_{0,0}$ and $\alpha_{0,1}$ emissions, the energies are from A. Rytz (1991Ri01).

The measured α-emission intensities are given in Table 4.

Table 4: Measured α-emission intensities, in %.

Energy (keV)	1955Go57	1960Ba44	1961Ko11	1963Bj03	1984Va41	1987Bo25	Recommended Value
4774.6 ($\alpha_{0,0}$)	72	72.5 (30)	73		71.38 (5)	71.37 (2)	71.37 (2)
4722.4 ($\alpha_{0,1}$)		27.15 (15)	27		28.42 (5)	28.42 (2)	28.42 (2)
4603.5 ($\alpha_{0,2}$)		≤ 0.37 (11)	0.3		0.206 (4)	0.199 (2)	0.210 (2)
4275.2 ($\alpha_{0,3}$)				4 (1) 10^{-5}			4 (1) 10^{-5}
4150.6 ($\alpha_{0,4}$)				1.2 (5) 10^{-5}			2.6 10^{-5}
4108.6 ($\alpha_{0,5}$)				0.3 10^{-5}			7.0 10^{-6}

The U-234 spectrum was recorded by 1984Va41, a second analysis of the same data was done by 1987Bo25, these latest values are the adopted results for the 4774- and 4722-keV α-emissions intensity. The 4603-keV intensity is deduced from the decay scheme, the tree others being negligible.
The 4275-, 4150-, 4108- keV emission intensities are deduced from 1963Bj03 and decay scheme transition probability balance (§6.2).

6 Photon Emissions

6.1 X-rays

The X-ray and Auger electrons absolute intensities have been calculated from γ-ray data and ICC by using the EMISSION computer program.

In the Table 5 the recommended values of ^{230}Th X-ray emission probabilities are compared with the experimental results. Good agreement was found between the experimental results given by 1977Bemis, 1984Va41 and 1995Jo23 and the recommended values calculated from the decay scheme data set. This agreement confirms the completeness and consistency of the decay scheme.

Table 5: Experimental and recommended (calculated) values of ^{230}Th X-ray emission intensities.

Reference	1977Bemis	1984Va41	1995Jo23	Recommended value
11.118 – 19.504 (L X-ray)	9.81 (13)	10.35 (14)	10.02 (7)	10.2 (4)
Lℓ - 11.118			0.206 (3)	0.209 (12)
Lα - 12.808 – 12.967			3.42 (2)	3.48 (17)
Lη - 14.509				0.118 (7)
Lβ - 14.972 – 16.425			5.17 (4)	5.16 (26)
Lγ - 18.363 – 19.504			1.22 (1)	1.21 (6)
89.95 (X $K_{\alpha2}$)		2.53 (7) 10^{-3}		2.69 (25) 10^{-3}
93.35 (X $K_{\alpha1}$)		4.15 (10) 10^{-3}		4.4 (4) 10^{-3}

6.2 Gamma emissions

The energies of the γ-ray emissions given in Section 6 are from Y.A. Akovali (1993Ak02).
The experimental intensity of the 120-keV γ emission given in Table 6 is relative to the 53-keV γ-ray.

Table 6: Experimental relative γ emission intensity (P_{rel}) in %.

γ Energy (keV)	1966Ah02	1974HeYW	1984Va41	Recommended value
53.20	100	100 (5)	100	100.0 (25)
120.90	34 (4)	34.2 (18)	27.5 (5)	30.8 (24)

The recommended values are the weighted averages of the three values given with uncertainties. The normalization factor to convert the relative emission intensities to absolute emission intensities is calculated with the formula:

$$\text{Normalization factor} = \frac{(100\,\% - 71.371\,(19)\,\%)}{\sum\,[(1 + \alpha_T)P_{rel}]} = 0.001\,253\,(40),$$

where the sum is over all the γ transitions to the ground state and α_T is the relevant conversion coefficient. In this case, the contribution of 508- (see next), 634- and 677-keV γ transitions are considered negligible. The uncertainty was calculated through the propagation on the formula given above.

For the 454- and 508-keV absolute emission probabilities, the evaluators have following relations:
P_γ (454) + P_γ (508) = 4 (1) 10^{-5} (from 1963Bj03) and
P_γ (508) = 0.60 (4) × P_γ (454) (from average value of measured ratios in ^{230}Pa and ^{230}Ac decays. See 1993Ak02).Then the evaluator obtains P_γ (454) = 0.000 025 (6) % and P_γ (508) = 0.000 015 0 (39) %. For the others γ rays, the evaluators present the experimental absolute emission values given in 1993Ak02. The evaluated relative and absolute γ-rays emission intensities are given in Table 7.

Table 7: Evaluated relative and absolute γ-ray emission intensities.

Energy (keV)	Relative emission intensity (%)	Absolute emission intensity (%)
53.20 (2)	100.0 (25)	0.125 3 (40)
120.90 (4)	30.8 (24)	0.038 6 (32)
454.96 (5)		0.000 025 (6)
503.5 (1)		0.000 000 95
508.16 (5)		0.000 015 0 (39)
581.7 (1)		0.000 012 (5)
624.4 (1)		0.000 000 82
677.6 (1)		0.000 001

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^{235}U - Comments on evaluation of the decay data
by Huang Xiaolong, Wang Baosong

This evaluation was completed in 2008, and data available in the literature by June 2008 was included.

1 Decay Scheme

^{235}U disintegrates 100 % by α emission to levels in ^{231}Th. ^{235}U ground state has J^{π} = 7/2^{-} (2003Br12). The spontaneous fission branching ratio is 7.0 (20) 10^{-9} % (from $T_{1/2}$(SF) = 1.0 (3) 10^{19} a (2000Ho27) and $T_{1/2}$= 7.04 (1) 10^{8} a.)

The α decay scheme of ^{235}U was built based on the measurements described in 1974Te03, 1975Va11 and 1977Ba72. A study of 2004Da24 showed the existence of weak α decay branches to some levels in ^{231}Th.

2 Nuclear Data

A Q value of 4678.3 (7) keV is given in 2003Au03 atomic mass adjustment.
Level energies, have been obtained from a least-squares fit to γ-ray energies (GTOL computer code). Spin and parities are from 2003Br12.
The measured and evaluated ^{235}U half-life values are listed in Table 1. Notice that the uncertainties in all the tables are in the two least significant digits.

Table 1 Measured half-life values of ^{235}U and recommended value (10^{8} a).

References	Original value (10^{8} a)	Materials	Revised value by 2004Sc03	Comments
1939Ni03	7.13 (16)	Natural U	6.97 (24)	Pb/U activity ratio, Mass spectrometry
1950Kn17	7.53 (22)	Enriched U	7.11 (14)	Specific activity, Ionization chamber
1951Sa30	7.07	Natural U	6.77 (21)	^{235}U/^{238}U activity ratio, Ionization chamber
1952Fl20	7.13 (16)	Enriched U	7.12 (16)	Specific activity, proportional counter
1957Cl16	7.67	Natural U	7.64 (43)	activity ratio, Ionization chamber
1957Wu39	6.84 (15)	Natural U	6.95 (16)	^{235}U/^{234}U activity ratios, Ionization chamber
1965De06	6.92 (9)	Natural U		^{235}U/^{238}U activity ratio, Solid-state detector, Updated by 1974De19
1965Wh05	7.13 (9)	Enriched U	7.12 (9)	Specific activity, Solid-state detector
1971Ja07	7.0381 (48)	Highly enriched U	7.04 (1)	Specific activity, proportional counter
1974De19	6.85 (9)	Highly enriched U	6.79 (13)	^{235}U central peak branching ratio, Solid-state detector
1993Bu10	7.04 (1)	Enriched U		Specific activity, gas+NaI scintillator Systematic error excluded
2003Br12	7.04 (1)			NDS, Weighted average of 1993Bu10, 1974De19, 1971Ja07, 1965Wh05, 1965De06 and 1957Wu39
			7.06 (9)	Unweighted mean
			7.04 (1)	Weighted mean,χ^2=1.12. Recommended value

2004Sc03 studied in detail various problems with the measurements of the half-life of ^{235}U and decided to recommend the half-life given by 1971Ja07, but multiplied by 2 its original uncertainty in order to include the systematic uncertainties that had not been considered in 1971Ja07. The weighted mean is the same as this precise measurement given in 1971Ja07.

The measured and evaluated ^{235}U spontaneous fission half-life values are listed in Table 2. The value in 1981Vo02 is recommended here.

Table 2 Measured spontaneous fission half-life values of ^{235}U and recommended value (10^{19} a).

$T_{1/2}$ (10^{19} a)	References	measurement method
0.018	1952Se67	Ionization chamber; not used
0.035 (9)	1966Al23	Fission track detectors; not used
> 0.18	1974GrZA	Rotating bubble chamber; no corrections; not used
0.98 (28)	1981Vo02	99.76 % enriched; rotating bubble chamber; corrected for the (a,n,f) reaction
1.0 (3)	2003Br12	NDS,from evaluation of 2000Ho27
0.98 (28)	Recommended value	From 1981Vo02

2.1 g-Ray Transitions

The γ-ray transition probabilities were deduced from the γ-ray emission probabilities and the relevant internal conversion coefficients.

Multipolarities and mixing ratios of γ-ray transitions are from 2003Br12.

Theoretical internal conversion coefficients (ICC) and their associated uncertainties for γ-ray transitions have been obtained using the BrIcc computer program, which uses the “Frozen Orbital” approximation (2002Ba85).

2.2 a-Particle Transitions

Measured energies of alpha particles are listed in Table 3. Our recommended values are from 1975Va11, 1991Ry01, 2004Da24, and from Q_{α} (2003Au03) and level energies.

Table 3 Measured and recommended values of α-particle energies (in keV) from ^{235}U α decay

1960Ba44	1962Pi06	1966Ga03	1975Va11	1991Ry01	2004Da24	Calc. from level energy and Q(α)	Recommended
						3897.2 (7)	3897.2 (7)
		3977 (10)			3976 (5)	3975.3 (7)	3976 (5)
						3990.5 (9)	3990.5 (9)
						4013.2 (8)	4013.2 (8)
						4053.9 (7)	4053.9 (7)
		4069 (10)			4077	4077.5 (7)	4077.5 (7)
	4153	4140 (3)	4145 (6)		4152 (5)	4154.2 (7)	4152 (5)
4214	4210	4210 (3)	4209 (4)	4214.7 (19)	4215.8 (5)	4217.4 (7)	4214.7 (19)[b]
						4219.6 (7)	4219.6 (7)
			4219 (6)			4227.6 (7)	4227.6 (7)
		4240 (10)			4248 (5)	4252.6 (7)	4248 (5)

1960Ba44	1962Pi06	1966Ga03	1975Va11	1991Ry01	2004Da24	Calc. from level energy and Q(α)	Recommended
	4261				4266 (5)	4270 (4)	4266 (5)
		4267 (10)				4279.3 (7)	4279.3 (7)
			4280		4282 (5)[a]	4286.9 (7)	4286.9 (7)
		4289 (10)	4295			4302.1 (7)	4302.1 (7)
4320	4318	4319 (3)	4322 (4)		4322.9 (6)[a]	4325.4 (7)	4322 (4)
4326						4327.9 (7)	4327.9 (7)
					4364.3 (4)[a]	4361.9 (7)	4361.9 (7)
4368	4361	4362 (3)	4358 (4)	4366.1 (20)		4365.8 (7)	4366.1 (20)[b]
		4368 (5)				4381.1 (7)	4381.1 (7)
4394	4391	4394 (3)	4392 (3)	4397.8 (13)	4395.3 (4)	4396.8 (7)	4397.8 (13)[b]
4412	4414	4411 (5)	4411 (5)		4414.9 (5)	4416.1 (7)	4414.9 (5)
4438	4440	4424 (5)	4435 (5)		4437.9 (40)	4439.3 (7)	4437.9 (40)
4496	4497	4496 (3)	4501 (4)		4502.4 (7)	4504.2 (7)	4502.4 (7)
4550	4551	4550 (3)	4555 (3)		4556.0 (4)	4557.4 (7)	4556.0 (4)
4592	4592	4592 (3)	4597 (3)	4596.4 (13)	4597.3 (4)	4598.7 (7)	4596.4 (13)[b]

a: May be a multiplet; b: From 1991Ry01.

Experimental and recommended α-particle emission probabilities are listed in Table 4. Our recommended alpha particle emission probabilities are LWM average values of measured α-particle intensities given in 1975Va11, 2004Da24 and 2006Ga36 ; other recommended values are from results deduced from γ-ray transition intensity balance at each nuclear level.

Table 4 Measured and recommended values of α-particle emission probabilities from ^{235}U decay

E_α(keV)	P_α(%)								
	1960Ba44	1962Pi06	1966Ga03	1975Va11	2004Da24	2006Ga36	Deduced from I_γ	LWM	Recommended[†]
3976					~ 0.007		≈ 0.0011		≈ 0.0011
4013.2							0.040 (1)		0.0396 (10)
4077.5						0.016 (12)	0.0177 (3)		0.016 (12)
4152		~ 0.3	1.0	0.9 (2)[a]	0.31 (2)	0.286 (18)	0.506 (14)	0.297 (13)	0.294 (13)
4214.7	5.5	5.5	6.2	5.7 (6)	6.28 (11)	5.91 (7)	6.0 (4)	6.01 (12)	5.95 (12)
4219.6							0.0175 (2)		0.01732 (12)
4227.6				~ 0.9			0.123 (6)		0.122 (6)
4248 ?			< 0.5		0.07 (1)		0.07 (1)		0.069 (10) ?
4266					0.26 (2)	0.200 (16)	0.22 (8)	0.22 (3)	0.22 (3)
4279.3			< 0.3				0.0332 (4)		0.0329 (5)
4286.9		0.6			0.14 (1)[a]	0.066 (13)	0.096 (12)		0.065 (13)
4302.1			< 0.5				0.00969 (12)		0.00959 (13)
4322	3	2.9	3.5	4.7 (5)[a]	3.78 (8)[a]	3.37 (6)	3.3 (7)		3.33 (6)
4327.9	11						0.409 (13)		0.405 (13)
4361.9							0.208 (21)		0.206 (21)

E_α(keV)	P_α(%)								
	1960Ba44	1962Pi06	1966Ga03	1975Va11	2004Da24	2006Ga36	Deduced from I_γ	LWM	Recommended†
4366.1	6	19	12.3	17 (2)[a]	18.8 (2)[a]	19.00 (13)	19 (5)		18.80 (13)
4381.1			6.1				0.107 (16)		0.106 (16)
4397.8	62	58	53.0 (13)	54 (3)	57.11 (41)	57.98 (22)	58 (5)	57.8 (3)	57.19 (20)
4414.9	2	~ 4	2.3	2.1 (2)	3.07 (7)	3.11 (6)	3.5 (22)	3.04 (16)	3.01 (16)
4437.9	3	~ 0.6	1.8	~ 0.7	0.27 (2)	0.219 (16)	0.206 (16)	0.239 (25)	0.236 (25)
4502.4	1	1.2	1.4	1.7 (2)	1.32 (5)	1.25 (4)	1.23 (24)	1.29 (5)	1.28 (5)
4556.0	3	3.7	1.7	4.5 (5)	3.74 (8)	3.87 (6)	3 (3)	3.83 (6)	3.79 (6)
4596.4	< 1	4.7	1.2	5.4 (5)	4.84 (9)	4.74 (7)	4 (4)	4.79 (6)	4.74 (6)

† Normalized to a total of 100 %.

a: May be a multiplet.

3. Atomic data

Atomic fluorescence yields (ω_K,ϖ_L, ϖ_M, η_{KL} and η_{LM}) are from Schönfeld (1996Sc06).

The X-ray and Auger electron emission probabilities have been deduced from γ-ray and conversion electron data by using the computer code RADLST. The deduced K X-ray emission probabilities $P_{K\alpha1}$ = 5.75 (14) agree with the measured value of 5.55 (14) in 1996Ru11, thus confirming the completeness of the decay scheme.

4. Electron Emissions.

The conversion electron emission probabilities have been deduced from γ-ray transition data using theoretical internal conversion coefficients.

5. Photon Emissions

5.1 g-ray energy values

The experimental and our recommended γ-ray energies from ^{235}U α decay are listed in table 5. Our recommended values are mainly from the LWM averages based on measurements of 1971Cl03, 1974Te03, 1975Va11, 1977Ba72 and 1984He12 unless otherwise specified. Values in 1986LoZT are from the CRP evaluations done in 1986.

5.2 Absolute g-ray emission probabilities

Measured relative, and absolute γ-ray intensities from ^{235}U are listed together with evaluated values in Table 6. Among these measurements, 1966Ga03, 1971Cl03, 1971KrZH, 1974Te03, 1975Va11, 1977Ba72 and 1996Ru11 measured relative γ-ray intensities. Other values reported in 1982Va04, 1983BaZZ, 1983Ol01, 1984He12, 1992Li05 and 2006Al28 are measured absolute γ-ray intensities. Thus we evaluated and recommended the γ-ray emission probability of the 185.7 keV reference line firstly.

There are 7 independent measurements of the absolute γ-ray emission probability of the 185.7 keV reference line. Among these absolute measurements, 1982Va04, 1983BaZZ and 1984He12 belong to CRP measurements. The measurement reported in 2006Al28 has not been recommended because of interference with gamma rays from a ^{226}Ra impurity.

The CRP evaluations done in 1986 are reported in 1986LoZT where a recommended P_γ(185.7) = 57.2 (2) is given. We re-calculated P_γ(185.7) and found that the LWM average value based on CRP measurements reported in 1982Va04, 1983BaZZ and 1984He12 is 57.3 (4), and LWM of 1982Va04, 1983BaZZ, 1983Ol01, 1984He12 is 57.1 (3). Our recommended value is taken from the LWM average of values given in 1982Va04, 1983BaZZ, 1983Ol01, 1984He12, 1992Li05 and 1999Ch12, that is, P_{γ}(185.7) = 57.0 (3) %.

Results for most γ rays given in 1966Ga03 and 1977Ba72 were not used because they did not have uncertainties, unless these were the only measurements for such γ-rays. Relative γ-ray intensities reported in 1971Cl03, 1971KrZH, 1974Te03, 1975Va11 and 1996Ru11 have been normalized using the present recommended P_{γ}= 57.0 (3) for the 185.7 keV reference line.

Our "best" recommended absolute γ-ray emission probabilities are mainly from LWM averages of measurements reported in 1971Cl03, 1971KrZH, 1974Te03, 1975Va11, 1982va04, 1983BaZZ, 1983Ol01, 1984He12, 1992Li05 and 1996Ru11 unless otherwise specified.

Table 5. Measured and recommended values of γ-ray energies for ^{235}U α decay (keV).

1966Ga03	1971Cl03	1974Te03	1975Va11	1977Ba72	1984He12	1986LoZT	LWM	Recommended
			19.59	19.55 (5)				19.55 (5)
		31.50 (20)	31.59 (14)	31.60 (5)			31.60 (5)	31.60 (5)
				34.7 (1)				34.7 (1)[×]
		41.70 (15)	41.1			41.4 (3)		41.4 (3)[a]
		41.96 (15)	42.1 (1)	41.95 (10)		41.96 (15)	42.01 (6)	42.01 (6)
		51.20 (10)	51.7 (4)	51.20 (5)			51.21 (4)	51.21 (4)
				54.1 (1)				54.1 (1)
			54.1	54.25 (5)				54.25 (5)
				64.45 (5)				64.45 (5)
			72.7 (2)			72.7 (2)		72.7 (2)
				73.72 (5)				73.72 (5)
	74.923 (23)	74.76 (20)	75.02 (5)			75.02 (5)	74.94 (3)	74.94 (3)
			95.7					95.7
		96.09 (2)	96.1	96.2				96.09 (2)
97 (4)								97 (4)
109 (4)	109.120 (8)	109.145 (10)	109.25 (5)	109.25 (5)		109.16 (2)	109.19 (7)	109.19 (7)
115 (4)	115.2 (3)		115.5 (2)	115.45 (5)			115.45 (5)	115.45 (5)
			120.0	120.35 (5)				120.35 (5)
			136.6	136.55 (5)				136.55 (5)
	140.75 (10)	140.758 (20)	140.80 (8)	140.75 (5)		140.76 (4)	140.76 (2)	140.76 (2)
				142.40 (5)				142.40 (5)
144 (2)	143.776 (10)	143.753 (8)	143.77 (2)	143.75 (5)	143.768 (3)	143.76 (2)	143.767 (3)	143.767 (3)
			147.0					147
151 (4)	150.960 (33)	150.939 (20)	150.94 (3)	150.85 (5)		150.93 (2)	150.936 (15)	150.936 (15)
	163.363 (10)	163.349 (9)	163.36 (2)	163.25 (5)	163.357 (3)	163.33 (2)	163.356 (3)	163.356 (3)
			173.0 (10)					173 (1)

1966Ga03	1971Cl03	1974Te03	1975Va11	1977Ba72	1984He12	1986LoZT	LWM	Recommended
			182.1					182.1
	182.72 (20)	182.65 (15)	182.7 (2)	182.60 (5)		182.61 (5)	182.62 (5)	182.62 (5)
184 (2)	185.718 (11)	185.712 (10)	185.72 (2)	185.65 (5)	185.722 (4)	185.715 (5)	185.720 (4)	185.720 (4)
196 (4)	194.941 (9)	194.938 (10)	194.94 (2)	194.95 (5)		194.94 (1)	194.940 (6)	194.940 (6)
	198.91 (15)	198.898 (15)	198.88 (6)	198.75 (10)		198.90 (2)	198.894 (14)	198.894 (14)
				199.6 (1)				199.6 (1)$^{\times}$
	202.133 (14)	202.105 (12)	202.12 (2)	202.05 (5)		202.11 (2)	202.12 (1)	202.12 (1)
	205.311 (12)	205.312 (10)	205.31 (2)	205.25 (5)	205.318 (4)	205.311 (10)	205.316 (4)	205.316 (4)
		215.26 (20)	215.28 (5)	215.3 (1)			215.28 (4)	215.28 (4)
	221.375 (40)	221.397 (25)	221.38 (2)	221.40 (5)		221.38 (2)	221.386 (14)	221.386 (14)
			228.78 (5)	228.7 (1)			228.76 (5)	228.76 (5)
	233.53 (4)	233.49 (3)	233.50 (3)	233.55 (10)		233.50 (3)	233.50 (2)	233.50 (2)
	240.93 (4)	240.95 (4)	240.87 (3)	240.75 (5)		240.87 (3)	240.88 (4)	240.88 (4)
	246.83 (4)	246.59 (10)	246.84 (2)	246.85 (5)		246.84 (4)	246.83 (2)	246. (83 (2)
				251.5 (1)				251.5 (1)$^{\times}$
	266.44 (8)	266.40 (10)	266.50 (5)				266.47 (4)	266.47 (4)
		275.35 (15)						275.35 (15)
			275.24 (20)	275.50 (5)			275.49 (6)	275.49 (6)
				279.50 (5)				279.50 (5)$^{\times}$
			281.42 (5)					281.42 (5)
285 (5)			282.92 (5)	283.0 (1)			282.94 (5)	282.94 (5)
			289.56 (4)					289.56 (4)
			291.2					291.2
		291.58 (15)	291.65 (3)	291.65 (5)			291.65 (3)	291.65 (3)
				294.3 (1)				294.3 (1)$^{\times}$
			301.7 (1)					301.7 (1)
			310.69 (6)					310.69 (6)
			317.10 (8)					317.10 (8)

1966Ga03	1971Cl03	1974Te03	1975Va11	1977Ba72	1984He12	1986LoZT	LWM	Recommended
				325.8 (1)				325.8 (1)
			343.5 (2)					343.5 (2)
				345.4 (1)				345.4 (1)$^{\times}$
		345.84 (15)	345.93 (3)	345.90 (5)			345.92 (3)	345.92 (3)
350 (5)								350 (5)
			356.03 (5)					356.03 (5)
				368.5 (1) ?				368.5 (1) ?
				371.8 (1)				371.8 (1)$^{\times}$
		387.79 (15)	387.84 (3)	387.85 (10)			387.84 (3)	387.84 (3)
		390.27 (20)						390.27 (20)
			410.29 (4)					410.29 (4)
430 (5)				~ 433.0 (5)				433.0 (5)
			448.40 (6)					448.40 (6)
			455.1 (1)					455.1 (1)$^{\times}$
			517.9 (2)					517.9 (2)$^{\times}$
			742.5 (2)					742.5 (2)$^{\times}$
			794.7 (1)					794.7 (1)$^{\times}$

×: Not placed in level scheme. a: From 1986LoZT.

Table 6 Measured and recommended absolute γ-ray emission probabilities for ^{235}U (%)

E_γ(keV)	1966Ga03 a	1971Cl03 a	1971KrZH a	1974Te03 a	1975Va11 a	1977Ba72 a	1982va04	1983Bazz	1983Ol01	1984He12	1986LoZT	1992Li05	1996Ru11 a	LWM	Adopted *
19.55															60 (1)[#$]
31.60				0.017 (6		0.046									0.017 (6)
34.7[×]						0.037									0.037
41.4				0.029 (11)											0.029 (11)
42.01			0.053	0.04 (2)	0.0169	0.063		0.06 (1)			0.06 (1)			0.056 (9)	0.056 (9)
51.21				0.004 (2)[b]	0.034 (7)	0.017									0.034 (7)
54.1						0.03 ?									≈ 0.00115[#]
54.25						0.03 ?									≈ 0.0285[#]
64.45						0.018									0.018
72.7					0.116										0.116
73.72						0.01									0.01
74.94		0.0012 (1)[b]	0.137	0.051 (6)	0.074			0.51 (5)[b]			0.06 (1)				0.051 (6)
95.7															
96.09				0.091 (11)											0.091 (11)
97	< 1														0.016 (4)[#]
109.19	5.1	1.60 (12)	1.59 (21)	1.77 (17)	1.48 (21)	1.03		1.53 (5)			1.54 (5)	2.17 (17)	1.80 (6	1.66 (13)	1.66 (13)
115.45	< 1	0.14 (1)[b]	0.12 (3)[b]		0.033 (12)	0.017									0.03 (1)
120.35						0.026									0.026
136.55						0.012									0.012
140.76		0.183 (13)	0.18 (2)	0.26 (3)	0.22 (3)	0.171		0.214 (15)			0.22 (2)			0.200 (12)	0.20 (1)
142.40						0.0051									0.0051
143.767	11.7	10.3 (8)	10.3 (6)	11.2 (11)	11.1 (12)	9.92	10.9 (2	10.7 (2)	10.93 (15)	11.01 (8)	10.96 (8)	10.99 (61)	10.9 (2)	10.94 (6)	10.94 (6)
147															
150.936	< 1	0.114 (9)	0.116 (32)	0.080 (11)	0.080 (11)	0.074		0.066 (10)			0.08 (1)			0.088 (26)	0.09 (3)
163.356		4.9 (4)	4.9 (3)	4.99 (51)	5.1 (5)	4.16	5.0 (1)	4.97 (10)	5.07 (8)	5.12 (4)	5.08 (4)	4.98 (12)	5.08 (5)	5.076 (26)	5.08 (3)

E_γ(keV)	1966Ga03[a]	1971Cl03[a]	1971KrZH[a]	1974Te03[a]	1975Va11[a]	1977Ba72[a]	1982va04	1983Bazz	1983Ol01	1984He12	1986LoZT	1992Li05	1996Ru11[a]	LWM	Adopted[*]
173			0.016		0.006 (5)										0.006 (5)
182.1															
182.62		0.43 (3)	0.42 (4)	0.42 (14)	0.44 (10)	0.312		0.339 (17)			0.34 (2)	0.803 (103)	0.43 (5)	0.39 (5)	0.39 (5)
185.720							57.5 (9)	57.3 (6)	56.1 (8)	57.2 (5)	57.2 (2)	56.8 (13)		57.0 (3)	57.0 (3)
194.940	4.7	0.69 (5)	0.69 (6)	0.61 (9)	0.62 (6)	0.67		0.626 (13)			0.63 (1)	0.618 (48)	0.61 (2)	0.626 (10)	0.63 (1)
198.894		0.032 (3)	0.032	0.046 (6)	0.033 (5)	0.097 ?		0.047 (6)			0.42 (6)			0.036 (2)	0.036 (2)
199.6[×]						0.097 ?									~ 0.06[&]
202.12		1.06 (8)	1.1 (5)	1.07 (11)	1.07 (11)	1.25		1.08 (2)			1.08 (2)	1.16 (7)	1.06 (4)	1.080 (17)	1.08 (2)
205.316		5.3 (4)	5.18 (32)	4.9 (4)	5.0 (5)	5.51	5.0 (2)	5.05 (5)	5.03 (9)	4.96 (5)	5.01 (5)	4.98 (14)	5.03 (5)	5.015 (26)	5.02 (3)
215.28			0.42	0.029 (6)	0.029 (3)	0.025								0.029 (3)	0.029 (3)
221.386		0.126 (9)	0.08	0.12 (3)	0.116 (11)	0.125		0.114 (6)			0.12 (1)			0.118 (5)	0.118 (5)
228.76			0.0085		0.0074	0.0011									0.0074
233.50		0.042 (3)	0.021	0.034 (11)	0.032			0.029 (5)			0.029 (5)			0.038 (4)	0.038 (4)
240.88		0.074 (6)	0.0032	0.063 (17)	0.085	0.089		0.076 (6)			0.075 (6)			0.074 (4)	0.074 (4)
246.83		0.063 (5)	0.021	0.046 (17)	0.085	0.067 ?		0.053 (3)			0.053 (3)			0.055 (3)	0.055 (3)
251.5[×]						0.067 ?									~ 0.012[^]
266.47		0.0080 (6)	0.0053	0.0063 (17)	0.0095									0.0078 (6)	0.0078 (6)
275.35				0.051 (6)											0.051 (6)
275.49			0.042		0.032	0.114									0.032
279.5[×]						0.264									0.264
281.42					0.0063										0.0063
282.94	0.001		0.0032		0.0063	0.004									0.0063
289.56					0.0074										0.0074
291.2															
291.65			0.021	0.040 (6)	0.032	0.095									0.040 (6)
294.3[×]						0.033									0.033
301.7					0.0053										0.0053

E_γ(keV)	1966Ga03 [a]	1971Cl03 [a]	1971KrZH [a]	1974Te03 [a]	1975Va11 [a]	1977Ba72 [a]	1982va04	1983Bazz	1983Ol01	1984He12	1986LoZT	1992Li05	1996Ru11 [a]	LWM	Adopted *
310.69			0.0017		0.0053										0.0053
317.10					0.0011										0.0011
325.8						0.004									0.004
343.5					0.0032										0.0032
345.4$^{\times}$						0.072 ?									~ 0.03^{+}
345.92			0.0017	0.040 (6)	0.074	0.072 ?									0.040 (6)
350	0.006														0.006
356.03					0.0053										0.0053
371.8$^{\times}$						0.069 ?									
387.84				0.040 (6)	0.0085	0.159									0.040 (6)
390.27				0.040 (1)											0.040 (1)
410.29					0.0032										0.0032
433.0	0.001					0.004									0.004
448.40					0.0011										0.0011
455.1$^{\times}$					0.0085										0.0085
517.9$^{\times}$					0.00042										0.00042
742.5$^{\times}$					0.00042										0.00042
794.7$^{\times}$					0.00063										0.00063

×: Not placed in level scheme. #: From intensity balance. $: I(γ+ce).

&: From P_γ(198.9 + 199.6) = 0.097.

^: From P_γ(246.8 + 251.5) = 0.067.

+: From P_γ(345.4 + 345.9) = 0.072.

*: Deduced using the LWM statistical method, unless otherwise specified.

a: The P_γ values have been deduced from the measured relative intensities and normalized to P_γ= 57.1 ± 0.3 for the 185.7 keV reference line.

b: This value, which deviates by a factor of about 10 from the results of the other measurements, was not used in the calculation of the recommended value.

6. References

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^{236}U – Comments on Evaluation of Decay Data by A. Luca

This evaluation was completed in April 2008. The literature available by February 2008 was included.

1. Evaluation Procedures

The Limitation of Relative Statistical Weight (LWM) (1988WoZO) method was applied for averaging numbers throughout this evaluation; this method was implemented by using the computer code LWEIGHT, ver. 4 (designed for Excel, MS Office), [1] [2]. The uncertainty assigned to an average value in this evaluation is never lower than the lowest uncertainty of any of the experimental input values.

2. Decay Scheme

^{236}U decays 100 % by alpha-particle emissions, mainly to the ground state and to the 49 keV excited level of ^{232}Th. ^{236}U decays also by spontaneous nuclear fission, with a weak branch (about 9 10^{-8} %). According to Tretyakova et al. (1994Tr12), a very weak cluster decay of ^{236}U (~10^{-13} probability relative to the alpha emission), consisting of Ne and Mg emission, was observed. The spin, parity, energy and half-life of the ^{232}Th excited levels, and the multipolarities of the γ-ray transitions have been adopted from the A=232 ENSDF mass-chain evaluation of E. Browne (2006Br19).

3. Nuclear Data

The adopted alpha-decay energy value $Q(\alpha) = 4573.1\ (9)$ keV, is from 2003Au03. This value is in agreement with the effective $Q(\alpha)$ value of 4570 keV (with an uncertainty of 260 keV), calculated from the decay scheme data, by using the SAISINUC software. This agreement proves the consistency and correctness of the decay scheme.

3.1. Half-life

The measured half-life ($T_{1/2}$) values, with the reviewed uncertainties (1989Ho24), are shown below in Table 1. After a new critical review (based on the most precise modern activity measurements by using the defined solid angle α-particle counting method, according to the Bureau International des Poids et Mesures (BIPM), Key Comparison Database, section "Calibration and Measurement Capabilities" (CMCs) - Ionizing Radiation, http://kcdb.bipm.org/AppendixC/), the uncertainty of the most recent half-life value (1972Fl03) was increased from about 0.06 % to 0.25 %; accordingly, the half-life was rounded from 2.3415 10^7 to 2.342 10^7 years. The set of data is consistent and the recommended value, 2.343 10^7 years, with the uncertainty of 0.006 10^7 years, is the weighted average (LWM, χ^2_ν=0.72) of the three input values. The references are expressed as NSR (Nuclear Science References) type keynumbers:

Table 1

$T_{1/2}$ (10^7 years)	Uncertainty of $T_{1/2}$ (10^7 years)	Reference
2.46	0.14	1951Ja09
2.391	0.057	1952Fl20
2.3415	0.0039	1972Fl03

The measured half-life ($T_{1/2}$) values for the ^{236}U spontaneous fission are presented below in Table2:

Table 2

$T_{1/2\ sf}$ (10^{16} years)	Uncertainty of $T_{1/2\ sf}$ (10^{16} years)	Reference
2.0	1.6	Jaffey and Hirsch, 1949 [3]
2.7	0.3	1971Co35
2.43	0.13	1981Vo02
2.7	0.4	1983Be66

The value mentioned in ref. [3] was unpublished, but it is cited in E.K. Hyde, 1964 [4]. This data set is consistent, and the recommended value, 2.49 10^{16} years, with the uncertainty of 0.13 10^{16} years, is the weighted average (LWM, χ^2_ν = 0.36) of the four input values from the first column.

3.2. Alpha transitions and emissions

In the literature, only one reference about measurements of energy and emission probability for ^{236}U alpha transitions was found: 1960Ko04. In another reference (1992It01), the measured energy of the main alpha-particle emission (4.49 MeV) was reported.
For this evaluation, the energies and the intensities of α_0 and α_{49} are from 1960Ko04. The energy of α_{162} is also from 1960Ko04, but its intensity is from γ-ray transition intensity balance. The energy of α_{333} is from Q(α) = 4573.1 (9) keV and E(level) = 333.40 keV; its intensity is from γ-ray transition intensity balance (2006Br19). These values, as well as their α hindrance factors (HF) are shown in Table 3.

Table 3

E_α (keV)	Uncertainty E_α (keV)	Emission intensity (%)	α Hindrance Factor (HF)
4494	3	73.8 (40)	1.0
4445	5	26.1 (40)	1.2
4332	8	0.149 (22)	27.3
4168	-	0.000 14 (5)	1160

3.3. g- transitions: g rays and internal conversion electrons

Measurements of the two main γ-ray transition energies are presented in a paper by Schmorak *et al.*, 1972Sc01. Their uncertainties may have been somewhat underestimated for the detection system that they used. Measurements of the energies and relative intensities for the γ rays following the decay of ^{236}U were published only by Gehrke et al. (2002Ge02), as shown in Table 4.
The decay-scheme normalization condition applied for the ^{232}Th ground state, allowed the determination of the absolute emission probability for the 49.46 keV γ ray ($I_{\gamma 49}$, expressed in %):
$(\alpha^T_{49}+1) \cdot I_\gamma(49) + I_\alpha(4494) = 100$ %, where α^T_{49} = 324.4 is the theoretical internal conversion coefficient (program BrIcc v2.0a, [5]) for the 49-keV γ ray and $I_\alpha(4494)$ = 73.8 (40) %. The resulting value for the absolute emission probability of the main γ ray following the ^{236}U alpha decay, is $I_\gamma(49)$ = 0.081 (12) %. Using this value and the relative intensity values of the 112 keV and 171 keV γ-ray emissions measured by Gehrke *et al.*, the corresponding absolute emission probabilities and their uncertainties were computed and are given below in Table 4.

Table 4:

E_γ (keV)	Uncertainty E_γ (keV)	Relative Emission probability (%)	Absolute Emission probability (%)	Total ICC (α_T)
49.46	0.10	100	0.081 (12)	324
112.79	0.10	24.1 (1)	0.019 5 (31)	6.67
171.15	0.20	0.080 (24)	0.000 065 (22)	1.186

4. Atomic data

The K-shell fluorescence yield (ω_K), the mean L-shell fluorescence yield ($\bar{\nu}_L$) and the mean number of vacancies in the L-shell produced by one vacancy in the K-shell (η_{KL}) were determined using the computer program EMISSION v3.10, 28-Jan-2003 [6]: 0.969 (4), 0.476 (18) and 0.797 (5) respectively.

4.1. Auger electrons and X-rays

The relative probability values of the K Auger electron emissions (KLL, KLX, KXY) normalized to the KLL value, were computed using the same EMISSION computer program. The total K Auger electron emission probability (absolute) and the emission probability of the L Auger electrons were also calculated. The energy ranges for K and L Auger electrons were filled-in by the SAISINUC program [7].
The relative probability (normalized to $K_{\alpha 1}$ X-rays emission) and the absolute emission probability values of the different groups of K and L X-rays were determined using the same EMISSION program. The energy range values of the K and L X-rays are from the tables linked to SAISINUC. The results for absolute emission probabilities of LX rays (I(LX) = 9.4 (10) %) agrees with I(LX) = 9.4 (13) % given in the Table of Radioactive Isotopes [8]. The KX ray emission probabilities are so weak that are not given in reference [8].
Neither measurements of X-ray energies nor of emission probabilities were found in the literature.

5. Main production mode

The main production mode of ^{236}U is by irradiating ^{235}U nuclei with thermal neutrons in nuclear reactors; the ^{236}U is produced by thermal neutron captures: $^{235}U(n,\gamma)^{236}U$. The neutron-capture cross section is 98.3 (8) barn [9].

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^{237}U - Comments on evaluation of decay data by V.P. Chechev and N.K. Kuzmenko

This evaluation was done originally in September 2005 and then revised in April 2009 with a literature cut-off by the same date.

1 Decay Scheme

The decay scheme is based on 2006Ba41.

2 Nuclear Data

Q^- value is from 2003Au03.

The recommended half-life of ^{237}U is based on the experimental results given in Table 1.

Table 1. Experimental values of the ^{237}U half-life (in days)

Reference	Author(s)	Value
1949Me43	Melander and Slatis	6,63 (5)
1953Wa05	Huizenga and Flynn	6,75 (1)
1958Ca16	Cabell et al.	6,752 (2)

The weighted mean of the 3 values from the Table 1 of 6,752 (2) is dominated by the very accurate value of 1958Ca16. The EV1NEW computer program, which uses the limitation of relative statistical weights by 0,5 (LRSW method), increased the 1958Ca16 uncertainty from 0,002 to 0,0098 and gave 6,749 (16).

Therefore, the recommended value of ^{237}U half-life is 6,749 (16) days.

2.1 Beta Transitions

The energies of β^- transitions have been obtained from the Q^- value and the level energies given in Table 2 from 2006Ba41.

Table 2. ^{237}Np levels populated in ^{237}U β^- decay

Level	Energy, keV	Spin and Parity	Half-life	Probability of β^- transitions (×100)
0	0,0	$5/2^+$	2,144 (7)×10^6 a	-
1	33,19629 (22)	$7/2^+$	54 (24) ps	-
2	59,54092 (10)	$5/2^-$	67 (2) ns	6,7 (42)
3	75,899 (5)	$9/2^+$	≈ 28 ps	-
4	102,959 (3)	$7/2^-$	80 (40) ps	-
5	267,556 (12)	$3/2^-$	5,2 (2) ns	40,9 (31)
6	281,356 (18)	$1/2^-$	-	48,2 (25)
7	332,376 (16)	$1/2^+$	≤ 1,0 ns	2,9 (9)
8	368,602 (20)	$5/2^+$	-	-
9	370,928 (23)	$3/2^+$	-	1,3 (9)

The probabilities of β^- transitions have been deduced from the P(γ+ ce) balance at each level of ^{237}Np.

The 459,1 keV $\beta^-_{0,2}$ transition probability of 7 (4) % has been obtained using the relation of 100-Σ $P_i(\beta^-)$. The value deduced from the P(γ+ ce) balance is 7 (6) %.

Some experimental estimations of the β^- transition energies and probabilities are given in 1949Me43, 1953Wa05 and 1957Ra04. More precise measurements would prove beneficial.

2.2 Gamma-ray Transitions and Internal Conversion Coefficients

The recommended energies of the gamma-ray transitions are mainly the same as the gamma-ray energies because nuclear recoil is negligible for ^{237}Np.

The gamma-ray transition probabilities have been obtained from the gamma-ray emission probabilities and the total internal conversion coefficients (ICCs). Multipolarities of gamma-ray transitions have been taken from 2006Ba41. The ICCs have been interpolated using the BRICC package with the so called "*Frozen Orbital*" approximation (2008Ki07). The relative uncertainties of the ICC for pure multipolarities have been taken as 2 %.

The ICC for the intense E1 anomalously converted gamma-ray-transitions $\gamma_{2,1}$ (26,3- keV) and $\gamma_{2,0}$ (59,5- keV) have been obtained from a joint analysis of the gamma-ray and L-, M- conversion electron probabilities measured in ^{241}Am α decay and ^{237}U β^- decay (1996Jo28, 2006Ba41). The experimental conversion electron data are given in 1959Sa10, 1964Wo03, 1966Ko06, 1966Le13, 1966Ya05, and 1998Ko61. For discussion of E1 anomalously converted gamma transitions see 1960As02, 1966Ya05, 1967Pa23, 1970Gr36, and 1996Jo28.

The E2/M1 mixing ratio of 16,6 (25) % for $\gamma_{4,2}$(43,4-keV) has been obtained by averaging the four measurement results from 1964Wo03 (17,6 (19) %), 1966Ko06 (13 (2) %), 1966Ya05 (11 (4) %), and 1998Ko61 (21,2 (22) %).

The E2/M1 mixing ratio of 15 (8) % for $\gamma_{9,7}$ (38,5- keV) has been deduced using the ratio P_{ce} (L_2; $\gamma_{9,7}$) / P_{ce} (M_3; $\gamma_{9,7}$) = 10 (5) from 1966Ya05 and the theoretical values from the BRICC package. $P_{\gamma+ce}$ ($\gamma_{9,8}$ 2,3-keV) has been deduced assuming that there is no β^- feeding to the 368,59-keV level.

$P_{\gamma+ce}$ ($\gamma_{3,1}$ 42,7-keV) and $P_{\gamma+ce}$ ($\gamma_{3,0}$ 75,8-keV) have been deduced from $P\gamma_{3,0}/P\gamma_{3,1}$ = 3/28 (see 2006Ba41) assuming that there is no β^- feeding to the 75,92-keV level.

The gamma-ray transitions with energies 114,09 keV and 340,45 keV have not been placed in the level scheme.

3 Atomic Data

The atomic data are from Schönfeld and Janβen (1996Sc06).

4 Electron Emissions

The energies of the conversion electrons have been obtained from the gamma-ray transition energies and the electron binding energies.

The absolute emission probabilities of the conversion electrons have been calculated using recommended P_γ and ICC values.
The total absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program.

β^- average energies have been calculated using the LOGFT computer program.

5. Photon Emissions

5.1 X-ray Emissions

The absolute emission probabilities of U KX and LX-rays have been calculated using the EMISSION computer program.

In Table 3 the calculated values are compared to the experimental data. The uncertainty in the detector efficiency (2 %) was added to the uncertainties listed in 1976GuZN.

Table 3. Experimental and recommended Np KX - ray emission probabilities in decay of ^{237}U

	Energy (keV)	1966Ya05	1976GuZN	Recommended (calculated)
$K\alpha_2$	97,069	16,2 (17)	15,8 (7)	14,8 (4)
$K\alpha_1$	101,059	22,6 (24)	25,2 (9)	23,5 (6)
$K'\beta_1$	113,944	9,8 (10)	9,22 (32)	8,57 (27)
$K'\beta_2$	117,463	3,1 (4)	2,3 (5)	2,95 (10)

5.2 Gamma-rays emissions

The energies of gamma rays $\gamma_{2,1}$ (26,3-keV) and $\gamma_{2,0}$ (59,5-keV) are from 2000He14. $E\gamma_{1,0}$ (33,2 keV) has been calculated as the difference $E\gamma_{2,0}$ - $E\gamma_{2,1}$. The energies of gamma rays $\gamma_{4,3}$, $\gamma_{3,1}$, $\gamma_{4,2}$ have been taken from 1998Ko61. The rest gamma-ray energies have been adopted from 2006Ba41 based on experimental data of 1996Ya05, and 1976GuZN. Other measurements: 1957Ra04, 1963Ak04, 1968Da24, 1971Cl03. The uncertainty in the detector efficiency (2 %) was added to the uncertainties listed in 1976GuZN.

In Table 4 the experimental and evaluated absolute gamma ray emission probabilities ($P\gamma$) are presented.

Table 4. Experimental and evaluated absolute gamma-ray emission probabilities (%) in decay of ^{237}U.

$E\gamma$, keV	1966Ya05	1971Cl03	1976GuZN	1982BuZF	1984BaYS	1985He02	1985Wi04	Evaluated
51,01	0,21 (10)		0,340 (14)		0,44 (6)			0,340 (14)
59,54	32,9 (40)	32,8 (25)	34,5 (8)		33,8 (9)			34,1 (9)
64,83	1,15 (16)	1,19 (9)	1,30 (3)		1,31 (5)		1,282 (17)	1,286 (17)
164,61	1,80 (9)	1,82 (14)	1,84 (5)		1,85 (5)	1,865 (23)	1,853 (23)	1,855 (23)
208,00			21,7 (5)	21,5 (14)		21,2 (3)	21,2 (3)	21,28 (30)
221,80	0,0199 (18)	0,0182 (14)	0,0212 (8)		0,0199 (25)			0,0204 (8)
234,40	0,0190 (18)	0,0273 (20)	0,0205 (8)		0,0224 (40)			0,0205 (8)
267,54	0,698 (30)	0,755 (20)	0,740 (18)		0,723 (25)	0,714 (22)	0,711 (10)	0,721 (10)
332,36	1,18 (8)	1,19 (9)	1,21 (3)		1,18 (4)		1,200 (16)	1,199 (16)
335,38	0,094 (9)	0,109 (9)	0,097 (3)		0,092 (5)		0,0951 (22)	0,0958 (22)
368,59	0,045 (4)	0,044 (3)	0,043 (2)		0,042 (3)		0,0392 (17)	0,0416 (17)
370,94	0,109 (9)	0,125 (10)	0,110 (4)		0,109 (6)		0,1073 (17)	0,109 (2)

The measurement results for gamma ray emission probabilities given in 1976GuZN, 1982BuZF, 1985He02, 1985Wi04 are absolute. The measurements results given in 1966Ya05, 1971Cl03, 1984BaYS are relative. The latter ones have been renormalized by evaluators at $P\gamma$(208 keV) = 21,3 (3) %.

$P\gamma_{6,5}$ has been deduced from Pce(M1) = 29,9 (3) %, as measured by 1966Ya05, and ICC α_{M1} = 281 (9).

$P\gamma_{4,1}$ has been deduced from $P\gamma_{4,1}$/ $P\gamma_{4,2}$ = 2,9 (4) / 73 (8), as measured in ^{241}Am α-decay (see 2006Ba41).

$P\gamma_{4,0}$ has been deduced from $P\gamma_{4,0}$/ $P\gamma_{4,2}$ = 19,5 (1) / 73 (8), as measured in ^{241}Am α-decay (see 2006Ba41).

$P\gamma_{8,2}$ has been deduced from $P\gamma_{8,2}$/ $P\gamma_{8,1}$ = 10,14 / 49,6 as measured in ^{241}Am α-decay (see 2006Ba41).

$P\gamma_{8,3}$ has been deduced from $P\gamma_{8,3}$/ $P\gamma_{5,2}$ = 0,000 12 (3), as measured by 1966Ya05.

$P\gamma_{9,7}$ has been deduced by evaluators from the ratio P_{ce} (L_2; $\gamma_{9,7}$) / P_{ce} (K; $\gamma_{5,2}$) = 0,0056 (20) from 1966Ya05 and total ICC's.

Pγ (340,4-keV) has been adopted from 1976GuZN.

6. Consistency of Recommended Data

The most accurate Q value, Q(M), is taken from the atomic mass adjustment table of Audi et al. (2003Au03). Comparison of Q(eff)(deduced as the sum of average energies per disintegration ($\sum E_i \times P_i$) for all emissions accompanying ^{237}U β^- decay) with the tabulated decay energy Q(M) allows to check a consistency of the recommended decay-scheme parameters obtained in this evaluation.

Here E_i and P_i are the evaluated energies and emission probabilities of the i-th alpha particle, beta particle, gamma ray, X-ray, etc. Consistency (percentage deviation) is determined by {[Q(M)– Q(eff))]/ Q(M)} × 100. "Percentage deviations above 5 % would be regarded as high and imply a poorly defined decay scheme; a value of less than 5 % indicates the construction of a reasonably consistent decay scheme" (quoted from the article by A.L. Nichols in Appl. Rad. Isotopes 55 (2001) 23-70).

For the above ^{237}U decay data evaluation we have Q(M) = 518,6(6) keV and Q(eff) = 519(23) keV, i.e. consistency is not worse than 4,4 %.

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^{238}U - Comments on evaluation of decay data by V. Chisté and M.M. Bé

This evaluation was completed in January 2006, and the literature available at this date has been included here.

1 Decay Scheme

^{238}U disintegrates by alpha emission to two excited levels and to the ground state of ^{234}Th. Spin and half-lives of excited states are from the mass-chain evaluation of Y.A. Akovali (1983El11 and 1994Ak05 for A = 234) and F.E. Chukreev (2002Ch52 for A = 238).

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).

Experimental ^{238}U half-life values (in years x 10^9) are given in Table 1:

Table 1: Experimental values of ^{238}U half-life.

Reference	Original value (10^9 a)	Revised Value by Schön (2004Sc03)	Comments
Kovarik (1932Ko02)	4.52		**Not used**. Natural U.
Schiedt (1935Schiedt)	4.42 (3)	4.46 (3) **(a)** 4.41 (5) **(b)**	**Not used**. Natural U. Corrected for ^{235}U. **(a)** ^{234}U and ^{238}U assumed to be in equilibrium. **(b)** ^{234}U and ^{238}U assumed to be not in equilibrium.
Curtis (1941Curtis)	4.514 (9)		**Not used**. Natural U. Lacking details.
Kienberger (1949Ki26)	4.490 (10)	4.495 (18)	**Not used**. Enriched U.
Kovarik (1955Ko13)	4.507 (9)	4.51 (2) **(a)** 4.46 (5) **(b)**	**Not used**. Natural U. **(a)** ^{234}U and ^{238}U assumed to be in equilibrium. **(b)** ^{234}U and ^{238}U assumed to be not in equilibrium.
Lechman (1957Le21)	4.56 (3)		**Not used**. Enriched U.
Steyn (1959St45)	4.460 (10)	4.457 (4) **(a)** 4.41 (4) **(b)**	**Not used**. Natural U. **(a)** ^{234}U and ^{238}U assumed to be in equilibrium. **(b)** ^{234}U and ^{238}U assumed to be not in equilibrium.
Jaffey (1971Ja07)	4.4683 (24)	4.468 (5)	Highly enriched U.
Recommended value		**4.468 (5)**	

The evaluators have chosen to follow the recommendations given by R. Schön (2004Sc03), who studied in detail various problems with the measurements of the half-life of ^{238}U. So, the recommended value is the half-life obtained by Jaffey (1971Ja07), but its original uncertainty was multiplied by 2 (as suggested by Schön (2004Sc03)) in order to take into account the systematic uncertainties which were not considered by 1971Ja07.

Experimental ^{234}Th half-life values (in days) are given in Table 2:

Table 2: Experimental values of ^{234}Th half-life.

Reference	Value (d)	Uncertainty (d)
M. Curie (1931Cu01)	24.5	
B.W. Sargent (1939Sa11)	24.1	0.2
G.B. Knight (1948Kn23)	24.101	0.025
Recommended value is (from 1994Ak05)	24.10	0.03

The recommended value is *24.10 d* with an uncertainty of *0.03 d*, from Y. A. Akovali (1994Ak05).

The evaluated spontaneous fission partial half-life of ^{238}U is based on the experimental results given in Table 3.

Table 3: Experimental values of spontaneous fission decay rate of ^{238}U (λ^{238}, in 10^{-17} years^{-1}).

Reference	Value	Uncertainty	Comments by Holden (2000Ho27)
W.J. Withehouse (1950Whitehouse)	8.38	0.52	Ionization chamber.
E. Sègres (1952Se67)	8.60	0.29	Ionization chamber.
R.L. Fleischer (1964Fl07)	6.85	0.20	**Not used.** Mica-uranium sandwich.
A. Spadavecchia (1967Sp12)	8.42	0.10	Rotating bubble chamber.
J.H. Roberts (1968Ro15)	7.03	0.11	**Not used.** Mica-uranium sandwich.
H.R. von Gunten (1969Vo24)	8.66	0.22	Fission products of ^{238}U.
D. Galliker (1970Ga27)	8.46	0.06	Rotating bubble chamber.
D. Storzer (1970Storzer)	8.49	0.76	Fission tracks in dated uranium glass.
J.D. Kleeman (1971Kl14)	6.8	0.6	**Not used.** Lexam-uranium sandwich.
W.M. Thury (1971Th17)	8.66	0.43	Third order coincidence.
M.P.T. Leme (1971Le11)	7.30	0.16	**Not used.** Mica-uranium sandwich.
H.A. Khan (1973Kh10)	6.82	0.55	**Not used.** Mica-uranium sandwich.
K.N. Ivanov (1974Iv04)	7.12	0.32	**Not used.** Mica-uranium sandwich.
V. Emma (1975Em03)	7.2	0.2	**Not used.** Mica-uranium sandwich.
G.A. Wagner (1975Wa37)	8.7	0.6	Fission tracks in dated uranium glass.
K. Thiel (1976Th12)	8.57	0.42	Fission tracks in dated uranium glass.
M. Kase (1978Ka40)	8.22	0.20	Ionization chamber.
A.G. Popeko (1980Po09)	7.9	0.4	Multiple neutron coincidence.
E.R.V. Spaggiari (1980Sp10)	9.26	0.17	**Not used.** Mica-uranium sandwich.
Z.N.R. Baptista (1981Ba70)	6.6	0.2	**Not used.** Mica-uranium sandwich.
J.C. Hadler (1981Hadler)	8.6	0.4	**Not used.** Mica-uranium sandwich.
H.G. de Carvalho (1982De22)	11.8	0.7	**Not used.** Fission tracks in ordinary glass.
S.N. Belenky (1983Be66)	8.35	0.40	Multiple neutron coincidence.
B. Vartanian (1984Va34)	8.23	0.43	**Not used.** Fissions tracks (plastic, uranium foils).
M.P. Ivanov (1985Iv01)	8.29	0.27	Double ionization chamber.
S.S. Liu(1991Liu)	7.03	0.21	**Not used.** Solid-state track detectors.
Recommended value of λ^{238} (in 10^{-17} years^{-1})	**8.451**	**0.060**	reduced χ^2 = 0.30
Recommended half-life value (in 10^{15} years)	**8.202**	**0.060**	

The evaluators, following the recommendations of N.E. Holden (2000Ho27), have not used in their calculations the measurements with fission tracks in mica-uranium, lexan-uranium sandwiches or ordinary glass, because they significantly disagree with the rest (for more details see 2000Ho27). Thus the experimental values with associated uncertainties used in the weighted average calculation are those from 1950Whitehouse, 1952Se67, 1967Sp12, 1969Vo24, 1970Ga27, 1970Storzer, 1971Th17, 1975Wa37, 1976Th12, 1978Ka40, 1980Po09, 1983Be66 and 1985Iv01. A weighted average has been calculated using LWEIGHT computer program (version 3). Based on the Chauvenet's criterion, Popeko's value (1980Po09) has been shown to be an outlier.

The recommended value of λ^{238} is the weighted average (calculated with LWEIGHT computer program) of $8.451\ 10^{-17}\ a^{-1}$ with an internal uncertainty of $0.046\ 10^{-17}\ a^{-1}$. However, evaluators have adopted an uncertainty of $0.060\ 10^{-17}\ a^{-1}$, minimum input value.

Using this value of λ^{238} and the formula:

$$t_{1/2} = \frac{\ln(2)}{\lambda^{238}},$$

the evaluators have deduced a partial spontaneous fission half-life of *8.202 (60)* 10^{15} *a* for ^{238}U and a spontaneous fission branching of 5.45 (4) 10^{-5} %.

2.1 α Transitions and Emissions.

The energies of the α-particle transitions given in Section 2.1 have been calculated from Q_α (2003Au03) and level energies.

The energies of $\alpha_{0,0}$, $\alpha_{0,1}$ and $\alpha_{0,2}$ emissions given in Section 4 are from A. Rytz (1991Ri01).

Measured α-emission intensities are given in Table 4.

Table 4: Measured α-emission intensities, in %.

Energy (keV)	1959Ko58	2000Ga05	Recommended Value
4198 ($\alpha_{0,0}$)	77 (4)	77.54 (50)	77.54 (50)
4151 ($\alpha_{0,1}$)	23 (4)	22.33 (50)	22.33 (50)
4038 ($\alpha_{0,2}$)	0.23 (7)	0.13 (3)	0.13 (3)

The results of these two intensity measurements (1959Ko58 and 2000Ga05) are consistent with each other. Evaluators have adopted the most recent and precise results of Garcia-Toraño (2000Ga05).

2.2 γ Transitions

The γ-ray probabilities of the 49- and 113-keV transitions have been deduced from decay-scheme balance by using the recommended experimental alpha emission intensity values (2000Ga05). (see **2.1 α Transitions and Emissions**).

Multipolarities of γ-ray transitions in the decay of ^{234}Th are from 1994Ak05:
49-keV γ-ray : E2
113-keV γ-ray: [E2]

The internal conversion coefficients (ICC's) have been calculated using the Icc99v3a computer program (GETICC dialog), which uses the new tables of Band et al (2002Ba85) (results of calculation for "hole" and "no hole" are the same). The evaluators have used a fractional uncertainty of 3 % for all conversion coefficients.

3 Atomic Data

Values of atomic values quantities ω_K, ϖ_L and n_{KL}, are from Schönfeld and Janβen (1996Sc06).

3.1 X rays and Auger electrons

The relative probabilities of X-ray and Auger electrons have been calculated from γ-ray data using the EMISSION computer program.

4 α Emissions

See **2.1 α Transitions and Emissions.**

5 Electron emissions

The Auger electrons emission probabilities have been calculated from γ-ray data using the EMISSION computer program.

6 Photon Emissions

6.1 K x-rays

X-ray emission probabilities have been calculated from γ-ray data using the EMISSION computer program.

6.2 γ-ray emissions

The energies of the γ-ray emissions given in Section 6 are from Y.A. Akovali (1994Ak05).

The absolute γ-ray emission intensities have been deduced from the absolute γ-ray transition probabilities and the internal conversion coefficients (ICC's). (see **2.2 γ Transitions.**).

Table 5 shows the recommended absolute γ-ray (photon) emission intensities of the 49- and 113-keV emissions as well as the experimental results obtained from direct measurements of emission intensities.

The agreement is not good, maybe due to experimental difficulties (many peaks of different contaminant isotopes in this energy region) when measuring these weak γ-ray intensities.

Table 5: Experimental absolute γ emission intensity in %.

γ Energy (keV)	1984Ro21	1990Ko40	1996Ru11	Recommended value
49.55	0.064 (8)	0.059 (2)		0.0698 (26)
113.5	0.0102 (15)		0.07 (1)	0.0174 (47)

A fair agreement has been found between the results given by J-C. Roy (1984Ro21) and the evaluators' recommended value for the 49-keV γ-ray.

For the 113-keV γ-ray, there is no good agreement either between results of direct experimental measurements or between those latter and the recommended value. In this energy region the experimental difficulties are associated with presence of many small peaks from different isotopes in the γ-ray spectrum.

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^{239}U – COMMENTS ON EVALUATION OF DECAY DATA

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This evaluation was completed in October 2008 and updated in March 2009 with a literature cut-off by the same date.

1. DECAY SCHEME

Decay scheme is based on 2003Br12. Most (99 %) of ^{239}U beta decay feeds the well-studied ^{239}Np levels below 118 keV. However more than 30 excited states of ^{239}Np have been associated with weak ^{239}U beta transitions and in this part the decay scheme cannot be considered as completed.

Several unplaced gamma rays were observed in 2006Wo03. These gamma rays carry ≤ 2 % of the total intensity of all the gamma rays placed in the decay scheme.

Wong and Griffin (2006Wo03), based on the energies of many of these gamma rays, suggested different versions of their placement including alternative with respect to 2003Br12. These suggestions require an additional careful analysis. Therefore the evaluators have been accepted only small change in the decay scheme from 2003Br12 associated with moving the 1197-keV level off and adding the new 849,45-keV level.

The 1197-keV level stated in 2003Br12 has been deleted from the level scheme since the 535-, 1122- and 1197- keV gamma transitions previously reported were not observed in 2006Wo03 and attributed to possible impurities. The new (declared in 2006Wo03) 849,45-keV level de-exciting via 502-, 608-, 728-, 775- and 849- keV gamma rays has been placed to the decay scheme.

It should be noted that a number of ^{239}Np levels reported only from nuclear reactions may be populated (according to the data of 2006Wo03) in ^{239}U β^--decay.

Several gamma rays previously reported were not observed with high reliability in 2006Wo03. They were ascribed to fission product impurities in their study.

2. NUCLEAR DATA

Q^- value is from 2003Au03.

The recommended half-life of ^{239}U is based on the experimental results given in Table 1.

Table 1. Experimental values of ^{239}U half-life (in minutes)

Reference	Author(s)	Original value	Re-estimated	Measurement method
1943Mi10	Mitchell et al.	23,54 (5)		β-counting
1947Fe05	Feather and Krishnan	23,5 (7)		β- and gamma-ray counting
1969Hu21	Hunt et al.	23,40 (5)		β-counting
1989Ab05	Abzouzi et al.	23,44 (2) [a]	23,44 (11)	Gamma-ray counting
2008Griffin	Griffin	23,37 [b]	23,37 (10)	Liquid scintillation counting

[a] Uncertainty may include only statistical errors. The evaluators have taken into account the contribution of possible systematic errors (uncertainty of the Type B) associated with the gamma-ray counting method (see Comments on evaluation of ^{233}Th half-life).

[b] Author did not report the uncertainty. Possible statistical and systematic errors associated with the used LSC method were discussed in 2008De10 under the measurements of ^{233}Th half-life (22 min). The evaluators have estimated an overall relative uncertainty of ~ 0,4 % (see Comments on evaluation of ^{233}Th half-life).

The unweighted mean of the 6 values from Table 1 is 23,45 (3), the weighted mean is 23,46, the internal uncertainty is 0,032, the external uncertainty is 0,035. The LWEIGHT computer program recommended the weighted mean and its internal uncertainty. The smallest experimental uncertainty is 0,05. Therefore, the recommended value of ^{239}U half-life is 23,46 (5) minutes.

2.1. Beta Transitions

The energies of β^- transitions have been obtained from the Q^- value and the ^{239}Np level energies given in Table 2 from 2003Br12.

Table 2. ^{239}Np levels populated in ^{239}U β^--decay

Level	Energy (keV)	Spin and Parity	Half-life	
0	0,0	5/2+	2,356 (3) d	14,4 (22)
1	31,1310 (12)	7/2+		9,4 (15)
2	71,210 (2)	9/2+		
3	74,664 (1)	5/2-	1,39 (3) ns	72,8 (19)
4	117,727 (20)	7/2-	= 40 ps	2,2 (4)
5	122,5 (10)	(11/2+)		
6	173,10 (4)	9/2-		
7	241,36 (5)	(11/2-)		
8	260,799 (17)	(3/2-)		
9	438,83 (5)	(11/2+)		
10	448,178 (16)	(3/2-)		
11	452,736 (2)	(5/2+,7/2-)		
12	474,36 (6)			0,0033 (4)
13	517,998 (20)	(7/2-)		0,063 (2)
14	530,29 (6)			0,0029 (4)
15	563,89 (4)			0,0247 (7)
16	579,40 (4)	(9/2-)		
17	662,282 (17)	(5/2-)		0,261 (6)
18	695,229 (23)	(7/2-)		0,0118 (11)
19	781,93 (4)			
20	784,94 (5)			
21	819,26 (3)	(7/2)		0,228 (3)
22	844,10 (3)	(5/2,7/2)		0,215 (3)
23	849,44 (9)			0,0264 (4)
24	863,46 (6)	(3/2,5/2,7/2)		0,0005 (2)
25	959,18 (3)			0,0284 (7)
26	964,234 (20)	(7/2-)		0,211 (3)
27	966,55 (5)	(7/2,9/2-)		0,0008 (2)
28	992,158 (22)	(7/2-)		0,0262 (9)
29	1013,64 (8)			0,0074 (4)
30	1040,37 (4)	(5/2-,7/2)		0,0077 (4)
31	1049,24 (4)	(9/2-)		0,0059 (4)
32	1096,99 (3)			0,0060 (5)

The emission probabilities of β^--transitions have been deduced from the P(γ+ce) balance at each level of ^{239}Np. β^--transitions with $P(\beta) < 0,5$ % are tentative because of unplaced γ-ray transitions (see 2006Wo03).

2.2. Gamma-ray Transitions and Internal Conversion Coefficients

The recommended energies of the gamma-ray transitions are virtually the same as the gamma-ray energies because nuclear recoil is negligible for ^{239}Np.

The gamma-ray transition probabilities have been obtained from the gamma-ray emission probabilities and the total internal conversion coefficients (ICC). Multipolarities of gamma-ray transitions have been taken from 2003Br12. The ICC have been interpolated using the BrIcc package with the so called "*Frozen Orbital*" approximation (2008Ki07). The relative uncertainties of the ICC for pure multipolarities have been taken as 2 %.

P($\gamma_{2,0}$ + ce)(71,2-keV) and P($\gamma_{7,2}$ + ce)(170,2-keV) have been obtained from the level P(γ+ce) balance assuming that there is no beta-feeding to the 2- and 7- levels, respectively.

The M1/E2 mixing ratios for $\gamma_{1,0}$ - 31,1 keV (0,028), $\gamma_{4,3}$ - 43,1 keV (0,126) and $\gamma_{6,4}$ -55,2 keV (0,26) have been taken from ^{243}Am α decay (2003Br12).

The remaining gamma transition multipolarities and M1/E2 mixing ratios have been adopted from ^{239}U β^--decay (see 2003Br12) based on measurements of 1957Ho07, 1964Bl11, 1969En02.

3. ATOMIC DATA

The atomic data (fluorescence yields, X-ray energies and relative probabilities, and Auger electrons energies and relative probabilities) have been deduced by using the SAISINUC software (2002Be).

4. ELECTRON EMISSIONS

The energies of the conversion electrons have been calculated from the gamma-ray transition energies and the electron binding energies.

The absolute emission probabilities of the conversion electrons have been obtained using the recommended P_γ and ICC values.

The absolute emission probability of K Auger electrons has been deduced from the recommended ΣKX = 0,305 (10) %. The absolute emission probability of L Auger electrons has been obtained using the recommended P_γ and ICC values with the EMISSION computer program.

β^- average energies have been calculated using the LOGFT computer program.

5. PHOTON EMISSIONS

5.1. X-Ray Emissions

The recommended absolute emission probabilities of KX- rays have been obtained using the total number of K vacancies of 0,314 (10) % deduced in 2008Griffin from their KX-ray measurements.

The recommended absolute emission probabilities of LX-rays have been obtained using the recommended P_γ , ICC values and the total number of K vacancies with the EMISSION computer program. The calculated total absolute intensity of LX-rays of 16,1 (5) % can be compared with the value of 17 (4) % measured in 2008Griffin (here the author's value of 18,1 % has been corrected to the evaluated $P\gamma_{2,0}$ (74,7 keV) = 51,6 (13) % used instead of 53,9 (5) % measured in 2008Griffin). The uncertainty of the measured LX-ray intensity was not given in 2008Griffin. It has been accepted by the evaluators using the relative uncertainty of the detection efficiency for energies at and below 20 keV ~ 20 % estimated in 2008De10.

5.2. Gamma-Ray Emissions

The gamma ray energies < 120 keV have been obtained from the adopted level energies.

The gamma ray energies > 120 keV have been adopted from 2006Wo03. They agree mainly with the values from 2003Br12 based on experimental data of 1964Bl11, 1969Cl12, 1971Ar47, 1975Pa04, 1979Bo30, 1982Ah04 and data from nuclear reactions. The exceptions comprise the gamma-ray transitions feeding the ^{239}Np ground state and the gamma rays with energies from 2006Wo03 different from 2003Br12. In such cases the recommended gamma ray energies have been obtained from the adopted level energies.

Several unplaced gamma rays observed in decay of ^{239}U, a-decay of ^{243}Am, and the particle transfer reactions were discussed in 2006Wo03 in detail. The transfer reactions and a-spectroscopy give direct information on level energies, but with uncertainties ~ 3 keV. Gamma ray spectroscopy, unsupported by coincidence correlations, gives relatively precise energies, but often placements are ambiguous. Therefore, all such gamma rays have been qualified by the evaluators as unplaced in the decay scheme.

The absolute emission probabilities for most intense gamma rays have been evaluated from experimental data (Table 4). The results of 1984Holloway are superseded by the same group in 1996Sa23 and have not been included in the procedure of averaging.

Table 4. Experimental and evaluated absolute emission probabilities (%) for most intense gamma-rays in decay of ^{239}U.

Eγ (keV)	1964 Bl11	1965 Yurova	1968 Ma06	1969 Cl12	1984 Holloway	1996 Sa23	2008 Griffin	**Evaluated**
31,1					0,065 (7)	0,064 (7)	0,075 (4)	**0,072 (4)**
43,5	4,1 (2)			4,45 (60)	4,18 (13)	4,07 (11)	4,93 (15)	**4,35 (28)**
74,7		47 (4)	62 (9)	50 (5)	48,2 (10)	49,2 (12)	53,9 (5)	**51,6 (13)**
86,7				0,060 (6)	0,052 (6)	0,053 (6)	0,054 (5)	**0,055 (5)**
117,7				0,145 (15	0,13 (4)	0,14 (3)	0,099 (9)	**0,113 (9)**

$P\gamma_{2,0}$ (71,2 keV) and $P\gamma_{7,2}$(170,2 keV) have been obtained from the P(γ+ce) and α_T .The value of $P\gamma_{4,3}$ (43,1 keV) has been deduced using the ratio $P\gamma_{4,3}$ / $P\gamma_{4,0}$ = 0,115 (12) from 1969En02.

The remaining absolute gamma ray emission probabilities for gamma rays with energy more than 120 keV have been deduced from relative gamma ray emission probabilities P_γ^{rel} (2006Wo03). Thereto the evaluators have used the coefficient k = P_γ^{rel} (74,7 keV) / 0,539 (5) given in 2008Griffin. It was corrected to the evaluated P_γ (74,7 keV) = 0,516 (13) taking also into account the detection efficiency uncertainty (0,7 %): k = 218,1 (48). The obtained P_γ agree with the values from 2003Br12 based on experimental data of 1964Bl11, 1965Yurova, 1968Ma06, 1969Cl12, 1971Ar47 and 1984Holloway.

6. CONSISTENCY OF RECOMMENDED DATA

The most accurate Q value, Q(M), is taken from the atomic mass adjustment table of Audi et al. (2003Au03). Comparison of Q(eff)(deduced as the sum of average energies per disintegration ($\sum E_i \times P_i$) for all emissions accompanying ^{233}Th β- decay) with the tabulated decay energy Q(M) allows to check a consistency of the recommended decay-scheme parameters obtained in this evaluation.

Here E_i and P_i are the evaluated energies and emission probabilities of the i-th alpha particle, beta particle, gamma ray, X-ray, etc. Consistency (percentage deviation) is determined by {[Q(M) – Q(eff))]/ Q(M)} × 100. “Percentage deviations above 5 % would be regarded as high and imply a poorly defined decay scheme; a value of less than 5 % indicates the construction of a reasonably consistent decay scheme” (quoted from the article by A.L. Nichols in Appl. Rad. Isotopes 55 (2001) 23-70).

For the above ^{239}U decay data evaluation we have Q(M) = 1261,5 (16) keV and Q(eff) = 1263 (36) keV, i.e. consistency is better than 2 %.

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^{236}Np – Comments on evaluation of decay data by V.P. Chechev and N.K. Kuzmenko

This evaluation was done originally in June 2006 and then updated in April 2009 with a literature cut-off by the same date.

1. DECAY SCHEME

From the systematics of the isomer levels it has been assumed in 1981Li30 (see also the analysis carried out in 1991Sc08) that the short-lived state of ^{236}Np (22,5 h) lies higher in energy than the long-lived state of ^{236}Np (1,55 × 10^5 a). In line with this assumption we consider the long-lived state of ^{236}Np as the ground state. Using Q values for electron capture decay of the isomer and ground state and a close energy cycle we can estimate the energy level spacing between these states as 60 (50) keV.

The decay scheme of the long-lived ^{236}Np includes three decay modes: β^- decay to ^{236}Pu, electron capture decay (EC) to ^{236}U and α decay to ^{232}Pa (see 2006Br20). A favored α-particle branch to the (6$^-$) level at ≈ 400 keV is expected in ^{232}Pa from α systematics (1972El21, 1980Sc26, 2006Br20). However, this decay was not observed experimentally.

The β^- -decay branching, $\Sigma P(\beta^-)$, and alpha-decay branching, $\Sigma P(\alpha)$, have been deduced by the evaluators from the partial half-lives $T_{1/2}(\beta^-)$ and $T_{1/2}(\alpha)$, respectively, measured in 1981Li30. The EC-decay branching, $\Sigma P(EC)$, has been obtained as the difference of $1 - \Sigma P(\beta^-) - \Sigma P(\alpha)$.

2. NUCLEAR DATA

Q^-, Q_{EC}, $Q(\alpha)$ values are from 2003Au03.

The total half-life of ^{236}Np is based on the evaluated partial half-lives $T_{1/2}(\alpha)$, $T_{1/2}(\beta^-)$, $T_{1/2}(EC)$ measured in 1981Li30.

The evaluated $T_{1/2}(\alpha)$ = 9,5 (35) × 10^7 years has been obtained as an average of the two measurements of 1981Li30 (specific activity, ^{232}U gamma-ray of 894 keV was measured): 9,4 (35) × 10^7 and 9,6 (35) × 10^7 years. A standard deviation of the individual measurement has been adopted for the uncertainty of the evaluated alpha-decay half-life using a rule that the uncertainty assigned to the recommended value should be greater than or equal to the smallest uncertainty in any experimental value.

$T_{1/2}(\beta^-)$ = 1,29 (3) × 10^6 years has been adopted here from the ^{236}Pu growth measurement of 1981Li30. The result of this measurement is independent of the decay scheme, and it is equal to the weighted average of 1,34 (15), 1,29 (3), 1,32 (9), 1,69 (30), 1,29 (3), 1,31 (8) (in 10^6 years) given in 1981Li30. The uncertainties of these measurements do not include any estimation of uncertainties from the decay scheme parameters. It agrees well with an earlier measurement in 1972En06 (1,29 (+ 0,07, - 0,05) × 10^5 a).

The evaluated $T_{1/2}(EC)$ = 1,77 (10) × 10^5 years has been obtained as an average of the two ^{236}U/^{235}U mass ratio measurements in 1981Li30: 1,75 (10) × 10^5 and 1,79 (10) × 10^5 years. These ^{236}U growth measurement results are independent of the decay scheme. A standard deviation of the individual measurement has been adopted for the uncertainty of the evaluated partial EC-decay half-life. The specific gamma-ray activity method (^{236}U 160,3-keV gamma-ray was measured) was used in other measurements presented in 1981Li30 (in 10^5 years): 1,60 (4), 1,73 (2), 1,77 (11), 1,75 (10), 1,79 (10), 1,74 (1), 1,78 (10). The uncertainties of these measurements do not include an estimation of uncertainties from the decay scheme parameters.

Thus, the recommended value of the total ^{236}Np half-life obtained from the relation
$T_{1/2} = [(T_{1/2}(\alpha))^{-1} + (T_{1/2}(\beta^-))^{-1} + (T_{1/2}(EC))^{-1}]^{-1}$ is 1,55 (8) × 10^5 years.

2.1.1. Electron Capture Transitions

The energies of the electron capture transitions have been deduced from the Q_{EC} value and the level energies given in Table 1 from 2006Br20 where they were deduced from a least squares fit to gamma-ray energies.

Table 1. ^{236}U levels populated in ^{236}Np electron capture decay

Level number	Energy (keV)	Spin and parity	Half-life	Probability of ε - transition (x 100)
0	0,0	0^+	$2,342 \cdot 10^7$ a	-
1	45,2440 (20)	2^+	234 (6) ps	-
2	149,477 (6)	4^+	124 (7) ps	0,0 (44)
3	309,785 (7)	6^+	58 (3) ps	87,8 (43)
4	687,59 (4)	1^-	3,78 (9) ns	-
5	744,18 (7)	3^-	< 0,1 ns	-
6	848,1 (8)	5^-		~ 0,09

The probabilities of the electron capture transitions $P(EC_{0,2})$ and $P(EC_{0,3})$ have been deduced from the correlations of:
$P(EC_{0,2}) + P(EC_{0,3}) = 100\ \% - \sum P(\beta^-) - \sum P(\alpha) = 87,8\ (6)\ \%$ and $P(EC_{0,3}) = P(\gamma_{3,2} + ce)$(160-keV).
The upper limit of $P(EC_{0,2}) < 4,4\ \%$ has been obtained from the level intensity balance: $P(EC_{0,2}) = 0,0\ (44)\ \%$. The estimate of $P(EC_{0,6}) \sim 0,1\ \%$ is given in 1996FiZX.

2.1.2. Beta Transitions

The energies of the β^-- transitions have been deduced from the Q^- value and the level energies given in Table 2 from 2006Br20 where they were deduced from a least squares fit to gamma-ray energies.

Table 2. ^{236}Pu levels populated in ^{236}Np β^--decay

Level number	Energy (keV)	Spin and parity	Half-life	Probability of β^-- transition (x100)
0	0,0	0^+	2,858 a	-
1	44,63 (10)	2^+		-
2	147,45 (10)	4^+		0,2 (14)
3	305,80 (11)	6^+		11,8 (12)

The β^- transition probability $P(\beta_{0,3}) = P(\gamma_{3,2}+ce)$(158-keV) and $P(\beta_{0,2}) = 12,0\ (6)\ \% - P(\beta_{0,3}) = 0,2\ (14)\ \%$. An upper limit of $P(\beta_{0,2}) < 1,6\ \%$ follows this result.

2.2. Gamma Transitions and Internal Conversion Coefficients

The evaluated energies of gamma-ray transitions are virtually the same as the photon energies because nuclear recoil is negligible.

The gamma-ray transition probabilities have been obtained from the gamma-ray emission probabilities and the total internal conversion coefficients (ICCs).

Multipolarities of gamma-ray transitions have been taken from 2006Br20. The ICCs have been interpolated using the BrIcc package with the so called "*Frozen Orbital*" approximation (2008Ki07) except for $\gamma_{4,1}$ (642,3-keV) and $\gamma_{4,0}$ (687,6-keV). The relative uncertainties of the ICCs for pure multipolarities have been taken as 2 %.

For $\gamma_{4,1}$(642,3-keV) and $\gamma_{4,0}$(687,6-keV) the ICC values of α_K and α_L are experimental results from ^{240}Pu α-decay study (1969Le05, 1977Po05). The ICC values of α_M and α_T for these transitions have been deduced using α_M/α_L and α_{NO}/α_M from 1971Dr11. More accurate ICC measurements for these E1 anomalously converted gamma-ray-transitions are required.

3. ATOMIC DATA

The atomic data are from Schönfeld and Janβen (1996Sc06).

4. ELECTRON EMISSIONS

The energies of the conversion electrons have been obtained from the gamma transition energies and the atomic electron binding energies.

The emission probabilities of the conversion electrons have been obtained using evaluated P(γ) and ICC values.

The absolute emission probabilities of K and L Auger electrons have been obtained using the EMISSION computer program.

β^- average energies have been obtained using the LOGFT computer program.

5. PHOTON EMISSIONS

5.1. X-Ray Emissions

The absolute emission probabilities of U and Pu KX- and LX-rays have been deduced using the EMISSION computer program.
For U LX-ray intensity calculations the theoretical fractional ratios $P_{EC}(L2)/P_{EC}(L1) = 0,115$ and $P_{EC}(L3)/P_{EC}(L1) = 0$ for the EC-transition to the level ''3'' (309 keV) of ^{236}U have been used (1972Dzhelepov). The calculated relative intensities of U KX- rays accompanying the electron capture of ^{236}Np are in a good agreement with the experimental results (Table 3).

Table 3. Intensities of U KX- rays (relatively to P($\gamma_{3,2}$ -160,3 keV)) accompanying ^{236}Np electron capture

	1983Ah03 (experimental)	Adopted (deduced)
X_K		
$K\alpha_2$	0,61 (2)	0,64 (3)
$K\alpha_1$	0,99 (3)	1,02 (5)
$K\beta_1$'	0,38 (2)	0,368 (19)
$K\beta_2$'	0,131 (7)	0,126 (7)

5.2. Gamma Ray Emissions

5.2.1. Gamma Ray Energies (^{236}U)

The energies of gamma-rays in ^{236}Np electron capture have been taken from 2006Br20.

5.2.2. Gamma Ray Energies (^{236}Pu)

The energies of gamma-rays $\gamma_{1,0}$ (44,6 keV), $\gamma_{2,1}$ (102,8 keV), $\gamma_{3,2}$ (158,3 keV) accompanying β^- decay of ^{236}Np have been adopted from measurements given in 1983Ah02 (see also 2006Br20).

5.2.3. Gamma-Ray Emission Probabilities (^{236}U)

The evaluated gamma-ray emission probabilities P(γ) have been deduced using the relative gamma-ray intensities from 1983Ah02 (Table 4), the relation of $\sum P(EC_{0,i})$ = 87,8 (6) % = P($\gamma_{2,1}$ +ce)(104,23 keV) and the intensity balance at ^{236}U each level. We have assumed that the populations to the two lower levels ("0" and "1") in the ^{236}Np electron capture decay are negligible and have taken into account the intensity balance correlation for the gamma-ray transitions to these levels, that is P($\gamma_{1,0}$ +ce)(45,2 keV) = P($\gamma_{2,1}$ +ce) (104,2 keV).

The recommended gamma-ray emission probabilities for γ-rays de-exciting level ''4'' ($\gamma_{4,2}$(538,1 keV), $\gamma_{4,1}$(642,3 keV), and $\gamma_{4,0}$(687,6 keV)) have been deduced from the correlation:
P($\gamma_{5,4}$ +ce)(56,6 keV) = P($\gamma_{4,2}$ +ce)(538,1 keV) + P($\gamma_{4,1}$ +ce)(642,3 keV) + P($\gamma_{4,0}$ +ce)(687,6 keV) using the relative intensities for these γ-rays evaluated from the ^{240}Pu α-decay (Table 5) and assuming P($EC_{0,4}$) = 0.

Table 4. Gamma rays in decay of the long-lived ^{236}Np measured in 1983Ah02

	Energy (keV)	Relative intensity
$\gamma_{1,0}$ (^{236}U)	45,23 (3)	0,4 (1)
$\gamma_{2,1}$ (^{236}Pu)	102,82 (2)	2,9 (2)
$\gamma_{2,1}$ (^{236}U)	104,23 (2)	23 (1)
$\gamma_{3,2}$ (^{236}Pu)	158,35 (2)	13,5 (7)
$\gamma_{3,2}$ (^{236}U)	160,33 (2)	100

Table 5. Experimental and evaluated absolute emission probabilities of gamma-rays de-exciting the ^{236}U level with energy of 687,6 keV in decay of ^{240}Pu (per 10^8 α-decays) and the deduced relative intensities of these gamma-rays

	Energy (keV)	1969Le05	1971GuZY	1975OtZX	1975Dr05	1976GuZN	Evaluated	Evaluated relative intensities
$\gamma_{4,2}$	538,1	≈ 0,23 [a]		0,147 (12)			0,147 (12)	1,17 (10)
$\gamma_{4,1}$	642,3	14,5 [a]	14,5 (5) [b]	12,6 (4)	13 (1)	12,45 (30)	12,6 (3) [c]	100 (3)
$\gamma_{4,0}$	687,6	3,77 (11)	3,70 (15) [b]	3,30 (13)		3,55 (9)	3,56 (15) [d]	28,3 (13)

[a] Omitted from averaging as uncertainty is not quoted
[b] Omitted from averaging as the data of 1971GuZY have been revised in 1976GuZN
[c] Weighted average of 3 experimental values; the uncertainty is the smallest quoted uncertainty
[d] Weighted average of 3 experimental values; the uncertainty is external

5.2.4. Gamma-Ray Emission Probabilities (^{236}Pu)

The recommended gamma-ray emission probabilities P(γ) have been deduced using the relative gamma-ray intensities from 1983Ah02 (Table 4), the quantity $\sum P(\beta^-)$ = 12,05 (60) % = P($\gamma_{2,1}$+ce)(102,8 keV) and the intensity balance at each ^{236}Pu level. We have assumed that the populations to the two lower levels ("0" and "1") in the ^{236}Np beta minus decay are negligible and have taken into account the intensity balance of the gamma-ray transitions to these levels, that is P($\gamma_{1,0}$+ce)(44,6 keV) = P($\gamma_{2,1}$+ce)(102,8 keV).

6. CONSISTENCY OF RECOMMENDED DATA

The most accurate Q value, Q(M), is taken from the atomic mass adjustment table of Audi et al. (2003Au03). Comparison of Q(eff) (deduced as the sum of average energies per disintegration ($\sum E_i \times P_i$) for all emissions accompanying ^{236}Np β$^-$-decay or ^{236}Np electron capture) with the tabulated decay energy $Q^-(M) \times P(\beta^-)$ for β$^-$-decay or $Q_{EC}(M) \times P(EC)$ for electron capture allows to check a consistency of the recommended ^{236}Np decay-scheme parameters obtained in this evaluation.

Here E_i and P_i are the evaluated energies and emission probabilities of the i-th beta particle, gamma ray, X-ray, etc. The values of P(β$^-$), P(EC) are β$^-$ -decay and EC branching, respectively. Consistency (percentage deviation) is determined by {[Q(M) − Q(eff))]/ Q(M)} × 100. "Percentage deviations above 5 % would be regarded as high and imply a poorly defined decay scheme; a value of less than 5 % indicates the construction of a reasonably consistent decay scheme" (quoted from the article by A. L. Nichols in Appl. Rad. Isotopes 55(2001)23-70).

For the above ^{236}Np decay data evaluation we have for β$^-$-decay $Q^-(M) \times P(\beta^-)$ = 58 (7) keV and Q(eff, β$^-$) = 57 (7) keV, i.e. consistency is less than 2 % if we do not take into account the uncertainties, and the exact percentage deviation is (1.7 ± 17) % if we consider the uncertainties. Similarly, for ^{236}Np electron capture we have $Q_{EC}(M) \times P(EC)$ = 817 (44) keV and Q(eff, EC) = 817 (50) keV and the percentage deviation is 0 ± 8 %. These values indicate the right evaluation and inaccurate measurements of ^{236}Np decay-scheme parameters.

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$^{236}Np^m$ – COMMENTS ON EVALUATION OF DECAY DATA

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

This evaluation was completed in June 2006. The literature available by May 2006 was included.

1. DECAY SCHEME

From the systematics of isomer levels it was assumed in 1981Li30 (see also the analysis carried out in 1991Sc08) that the short-lived state of ^{236}Np (22,5 h) lies higher in energy than the long-lived state of ^{236}Np (1,55 10^5 y). In line with this assumption we have considered the long-lived state of ^{236}Np as the ground state. Using Q values for electron capture decays of the isomer and ground states together with closed energy cycles we can estimate the energy level spacing between these states as 60(50) keV.
The decay scheme of the isomer $^{236}Np^m$ includes two decay modes: $ß^-$ decay to ^{236}Pu and electron capture decay (EC) to ^{236}U (see evaluations of 1991Sc08, 1996FiZX). The $ß^-$ -decay branching, $\Sigma P(ß^-)$, has been adopted from 1969Le05. The EC -decay branching, $\Sigma P(EC)$, has been obtained as the difference of $1-\Sigma P(ß^-)$.

2. NUCLEAR DATA

Q^- ($^{236}Np^m$) is from 1969Le05 (the end-point energy of the β^- spectrum was measured). Q_{EC}($^{236}Np^m$) has been calculated from the closed energy cycle of decays ending in ^{232}Th. The values of Q^- ($^{236}Np^m$), Q_α (^{236}Pu), Q^- (^{232}Pa), Q_{EC}(^{232}Pa) and Q_α(^{236}U) from 2003Au03 were used in this calculation.
The half-life of $^{236}Np^m$ is from 1969Le05. This result agrees with other (less accurate) measurements (1949Ja01 – 22 h, 1984Gr33 – 22,5 h).

2.1. Electron Capture Transitions

The energies of the electron capture transitions have been deduced from the Q_{EC} value and the level energies (Table 1) obtained from the evaluated gamma-ray energies.

Table 1. ^{236}U levels populated in the $^{236}Np^m$ electron capture decay

Level number	Energy, keV	Spin and parity	Half-life	Probability of EC - transition (×100)
0	0,0	0^+	$2{,}342 \cdot 10^7$ yr	43,1(32)
1	45,242(3)	2^+	234 ps	8,3(30)
2	149,476(15)	4^+	124 ps	-
4	687,60(5)	1^-	3,8 ns	1,64(9)

The individual EC- transition probabilities $P(EC_{1,i})$ have been deduced from the intensity balance for each level and the total EC -decay probability $\Sigma P(e_{1,i})$.

2.2. Beta Transitions

The $ß^-$- transition energies have been deduced from the Q^- value and the level energies (Table 2) obtained from the evaluated gamma-ray energies.

Table 2. ^{236}Pu levels populated in the $^{236}Np^m$ $ß^-$ -decay

Level number	Energy, keV	Spin and parity	Half-life	Probability of $ß^-$- transition (× 100)
0	0,0	0^+	2,858 yr	36(4)
1	44,63(10)	2^+		11(4)

The ß⁻- transition probabilities $P(\beta_{1,0})$, $P(\beta_{1,1})$ have been obtained from the ratio $P(\beta_{1,0})/P(\beta_{1,1})$ =38(7)/12(5) measured in 1959Gi58 and the total ß⁻ -decay probability $\Sigma P(\beta_{1,i})$.

2.3. Gamma Transitions and Internal Conversion Coefficients (^{236}U)

The evaluated transition energies are virtually the same as the photon energies because nuclear recoil is negligible.

The gamma-ray transition probabilities have been obtained from the gamma-ray emission probabilities and the total internal conversion coefficients (ICC's). Multipolarities of gamma-ray transitions have been taken from 1991Sc08 and 1996FiZX. The gamma-ray transition probability $P(\gamma_{1,0}$ +ce)(44,6-keV) has been deduced from the relation of $P(\gamma_{1,0}$ +ce)(44,6-keV)= $P(\beta_{0,1})$.

ICC's have been interpolated using the BRICC computer program, except for $\gamma_{4,1}$ (642,3-keV) and $\gamma_{4,0}$ (687,6-keV) because of nuclear penetration effects. The relative uncertainties of α_K, α_L, $\alpha_{M,}$ α_T for pure multipolarities have been taken as 2%.

α_K and α_L for $\gamma_{4,1}$(642,3-keV) and $\gamma_{4,0}$(687,6-keV) are experimental values from data in ^{240}Pu α-decay (1969Le05 and 1977Po05, see also the evaluation of 2004Be). α_M and α_T for these transitions have been evaluated using α_M/α_L and α_{NO}/α_M from 1971Dr11. More accurate ICC measurements for these transitions are required.

3. ATOMIC DATA

3.1. Fluorescence yields

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

3.2. X Radiations

The LX-ray energies are from 1996FiZX. The KX-ray energies and the relative KX-ray emission probabilities are from 1999Schönfeld.

The X-ray energies are based on the wavelengths given in the compilation of 1967Be65 (Bearden).

The relative KX-ray emission probabilities have been taken from 1999Schönfeld.

3.3. Auger Electrons

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

4. ELECTRON EMISSIONS

The energies of the conversion electrons have been deduced from the gamma transition energies and the electron binding energies.

The emission probabilities of the conversion electrons have been deduced using evaluated P_γ and ICC values.

The absolute emission probabilities of K and L Auger electrons have been obtained with the EMISSION computer program.

β^- average energies have been obtained using the LOGFT computer program.

5. PHOTON EMISSIONS

5.1. X-Ray Emissions

The absolute emission probabilities of KX- and LX-rays have been obtained with the EMISSION computer program.

For U LX-ray calculations the ratios $P_{EC}(L2)/P_{EC}(L1)$ =0,115 and $P_{EC}(L3)/P_{EC}(L1)$ =0 from the theoretical calculations of 1972Dzhelepov were used for all levels populated in the $^{236}Np^{m}$ electron capture decay.

5.2. Gamma Ray Emissions

5.2.1. Gamma Ray Energies (^{236}U)

The energies of gamma rays accompanying the $^{236}Np^{m}$ electron capture decay have been adopted from the evaluated DDEP data in ^{240}Pu α-decay (2004Be).

5.2.2. Gamma Ray Energies (^{236}Pu)

The energy of $\gamma_{1,0}$ (44,6 keV) accompanying the ß⁻ - decay of $^{236}Np^{m}$ has been adopted from measurements in 1983Ah02.

5.2.3. Gamma-Ray Emission Probabilities (^{236}U)

The gamma-ray emission probability P(γ) for $\gamma_{1,0}$ (45,2 keV) has been obtained from the ratio $\Sigma P(e_i)$(45,2 keV) / $P(\gamma_{4,1})$(642,3 keV) = 9(3) measured in 1969Le05.

The evaluated gamma ray emission probability $P(\gamma_{4,1})$(642,3 keV) = 0,96(20)% has been deduced using the following values:

1) $\Sigma P(e_{1,i})$=53(1)%;
2) measured ratio P(XKa) / $P(\gamma_{3,1})$(642,3 keV)=27,6(10) from 1969Le05;
3) theoretical value of the ratio P(XKa)/P(XKß)=0,298(5);
4) relative (partial) intensities of gamma rays de-exciting level ''4'' [$\gamma_{4,2}$ (538,1 keV), $\gamma_{4,1}$ (642,3 keV), $\gamma_{4,0}$ (687,5 keV)], which have been deduced from the absolute gamma-ray emission probabilities evaluated in the ^{240}Pu α-decay (Table 5), and a_K for these gamma-rays;
5) the measured ratio ΣP_K (i) $P(EC_{1,i})$/ $\Sigma P(ß^-_{1,i})$=0,75(15) from 1956Gr11, which can be represented as $P_K^{(average)}$ = ΣP_K (i) $P(EC_{1,i})$/ Σ $P(EC_{1,i})$=0,67(13).

The most accurate evaluation of $P_K^{(average)}$ (and also the new evaluation of $P(\gamma_{4,1})$ (642,3 keV) and other values) may be obtained by using the theoretical P_K(i), the values of $P(EC_{1,i})$ deduced from $P(\gamma_{4,1})$(642,3 keV) = 0,96(20)%, and the fact that a contribution of the third term (with $P(EC_{1,4})$) to $P_K^{(average)}$ comprises ˜ 2,5%. This value has been taken as a fractional uncertainty for the $P_K^{(average)}$ = 0,75(2).Using the latter and the relations 1) - 4) we have deduced a more accurate evaluation of $P(\gamma_{4,1})$(642,3 keV) = 1,08(6)%, and correspondingly a more accurate evaluation for other decay data.

The gamma-ray emission probability $P(\gamma_{2,1}$) (104,2 keV) has been calculated from $P(\gamma_{2,1}$ +ce) (104,2 keV) = $P(\gamma_{4,2}$ +ce)(538,1 keV) assuming that the electron capture feeding of level "2" is negligible.

Table 5. Experimental and evaluated absolute emission probabilities of gamma rays de-exciting the ^{236}U level with energy of 687,6 keV in the decay of ^{240}Pu (per 10^8 a-decays) and the deduced relative intensities of these gamma rays

	Energy, keV	1969Le05	1971GuZY	1975OtZX	1975Dr05	1976GuZN	Evaluated	Evaluated relative intensities
$\gamma_{4,2}$	538,1	≈0,23 [a]		0,147(12)			0,147(12)	1,17(10)
$\gamma_{4,1}$	642,3	14,5 [a]	14,5(5) [b]	12,6(4)	13(1)	12,45(30)	12,6(3) [c]	100 (3)
$\gamma_{4,0}$	687,6	3,77(11)	3,70(15) [b]	3,30(13)		3,55(9)	3,56(15) [d]	28,3(13)

[a] Omitted from averaging as uncertainty is not quoted
[b] Omitted from averaging as the data of 1971GuZY have been revised in 1976GuZN
[c] Weighted mean of 3 experimental values; the uncertainty is the smallest quoted uncertainty
[d] Weighted mean of 3 experimental values; the uncertainty is external

5.2.3. Gamma-Ray Emission Probability (^{236}Pu)

The gamma-ray emission probability P(γ) for $\gamma_{1,0}$ (44,6 keV) has been obtained from $P(\beta_{1,1})$ and the adopted α_T for this gamma-ray transition.

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^{237}Np – Comments on evaluation of decay data by V. P. Chechev and N.K. Kuzmenko

This evaluation was done originally in October 2007 and then updated in April 2009 with a literature cut-off by the same date. The Saisinuc software (2002Be) and associated supporting programs were used in assembling the data following the established protocol within DDEP.

1. DECAY SCHEME

Decay scheme is based on 2005Si15. It cannot be considered complete since the α-feedings measured directly in ^{237}Np α-decay and those deduced from the level gamma-ray intensity balances are not always in good agreement as shown in Table 1 (see also 2005Si15).

Table 1. Comparison of the prominent α-feedings ($P_\alpha \times 100$) measured directly in ^{237}Np α-decay with those deduced from the level gamma-ray intensity balances

Level	Level energy (keV)	$P_\alpha \times 100$ Adopted from measurements	$P_\alpha \times 100$ Deduced from γ-ray intensity balance
0	0	}2.92 (4)	1 (3)
1	6.654 (25)		
2	57.101 (14)	2.430 (17)	8 (4)
3	70.510 (25)	2.02 (2)	1.4 (3)
4	86.469 (9)		
6	103.636 (20)	}80.1 (5)	}79.1 (24)
7	109.04 (5)		
13	212.342 (18)	3.46 (3)	2.8 (9)
14	237.895 (13)	6.43 (3)	5.1 (7)

2. NUCLEAR DATA

Q(α) value is from 2003Au03.

The recommended half-life of ^{237}Np is based on the experimental results given in Table 2.

Table 2. Experimental values of ^{237}Np half-life (in 10^6 years)

Reference	Author(s)	Value	Comments and method
1949Ma01	Magnusson and LaChapelle	2.20 (11)	First isolation of the element 93 and a determination of ^{237}Np half-life
1960Br12	Brauer et al.	2.14 (1)	Specific activity
1992Lo03	Lowles et al.	2.144 (7)	Specific activity, many sources, known geometry gas flow proportional counters for α-particle counting

The weighted mean of the 3 values is 2.143 with the internal uncertainty of 0.0057 and external uncertainty of 0.0025 and $\chi^2/\nu = 0.19$. The unweighted mean is 2.161 (19). *

The recommended value of ^{237}Np half-life of 2.144 (7) × 10^6 years has been adopted from the most accurate measurement of 1992Lo03.

The recommended ^{237}Np spontaneous fission half-life $T_{1/2}$(SF) ≥ 1×10^{18} years is from 1961Dr04. The theoretical values of $T_{1/2}$(SF) are about 10^{18} yr (1988Io05) and 10^{14} yr (1992Gr16).

2.1 Alpha Transitions

The energies of the alpha transitions have been deduced from the Q value and the level energies given in Table 3 from 2005Si15 where they were deduced from a least squares fit to gamma-ray energies. The energies of the gamma rays adopted from 2005Si15 are given below, in Table 7.

Table 3. ^{233}Pa levels populated in ^{237}Np α-decay

Level	Level energy (keV)	Spin and parity	Half-life	Energy of α-particles (keV)	Probability of alpha transition (%)
0	0	$3/2^-$	26.98 (2) d	4872.7 (14)	2.41 (3)
1	6.654 (25)	$1/2^-$		4866.4 (14)	0.51 (3)
2	57.101 (14)	$7/2^-$		4816.8 (10)	2.430 (17)
3	70.510 (25)	$5/2^-$		4803.5 (10)	2.02 (2)
4	86.469 (9)	$5/2^+$	35.8 (4) ns	4788.0 (9)	47.64 (6)
5	94.645 (16)	$3/2^+$			
6	103.636 (20)	$7/2^+$		4771.4 (8)	23.0 (3)
7	109.04 (5)	$9/2^+$		4766.5 (8)	9.5 (3)
8	133.2 (10)	$(11/2^+)$		4741.3 (20)	0.019
9	163.34 (10)	$(11/2^-)$		4712.3 (20)	1.174 (13)
10	169.152 (20)	$1/2^+$		4708.3 (20)	
11	179.1 (4)	$(9/2^-)$		4698.2 (8)	0.535 (10)
12	201.594 (19)	$3/2^+$		4676.4	0.38 (2)
13	212.342 (18)	$5/2^+$		4665.0 (9)	3.46 (3)
14	237.895 (13)	$5/2^+$		4640.0 (10)	6.43 (3)
15	257.1 (4)	$5/2^-$		4619.7 (21)	0.032 (8)
16	279.71 (3)	$(7/2^+)$		4599.1 (18)	0.37 (1)
17	300.48 (3)	$7/2^+$		4578.6 (14)	0.39 (2)
18	303.59 (7)	$(9/2^+)$		4573 (3)	0.048 (23)
19	306.05 (10)	$(7/2^+)$			
20	365.93 (8)	$9/2^+$		4515.1 (19)	0.038 (4)

The recommended α-transition probabilities have been obtained by averaging the experimental results (see Table 4). The probabilities of the $\alpha_{0,8}$ - and $\alpha_{0,12}$ - transitions have been deduced from the decay scheme. The α-decay hindrance factors have been calculated using the ALPHAD computer program from the ENSDF evaluation package with r_0 = 1.517 (4) fm (see 2005Si15).

New α-transition with energy of 4550.5 (22) keV and intensity of 0.011 (3) % unplaced in ^{237}Np decay scheme was seen by 2002Wo03 (also 2000Si02).

Table 4. Experimental and recommended probabilities of α-transitions (×100) from ^{237}Np α-decay

Level	Level energy (keV)	Energy of α-particles (keV)	1961Ba44	1969Br12	1990Bo44	2002Wo03	Recommended $P_\alpha \times 100$
0	0	4872.7 (14)	0.925	2.6 (2)	2.43 (3)	2.39 (4)	2.41 (3)
1	6.654 (25)	4866.4 (14)	0.24		0.49 (3)	0.53 (4)	0.51 (3)
2	57.101 (14)	4816.8 (10)		2.5 (4)	2.47 (2)	2.430 (17)	2.430 (17)
3	70.510 (25)	4803.5 (10)	2.014 (17)		2.06 (5)		2.014 (17)
4	86.469 (9)	4788.0 (9)		47 (9)	47.75 (20)	47.64 (6)	47.64 (6)
5	94.645 (16)						
6	103.636 (20)	4771.4 (8)		25 (6)	22.7 (4)	23.2 (3)	23.0 (3)
7	109.04 (5)	4766.5 (8)		8 (3)	9.7 (3)	9.3 (3)	9.5 (3)
8	133.2 (10)	4741.3 (20)					0.019
9	163.34 (10)	4712.3 (20)				< 1.17	< 1.17
10	169.152 (20)	4708.3 (20)				< 1.17	< 1.17
11	179.1 (4)	4698.2 (8)		0.48 (20)	0.54 (4)	0.535 (10)	0.535 (10)
12	201.594 (19)	4676.4					0.38 (2)
13	212.342 (18)	4665.0 (9)		3.32 (10)	3.43 (4)	3.478 (24)	3.46 (3)
14	237.895 (13)	4640.0 (10)		6.18 (12)	6.45 (4)	6.43 (3)	6.43 (3)
15	257.1 (4)	4619.7 (21)				0.032 (8)	0.032 (8)
16	279.71 (3)	4599.1 (18)		0.34 (4)	0.39 (2)	0.371 (9)	0.373 (9)
17	300.48 (3)	4578.6 (14)		0.40 (4)	0.41 (2)	0.369 (23)	0.393 (23)
18 19	303.59 (7) 306.05 (10)	4573 (3)	0.048 (23)				0.048 (23)
		4550.5 (22)				0.011 (3)	0.011 (3)
20	365.93 (8)	4515.1 (19)		0.04 (2)	0.041 (4)	0.035 (4)	0.038 (4)

2.2. Gamma Transitions and Internal Conversion Coefficients

The energies of the gamma-ray transitions are virtually the same as the gamma-ray energies because nuclear recoil is negligible.

The gamma-ray transition probabilities have been deduced from their gamma-ray emission probabilities and total internal conversion coefficients (ICCs) deduced with a computer program supplied with the Saisinuc software (2002Be). The ICCs have been interpolated using the BrIcc package with the so called "*Frozen Orbital*" approximation (2008Ki07, see also 2002Ba85). The multipolarities and admixture coefficients δ have been taken from 2005Si15. The uncertainties in the ICCs for pure multipolarities have been taken as 2 %.

ICCs for the anomalously converted E1 gamma-ray transition $\gamma_{4,0}$ (86.477 keV) have been adopted from 1988Wo01 (see also 1960As02 and 1969Br12).

The conversion electron data of 1988Wo01 indicate that the gamma-transition $\gamma_{4,2}$ (29.374 keV) may be an anomalous E1. However the evaluators have been adopted the theoretical ICCs since the detector efficiency was not completely reliable for such energy as pointed out in 1988Wo01.

3. Atomic Data

The atomic data (fluorescence yields, X-ray energies and relative probabilities, and Auger electrons energies and relative probabilities) are from Schönfeld and Janβen (1996Sc06).

4. Alpha Emissions

The alpha particle energies have been taken from 2002Wo03 (see also 2000Si02). They are somewhat different (in limits of uncertainties) from those obtained from alpha transition energies taking into account nuclear recoil for ^{233}Pa.

Details of alpha transition probability evaluation are given in Section 2.1.

5. Photon Emissions

5.1. X-Ray Emissions

The absolute X-ray emission probabilities (per 100 disintegrations) have been evaluated using the experimental data, see Tables 5, 6.

Table 5. Experimental and recommended absolute Pa KX- ray emission probabilities (×100)

	1984Va27	2000Sc04	2002Lu01	2004Sh07	2008De10	Recommended
$K\alpha_2$	1.90 (10)	1.82 (5)	1.80 (20)	1.80 (3)	1.813 (20)	1.813 (20)
$K\alpha_1$	3.00 (15)	2.98 (7)	2.89 (2)	2.89 (4)	2.932 (30)	2.906 (20)
$K'\beta_1$	1.03 (5)	0.86 (2)	1.06 (2)	1.02 (4)	1.154 (14)	1.06 (10)
$K'\beta_2$	0.35 (2)		0.373 (10)	0.38 (2)	0.380 (9)	0.380 (9)

Table 6. Experimental and recommended absolute Pa LX- ray emission probabilities (×100)

	2000Sc04	2004Sh07	2008De10	Recommended
Ll	1.55 (8)	1.31 (20)	1.33 (27)	1.32 (8)
Lα	26 (3)	23.3 (24)	23.1 (47)	24.0 (24)
Lβ	29.5 (20)[a]	24.3 (31)[b]	28 (6)	28.0 (20)
Lη	0.64 (6)	0.50 (4)		0.54 (4)
Lγ	5.8 (4)[c]	5.4 (8)[d]	7.8 (16)	5.8 (4)

[a] Obtained by the evaluators from the sum absolute intensity (Pa Lβ + U Lβ) of 47.5 (19) % using the intensities of Pa Lβ-components measured in 2000Sc04 and the U Lβ-intensity of 18.0 (6) % from ^{233}Pa decay data evaluation (2006Ch39) revised in April 2009.

[b] Obtained by the evaluators from the sum absolute intensity (Pa Lβ + U Lβ) of 42.3 (30) % using the intensities of Pa Lβ-components measured in 2000Sc04 and the U Lβ-intensity of 18.0 (6) % from ^{233}Pa decay data evaluation (2006Ch39) revised in April 2009.

[c] Obtained by the evaluators from the sum absolute intensity (Pa Lγ + U Lγ) of 10.0 (4) % using the intensities of Pa Lγ-components measured in 2000Sc04 and the U Lβ-intensity of 4.18 (13) % from ^{233}Pa decay data evaluation (2006Ch39) revised in April 2009.

[d] Obtained by the evaluators from the sum absolute intensity (Pa Lγ + U Lγ) of 9.6 (8) % using the intensities of Pa Lγ-components measured in 2000Sc04 and the U Lβ-intensity of 4.18 (13) % from ^{233}Pa decay data evaluation (2006Ch39) revised in April 2009.

5.2. Gamma-Ray Emissions

Energies

The gamma-ray energies have been adopted from 2005Si15. The gamma ray energy for $\gamma_{7,6}$ (5.18 keV) has been adopted from 1990Lo04. The energies for $\gamma_{1,0}$ (6.65 keV), $\gamma_{5,4}$ (8.22 keV) and $\gamma_{7,4}$ (17.4 keV) are from ^{233}Th decay. For $\gamma_{13,12}$ (10.7 keV) and $\gamma_{8,7}$ (21.4 keV) the energies are from 1979Go12. The gamma-ray energies of $\gamma_{6,5}$ (9.0 keV) and $\gamma_{7,4}$ (22.6 keV) have been deduced from ^{233}Pa level scheme (details of information of these and other gamma-ray transitions see in 2005Si15). Table 7 contains the experimental and adopted energies of the remaining gamma rays.

Table 7. Experimental and adopted energies (in keV) of gamma rays from ^{237}Np decay

1969Br12	1969HoXY	1971Cl03	1974HeYW	1976Sk01	1979Go12	1988Wo01 (Ge-detector)	1988Wo01 (LEPS-detector)	Adopted
29.29 (10)	29.30 (5)	29.38 (2)	29.375 (20)	29.373 (10)	29.374 (20)	29.5 (17)	29.18 (21)	29.374 (20)
46.46 (10)	46.6 (1)	-	46.60 (10)	46.53 (4)	46.53 (6)	46.7 (11)	46.28 (18)	46.53 (6)
57.15 (10)	57.1 (1)	57.11 (2)	57.112 (20)	57.15 (4)	57.104 (20)	57.15 (80)	56.88 (17)	57.104 (20)
	62.9	-	62.5 (5)					62.59 (10)
			63.92 (8)					63.90 (10)
	71.0		70.75 (10)					70.49 (10)
86.49 (10)	86.40 (5)	86.49 (2)	86.486 (10)	86.503 (20)	86.477 (10)	86.50 (48)	86.26 (14)	86.477 (10)
		-		88.04 (16)				87.99 (3)
			94.66 (10)	94.66 (5)				94.64 (5)
106.22 (10)	106.30 (8)	106.30 (20)	106.15 (25)	106.12 (5)		106.17 (48)		106.15 (25)
				108.6				108.7
				115.45 (20)	115.40 (35)			115.40 (35)
117.65 (7)	117.5 (1)	117.72 (2)	117.718 (20)	117.681 (30)	117.702 (20)	117.72 (50)	117.41 (15)	117.702 (20)
131.11 (7)	131.2 (1)	131.11 (2)	131.11 (2)	131.11 (7)	131.101 (25)	131.09 (52)	130.62 (15)	131.101 (25)
134.23 (7)	134.4 (1)	134.28 (2)	134.28 (3)	134.23 (4)	134.285 (20)	134.27 (53)		134.285 (20)
				140.60 (10)	-			139.9 (1)
143.26 (7)	143.35 (5)	143.25 (1)	143.254 (10)	143.208 (25)	143.249 (20)	143.27 (56)	142.96 (16)	143.249 (20)
151.31 (7)	151.5 (1)	151.41 (1)	151.410 (15)	151.37 (4)	151.414 (20)	151.42 (60)	151.06 (17)	151.414 (20)
				153.52				153.37 (10)
155.20 (7)	155.4 (1)	155.25 (2)	155.25 (2)	155.22 (4)	155.239 (20)	155.28 (63)		155.239 (20)
162.38 (7)	162.7 (1)	162.52 (3)	162.52 (3)	162.50 (6)	162.41 (8)	162.45 (68)		162.41 (8)
169.09 (7)	169.4 (1)	169.16 (3)	169.16 (3)	169.17 (5)	169.156 (20)	169.18 (73)		169.156 (20)
170.56 (10)	171.2 (3)	170.64 (5)	170.64 (5)	170.63 (8)	170.59 (6)			170.59 (6)
175.93 (10)	176.1 (1)	176.06 (5)	176.06 (5)	176.09 (7)	176.12 (6)	176.17 (80)		176.12 (6)
180.66 (10)	180.8 (1)	180.78 (5)	180.78 (5)	180.80 (8)	180.81 (10)	180.87 (85)		180.81 (10)
186.86 (30)				186.8 (5)	186.86 (35)			186.86 (35)
191.34 (10)		191.42 (3)	191.42 (3)	191.45 (6)	191.46 (5)	191.46 (97)		191.46 (5)
193.05 (10)		193.22 (3)	193.22 (3)	193.26 (4)	193.26 (5)	193.24 (98)		193.26 (5)
				194.67 (20)				194.67 (20)
194.91 (7)	195.00 (5)	194.97 (2)	194.97 (2)	195.096 (20)	194.95 (3)	195.1 (10)		194.95 (3)
196.81 (10)	-	196.80 (10)	196.80 (10)	196.84 (6)	196.86 (5)	196.9 (10)		196.86 (5)
			199.9 (1)	200.17 (10)	199.95 (6)			199.95 (6)
201.68 (8)	201.75 (10)	201.67 (20)	201.670 (25)	201.72 (5)	201.62 (5)	201.8 (11)		201.62 (5)
			202.9 (2)	202.69 (25)				202.9 (2)
209.07 (8)	209.1 (2)	209.18 (3)	209.18 (3)	209.25 (5)	209.19 (5)	209.2 (12)		209.19 (5)
212.28 (7)	212.4 (1)	212.33 (2)	212.33 (2)	212.42 (5)	212.29 (5)	212.4 (12)		212.29 (5)
213.92 (10)	-	213.96 (4)	213.96 (4)	214.09 (5)	214.01 (5)	214.1 (12)		214.01 (5)
				222.52 (25)				222.6 (2)
229.84 (10)	229.9 (1)	229.90 (10)	229.90 (10)	230.01 (10)	229.94 (5)			229.94 (5)
237.91 (7)	238.2 (1)	237.91 (2)	237.908 (10)	238.04 (4)	237.862 (60)	238.0 (14)		237.86 (2)
248.6 (4)	248.8 (1)	248.8 (5)	248.8 (5)	248.9 (1)	248.95 (10)			248.95 (10)
257.14 (40)	257.3 (2)	257.15 (50)	257.15 (50)	257.20 (20)	257.09 (20)			257.09 (20)
262.48 (40)	262.6 (2)	262.42 (50)	262.42 (50)	262.44 (15)	262.44 (20)			262.44 (20)

Emission Probabilities

The value $P\gamma_{14,12}$ (36.32 keV) of 0.000 05 (1) has been adopted from 1990Lo04. The values $P\gamma_{-1,1}$ (21.5 keV)) of 0.003 56 (13) and $P\gamma_{-1,2}$ (27.7 keV) of 0.008 4 (7) have been adopted from 2004Sh07. The values $P\gamma_{17,14}$ (62.59 keV) of 0.000 06 (2), $P\gamma_{3,1}$ (63.9 keV) of 0.000 108 (4) and $P\gamma_{10,5}$ (74.54 keV) of 0.000 12 (3) have been adopted from 1981Ba68. The value $P\gamma_{9,2}$ (106.15 keV) of 0.000 49 (1) has been adopted from 2002Lu01. For absolute gamma-ray emission probabilities see 1981Ba68, 1984Va27, 2000Sc04, 2000Wo01, 2002Wo03, 2004Sh07. The remaining relative emission probabilities are listed in Table 9. These have been renormalized by the evaluators to Pγ (86.48 keV) = 12.26 (12) % obtained as a weighted average of 1984Banham, 1984Va27, 2000Sc04, 2000Wo01, 2002Wo03, 2002Lu01, 2004Sh07, 2008De10.

There are significant unexplained (as stated in 2002Wo03) discrepancies in the intensities of several gamma rays with the following energies: 29.4, 46.5, 88.0, 117.7, 169.2, 193.3, 195.0, 257.1 and 279.6 keV.

The value of $P\gamma_{4,0}$ (86.48 keV) used for normalization of the decay scheme is itself discrepant since this gamma ray and the gamma ray with the energy 86.6 keV from the decay of its daughter ^{233}Pa become apparent as a complex peak, and the separated intensities in various studies are not always in good agreement. Table 8 contains the experimental and evaluated values of the absolute emission probability of gamma ray $\gamma_{4,0}$ (86.48 keV). The results of 2000Sc04, 2002Lu01 and 2004Sh07 given in Table 8 have been corrected taking into account the intensity of gamma ray with the energy 86.6 keV from the decay of ^{233}Pa: Pγ (^{233}Pa, 86.6 keV) = 1.99 (11) %, see 2006Ch39.

Table 8. Experimental and recommended values of the 86.48 keV γ ray emission probability

1984Banham	1984Va27	2000Wo01 2002Wo03	2000Sc04	2002Lu01	2004Sh07	2008De10	Recommended
12.20 (12)	12.44 (33)	12.86 (21)	12.1 (3)	12.02 (12)#	11.6 (5)	12.38 (13)	12.26 (12)

Although the $P\gamma_{4,0}$ (86.48 keV) =11.40 (24) % is given in 2002Lu01, the evaluators used more accurate value of 14.01 (6) % measured in 2002Lu01 for Pγ (86.48+86.6 from ^{233}Pa decay) to deduce $P\gamma_{4,0}$ (86.48 keV)=12.02 (12) %.

The recommended values of the gamma ray emission probabilities given in Table 9 have been obtained by averaging experimental data using the LWEIGHT computer program. The uncertainty assigned in this evaluation to the recommended value is always greater than or equal to the smallest uncertainty in any of the experimental values used in the statistical processing.

The systematic uncertainties (1 %) of U KX-ray emission probability from 2008De10 have been added to statistic uncertainties measured in 2008De10.

The systematic uncertainties (20 %) of U LX-ray emission probability from 2008De10 have been added to statistic uncertainties measured in 2008De10.

Table 9 (part 1). Experimental and recommended emission probabilities of gamma rays in ^{237}Np decay

Eγ	1969Br12	1976Sk01	1979Go12	1981Ba68 1984Banham	1984Va27	1988Wo01 (Ge-detector)	1988Wo01 (LEPS-detector)
29.37	13.7 (20)	16.2 (9)	10.1 (10)	15.4 (2)	15.03 (40)	-	19.2 (9)
46.53	0.137 (20)	0.12 (2)	0.10 (1)	0.104 (6)	0.10 (1)	0.12 (1)	0.14 (2)
57.10	0.412 (38)	0.433 (25)	0.37 (4)	0.373 (11)	0.39 (1)	0.34 (1)	0.43 (3)
62.6		0.012		0.006 (2)			
63.9				0.0108 (4)			
86.48	12.6	12.3	12.3	12.20 (12)	12.44 (33)	12.3	12.3
87.99	0.157 (20)	0.14 (4)	0.12 (1)	0.138 (3)	0.14 (1)	-	-
94.64		0.62 (4)	0.54 (5)				
106.15		0.044 (9)	0.05 (5)				
108.7							
115.40		0.26 (8)					
117.70	0.167 (20)	0.180 (12)	0.148 (15)	0.175 (2)	0.168 (5)	0.16 (7)	0.15 (2)
131.1	0.087 (9)	0.10 (1)	0.079 (8)	0.086 (1)	-	0.091 (5)	0.09 (2)
134.28	0.069 (8)	0.081 (16)	0.062 (6)	0.071 (1)	-	0.080 (5)	
143.25	0.412 (40)	0.462 (28)	0.40 (4)	0.430 (4)	0.434 (10)	0.43 (1)	0.42 (3)
151.41	0.244 (30)	0.249 (16)	0.223 (23)	0.236 (2)	0.232 (6)	0.248 (7)	0.20 (3)
153.4		0.007 (2)					

155.24	0.095 (9)	0.097 (7)	0.085 (9)	0.0917 (10)	-	0.086 (6)	-
162.4		0.041 (7)	0.027 (4)			0.032 (4)	-
169.16	0.074 (8)	0.082 (9)	0.072 (7)	0.0711 (7)	-	0.057 (4)	-
170.59		0.016 (2)	0.024 (5)				
176.12		0.017 (3)				0.02 (4)	-
180.8		0.022 (5)	0.021 (4)			0.015 (2)	-
186.86		0.003 (3)					
191.46		0.017 (3)	0.026 (5)			0.014 (5)	-
193.26		0.043 (4)	0.05 (5)			0.049 (3)	-
194.67		0.05 (2)					
194.95	0.206 (20)	0.169 (21)	0.16 (2)	0.184 (2)	0.188 (5)	0.191 (6)	-
196.86		0.023 (3)	0.019 (4)			0.021 (2)	-
201.6		0.044 (5)	0.044 (5)			0.041 (4)	-
209.2		0.019 (2)	0.016 (3)			0.010 (2)	-
212.3	0.157 (20)	0.166 (11)	0.157 (16)	0.150 (2)	0.155 (5)	0.156 (4)	
214.0		0.047 (4)	0.06 (4)			0.034 (1)	
222.6		0.002 (2)					
229.94		0.011 (3)	0.018 (4)				
237.86	0.067 (6)	0.075 (9)	0.062 (7)	0.0586 (12)	-	0.059 (3)	-
248.95		0.005 (2)	0.05 (1)				
257.09		0.007 (3)	0.019 (6)				
262.44		0.008 (2)	0.007 (1)				
279.65		0.002 (2)	0.011 (4)				
288.3							

Table 9 (part 2). Experimental and recommended emission probabilities of gamma rays in ^{237}Np decay

Eγ	1990Lo04	2000Sc04	2000Wo01	2002Lu01	2004Sh07	2008De10	Recommended
29.37	13.7 (1)	14.1 (15)	13.2 (4)	13.51 (16)	13.15 (36)	15.08 (16)	14.3 (6)
46.53	0.112 (1)	0.104 (4)	0.1067 (19)	0.163 (5)	0.100 (13)	0.114 (3)	0.109 (4)
57.10	0.360 (2)	0.354 (8)	0.360 (5)	0.366 (3)	0.356 (16)	0.458 (6)	0.381 (21)
62.6							0.006 (2)
63.9	0.0090 (9)						0.0107 (4)
86.48	12.3	14.1 (3)&	12.86 (21)	14.01 (6)&	13.6 (5)&	12.38 (13)&	12.26 (12)
87.99	0.143 (1)			0.167 (4)	0.134 (13)	0.144 (5)	0.143 (3)
94.64				0.615 (23)	0.575 (19)	0.730 (10)	0.66 (7)
106.15	0.048 (1)				0.0509 (26)	0.0573 (28)	0.0509 (29)
108.7		0.0864 (19)		0.070 (3)	0.0723 (36)		0.071 (3)
115.40	0.47 (11)*	0.332 (10)*					0.0026 (8)#
117.70	0.168 (1)	0.169 (4)	0.188 (3)	0.184 (12)	0.169 (17)	0.1660 (29)	0.171 (4)
131.1	0.079 (1)	0.0857 (22)		0.088 (3)	0.075 (5)		0.084 (5)
134.28	0.064 (1)	0.0670 (28)		0.075 (3)	0.073 (6)		0.069 (5)
143.25	0.387 (2)	0.443 (8)	0.439 (5)	0.428 (3)	0.394 (24)	0.423 (6)	0.42 (4)
151.41		0.232 (24)	0.228 (3)	0.244 (3)	0.223 (14)	0.234 (4)	0.234 (2)
153.4							0.007 (2)
155.24	0.080 (1)	0.0889 (18)		0.091 (6)	0.087 (6)		0.088 (8)
162.4		0.0327 (12)					0.033 (1)
169.16		0.0633 (19)		0.092 (11)			0.0672 (3)
170.59							0.020 (4)
176.12		0.012 (4)					0.015 (3)
180.8		0.0158 (10)					0.016 (1)
186.86							0.003 (3)
191.46		0.0192 (12)		0.015 (4)	0.023 (5)		0.019 (1)
193.26		0.0437 (10)		0.030 (5)	0.041 (8)		0.044 (1)
194.67	0.033 (1)			0.033 (8)	0.03 (1)		0.033 (1)

194.95	0.156 (2)	0.177 (5)	0.161 (4)	0.164 (7)	0.161 (34)		0.174 (20)
196.86		0.0208 (12)		0.024 (5)	0.020 (4)		0.0208 (1)
201.6		0.0393 (9)					
209.2		0.0142 (9)		0.019 (2)	< 0.02		0.0150 (15)
212.3		0.151 (3)	0.148 (3)	0.150 (4)			0.17 (1)
214.0	0.132 (2)	0.0362 (8)		0.039 (2)			0.037 (2)
222.6							0.002 (2)
229.94							0.014 (3)
237.86		0.0569 (6)		0.056 (3)	0.067 (4)		0.0573 (6)
248.95		0.0050 (14)		0.006 (3)			0.005 (1)
257.09							0.02 (1)
262.44		0.00471 (18)					0.0048 (2)
279.65		0.0109 (4)					0.0108 (4)
288.3		0.0164 (5)					0.0162 (5)

* Sum intensity of $\gamma_{12,14}$ and KX(Pa)
# Adopted from 2005Si15
& Measured Pγ86.48+86.6 keV from ^{233}Pa decay)

6. Electron Emissions

The energies of the conversion electrons have been obtained from the gamma transition energies and the electron binding energies. The emission probabilities of conversion electrons have been deduced from the evaluated P(γ) and ICC values.

The number of K- and L- Auger electrons per 100 disintegrations has been deduced using the evaluated XK- and XL- emission probabilities.

7. Consistency of recommended data

The most accurate Q value, Q(M), is taken from the atomic mass adjustment table of Audi et al. (2003Au03). Comparison of Q(eff) (deduced as the sum of average energies per disintegration ($\sum E_i \times P_i$) for all emissions accompanying ^{237}Np α- decay) with the tabulated decay energy Q(M) allows to check a consistency of the recommended decay-scheme parameters obtained in this evaluation.

Here E_i and P_i are the evaluated energies and emission probabilities of the i-th alpha particle, beta particle, gamma ray, X-ray, etc. Consistency (percentage deviation) is determined by {[Q(M)– Q(eff))]/ Q(M)} ×100. "Percentage deviations above 5 % would be regarded as high and imply a poorly defined decay scheme; a value of less than 5 % indicates the construction of a reasonably consistent decay scheme" (quoted from the article by A.L. Nichols in Appl. Rad. Isotopes 55 (2001) 23-70).

For the above ^{237}Np decay data evaluation we have Q(M) = 4958.3 (12) keV and Q(eff) = 4966 (21) keV, i.e. consistency is not superior, but better than 1 %.

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^{238}Np - Comments on evaluation of decay data by V. P. Chechev and N.K. Kuzmenko

This evaluation was completed in November 2006 with a literature cut off by the same date.

1. Decay Scheme

The decay scheme is based on the evaluation of Chukreev *et al.* (2002Ch52) and can be basically considered completed.

2. Nuclear Data

Q^- value is from 2003Au03.

The evaluated half-life of ^{238}Np is based on the experimental results given in Table 1.

Table 1. Experimental values of the ^{238}Np half-life (in days)

Reference	Author(s)	Value
1950Fr53	Freedman *et al.*	2,10 (1)
1958Al92	Albridge *et al.*	2,16 (15)
1966Qa01	Qaim	2,117 (2)
1990Ch35	Chang *et al.*	2,0980 (3)*
2006Re09	Rengan *et al.*	2,1024 (5)*

* Only statistical uncertainty

The evaluators increased the relative uncertainties of 1990Ch35 and 2006Re09 to 0,05 % to take into account possible systematic uncertainties. The LWEIGHT computer program has omitted the outlier of 1958Al92 and used a weighted average of 2,1024 with the expanded uncertainty of 0,0044 to give a recommended value.

The adopted value of the ^{238}Np half-life is 2,102 (5) days.

2.1. Beta Transitions

The energies of β^- transitions have been calculated from the Q^- value and the level energies given in Table 2 from 2006Re09. The probabilities of β^--transitions have been deduced from the P(γ+ce) balance for each level of ^{238}Pu.

The β transition probability to the 44-keV level has been deduced from the 44-keV level intensity balance using P($\gamma_{1,0}$ +ce)(44,07-keV) obtained from the intensity balance for the ground state (see 2.2)

Table 2. ^{238}Pu levels populated in the ^{238}Np β^--decay

Level number	Level Energy, keV	Spin and parity	Half-life	Probability of β^--transition (%)
0	0,0	0^+	87,74 (3) a	-
1	44,08 (2)	2^+	177 (5) ps	41,0 (25)
2	145,95 (2)	4^+		-
3	303,38 (6)	6^+		-
4	605,14 (4)	1^-		0,103 (3)
5	661,40 (6)	3^-		0,036 (3)
6	763,24 (11)	5^-		-
7	941,46 (8)	0^+		-
8	962,78 (2)	1^-		1,25 (1)
9	968,2 (4)	(2^-)		0,082 (6)
10	983,09 (7)	2^+		0,27 (3)
11	985,45 (5)	2^-		0,49 (1)
12	1028,54 (2)	2^+		44,75 (19)
13	1069,94 (2)	3^+		11,50 (7)
14	1082,56 (6)	$(4)^-$		-
15	1202,46 (8)	$(3)^-$		0,51 (6)

Table 3. Measured and evaluated β^- energies (keV) and probabilities (%) in the ^{238}Np decay

1955Ra28		1956Ba95	1962Bo03		**Evaluated**	
E$_{\beta^-}$	**P**$_{\beta^-}$	**P**$_{\beta^-}$	**E**$_{\beta^-}$	**P**$_{\beta^-}$	**E**$_{\beta^-}$	**P**$_{\beta^-}$
			200	8	221,6 (4)	11,50 (7)
			250 (10)	31		
258	53	55			263,0 (4)	44,75 (19)
			280 (10)	20		
			1133	2,8		
1272	47	45	1236 (5)	38	1247,4 (4)	41,0 (25)

2.2. Gamma Transitions and Internal Conversion Coefficients

The evaluated energies of gamma-ray transitions are essentially the same as the gamma-ray energies because nuclear recoil is negligible.

The P(γ+ce) values have been calculated from the gamma-ray emission probabilities and the total internal conversion coefficients (ICC's).

For E0- gamma transition 941,5-keV ($\gamma_{7,0}$) the value P(ce) = 0,0106 (9) is based on measurements P(ceK) of 1981Le15 and ICC ratios from the BrIcc package.

The experimental values of ICC's (from 1981Le15) have been adopted for the following gamma-ray transitions: 120,11-keV ($\gamma_{15,14}$), 220,9-keV ($\gamma_{-1,6}$), 923,9-keV ($\gamma_{13,2}$), (E0+E2) gamma-ray transition 939-keV ($\gamma_{10,1}$) (see also 1960Al29), 983,0-keV ($\gamma_{10,\ 0}$) and 984,5-keV ($\gamma_{12,1}$). ICC's have been interpolated from the BrIcc package. The relative uncertainties of α_K, α_L, $\alpha_{M,}$ α_T for pure multipolarities have been taken as 2 %. The multipolarities and E2/M1, M2/E1 mixing ratios have been taken from 2002Ch52. These are based on conversion electron measurements of 1952Du12, 1956Ba95, 1956Sm18, 1960As10, and 1965Ak02.

$P(\gamma_{1,0}$ +ce)(44,08-keV) has been deduced from the intensity balance for the ground state assuming that there is no beta-feeding to the ''0''-level. The second forbidden beta-transition is expected to the ground state with lg *ft* > 15 which implies < 0,01 % (2006Re09).

3. Atomic Data

3.1. Fluorescence yields

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

3.1.1. X rays

The Pu KX-ray relative emission probabilities have been taken from 1999ScZX

3.1.2. Auger Electrons

The energies of Auger electrons have been calculated from atomic electron binding energies.
The P(KLX)/P(KLL), P(KXY)/P(KLL) ratios have been taken from 1996Sc06.

5. Electron Emissions

The energies of the conversion electrons have been calculated from the gamma transition energies and the electron binding energies.

The emission probabilities of the conversion electrons have been calculated using evaluated P_γ and ICC values.

The absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program.

β^- average energies have been calculated using the LOGFT computer program.

6. Photon emissions

6.1. X-Ray Emissions

The absolute emission probabilities of Pu KX- and LX-rays have been calculated using the EMISSION computer program.

Table 4. Measured and evaluated probabilities of Pu KX in the decay of ^{238}Np.

	1972Wi22	1981Le15	Evaluated
$K\alpha_2$	0,18(1)		0,210 (8)
$K\alpha_1$	0,272(12)		0,332 (12)
$K\beta'_1$		0,11	0,122 (5)
$K\beta'_2$		0,050	0,042 (2)

6.2. Gamma Emissions

The gamma ray energies have been evaluated from experimental data (Table 3)

Table 5. The measured and recommended gamma ray energies in the ^{238}Np β^--decay (keV).

1970Lederer	1972Wi22	1981Le15	2006Re09	Recommended
44	44,08 (3)		44,06 (2)	44,07 (2)
101,93 (4)	101,88 (2)		101,88 (3)	101,88 (2)
			103,74 (2)	103,74 (2)
			116,27 (8)	116,27 (8)
			117,27 (8)	117,27 (8)
119,9 (1)	120,14 (5)		120,09 (5)	120,11 (5)
			120,5	120,5
			120,70 (8)	120,70 (8)
			121,70 (8)	121,70 (8)
132,49 (11)	132,6 (6)		132, 8 (5)	132,5 (1)
157,4 (3)		157,42 (5)	157,42	157,42 (5)
173,78 (11)	174,06 (8)		174,08 (5)	174,08 (5)
220,87 (11)			220,87	220,87 (11)
301,19 (12)	301,81 (19)		301,37 (7)	301,37 (7)
319,29 (11)			319,96 (20)	319,29 (11)
321,75 (20)			321,75	321,75 (20)
323,98 (9)	324,08 (17)		324,07 (15)	324,02 (9)
357,60 (9)	357,64 (7)		357,68 (9)	357,64 (7)
378,05 (13)			378,0 (10)	378,05 (13)
380,28 (13)	380,33 (22)		380,33 (10)	380,31 (10)
421,15 (11)	421,12 (16)		421,05 (10)	421,10 (10)
459,8 (2)		459,80 (22)	459,8 (2)	459,8 (2)
515,58 (12)	515,47 (17)	515,25 (19)	515,53 (7)	515,51 (7)
561,09 (10)	561,15 (7)	561,02 (10)	561,17 (5)	561,14 (5)
605,24 (13)	605,14 (9)	605,04 (10)	605,18 (5)	605,16 (5)
617,45 (12)	617,39 (11)	617,22 (12)	617,41 (5)	617,39 (5)
837,18 (15)	837,0 (4)	837,01 (15)	836,88 (7)	836,96 (7)
882,65 (7)	882,63 (3)		882,63 (3)	882,63 (3)
897,28 (20)		897,33 (10)	897,55 (30)	897,34 (10)
918,70 (7)	918,69 (4)	918,7 (2)	918,70 (4)	918,70 (4)
923,99 (6)	923,98 (2)		923,99 (2)	923,99 (2)
936,57 (9)	936,61 (6)		936,60 (5)	936,60 (5)
939,00 (10)	938,6 (5)	938,91 (10)	938,85 (30)	938,94 (10)
941,39 (6)	941,38 (5)		941,41 (4)	941,40 (4)
941,5 (3)				941,5 (3)
962,80 (7)	962,77 (3)	962,8 (2)	962,76 (2)	962,76 (2)
984,46 (7)	984,45 (2)	984,5 (1)	984,45	984,45 (2)
1025,87 (6)	1025,87 (2)		1025,87 (2)	1025,87 (2)
1028,54 (6)	1028,54 (2)	1028,5 (2)	1028,53 (2)	1028,54 (2)

The absolute emission probabilities for gamma-rays have been deduced from the evaluated relative intensities (see Table 6) using the weighted mean P($\gamma_{12,1}$)(984,5-keV) = 0,2518 (13) of the two absolute measurement results: 0,2517 (13) from 2006Re09 and 0,2519 (21) from 1990Ch15.

It should be noted that in 1981Le15 the differing absolute value of P($\gamma_{12,1}$)(984,5-keV) = 0,278 (8) was deduced from an intensity balance for the ground state of ^{238}Pu.

Using the value of 0,397 (6) from 2006Re09 for the relative gamma ray intensity of $\gamma_{1,0}$ (44,07-keV) and the evaluated relative intensities for the remaining gamma-rays from Table 4, we obtain from the ground state intensity balance the value of P($\gamma_{12,1}$)(984,5-keV) = 0,257 (6) which supports our above more exact value and disagree with 1981Le15.

The absolute gamma ray intensity for $\gamma_{1,0}$ (44,07-keV) has been deduced from the evaluated P($\gamma_{1,0}$ + c.e.)(44.07 keV) and the adopted total ICC.

The absolute gamma ray intensities for $\gamma_{5,1}$ (617,36-keV) and $\gamma_{6,2}$ (617,36-keV) have been deduced using the ratio P($\gamma_{5,1}$)(617,36-keV) /P($\gamma_{6,2}$)(617,36-keV) = 65/9 adopted from 1981Le15.

The relative gamma ray intensity (P'(γ)) and energy for $\gamma_{9,4}$ (924-keV) have been adopted from 1970Be57.

The recommended P'(γ) for $\gamma_{1,0}$ (44,07-keV) has been obtained as a ratio of the evaluated P($\gamma_{1,0}$)(44,07-keV) to P($\gamma_{12,1}$)(984,5-keV) and it has also been compared to measured values.

Table 6. Measured and evaluated relative gamma-ray intensities.

Energy (keV)	1972Wi22	1981Le15*	1990Ch35	2006Re09	Recommended
44,07	≈0,2	0,32 (4) [a]	0,35 (4)	0,397 (6)	0,406 (9)
99,53				0,771 (8)	0,771 (8)
101,9	0,88 (2)	0,97 (4)	1,01 (3)	1,01 (1)	1,00 (3)
103,7				1,24 (1)	1,24 (1)
116,3				0,158	0,158
117,3				0,295	0,295
120,1	0,41 (2)	0,37 (3)		0,453 (9)	0,40 (2)
120,5				0,079	0,079
120,7					
121,7				0,040 (4)	0,040 (4)
132,5	0,013 (7)	0,0101 (7)		0,0056 (3)	0,0056 (3)
157,4		≈0,004			≈0,004
174,0	0,11 (1)	0,094 (4)	0,091 (3)	0,088 (6)	0,091 (3)
220,9		0,0122 (14)		0,007 (6)	0,012 (2)
301,4	0,05 (1)	0,043 (4)	0,040 (4)	0,054 (11)	0,042 (4)
319,3		0,032 (4)		0,038 (12)	0,033 (4)
321,8		0,0047 (22)		0,008 (8)	0,005 (2)
324,0	0,070 (11)	0,058 (4)	0,057 (3)	0,061 (10)	0,058 (3)
336,4					0,0009 (5)
357,6	0,22 (2)	0,191 (11)	0,200 (5)	0,20 (1)	0,200 (5)
378,0		0,012 (2)		0,008 (8)	0,012 (2)
380,3	0,05 (1)	0,043 (2)		0,064 (12)	0,044 (2)
421,1	0,096 (15)	0,083 (4)	0,087 (4)	0,079 (12)	0,085 (4)
459,8		≈0,011		0,009 (6)	0,009 (6)
515,5	0,14 (2)	0,155 (7)	0,148 (5)	0,14 (1)	0,150 (5)
561,1	0,43 (2)	0,41 (2)	0,416 (7)	0,461 (16)	0,423 (7)
605,2	0,31 (3)	0,284 (14)	0,318 (9)	0,29 (2)	0,306 (9)
617,39 (5) } 617,4	0,29 (3)	0,266 (14)	0,270 (9)	0,262 (12)	0,268 (9)
837,0	0,076 (22)	0,101 (7)		0,079 (3)	0,082 (3)
882,6	3,19 (16)	3,13 (11)	3,23 (3)	3,17 (2)	3,19 (2)
885,0				0,16 (2)	0,16 (2)
897,3		0,029 (4)	0,029 (4)	0,032 (8)	0,029 (4)
918,7	2,16 (11)	2,12 (7)	2,11 (2)	2,09 (2)	2,10 (2)
923,99	10,4 (5)	10,3 (3)	10,4 (1)	10,32 (6)	10,34 (6)
924					0,26
936,6	1,39 (7)	1,44 (4)	1,46 (2)	1,41 (11)	1,45 (2)
938,9	0,13 (6)	0,10 (3)	0,13 (1)	0,13 (1)	0,13 (1)
941,4	1,91 (10)	1,98 (7)	2,04 (2)	1,97 (2)	2,00 (2)
941,5					
962,8	2,56 (13)	2,52 (7)	2,56 (3)	2,56 (3)	2,56 (3)
968,5	0,06 (2)	-	-	0,004	0,06 (2)
983,0					0,27 (8)
984,4	100	100	100	100	100
1025,9	34,5 (17)	34,9 (22)	34,59 (50)	34,82 (18)	34,79 (18)
1028,5	72,5 (36)	73,0 (29)	72,61 (70)	72,42 (37)	72,47 (37)

* Absolute gamma-ray emission probabilities cited in 1981Le15 (normalized to 27,8 for the 984,5-keV gamma- ray) have been converted to the relative gamma-ray intensities.
[a] Measured value. In 1981Le15 it is noted that the value deduced from an intensity balance is 0,36 (2).

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^{239}Np – Comments on evaluation of decay data by V.P. Chechev and N.K. Kuzmenko

This evaluation was completed in June 2006. The literature available by May 2006 was included.

1. Decay Scheme

Decay scheme has been taken from 2003Br12.

2. Nuclear Data

Q^- value is from 2003Au03.

The evaluated half-life of ^{239}Np is based on the experimental results given in Table 1.

Table 1. Experimental values of the ^{239}Np half-life (in days)

Reference	Author(s)	Value
1956Wi25	Wish	2,346 (4)
1959Co63	Connor and Fairweather	2,34 (2)
1959Co93	Cohen *et al.*	2,366 (3)
1966Qa01	Qaim	2,354 (8)
1969Bi12	Bigham *et al.*	2,346 (4)
1990Ab06	Abzouzi *et al.*	2,3565 (4)

The weighted average of 2,3564 for this discrepant data set of the 6 values is dominated by the very accurate value of 1990Ab06. The LWEIGHT computer program, which uses a limitation of relative statistical weights (LRSW method), has increased the 1990Ab06 uncertainty from 0,0004 to 0,0020 and used a weighted average and an external uncertainty having led to 2,356 (3) as a recommended value.

Thus, the adopted value of the ^{239}Np half-life is **2,356 (3) days**.

2.1. Beta Transitions

The energies of β^- transitions have been calculated from the Q^- value and the level energies given in Table 2 from 2003Br12 where they have been deduced from a least squares fit to gamma-ray energies (see also 1996FiZX).

Table 2. ^{239}Pu levels populated in the ^{239}Np β^--decay

Level	Energy (keV)	Spin and parity	Half-life	Probability of β^--transition (%)
0	0	1/2+	24100 (11) a	-
1	7,861 (2)	3/2+	36 (3) ps	6,5 (10)
2	57,276 (2)	5/2+	101 (5) ps	0,4 (72)
3	75,706 (3)	7/2+	83 (8) ps	-
4	163,76 (2)	9/2+	73 (4) ps	-
5	285,460 (2)	5/2+	1,12 (5) ns	43,0 (22)
6	330,125 (4)	7/2+		9,4 (14)
7	387,41 (2)	9/2+		-
8	391,586 (3)	7/2-	193 (4) ns	38,8 (9)
9	469,8 (4)	(1/2-)		0,0027

Level	Energy (keV)	Spin and parity	Half-life	Probability of β^--transition (%)
10	492,2 (3)	3/2-		0,02
11	505,2	(5/2-)		0,0074
12	511,81 (6)	7/2+		1,56 (16)
13	556,2	(7/2-)		0,0026

The probabilities of β^--transitions have been deduced from the P(γ+ce) balance for each level of ^{239}Np. Measured and evaluated β^--transition probabilities are given in Table 3.

Table 3. Measured and evaluated probabilities (%) of β^- -transitions

	1952Fr25	1956Ba95	1959SCo63	Adopted
$\beta_{0,8}$	52	45	28	38,8 (9)
$\beta_{0,6}$	10	27	13,5	9,4 (14)
$\beta_{0,5}$	31	21	48	43,0 (22)
$\beta_{0,2}$	1,7	}	4	0,4 (72)
$\beta_{0,1}$	4,8	}7	6,5	6,5 (10)

2.2. Gamma-ray Transitions and Internal Conversion Coefficients

The evaluated energies of gamma-ray transitions are virtually the same as the photon energies because nuclear recoil is negligible.

The gamma-ray transition probabilities, P(γ+ce), have been calculated from the gamma-ray emission probabilities and the total internal conversion coefficients (ICC's). Multipolarities of gamma-ray transitions have been taken from 2003Br12 (see also 1996FiZX). ICC's have been interpolated from the BrIcc package. The relative uncertainties of α_K, α_L, $\alpha_{M,}$ α_T for pure multipolarities have been taken as 2 %. The transition $\gamma_{8,5}$ is anomalously converted, ICC's for this transition have been taken from the measurements of 1959Ew90.

P($\gamma_{1,0}$ +ce)(7,86-keV) has been deduced from the intensity balance for the ground state assuming that there is no beta-feeding to the ''0''-level. P($\gamma_{3,2}$ +ce) (18,43-keV) has been deduced from the intensity balance for the level ''3'' (75,70-keV) assuming that there is no beta-feeding to the ''3''-level.

The mixing ratios (d) for gamma-ray transitions have been taken from 2003Br12 based on measurements of 1959Ew90, 1972Kr07, 1990Si12 and 1991Sh06.

3. Atomic Data

3.1. Fluorescence yields

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

3.2. X Radiations

The LX-ray energies are from 1996FiZX. The KX-ray energies and the relative KX-ray emission probabilities are from 1999Schönfeld .

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

4. Electron Emissions

The energies of the conversion electrons have been calculated from the gamma transition energies and the electron binding energies.

The emission probabilities of the conversion electrons have been calculated using evaluated P_{γ} and ICC values.

The absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program.

β^{-} average energies have been calculated using the LOGFT computer program.

5. Photon Emissions

5.1. X-Ray Emissions

The absolute emission probabilities of Pu KX- and LX-rays have been calculated using the EMISSION code.

Measured and calculated absolute emission probabilities of Pu KX-rays are given in Tables 4.

Table 4. Measured and calculated absolute emission probabilities (%) of Pu KX-rays.

	1972Ah02	1982Ah04	Calculated
$K\alpha_2$ (Pu)	14,4 (6)	12,8 (4)	13,5 (4)
$K\alpha_1$ (Pu)	22,2 (6)	20,4 (6)	21,4 (6)
$K\beta'_1$ (Pu)	-	7,3 (3)	7,84 (25)
$K\beta'_2$ (Pu)	2,8 (1)	2,6 (1)	2,72 (10)

5.2. Gamma-Ray Emissions

The gamma ray energies, $E\gamma$, for $\gamma_{1,0}$ (7,86-keV) , $\gamma_{2,1}$ (49,4-keV) and $\gamma_{4,2}$ (106,5-keV) were calculated from the level energies. The gamma ray energies with $E\gamma$ > 334,3 keV have been taken from 1974HeYW. The other gamma energies were adopted from 2003Br12 based on experimental data of 1959Ew90, 1965Ma17, 1972Po04, 1979Bo30 and 1982Ah04.

$P(\gamma_{1,0})$(7,86-keV) has been deduced from $P(\gamma_{1,0}$ +ce) (7,86-keV) and the adopted α_T.

$P(\gamma_{3,2})$(18,43-keV) has been deduced from $P(\gamma_{3,1})$ (67,84-keV) and the ratio of $P(\gamma_{3,2}$ +ce) (18,43-keV)/$P(\gamma_{3,1}$) (67,88-keV) < 0,2 from 1996FiZX.

$P(\gamma_{2,0})$(57,273-keV) = 0,12 (3) % has been deduced from $P(\gamma_{2,1})$ (49,41-keV) and $P(\gamma_{2,1})$ (49,41-keV)/ $P(\gamma_{2,0}$)(57,27-keV) = 0,85 (12) from 1996FiZX.

$P(\gamma_{7,6})$(57,29-keV) ~ 0,012 % has been deduced from $P(\gamma_{7,6})$(57,3-keV) + $P(\gamma_{2,0})$(57,273 -keV) = 0,135 (7) % and $P(\gamma_{2,0})$(57,273-keV).

$P(\gamma_{8,6})$(61,88-keV) and $P(\gamma_{3,1})$(67,84-keV) have been taken from 1974HeYW.

$P(\gamma_{7,5})$(101,96-keV) has been taken from ^{239}Am e decay (see 2003Br02).

$P(\gamma_{8,4})$(227,83-keV) has been taken from the decay scheme (see 2003Br02).

$P(\gamma_{6,1})$(322,3-keV) has been deduced from the $P\gamma$ branching in ^{239}Am e decay and ^{243}Cm a decay (see 2003Br02).

$P(\gamma_{4,3})$(88,06-keV), $P(\gamma_{4,2})$(106,50-keV) and $P(\gamma_{6,4})$(166,39-keV) have been calculated from the conversion data of 1959Ew90 and the adopted α_T.

$P(\gamma_{7,3})$(311,70-keV) = 0,002 (2) % has been deduced from $P(\gamma_{7,3})$(311,70-keV)/$P(\gamma_{7,6})$(57,29-keV) = 0,34 (14) from 1996FiZX.

The absolute emission probabilities of the other gamma-rays have been evaluated from experimental data (Table 5).

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Table 5. Experimental and evaluated absolute emission probabilities (%) for gamma-rays in the decay of ^{239}Np.

E $_{\gamma}$(keV)	1972Ah02	1974Yu04	1974HeYW	1977St35 1991Po17	1979Mo25	1982Ah04	1984Va41	1986Ch17	1986Wo05	1992Ha02	Adopted
44,66						0,13 (1)					0,13 (1)
49,41			0,18 (3)			0,11 (1)					0,145 (35)
57,273						0,135 (7)					0,12 (3)
57,3											~0,012
61,46						1,29 (6)	1,29 (2)		1,40 (7)	1,27 (3)	1,29 (2)
106,12	27,8 (9)			26,6 (10)		26,4 (8)	27,50 (40)	26,08 (38)	25,23 (28)	25,6 (2)	25,9 (3)
181,69	0,075 (8)					0,083 (4)	0,07 (1)		0,085 (5)	0,088 (2)	0,086 (2)
209,75	3,42 (10)			3,36 (14)		3,30 (10)	3,46 (5)	3,28 (5)	3,43 (7)	3,47 (3)	3,42 (3)
226,38				0,24 (3)		0,290 (16)	0,28 (2)		0,230 (14)	0,25 (1)	0,255 (14)
228,18	11,4 (3)			11,78 (44)		11,2 (3)	11,21 (18)	11,05 (14)	10,91 (16)	11,54 (5)	11,32 (22
254,41	0,11 (1)					0,110 (6)	0,12 (1)		0,1078 (27)	0,113 (4)	0,110 (3)
272,84	0,08 (1)					0,077 (4)	0,08 (1)		0,0762 (24)		0,077 (3)
277,60	14,5 (5)	14,1 (4)		15,0 (4)	14,30 (24)	14,5 (4)	14,38 (21)	14,21 (13)	14,53 (17)	14,46 (10)	14,4 (1)
285,46	0,76 (2)			0,93 (6)		0,790 (25)	0,77 (2)	0,765 (9)	0,797 (10)	0,80 (1)	0,78 (1)
315,88	1,52 (5)			1,63 (7)		1,60 (5)	1,60 (3)	1,55 (2)	1,604 (20)	1,60 (1)	1,59 (1)
334,31	1,95 (7)			2,1 (1)		2,06 (6)	2,08 (3)	1,99 (2)	2,050 (25)	2,05 (2)	2,04 (2)
392,4			0,0016								0,0016
429,5			0,0039								0,0039
434,7			0,013								0,013
447,6			0,00026								0,00026
454,2			0,00082								0,00082
461,9			0,0016								0,0016
469,8			0,0011								0,0011
484,3			0,001								0,001
492,3			0,006								0,006
497,8			0,0032								0,0032
498,7			0,001								0,001
504,2			0,00078								0,00078

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

This evaluation was done originally in March 2003, corrected in June 2004, and then updated in June 2009 with a literature cut-off by the same date.

1. DECAY SCHEME

The decay scheme is based on 2007Br04. Some expected weak gamma-ray transitions were not observed directly in ^{238}Pu α-decay but have been adopted from decay of ^{234}Pa and ^{234}Np.

2. NUCLEAR DATA

Q(α) value is from 2003Au03.

The recommended half-life of ^{238}Pu is based on the experimental results given in Table 1.

Table 1. Experimental values of ^{238}Pu half-life (in years)

Reference	Author(s)	Original value [a]	Re-estimated value [a]	Measurement method	Used for final averaging
1950Jaffey	Jaffey and Lerner	89.59 (37)	89.3 (9) [b]	Direct decay (4 samples)	No
1951Jaffey-1	Jaffey and Magnusson	77	-	Growth of ^{238}Pu from ^{238}Np	No
1951Jaffey-2	Jaffey	89 (9)	-	Direct decay	No
1951Seaborg	Seaborg et al.	92 (2)		Growth of ^{238}Pu from ^{242}Cm	No
1954Jo10	Jones et al.	89			No
1957Ho71	Hoffman et al.	86.41 (30)	86.4 (5) [b]	Growth of ^{238}Pu from ^{242}Cm	No
1965Eichelber	Eichelberger et al.	87.60 (6)	-	Calorimetry	No
1967Jordan	Jordan	87.22 (52)	-	Calorimetry	No
1969Benson	Benson	87.75 (5)	-	Calorimetry	No
1974StYG	Strohm and Jordan	87.77(3)	-	Calorimetry	Yes
1976Po08	Polyukhov et al.	86.98 (20)	87.0 (7) [c]	Specific activity	Yes
1977Di04	Diamond et al.	87.71 (3)	-	Growth of ^{238}Pu from ^{242}Cm	Yes
1981Ag06	Aggarwal et al.	87.98 (51)	-	Relative activity ^{238}Pu/^{239}Pu	Yes
1981 Sevastyanov	Sevastyanov and Yarina	86.51 (30)	86.5 (9) [d]	Direct decay (1 sample)	No

[a] Uncertainty at the level of 1σ.
[b] Re-estimated in 1977Di06.
[c] Re-estimated by the evaluator using analysis of 1977Di06.
[d] Re-estimated by the evaluator.

By omitting two values reported without uncertainties, the weighted average of the remaining 12 values is 87.73 with an internal uncertainty of 0.019 and $\chi^2/\nu = 2.0$. The average value of 87.73 (3) could be adopted for half-life of ^{238}Pu. However several calorimetric results obtained in the same laboratory (MLM) may be correlated. In fact, the value 87.77 (3) (1974StYG) comes from the latest calorimetric measurement at this laboratory. Also, the early inaccurate experimental results published in 1950 – 1957 may be omitted, as they were obtained with samples of low isotopic purity. Besides, there are grounds for omitting the result of 1981Sevastyanov (V. D. Sevastyanov and V. P. Jarina, Voprosi Atomnoi Nauki i Tekhniki, seriya Jadernie Konstanti. 5(44)(1981)21), as it was obtained only from one sample using an inaccurate method of direct decay.

Therefore, the four best experimental results obtained by different methods were used for the final statistical analysis. These are 87.77 (3) – 1974StYG; 87.0 (7) – 1976Po08; 87.71 (3) –1977Di04 and 87.98 (51) – 1981Ag06. The weighted average of these data sets is 87.74 with an internal uncertainty of

0.021 and χ^2/ν = 1.1. The recommended value of ^{238}Pu half-life is 87.74 (3) years where the uncertainty is the smallest experimental uncertainty.

The evaluated spontaneous fission half-life of ^{238}Pu has been based on the experimental results given in Table 2. The weighted average of 5 selected values (with reported uncertainties) is 4.74 with an internal uncertainty 0.081 and χ^2/ν = 0.72.

The recommended value of ^{238}Pu spontaneous fission is 4.74 (12)·10^{10} years where the uncertainty is the smallest experimental uncertainty.

Table 2. Experimental values of ^{238}Pu spontaneous fission half-life (in 10^{10} years)

Reference	Author(s)	Original value [a]	Re-estimated value [a]	Measurement method	Used for final averaging
1949Jaffey	Jaffey and Hirsch	4.9 (4)	4.7 (6) [b]	Ioniz. chamber	Yes
1952Se67	Segre	2.6	3.9 [b]	Ioniz. chamber	No
1961Dr04	Druin et al.	5.0 (6)	5.1 (6) [b]	Photoemulsion	Yes
1972Ha11	Hastings and Strohm	4.77 (14)	-	Si(Au)	Yes
1975GaZX	Gay and Sher	4.63 (12)	-	Fission fragm. coincid. in mica	Yes
1988SeZY	Selitsky et al.	5.01 (21)	-	2π ioniz. chamber	Yes

[a] Uncertainty at the level of 1σ.
[b] Adjusted in 1972Ha11 to ^{238}Pu half-life of 87.77 yr. See also 2000Ho27.

2.1. Alpha Transitions

The energies of the alpha transitions have been obtained from the Q value and the level energies given in Table 3 from 2007Br04.

Table 3. ^{234}U levels populated in ^{238}Pu α decay

Level number	Energy, keV	Spin and parity	Half-life	Probability of α-transition (x100)
0	0,0	0+	2.455 (6) 10^5 yr	71.04 (6)
1	43.4981 (10)	2+	0.252 (7) ns	28.85 (6)
2	143.352 (4)	4+		0.104 (3)
3	296.072 (4)	6+		0.00292 (4)
4	497.04 (3)	8+		6.80 (23)·10^{-6}
5	786.288 (16)	1-		8.21 (16)·10^{-6}
6	809.907 (18)	0+	< 0.1 ns	1.0·10^{-4}
7	849.266 (18)	3-		7.5 (22)·10^{-8}
8	851.74 (3)	2+	> 1.74 ps	8.1·10^{-6}
9	926.720 (15)	2+	1.38 (17) ps	1.30 (5)·10^{-6}
10	947.64 (6)	4+		2.3·10^{-7}
11	989.430 (13)	2-	0.76 (4) ns	1.50 (15)·10^{-7}
12	1023.77 (3)	4+		~ 2.0·10^{-7}
13	1044.536 (23)	0+		1.17(7)·10^{-6}
14	1085.26 (4)	2+		~ 1.2·10^{-6}

The probabilities of the most intense transitions $\alpha_{0,0}$ and $\alpha_{0,1}$ have been obtained by averaging experimental data (Table 4). The probabilities of all the remaining α-transitions have been deduced from the P(γ+ce) balances at relevant levels in ^{234}U.

Table 4. Experimental and recommended values of α-transition probabilities (×100) in the decay of ^{238}Pu

	Energy keV	1954 As07	1957 Ko33	1970 Ba72	1971 So15	1984 Ah06	1984 Bo41	1984 Burns	1987 Bo25	1998 Ya17	Recommended
$\alpha_{0,0}$	5499	72 [a]	71.1 (12)	72.2 [a]	70.7 (2)	70.9 (1)	70.91 (10)	71.11 (4)	71.3 (6)	71.14 (10)	71.04 (6) [b]
$\alpha_{0,1}$	5456	28 [a]	28.7 (12)	27.8 [a]	29.3 (2)	29.0 (1)	28.98 (10)	28.78 (4)	28.6 (4)	28.74 (10)	28.85 (6) [b]
$\alpha_{0,2}$	5358		0.13 (1)	0.068 [a]	0.1 [a]	0.106 (3)	0.105 (5)	0.1002 (17)		0.114 (10)	0.104 (3) [c]
$\alpha_{0,3}$	5208		0.005 (1)	0.0018 [a]		0.036 (5)	0.0030 (1)				0.00292 (4) [d,e]
$\alpha_{0,4}$	5010			$\sim 4\cdot10^{-6}$							$6.80\ (23)\cdot10^{-6}$ [e]
$\alpha_{0,5}$	4726			$2.2\cdot10^{-5}$							$8.21\ (16)\ 10^{-6}$ [e]
$\alpha_{0,6}$	4703			$5\cdot10^{-5}$							$1.0\cdot10^{-4}$ [e,f]
$\alpha_{0,7}$	4664										$7.5\ (22)\cdot10^{-8}$ [e]
$\alpha_{0,8}$	4662			$< 2\cdot10^{-5}$							$8.1\cdot10^{-6}$ [e]
$\alpha_{0,9}$	4588			$(1.2\cdot10^{-5})$							$1.30\ (5)\cdot10^{-6}$ [e]

[a] Omitted from averaging because no uncertainty was reported.
[b] Weighted average of 7 experimental values; uncertainty is external.
[c] Weighted average of 5 experimental values (with quoted uncertainties) is 0.104 (3); the value deduced from P(γ+ce) balance is 0.1030 (24); the recommended value is 0.104 (3).
[d] Agrees well with the experimental value from 1984Bo41
[e] Evaluated from P(γ+ce) balance.
[f] Value of $1.2\ (4)\cdot10^{-4}$ was obtained by α–γ and α-ce coincidences in 1963Bj03.

2.2. Gamma Transitions and Internal Conversion Coefficients

The recommended energies of gamma-ray transitions are virtually the same as the gamma-ray energies because nuclear recoil is negligible for ^{234}U.

Gamma-ray transition probabilities [P(γ+ce)] have been deduced from the gamma-ray emission probabilities and total internal conversion coefficients (ICCs). The ICCs have been interpolated using the BrIcc package with the so called "*Frozen Orbital*" approximation (2008Ki07). The uncertainties in the ICCs for pure multipolarities have been taken as 2 %.

The emission probabilities of E0- and (E0+E2)- transitions have been obtained by using experimental conversion electron intensities from ^{234}Pa and ^{234}Np decays (see 2007Br04) and data from ^{238}Pu α-decay of 1963Bj03, 1964Le17, 1964Le22.

3. ATOMIC DATA

3.1. Fluorescence yields

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

3.2. X Radiations

The U KX-ray energies have been taken from 1999Schönfeld where the calculated values based on X-ray wavelengths from 1967Be65 (Bearden). In Table 5 the recommended values of U KX-ray energies are compared with experimental values.

The relative K X-ray emission probabilities have been taken from 1999Schönfeld.

Table 5. Experimental and recommended (calculated) values of U KX-ray energies (keV)

	1976GuZN	1982Ba56	1983Ah02	Recommended
$K\alpha_2$	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)- $K\beta_5''$ 112.043 (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 taken from the SAISINUC software supporting programs agree with the measurements of 1994Le37 where the fine structure of LX-radiation was measured in decays of ^{239}Pu and ^{240}Pu.

3.3. Auger Electrons

The energies of Auger electrons are from the SAISINUC software supporting programs.

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

4. ALPHA EMISSIONS

The energy of alpha particles corresponding to the alpha transition to the ground state of ^{234}U, $E(\alpha_{0,0})$, has been adopted from the absolute measurement of 1971Gr17 with a correction of – 0.18 keV recommended by A. Rytz in 1991Ry01 because of changes in calibrations energies.

The energies of all other alpha particles have been calculated from $Q(\alpha)$, $E(\alpha_{0,0})$ and the level energies taking into account the recoil energies.

In Table 6 the deduced (recommended) values of α-particle energies are compared with the experimental results obtained by using magnetic and semiconductor spectrometry.

Table 6. Experimental and recommended values of α-particle energies (keV) in decay of ^{238}Pu.

	Measured [a]						Recommended
	1954As07	1957Ko33	1962Le11	1968Ba25	1970Ba72	1971Gr17	
$\alpha_{0,0}$	5499	5497.7 (10)	5499.2 (8)	5499.2 (10)	5499.2 (8) [c]	5499.03 (20) [b]	5499.03 (20) [b]
$\alpha_{0,1}$	5456	5454.7 (10)	5456.3 (8)	5456.1 (10)	5456.1	5456.3 (4)	5456.3 (2)
$\alpha_{0,2}$	5358	5358.6 (10)	5362 (1)		5357.7		5358.1 (2)
$\alpha_{0,3}$		5215 (5)			5205.6		5208.0 (2)
$\alpha_{0,4}$					≈5015		5010.4 (2)
$\alpha_{0,5}$					4724		4726.0 (2)
$\alpha_{0,6}$					4704		4702.8 (2)
$\alpha_{0,7}$					-		4664.1 (2)
$\alpha_{0,8}$					4661		4661.7 (2)
$\alpha_{0,9}$					≈4590		4587.9 (2)

[a] Original values have been adjusted for changes in calibration energies as suggested in 1991Ry01.
[b] Absolute measurement; this value is recommended in 1991Ry01 and used in 2003Au03 for obtaining $Q(\alpha)$.
[c] Value is from 1962Le11; adopted in 1970Ba72 as calibration energy.

5. ELECTRON EMISSIONS

The energies of conversion electrons have been obtained from the gamma-ray transition energies and atomic-electron binding energies.

The emission probabilities of conversion electrons have been deduced from the evaluated P(γ) and ICC values. Below the experimental L1:L2:L3 conversion electron sub-shell intensities from 1969Am02 are compared with theoretical values for the most intense E2 transition of $\gamma_{1,0}$ (43.498 keV).

Theoretical	Measured
3.85 (11) : 113 (3) : 100	3.99 (22) : 114.7 (20) : 100

The total absolute emission probabilities of K Auger electrons have been deduced using the evaluated total P(XK) and the adopted fluorescence yield ω_K.

The total absolute emission probability of L Auger electrons have been deduced using the total evaluated P(XL) and the adopted fluorescence yield ϖ_L.

6. PHOTON EMISSIONS

6.1. X-Ray Emissions

6.1.1. M X-Rays

The total absolute emission probability of MX–rays is based on the measurement (1990Po14) of the relative emission probability P(MX)/P(LX) = 0.194 (24).

6.1.2. L X-Rays

The calculation of the total absolute emission probability of LX-rays [P(XL)], using the EMISSION computer program (2000Schönfeld), gives P(XL) = 10.55 (25) %. The available experimental results for P(XL) are discrepant: 13 % - 1954As07; 10.6 (3) % - 1964Ha14; 12.83 (14) % - 1968By01; 9.2 (1) % - 1968Salgueiro; 11.2 (4) % - 1968Swinth; 11.4 (3) % - 1971Swinth; 14.18 (11) % - 1976Va23; 11.38 (10) % - 1977Bemis; 11.55 (18) % - 1984Bo41; 10.62 (32) % - 1984DrZX and 1984BaYT; 10.63 (8) % - 1995Jo23.

The result of the most accurate and latest measurement (1995Jo23) agrees well with the calculated values and with the value from 1984DrZX where the fine structure of LX-radiation was measured. The value from 1995Jo23 has been adopted as the recommended absolute emission probability of U LX–rays from decay of ^{238}Pu: P(XL) = 10.63 (8) %.

For the evaluation of emission probabilities of the LX-ray components Ll, Lα, Lβη, Lγ the measured values given in Table 7 were renormalized by the evaluator to the adopted value P(XL) = 10.63 (8) % and then averaged. In Table 8 the evaluated emission probabilities are compared with values calculated in 1995Jo23 from alpha-branching ratios, theoretical ICC and theoretical atomic branching ratios.

Table 7. Experimental absolute emission probabilities of U LX-rays from α decay of ^{238}Pu

	1976Va23	1977Bemis	1984Bo41	1995Jo23
Ll	-	0.26 (1)	0.260 (7)	0.231 (3)
Lα	5.05 (6)	4.15 (7)	4.06 (6)	3.81 (3)
Lβη	7.41 (9)	5.61 (7)	5.85 (9)	5.31 (4)
Lγ	1.48 (2)	1.36 (2)	1.38 (2)	1.29 (1)

Table 8. Renormalized experimental, evaluated, and calculated absolute emission probabilities of U LX-rays from α decay of ^{238}Pu

	1976Va23 (measured)	1977Bemis (measured)	1984Bo41 (measured)	1995Jo23 (measured)	Adopted (averaged)	Calculated (1995Jo23)	Calculated (EMISSION code)
Ll	-	0.24 (1)	0.239 (7)	0.231 (3)	0.235 (4) [b]	0.234	0.232 (8)
Lα	3.77 (5)	3.88 (7)	3.74 (6)	3.81 (3)	3.80 (3) [c]	3.78	3.73 (12)
Lβη	5.53 (7) [a]	5.24 (7)	5.38 (8)	5.31 (4)	5.31 (4) [c]	5.42	5.23 (16)
Lγ	1.10 (2) [a]	1.27 (2)	1.27 (2)	1.29 (1)	1.28 (1) [c]	1.26	1.23 (4)

[a] Omitted from averaging based on statistical considerations.
[b] Weighted average; uncertainty is internal.
[c] Weighted average; uncertainty is the smallest experimental one.

6.1.3. KX-Rays

The absolute X-ray emission probability of U $K\alpha_2$ with energy 98.44 keV ($P(K\alpha_2)$) has been adopted from 1976GuZN. The absolute emission probabilities of all other X-rays have been deduced from their relative emission probabilities using the adopted $P(K\alpha_2) = 1.69\ (4) \cdot 10^{-4}$ %. (The uncertainty of this value includes an additional 2 % detector efficiency uncertainty).

The total absolute KX-ray emission probability P(XK) = $3.56\ (11) \cdot 10^{-4}$ %, obtained using $P(K\alpha_2)$ and the ratio of $P(XK) / P(K\alpha_2)$, exceeds the value calculated from ω_K and the total emission probability of K–conversion electrons $P^{(ce)}(XK) = 2.6 \cdot 10^{-4}$ %. This disagreement may be due to an inaccurate estimation of K-conversion electron intensities from E0 and (E0 + E2) transitions in decay of ^{238}Pu.

6.2. Gamma-Ray Emissions

6.2.1. Gamma-Ray Energies

The energies of prominent gamma-rays $\gamma_{1,0}$(43.5 keV), $\gamma_{2,1}$(99.9 keV) and $\gamma_{3,2}$(152.7 keV) have been taken from 1984He19, with a correction of 5.8 ppm in the gamma-ray energy scale as provided by 2000He14. The energies of gamma-rays $\gamma_{13,5}$(258.2 keV) and $\gamma_{5,1}$(742.8 keV) are from 2000Ni13. The remaining gamma-ray energies have been taken from 2007Br04 based on the measurements of 1969LeZX and also 1954As07, 1955Ch02, 1956Ne17, 1971Cl03, 1971GuZY, 1971Ma68, 1976GuZN, 1984Ov01. Several of gamma-rays were not observed in ^{238}Pu α-decay and their energies have been taken from the decay of ^{234}Pa and ^{234}Np (2007Br04). The experimental and recommended gamma-ray energies are given in Table 9.

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

	1969LeZX	1971GuZY	1972Sc01	1976GuZN	1984He19	Recommended
$\gamma_{1,0}$		43.492 (10)	43.491 (9)	43.477 (5)	43.498 (1)	43.498 (1)
$\gamma_{2,1}$	99.84 (4)	99.871 (10)	99.85 (1)	99.864 (5)	99.853 (3)	99.852 (3)
$\gamma_{3,2}$	152.71 (5)	152.77 (3)	152.719 (19)	152.68 (2)	152.720 (2)	152.719 (2)
$\gamma_{4,3}$	200.9 (2)	200.98	201.017 (30)	200.98		200.97 (3)
$\gamma_{14,7}$	235.9 (3)					235.9 (3)
$\gamma_{13,5}$	258.3 (2)	258.23				258.227 (3)
$\gamma_{14,5}$	299.2 (2)					299.1 (2)
$\gamma_{7,2}$	706.1 (3)	705.6		705.6		705.9 (1)
$\gamma_{8,2}$	708.4 (2)	708.4		708.4		708.3 (2)
$\gamma_{5,1}$	742.77 (10)	742.82		742.82		742.813 (5)
$\gamma_{6,1}$	766.39 (10)	766.41 (2)		766.41		766.38 (2)
$\gamma_{5,0}$	786.30 (10)	786.30		786.30		786.27 (3)
$\gamma_{7,1}$	805.8 (3)	805.42		805.4		805.80 (5)
$\gamma_{8,1}$	808.25 (15)	808.23		808.2		808.20 (10)
$\gamma_{8,0}$	851.70 (10)	851.73		851.7		851.70 (10)
$\gamma_{12,2}$	880.5 (3)					880.5 (1)

	1969LeZX	1971GuZY	1972Sc01	1976GuZN	1984He19	Recommended
$\gamma_{9,1}$	883.23 (10)	883.21				883.24 (4)
$\gamma_{10,1}$	904.37 (15)	904.34				904.37 (15)
$\gamma_{9,0}$	926.72 (15)	926.73				926.72 (10)
$\gamma_{14,2}$	941.9 (2)	942.02				941.94 (10)
$\gamma_{11,1}$	946.0 (3)	946.12				946.00 (3)
$\gamma_{13,1}$	1001.03 (15)	1001.10				1001.03 (3)
$\gamma_{14,1}$	1041.8 (3)	1041.90				1041.7 (2)
$\gamma_{14,0}$	1085.4 (3)	1085.40				1085.4 (2)

[a] Other much more inaccurate measurement results can be found in 1954As07, 1955Ch02, 1956Ne17, 1971Cl03 and 1971Ma68. They agree with those given in Table 9.

6.2.2. Gamma-Ray Emission Probabilities

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

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

	E_γ (keV)	1976GuZN	1976Um01	1979 Vaninbroukx	1984Bo41	1984He19	1984Ov01	1994Ba91	Recommended (averaged) [a]	Deduced [b]
$\gamma_{1,0}$	43.5	3.93 (8)	4.11 (8)	3.93 (12)	3.96 (10)	3.82 (8)			3.97 (8)	4.06 (8)
$\gamma_{2,1}$	99.8	0.724 (14)			0.730 (11)	0.743 (8)	0.631 (38) [c]		0.735 (8)	0.741 (25)
$\gamma_{3,2}$	152.7	0.0956 (20)			0.0928 (14)	0.0936 (10)	0.086 (4) [c]	0.0923(7)	0.0930 (7)	0.095 (4)

[a] Weighted averages; uncertainties are the smallest experimental values.
[b] Deduced from P(α) values and total ICCs.
[c] Omitted based on statistical considerations.

The relative emission probabilities of $\gamma_{14,7}$(235.9 keV), $\gamma_{13,8}$(258.2 keV) and $\gamma_{14,5}$(299.1 keV) have been adopted from 1969LeZX. The absolute emission probability of $\gamma_{10,2}$ (804.4 keV) has been deduced using the ratio of P(γ 804.4 keV) / P(γ 904.4 keV) = 1.8 (7) measured in ^{234}Pa β^--decay (2007Br04). P(γ) values for other gamma-rays, which were also not observed in the ^{238}Pu α-decay, have been deduced from decay of ^{234}Pa and ^{234}Np (2007Br04) using experimental relative gamma-ray emission probabilities.

The absolute emission probabilities of all other weak gamma-rays (with energies more than 200 keV) have been deduced from their evaluated relative emission probabilities given in Table 11.

The value P(γ766) = 2.19 (5)·10^{-7} measured in 1976GuZN (the uncertainty includes an additional 2 % detector efficiency uncertainty) was used as a normalization factor. This value agrees well with the value of 2.19 (9)·10^{-7}, deduced from the measured in 1979Ce04 P(γ786) = 3.16 (9)·10^{-8} and the relative intensity P(γ786) / P(γ766) = 0.144 (4), as well as with the value of 2.21 (15)·10^{-7} measured in 1984Ov01. The latter value has been obtained by the evaluator from authors' Pγ renormalized to P(γ 152.7-keV) = 9.30 (7)·10^{-6}.

Table 11. Experimental and recommended relative emission probabilities of gamma-rays with energy more than 200 keV from decay of ^{238}Pu

		1969LeZX	1971GuZY	1971Ma68	1976GuZN	1979Ce04	1984Ov01	Recommended
$\gamma_{4,3}$	201.0	15 (3)	17.8 (3)		18.6 (4)	17.0 (5)		17.9 (4)
$\gamma_{14,7}$	235.9	0.04 (2)						0.04 (2)
$\gamma_{13,5}$	258.2	0.35 (5)	0.28 (6)					0.32 (5)
$\gamma_{14,5}$	299.1	0.20 (5)						0.20 (5)
$\gamma_{7,2}$	705.9	0.42 (6) [a]	0.225 (23)		0.23 (10)		0.25 (10)	0.23 (5)
$\gamma_{8,2}$	708.3	1.15 (9) [a]	2.24 (23)	2.5 (6)	2.29 (23)	2.5 (6)	1.7 (3)	2.22 (14)
$\gamma_{5,1}$	742.8	23.2 (4)	23.1 (2)	25.7 (15)	23.6 (5)	23.8 (4)	22.6 (12)	23.3 (2)
$\gamma_{6,1}$	766.4	100	100	100	100	100	100	100
$\gamma_{5,0}$	786.3	14.5 (3)	14.7 (2)	14.9 (10)	15.0 (3)	14.4 (4)	13.7 (5)	14.6 (2)
$\gamma_{7,1}$	805.8	0.56 (6)	0.56 (6)		0.59 (3)		0.7 (2)	0.58 (3)
$\gamma_{8,1}$	808.2	3.40 (8)	3.57 (10)	3.2 (5)	3.65 (13)	3.52 (18)	4.0 (4)	3.50 (8)
$\gamma_{8,0}$	851.7	5.79 (20)	5.79 (11)	6.6 (6)	5.89 (17)		4.9 (5)	5.81 (11)
$\gamma_{12,2}$	880.5	0.7 (2)					0.65 (16)	0.68 (16)
$\gamma_{9,1}$	883.2	3.43 (15)	2.72 (27)	3.3 (5)		3.54 (25)	3.2 (6)	3.30 (17)
$\gamma_{10,1}$	904.4	0.30 (4)	0.26 (8)				0.25 (10)	0.28 (5)
$\gamma_{9,0}$	926.7	2.53 (10)	2.56 (10)	2.7 (6)		2.58 (13)	2.4 (3)	2.55 (10)
$\gamma_{14,2}$	941.9	2.06 (9)	2.19 (9)	2.2 (6)		2.23 (27)	1.9 (4)	2.13 (9)
$\gamma_{11,1}$	946.0	0.40 (6)	0.43 (9)					0.42 (6)
$\gamma_{13,1}$	1001.0	4.39 (14)	5.42 (33) [a]	4.0 (7)		4.61 (18)	4.1 (5)	4.46 (14)
$\gamma_{14,1}$	1041.7	0.84 (7)	0.95 (10)	0.7 (3)			1.3 (3)	0.90 (7)
$\gamma_{14,0}$	1085.4	0.34 (4)	0.95 (10) [a]	1.1 (4) [a]			0.5 (2)	0.35 (4)

[a] Omitted on the basis of statistical considerations.

7. Consistency of recommended data

The most accurate Q value, Q(M), is taken from the atomic mass adjustment table of Audi et al. (2003Au03). Comparison of Q(eff)(deduced as the sum of average energies per disintegration ($\sum E_i \times P_i$) for all emissions accompanying ^{238}Pu α- decay) with the tabulated decay energy Q(M) allows to check a consistency of the recommended decay-scheme parameters obtained in this evaluation.

Here E_i and P_i are the evaluated energies and emission probabilities of the i-th alpha particle, beta particle, gamma-ray, X-ray, etc. Consistency (percentage deviation) is determined by {[Q(M)– Q(eff))]/ Q(M)} ×100. "Percentage deviations above 5 % would be regarded as high and imply a poorly defined decay scheme; a value of less than 5 % indicates the construction of a reasonably consistent decay scheme" (quoted from the article by A.L. Nichols in Appl. Rad. Isotopes 55 (2001) 23-70).

For the above ^{238}Pu decay data evaluation we have Q(M) = 5593.20 (19) keV and Q(eff) = 5593(5) keV. Thereafter, the percentage deviation is (0.00 ± 0.09) %, i.e. consistency is superior.

8. References

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^{239}Pu – Comments on evaluation of decay data
by V. P. Chechev

This evaluation was originally done in October 2005 and then revised in January 2007. The literature available by January 2007 has been included.

1. Decay Scheme

The decay scheme is based on the evaluation of Browne (2003Br12). It can be considered as basically completed though there are weak gamma rays observed in experiment and unplaced in the decay scheme. Besides several weak gamma transitions expected from the decay scheme have not been observed in ^{239}Pu alpha decay yet. They have been taken from data on nuclear reactions, in particular, from ^{234}U(n,γ)-reaction (1979Al03), and also from ^{235}Pa β^- decay (1986Mi10).

Many alpha transitions to ^{235}U excited levels with energy more than 600 keV were not observed either. They are expected from data on level spins and gamma rays de-excited these levels (see 2003Br12).

2. Nuclear Data

Q(α) value is from 2003Au03.

The evaluated half-life of ^{239}Pu is based on the experimental results given in Table 1. Re-estimated values and uncertainties were used for averaging where necessary.

Table 1. Experimental values of the ^{239}Pu half-life (in years)

Reference	Author(s)	Value	Measurement method
1970OeZZ	Oetting	24 048 (25) [a, b]	Calorimetry
1975Al15	Alexandrov *et al.*	24 060 (19) [b]	Specific activity
1975GlZQ	Glover *et al.*	24 115 (80)	Specific activity
1977Ja08	Jaffe *et al.*	24 124 (14)	Specific activity
1977Ja08	Jaffe *et al.*	24 139 (13)	Mass spectrometry
1978Se12	Seabaugh *et al.*	24 101 (10) [b]	Calorimetry
1978Gunn	Gunn	24 102 (10) [b]	Calorimetry
1978Lu10	Lucas *et al.*	24 112 (33) [c]	Specific activity
1978Ma45	Marsch *et al.*	24 164 (17) [b]	Mass spectrometry
1978Pr07	Prindle *et al.*	24 019 (15) [d]	Specific activity
1978Pr07	Prindle *et al.*	24 089 (19) [d]	Mass spectrometry
1981Brown	Brown	24 088 (25) [b]	Specific activity

[a] Value corrected in 1977Ja08 is given.
[b] Uncertainty quoted by authors for the 95 % confidence level has been reduced by a factor 2.
[c] Uncertainty combined from a standard deviation of 16 yr and a systematic error of 50 yr by Holden (1989Ho24) is given.
[d] Uncertainty corrected by Holden (1989Ho24) is given.

The weighted mean of the 12 values is 24 100 with the internal uncertainty of 4,5 and external uncertainty of 11 and χ^2/ν = 5,9. The unweighted mean is 24 097 (12). The LWEIGHT computer program has chosen the weighted mean and the external uncertainty of 11.

Thus, the recommended value of the ^{239}Pu half-life is 24 100 (11) years. It agrees well with the value of 24 101 (12) years deduced from constant matching in a least-squares fit of thermal data for fissile nuclei (1984Di08) and can be compared to the recommended values from the Russian handbook

(1988ChZL) of 24 100 (20) years and from the critical review by Glover and Nichols (1990GlZZ) of 24 113 (11) years.

The adopted ^{239}Pu spontaneous fission half-life of 8 (2) × 10^{15} years is the value recommended in 2000Ho27. It is based on the experimental results given in Table 2.

Table 2. Experimental values of the spontaneous fission ^{239}Pu half-life (in 10^{15} years)

Reference	Author(s)	Value	Measurement method
1952Se67	Segre	5,5 (16)	Ionization chamber
1985Dr09	Druzhinin *et al.*	7,8 (16)	$\lambda_{SF} / \lambda_{\alpha}$ = 3,1 (6)·10^{-12}

2.1 Alpha Transitions

The energies of the alpha transitions have been deduced from the Q value and the level energies given in Table 3 from 2003Br12. The latter ones were deduced from a least squares fit to γ ray energies from ^{239}Pu α decay. The energies of the gamma rays adopted from 2003Br12 are given below, in Table 9.

Table 3. ^{235}U levels populated in the ^{239}Pu α-decay

Level number	Energy, keV	Spin and parity	Half-life	Probability of α-transition (%)
0	0	7/2–	7,04(1)·10^{8} y	~0,03 [b]
1	0,0765 (4)	1/2+	≈26 min	70,79 (10)
2	13,0400 (21)	3/2+	0,50(3) ns	17,14 (4)
3	46,207 (10)	9/2–		< 0,02
4	51,7007 (11)	5/2+	191(5) ps	11,87 (3)
5	81,741 (4)	7/2+		0,052 (8)
6	103,035 (10)	11/2–		0,0375 (12)
7	129,2961 (10)	5/2+		0,013 (4)
8	150,467 (15)	9/2+		0,0182 (27)
9	170,708 (14)	13/2–		
10	171,388 (5)	7/2+		0,0034 (10)
11	197,119 (14)	11/2+		0,007 (1)
12	225,423 (8)	9/2+		0,0050 (7)
13	249,130 (12)	15/2–		0,0030 (16)
14	291,144 (19)	11/2+		0,0007 (3)
15	294,669 (15)	13/2+		0,0018 (5)
16	332,845 (4)	5/2+		0,00354 (7)
17	338,52 (6)	17/2–		≈2,2·10^{-5}
18	357,30 (6) **?**	(15/2+)		1,7 (4)·10^{-5}
19	367,069 (8)	7/2+		0,000944 (17)
20	393,225 (6)	3/2+		0,00125 (3)
21	414,779 (11)	9/2+		0,00075 (11)
22	426,755 (3)	5/2+		0,00570 (5)
23	445,716 (20)	7/2+		4,00 (11)·10^{-5}
24	474,297 (13)	7/2+		0,00056 (5)
25	509,92 (17)	(9/2+)		3,3 (7)·10^{-6}
26	533,228 (10)	9/2+		0,00086 (3)
27	608,08 (5)	11/2+		1,2 (4)·10^{-5}
28	633,17 (6)	(5/2)–		2,84 (7)·10^{-6}
29	637,81 (5)	3/2–		3,22 (21)·10^{-6}
30	658,97 (4)	1/2–		2,64 (6)·10^{-5}
31	664,541 (23)	(5/2)–		6,31 (11)·10^{-6}
32	670,99 (4)	(7/2)–		< 3,4·10^{-8}
33	701,02 (3)	(7/2)–		7,07 (13)·10^{-6}
34	703,757 (19)	3/2–		1,14 (3)·10^{-5}
35	720,25 (3)	(9/2)–		2,13 (9)·10^{-6}
36	750,07 (16)	(9/2–)		3,4 (4)·10^{-7}
37	761,04 (5)	(1/2)–		1,03 (17)·10^{-7}

Level number	Energy, keV	Spin and parity	Half-life	Probability of α-transition (%)
38	769,27 (6)	1/2+		2,7 (3)·10^{-5}
39	769,5 (3)	3/2–		1,03 (12)·10^{-5}
40	777,59 (19)	(11/2)–		2,47 (19)·10^{-7}
41	779,51 (3)	3/2+		1,01 (11)·10^{-6}
42	805,72 (6)	3/2–		8,4 (14))·10^{-8}
43	821,25 (4)	5/2+		3,0 (3)·10^{-7}
44	843,859 (10)	(1/2)+		2,28 (12)·10^{-7}
45	845,3 (10) **?**	(7/2+)		~4,2·10^{-8}
46	865,20 (2) [a]	3/2+		9,8 (13)·10^{-8}
47	891,89 (15)	5/2+		1,99 (12)·10^{-7}
48	968,451 (20)	3/2+		6,1 (15)·10^{-8}
49	970,52 (22) **?**	(5/2,7/2)		4,1 (4)·10^{-8}
50	986,65 (17)	(13/2-)		7,7 (7)·10^{-8}
51	992,72 (22)	(5/2+)		2,0 (3)·10^{-7}
52	1057,58 (13)	(7/2)		9,3 (9)·10^{-8}
53	1116,20 (20) **?**	(5/2–)		2,1 (5)·10^{-8}

[a] Obtained as a sum of E(level '10') and E($\gamma_{46,10}$)

[b] Value based on systematics (see 2003Br12 and comments therein)

The probabilities of the most intense transitions $\alpha_{0,1,}$ $\alpha_{0,2}$ and $\alpha_{0,4}$ have been obtained by averaging experimental results from measurements with semi-conductor detectors of 1987Bo25, 1992Bl13, 1993Ga28, 1994Ra27, 1996Sa24, 1996Vi07 and 2002Da21 (see Table 4). They agree with each other and disagree with early measurements with magnetic spectrometers of 1961Dz05, 1963Ba09, 1976BaZZ (Table 4) and 1952As28, 1957As83, 1957No15. The values evaluated from the above experimental results have been recommended as more precise than those that are deduced from γ-ray transition intensity balances.

The probabilities of the transitions $\alpha_{0,k}$ (k =5÷8, 10, 13, 15, 16, 19÷22, 24, 26) evaluated from all the available experimental data reported with uncertainties are compared in Table 4 with the values deduced from intensity balances. The latter ones were recommended as more precise. The experimental P(α)-values have been recommended in those cases ($\alpha_{0,11,}$ $\alpha_{0,12,}$ $\alpha_{0,14}$) where the intensity balances were used for obtaining P(γ+ce)-values (see several γ-ray transitions with deduced ICC and (E2/M1)-admixture ratios in section 2.2).

The probabilities of the remaining α-transitions including unobserved but expected from the decay scheme have been evaluated from the P(γ+ce) balances for corresponding levels of ^{235}U.

The values of hindrance factors were calculated using ALPHAD code and r_0 (^{235}U) = 1,5122, average of r_0 (^{234}U) = 1,5075 and r_0 (^{236}U) = 1,5168 from 1998Ak04.

Table 4. Experimental and recommended probabilities (%) of most intense α-transitions observed in ^{239}Pu decay [*]

	α-part. energy	1961 Dz05	1963Ba09 1976BaZZ	1965 Ho04	1966 Ah02	1987 Bo25	1992 Bl13	1993 Ga28**	1994 Ra27	1996 Sa24	1996 Vi07	2002 Da21**	Evaluated from data of the measurements	Deduced from P(γ+ce) balance	Recommended
$\alpha_{0,1}$	5156	72	73,3 (8)			71,2 (7)	70,73 (46)	70,77 (14)	71,6 (2)	70,91 (11)	71 (5)	70,71 (10)	70,79 (10) [a]	70,8 (4)	70,79 (10)
$\alpha_{0,2}$	5144	17	15,1 (8)			16,7 (5)	17,56 (28)	17,11 (14)	16,6 (2)	17,12 (9)	18 (4)	17,16 (4)	17,14 (4) [b]	17,1 (3)	17,14 (4)
$\alpha_{0,4}$	5106	11	11,5 (8)	11,5		12,1 (2)	11,80 (19)	11,94 (7)	11,8 (1)	11,84 (5)	11,1 (15)	11,88 (3)	11,87 (3) [c]	11,9 (3)	11,87 (3)
$\alpha_{0,5}$	5076	0,038	0,036 (3)	0,043			0,03 (1)	0,078 (8)		0,054 (6)		0,057 (2)	0,050 (7) [d]	0,052 (8)	0,052 (8)
$\alpha_{0,6}$	5055	0,030	0,025 (5)	≥0,0033				0,047 (13)		0,036 (4)		0,044 (2)	0,038 (4) [e]	0,0375 (12)	0,0375 (12)
$\alpha_{0,7}$	5029		0,005 (1)	0,0038	0,005			0,009 (3)		0,016 (2)		0,023 (1)	0,014 (9) [f]	0,013 (4)	0,013 (4)
$\alpha_{0,8}$	5009	0,018	0,013 (5)	0,011				0,017 (2)		0,021 (6)		0,034 (2)	0,017 (2) [g]	0,0182 (27)	0,0182 (27)
$\alpha_{0,10}$	4988	0,008	0,007 (2)	0,0041	0,006			0,013 (2)				0,018 (1)	0,010 (2) [h]	0,0034 (10)	0,0034 (10)
$\alpha_{0,11}$	4963	0,008	0,006 (3)	0,0044				0,007 (1)				0,0157 (12)	0,007 (1) [h]		0,007 (1)
$\alpha_{0,12}$	4935	0,008	0,0040 (10)	0,0029	0,003			0,0060 (10)				0,0135 (11)	0,0050 (7) [h]		0,0050 (7)
$\alpha_{0,13}$	4912	~0,003	0,0005 (3)					0,0024 (9)				0,0097 (9)	0,0007 (3) [h]	0,0030 (16)	0,0030 (16)
$\alpha_{0,14}$	4870		0,0007 (3)									0,0089 (9)	0,0007 (3) [i]		0,0007 (3)
$\alpha_{0,15}$	4867	0,004	0,002 (2)	0,0007	0,0008			0,0019 (7)				0,011 (1)	0,0019 (7) [h]	0,0018 (5)	0,0018 (5)
$\alpha_{0,16}$	4829		0,0015	0,0021	0,0021			0,0024 (7)					0,0024 (7)	0,00354 (7)	0,00354 (7)
$\alpha_{0,19}$	4796		0,0007 (2)	0,0008	0,0007			0,0012 (6)					0,0075 (19) [j]	0,000944 (17)	0,000944 (17)
$\alpha_{0,20}$	4770		0,0008 (3)	≥0,001	0,0006			0,0015 (6)					0,00094 (27) [j]	0,00125 (3)	0,00125 (3)
$\alpha_{0,21}$	4749		≈0,0006		0,0004							0,0059 (8)	≈0,0005 [k]	0,00075 (11)	0,00075 (11
$\alpha_{0,22}$	4737	0,007	0,0045 (10)	0,003	0,005			0,0051 (8)				0,0109 (10)	0,0045 (10) [h]	0,00570 (5)	0,00570 (5)
$\alpha_{0,24}$	4690				0,0005 (2)								0,0005 (2)	0,00056 (5)	0,00056 (5)
$\alpha_{0,26}$	4632				0,0007 (2)								0,0007 (2)	0,00086 (3)	0,00086 (3)

[*] Other measurements: 1957No15, 1963Bj03, 1981AhZV, 1984Ah06, 1990An33. The 1957No15 results are from measurements with magnetic spectrometer. In 1963Bj03 the $\alpha_{0,30}$ and $\alpha_{0,38}$ probabilities (%) were measured: 0,00008(3) and 0,000025(8), respectively. These values have been adopted as recommended $\alpha_{0,30}$ and $\alpha_{0,38}$ probabilities. The value of α_{30} probability (%) calculated from γ-ray transition intensity balance of 0,000 026 4 (6) disagrees with 1963Bj03 and the calculated value of α_{38} probability (%) of 0,000 027 (4) agrees well with 1963Bj03. In 1984Ah06 the ($\alpha_{0,1}$+$\alpha_{0,2}$)- probability (%) was measured as 88,0 (6) in agreement with all the available measurements. In 1990An33 the $\alpha_{0,1}$, $\alpha_{0,2}$, $\alpha_{0,4}$ -probabilities (%) were measured: 73 (1), 15 (1), 12 (1), respectively.

** 2002Da21 analyzed α spectrum of 1993Ga28. The values of 1993Ga28 are combined results from measurements at CIEMAT (Spain) and IRMM (Belgium).

[a] The LWEIGHT computer program has identified one after another 1996Vi07, 1994Ra27 and 1987Bo25 values as outliers and recommended a weighted average (70,79) of the 4 remaining values and an internal uncertainty of 0,064. The smallest experimental uncertainty of 0,10 is adopted for the evaluated value.

[b] The LWEIGHT computer program has identified 1996Vi07 as outlier and (after omitting this value) recommended a weighted average (17,14) of the 6 remaining values and an internal uncertainty of 0,034. The smallest experimental uncertainty of 0,04 is adopted for the evaluated value.
[c] The LWEIGHT computer program has identified one after another 1996Vi07 and 1987Bo25 values as outliers and (after omitting these values) recommended a weighted average (11,87) of the 5 remaining values and an internal uncertainty of 0,023. The smallest experimental uncertainty of 0,03 is adopted for the evaluated value.
[d] The LWEIGHT computer program has increased the uncertainty of 2002Da21 to 0,00247 and recommended a weighted average (0,050) of the 5 discrepant experimental values (1976BaZZ, 1992Bl13, 1993Ga28, 1996Sa24, 2002Da21) with the expanded uncertainty of 0,007.
[e] The LWEIGHT computer program has increased the uncertainty of 2002Da21 to 0,00304 and recommended a weighted average (0,038) of the 4 experimental values (1976BaZZ, 1993Ga28, 1996Sa24, 2002Da21) with an external uncertainty (0,004).
[f] The LWEIGHT computer program has recommended a weighted average (0,014) of the 4 highly discrepant experimental values (1976BaZZ, 1993Ga28, 1996Sa24 and 2002Da21) and expanded the uncertainty to 0,009.
[g] A weighted average of the 3 experimental values (1976BaZZ, 1993Ga28, 1996Sa24). The value of 0,034 (2) from 2002Da21 has been omitted as outlier. This big value leads to the appreciable intensity disbalance for the level “8” (150,5 keV).
[h] A weighted average of the 2 experimental values (1976BaZZ, 1993Ga28). The value from 2002Da21 has been omitted as this big value leads to the considerable intensity imbalance. Reported experimental data are discrepant.
[i] Value from 1976BaZZ. The value from 2002Da21 has been omitted as this big value leads to the considerable intensity imbalance.
[j] A weighted average of the values from 1976BaZZ and 1993Ga28.
[k] An unweighted average of the values from 1976BaZZ and 1966Ah02. The value from 2002Da21 has been omitted as this big value leads to the considerable intensity imbalance

2.2. Gamma Transitions and Internal Conversion Coefficients

The gamma-ray transition probabilities and total internal conversion coefficients (ICC's) for (M1+E2)-transitions $\gamma_{2,1}$ (12,98 keV), $\gamma_{3,0}$ (46,21 keV), $\gamma_{4,2}$ (38,66 keV), $\gamma_{12,10}$ (54,04 keV), $\gamma_{11,8}$ (46,68 keV) and $\gamma_{14,12}$ (65,71 keV) were deduced from intensity balances for the corresponding levels ("2", "3", "4", "10", "11" and "14", respectively). The total internal conversion coefficients (ICC's) and (E2/M1)-admixture ratios for these transitions were obtained using the α-transition probabilities and γ-ray emission probabilities evaluated from experimental data. For the gamma-ray transition $\gamma_{3,0}$ (46,21 keV) the values of P(γ+ce), total ICC and (E2/M1)-admixture ratio have been deduced supposing a negligible intensity of the questionable α-transition to the level "3" (1/2+→9/2–).

For gamma-ray transition $\gamma_{5,4}$ (30,04 keV) the value P(γ+ce) = 0,033 (11) % is obtained from the intensity balance for the level "5" by use of the value P($\alpha_{0,5}$) = 0,050 (7) % evaluated directly from α-spectrometric experimental data. This corresponds to the adopted M1 multipolarity for $\gamma_{5,4}$ -transition: P($\gamma_{5,4}$+ce) = 0,0346 (14) % has been deduced using the theoretical α_T (M1) = 58,6 (12).

The multipolarity of the gamma-ray transition $\gamma_{10,7}$ (41,93 keV) has also been adopted as M1 because even small E2 admixture leads to larger total ICC disturbing P(γ+ce) - balance for the level "7"(129,3 keV).

The transition probabilities for the remaining gamma-rays have been deduced from their gamma-ray emission probabilities and total ICC's interpolated from theoretical values of 2002Ba85 using the BrIcc package (Table 11). The multipolarities and admixture coefficients δ(E2/M1) have been taken from 2003Br12 (see comments therein and in footnotes to Table 11). The uncertainties of α_K, α_L, α_M, α_T for pure multipolarities have been taken as 2 %.

The total ICC for E0+M1 transitions are experimental values from (n, γ) reaction data of 1979Al03 (see 2003Br12 and comments therein).

3. Atomic Data

3.1. Fluorescence yields

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

3.2. X Radiations

The energies of U LX-rays were deduced from 1994Le28 and 1994Le37 where the fine structure of LX radiation was measured in the decay of ^{239}Pu. Other measurements of U LX-rays can be found in 1983Ah02, 1984Bo41, 1992Ba08 and 1995Jo23.

The U KX-ray energies were taken from 1999ScZX where the calculated values based on X-ray wavelengths from 1967Be65 (Bearden). In Table 5 the adopted values of U KX-ray energies are compared with experimental values.

Table 5. Experimental and adopted (calculated) values of U KX-ray energies (keV)

	1976GuZN	1982Ba56	1983Ah02	Adopted
$K\alpha_2$	94,655 (5)	94,656 (2)	94,67 (2)	94,666
$K\alpha_1$	98,442 (5)	98,435 (2)	98,45 (2)	98,440
$K\beta_3$	110,42	110,416 (3)	110,42 (3)	110,421
$K\beta_1$	111,30	111,300 (2)	111,31 (2)	111,298
$K\beta_5$	-	111,868 (5)- $K\beta_5''$ 111,868 (5)- $K\beta_5'$	112,01 (5)	111,964
$K\beta_{2,4}$	114,54	-	114,50 (3)	114,46
$KO_{2,3}$	115,40	-	115,40 (5)	115,377

3.3. Auger Electrons

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

4. Alpha emissions

The energy of the alpha particles corresponding to the alpha transition to the first excited state of ^{235}U, E($\alpha_{0,1}$), has been adopted from the absolute measurement of 1980RyZX taking into account the correction of –0,11 keV recommended by A. Rytz in 1991Ry01.

The energies of all other α-emission energies have been deduced from the alpha transition energies taking into account the recoil energies.

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

Table 6. Experimental and evaluated α-emission energies in ^{239}Pu decay (keV)

	Measured [a]					Recommended in 1991Ry01	Evaluated
	1962Le11	1963Ba09	1966Ho09	1968Ba25	1981AhZV		
$\alpha_{0,1}$	5156,7 (6)	5156,6 (8)	5157	5156,6 (8)		5156,59 (14) [b]	5156,59 (14)
$\alpha_{0,2}$	5144,0 (7)	5144	5144	5144,3 (8)		5144,3 (8)	5143,82 (21)
$\alpha_{0,4}$	5106,0 (7)	5106	5105	5105,8 (8)		5105,8 (8)	5105,81 (21)
$\alpha_{0,5}$		5077	5075		5076 (5)		5076,28 (21)
$\alpha_{0,6}$		5055	5055		5054 (5)		5055,34 (21)
$\alpha_{0,7}$		5030	5029		5028 (3)		5029,51 (21)
$\alpha_{0,8}$		5009	5007		5006 (5)		5008,70 (21)
$\alpha_{0,10}$		4987	4988		4987 (3)		4988,13 (21)
$\alpha_{0,11}$		4962	4960		4960 (5)		4962,83 (21)
$\alpha_{0,12}$		4936	4932		4934 (3)		4935,00 (21)
$\alpha_{0,13}$		4913			4912 (5)		4911,69 (21)
$\alpha_{0,14}$		4872			4871 (5)		4870,38 (21)
$\alpha_{0,15}$		4867	4864		4866 (5)		4866,91 (21)
$\alpha_{0,16}$		4829	4829		4828 (3)		4829,38 (21)
$\alpha_{0,19}$		4800	4794		4795 (4)		4795,73 (21)
$\alpha_{0,20}$			4769		4769 (5)		4770,01 (21)
$\alpha_{0,21}$					4749 (5)		4748,81 (21)
$\alpha_{0,22}$		4738	4739		4736 (3)		4737,05 (21)
$\alpha_{0,24}$		4694	4694		4691 (3)		4690,29 (21)
$\alpha_{0,26}$ [c]		4635	4639		4632 (3)		4632,35 (21)

[a] Original values have been adjusted taking into account changes in calibration energies as suggested in 1991Ry01.
[b] Absolute measurement; the value has been adopted as recommended in 1991Ry01 (see text above).
[c] Other measurements: 1963Bj03, 1975Ba65, 1992Fr04, 1999Sa19. In 1963Bj03 the $\alpha_{0,38}$ and $\alpha_{0,30}$ energies were measured: ≈ 4380 keV and 4510 (20) keV, respectively. In 1975Ba65 the measurement value of the $\alpha_{0,1}$ energy (5156,77 (41) keV) is reported. In 1992Fr04 the $\alpha_{0,1}$ energy was measured by time-of-flight method: 5155,36 (19) keV. In 1999Sa19 alpha peak fitting parameters for analysis of the complex alpha spectrum ^{239}Pu + ^{240}Pu (keV) were deduced and the following alpha energies were used: $\alpha_{0,1}$.-5156,59; $\alpha_{0,2}$.-5143,90; $\alpha_{0,4}$.-5105,80; $\alpha_{0,5}$.-5076,00.

5. Electron Emissions

The energies of the conversion electrons have been calculated from the gamma transition energies and the electron binding energies. The emission probabilities of conversion electrons have been deduced from the evaluated P(γ) and ICC values. The experimental spectrum of the conversion electrons in the decay of ^{239}Pu is given in 1965Tr03. The conversion electrons were measured also in 1979Al03.

The total absolute emission probability of K Auger electrons has been calculated using the evaluated total emission probability of U KX-rays and the adopted ω_K = 0,970 (4).

The absolute total emission probability of L Auger electrons were computed using the evaluated total absolute emission probability of U LX–rays and the adopted ϖ_L = 0,500 (19).

6. Photon Emissions

6.1. X-Ray Emissions

6.1.1. LX-Rays

The evaluated absolute emission probabilities of U LX–rays have been obtained as weighted means of measurement values from 1992Bl07 (and 1994Mo36 by the same group), 1994Le28 and 1994Le37 (Table 7). The uncertainties of the evaluated values are not less than the smallest quoted experimental uncertainties.

Table 7. Experimental and evaluated values of absolute LX-ray emission probabilities in the decay of ^{239}Pu (per 100 disintegrations)

LX-ray	Energy, keV	1992Bl07, 1994Mo36	1994Le28	1994Le37	Evaluated
Ll	11,62	0,0996 (11)	0,1027 (21)	0,1016 (17)	0,1008 (11)
Lt	11,90	-	0,00214 (18)	-	0,00214 (18)
$L\alpha_2$	13,44	- [a]	0,143 (5)	0,150 (18)	0,146 (13)
$L\alpha_1$	13,62	- [a]	1,507 (19)	1,498 (31)	1,503 (22)
$L\eta$	15,40	0,0566 (10)	0,0498 (10)	0,0544 (9)	0,0537 (19)
$L\beta$	17,06	2,301 (23)[b]	2,27 (4)[b]	2,28 (5) [b]	2,288 (23)
$L\gamma$	20,30	0,568 (6)[b]	0,564 (10)[b]	0,579 (14)[b]	0,569 (6)
LX total		4,67 (5)	4,63 (5)	4,66 (6)	4,66 (5)

[a].In 1992Bl07 the total Lα-ray intensity of 1,649 (20) was measured in agreement with the value of 1,649 (18) from 1994Le28 and the value of 1,648 (36) from 1994Le37.

[b] In all the three quoted works the intensities of individual L_β and Lγ components were also measured.

The evaluated P(XL) = 4,66 (5) % exceeds slightly the value of 4,5 (1) % calculated using the evaluated total absolute emission probability of L conversion electrons and the adopted value ϖ_L = 0,500 (19).

Other measurement results of P(XL) are: 5,3 (5) % (1966Ah02), 4,76 (12) % (1968Swinth), 4,60 (10) % (1971Swinth), 4,50 (14) % (1984Geidelman).

6.1.2. KX-Rays

The evaluated absolute emission probabilities of U KX–rays have been obtained as weighted means of measurement values from 1976GuZN and 1994Mo36 (Table 8). Uncertainty in detector efficiency (2 %) was added to the uncertainties listed in 1976GuZN and their values were renormalized to the adopted absolute emission probability of the γ-ray $\gamma_{7,0}$ (129,3 keV) of 6,31 (4)×10^{-3}.

Table 8. Experimental and evaluated values of absolute U KX-ray emission probabilities in the decay of ^{239}Pu (per 100 disintegrations)

KX-ray	Energy, keV	1976GuZN	1994Mo36	Evaluated
$K\alpha_2$	94,666	0,004 25 (9)	0,004 17 (4)	0,004 18 (4)
$K\alpha_1$	98,440	0,006 81 (14)	0,006 52 (9)	0,006 61 (9)
$K\beta_3$	110,421	0,000 801 (16)	0,000 797 (6)	0,000 798 (6)
$K\beta_1$	111,298	0,001 56 (3)	0,001 536 (12)	0,001 536 (20)
$K\beta_5$	111,964	0,000 031 (3)	0,000 054 (11)	0,000 033 (3)
$K\beta_{2,4}$	114,46	0,000 633 (18)	0,000 629 (7)	0,000 629 (7)
K_{OP}	115,37-115,58	0,000 654 (16)	0,000 708 (9)	0,000 68 (3)
KX total		0,014 74 (29)	0,014 41 (14)	0,014 47 (14)

6.2. Gamma-Ray Emissions

The recommended γ-ray energies have been adopted from 2003Br12 based on experimental data of 1979Al03 ((n,γ)-results) and 1968Cl02, 1971GuZY, 1976GuZN, 1982He02, 1992Bl07, 1994Mo36 (^{239}Pu α-decay). Other measurements: 1965Tr03, 1966Ah02, 1966Ho09 (Table 9). For several weak transitions γ-ray the energies have been deduced directly from the level energies or adopted from 1979Al03 (see footnotes to Table 9).

The absolute γ-ray emission probabilities have been deduced using the evaluated γ-ray relative probabilities and the absolute emission probability of the γ-ray $\gamma_{7,0}$ (129,3 keV) of 6,31 (4)$\times10^{-5}$ obtained as a weighted average of the 5 absolute measurement results (per 10^5 disintegrations): 6,26 (13) from 1976GuZN, 6,23 (4) from 1980Despres, 6,41 (5) from 1982He02, 6,48 (10) from 1984Iw02 and 6,31 (4) from 1994Mo36. The uncertainty (0,04) of the evaluated value is the smallest experimental uncertainty.

The relative experimental and evaluated γ-ray emission probabilities are given in Table 10. The evaluated values have been obtained by averaging experimental values listed in Table 10 or have been adopted from one of the experimental works, in most cases from 1976GuZN. The averaging-out has been done using the LWEIGHT computer program. The uncertainties are not less than the smallest experimental uncertainties.

In Table 11 the multipolarities, E2/M1 mixing ratios and ICC are shown for soft gamma rays with energy less than 120 keV and comments of deducing multipolarities (with uncertainties for E2/M1 mixing ratios where possible) are given. The δ-mixing ratios for other gamma rays (with energy more than 120 keV) are given in the footnote at the bottom of Table 11.

Table 9. Experimental and adopted energies of gamma rays in ^{239}Pu decay (keV)

	1965 Tr03	1966 Ah02	1966 Ho09	1968 Cl02	1971 GuZY	1976 GuZN	1979 Al03	1982 He02	1994 Mo36	Adopted
$\gamma_{1,0}$										0,0765 (4)
$\gamma_{2,1}$					13,0				12,975 (10)	12,975 (10)
$\gamma_{-1,1}$									14,22 (3)	14,22 (3)
$\gamma_{5,4}$					30,09	30,04 (10)		30,251 (10)	30,03 (10)	30,04 (2)
$\gamma_{4,2}$		38,7 (1)	37		38,69			38,660 (2)		38,661 (2)
$\gamma_{-1,2}$					40,57	40,41 (5)				40,41 (5)
$\gamma_{10,7}$				41,99 (10)		42,06 (3)			41,93 (5)	41,93 (5)
$\gamma_{3,0}$		46,2 (1)			46,23			46,218 (10)		46,21 (5)
$\gamma_{11,8}$						46,69 (10)			46,68 (3)	46,68 (3)
$\gamma_{7,5}$					47,56				47,60 (3)	47,60 (3)
$\gamma_{4,1}$		51,6 (1)	52		51,628	51,629 (10)	51,628 (4)	51,624 (1)		51,624 (1)
$\gamma_{12,10}$					54,05	54,040	54,026 (5)	54,039 (8)		54,039 (8)
$\gamma_{6,3}$		56,8 (2)			56,828	56,838		56,825 (3)		56,828 (3)
$\gamma_{14,12}$					65,69	65,74 (10)		65,675 (20)		65,708 (30)
$\gamma_{9,6}$					67,69	67,67		67,674 (12)		67,674 (12)
$\gamma_{5,2}$		68,3 (2)	69		68,73	68,72	68,697 (3)	68,696 (6)		68,696 (6)
$\gamma_{8,5}$										68,73 (2) [b]
$\gamma_{-1,3}$										74,96 (10)
$\gamma_{7,4}$		77,6 (2)		77,60 (5)		77,607	77,599 (2)	77,592 (14)		77,592 (14)
$\gamma_{13,9}$				78,48 (5)	78,38	78,42		78,44 (3)		78,43 (2)
$\gamma_{17,13}$										89,39 (6) [b]
$\gamma_{10,5}$				89,59		89,59		89,73 (4)	89,64 (3)	89,64 (3)
$\gamma_{12,7}$						96,13 (5)			96,14 (3)	96,14 (3)
$\gamma_{15,11}$			97,4 (6)		97,6 (3)					97,6 (3)
$\gamma_{8,4}$			98,7 (5)		98,81	98,78 (2)				98,78 (2)
$\gamma_{6,0}$		103,0	102,8 (8)		103,03	103,02 (2)		103,086 (14)		103,06 (3)
$\gamma_{11,5}$			117,6 (11)		115,35	115,38 (5)				115,38 (5)
$\gamma_{7,2}$		116,0			116,24	116,26 (2)	116,262 (3)			116,26 (2)
$\gamma_{10,4}$					119,72	119,708		119,73 (3)	119,70 (3)	119,70 (3)

	1965 Tr03	1966 Ah02	1966 Ho09	1968 Cl02	1971 GuZY	1976 GuZN	1979 Al03	1982 He02	1994 Mo36	Adopted
$\gamma_{14,10}$										119,76 (2) [b]
$\gamma_{12,6}$				122,35 (12)						122,35 (12)
$\gamma_{37,29}$							123,228 (5)			123,228 (5)
$\gamma_{21,14}$					123,67	123,62 (5)				123,62 (5)
$\gamma_{9,3}$			124,3 (15)		124,52	124,51 (3)				124,51 (3)
$\gamma_{10,3}$		125,0			125,17	125,21 (10)				125,21 (10)
$\gamma_{7,0}$		129,3 (2)	129,3 (3)		129,28	129,294 (10)	129,302 (2)	129,296 (1)		129,296 (1)
$\gamma_{19,12}$		141,7 (3)			141,64	141,657 (20)		141,62 (4)		141,657 (20)
$\gamma_{12,5}$					143,4		143,655 (6)			143,35 (20)
$\gamma_{15,8}$		144,2	144,1 (8)		144,19	144,211		144,201 (3)		144,201 (3)
$\gamma_{13,6}$		146,0			146,05	146,077		146,094 (6)		146,094 (6)
$\gamma_{10,2}$					158,3	158,1 (3)				158,1 (3)
$\gamma_{18,11}$				159,6 (2)		160,19 (5)				160,19 (5)
$\gamma_{16,10}$			160,3 (11)	160,07 (13)	161,45		161,449 (3)	161,482 (12)		161,450 (15)
$\gamma_{17,9}$					168,1	167,81 (5)				167,81 (5)
$\gamma_{10,0}$		171,4	171,3 (5)		171,34	171,344	171,370 (11)	171,393 (6)		171,393 (6)
$\gamma_{42,28}$							172,560 (11)			172,560 (8)
$\gamma_{12,4}$					173,6	173,70 (5)				173,70 (5)
$\gamma_{12,3}$		179,2 (2)	178,6 (8)		179,17	179,19		179,220 (12)		179,220 (12)
$\gamma_{-1,4}$					184,3	184,55 (5)				184,55 (5)
$\gamma_{14,6}$					188,27	188,23 (10)				188,23 (10)
$\gamma_{21,12}$		189,1	189,2 (16)		189,34	189,32		189,360 (10)		189,360 (10)
$\gamma_{-1,5}$				193,13 (12)		193,13 (12)	195,220 (12)			193,13 (12)
$\gamma_{19,10}$		195,6	195,7 (8)		195,65	195,66	195,70 (2)	195,679 (8)		195,679 (8)
$\gamma_{-1,6}$					197,98	196,87 (5)	196,872 (7)			196,87 (5)
$\gamma_{16,7}$		203,5	203,5 (8)	203,34 (8)	203,52	203,537	203,553 (7)	203,550 (5)		203,550 (5)
$\gamma_{21,11}$										218,0 (5)
$\gamma_{12,0}$			224,9 (15)		225,43	225,37		225,384 (15)		225,42 (4)
$\gamma_{19,7}$				238,2 (2)	237,77	237,38	237,774 (6)	237,77 (10)		237,77 (10)
$\gamma_{26,14}$			241,2 (20)		242,09	242,08 (3)				242,08 (3)
$\gamma_{21,10}$					243,33	243,38		243,38 (3)		243,38 (3)
$\gamma_{14,3}$					244,80	244,95 (5)	244,583 (8)			244,92 (5)
$\gamma_{24,12}$					248,95	248,95		248,95 (5)		248,95 (5)
$\gamma_{22,10}$		255,5	255,1 (5)	258,20 (10)	255,33	255,38		255,384 (15)		255,384 (15)
$\gamma_{20,7}$		264,0			263,93	263,93	263,916 (4)	263,97 (3)		263,95 (3)
$\gamma_{30,20}$					265,54	265,7 (3)				265,7 (3)
$\gamma_{16,4}$					281,2	281,2 (2)				281,2 (2)
$\gamma_{19,5}$					285,3	285,3 (2)				285,3 (2)
$\gamma_{22,7}$		297,6	297,8 (8)		297,43	297,49	297,42 (3)	297,46 (3)		297,46 (3)
$\gamma_{24,10}$					302,87	302,87		302,87 (5)		302,87 (5)
$\gamma_{26,12}$					307,81	307,85		307,85 (5)		307,85 (5)
$\gamma_{21,6}$		311,8	312,8 (15)		311,69	311,74		311,78 (4)		311,78 (4)
$\gamma_{23,7}$					316,35	316,41	316,444 (6)	316,41 (4)		316,41 (3)
$\gamma_{16,2}$					319,7	319,68 (10)				319,68 (10)

	1965 Tr03	1966 Ah02	1966 Ho09	1968 Cl02	1971 GuZY	1976 GuZN	1979 Al03	1982 He02	1994 Mo36	Adopted
$\gamma_{19,3}$		321,1			320,8	320,88		320,862 (20)		320,862 (20)
$\gamma_{24,8}$	324	323,9	322,8 (8)		323,76	323,81	323,853 (4)	323,841 (29)		323,84 (3)
$\gamma_{16,0}$	331,1 (5)	333,0	333,2 (5)		332,80	332,838	332,841 (2)	332,845 (5)		332,845 (5)
$\gamma_{26,11}$	336,1 (7)	336,3			336,06	336,107		336,120 (12)		336,113 (12)
$\gamma_{20,4}$	342,6 (7)	341,7	340,0 (20)		341,48	341,510 (2)	341,510 (2)	341,502 (19)		341,506 (10)
$\gamma_{24,7}$										345,001 (13) [b]
$\gamma_{22,5}$	345,6 (7)	345,1 (3)	345,2 (5)		344,96	345,014	345,003 (4)	345,013 (4)		345,013 (4)
$\gamma_{-1,7}$						350,8 (3)				350,8 (3)
$\gamma_{19,2}$					354,1	354,0 (5)				354,0 (5)
$\gamma_{26,10}$	363,5 (10)		363,4 (20)		361,9	361,89		361,90 (6)		361,89 (5)
$\gamma_{19,0}$		367,4			367,02	367,050		367,096 (26)		367,073 (25)
$\gamma_{21,3}$		368,7	369,3 (15)		368,53	368,550		368,557 (27)		368,554 (20)
$\gamma_{22,4}$	375,2 (3)	375,2 (2)	376,3 (5)		375,02	375,042	375,043 (7)	375,054 (3)		375,054 (3)
$\gamma_{20,2}$	380,7 (7)	380,4	381,3 (15)		380,16	380,166	380,173 (3)	380,191 (6)		380,191 (6)
$\gamma_{26,8}$	383,2 (7)	382,9	382,7 (15)		382,72	382,751		382,698 (16)		382,75 (5)
$\gamma_{24,5}$	392,5 (7)				392,45	392,53	392,552 (6)	392,53 (3)		392,53 (3)
$\gamma_{20,1}$	393,4 (7)	393,4 (3)	393,5 (8)		393,06	393,14	393,138 (6)	393,14 (3)		393,14 (3)
$\gamma_{23,3}$					399,44	399,51	399,530 (12)	399,54 (9)		399,53 (6)
$\gamma_{25,6}$	406,2 (5)		408,0 (15)		406,2 (5)	406,9		406,77 (25)		406,8 (2)
$\gamma_{27,11}$					410,77	411,15 (30)				411,2 (3)
$\gamma_{42,20}$										412,49 (6) [b]
$\gamma_{22,2}$	414,0 (3)	413,7	414,2 (5)		413,69	413,712	413,710 (13)	413,713 (5)		413,713 (5)
$\gamma_{24,4}$	422,8 (7)	422,6	423,4 (8)		422,57	422,586	422,596 (8)	422,598 (19)		422,598 (19)
$\gamma_{22,1}$		426,7			426,67	426,68 (8)				426,68 (3)
$\gamma_{24,3}$						428,4 (3)				428,4 (3)
$\gamma_{26,6}$					430,0	430,08 (10)				430,08 (10)
$\gamma_{23,0}$			445,8 (8)		445,78	445,72 (3)	445,740 (17)	445,81 (10)		445,72 (3)
$\gamma_{-1,8}$						446,82 (20)				446,82 (20)
$\gamma_{26,5}$	452,0 (7)	451,6	451,9 (5)		451,45	451,474		451,481 (10)		451,481 (10)
$\gamma_{27,8}$					457,57	457,61 (5)				457,61 (5)
$\gamma_{24,2}$					461,29	461,25 (5)				461,25 (5)
$\gamma_{25,3}$					463,8	463,9				463,9 (3)
$\gamma_{24,0}$					474,4	473,9				473,9 (5)
$\gamma_{26,4}$			480,7 (20)		481,55	481,54		481,78 (12)		481,66 (12)
$\gamma_{26,3}$					487,0	487,06				487,06 (10)
$\gamma_{31,10}$					493,1	493,08 (5)				493,08 (5)
$\gamma_{-1,9}$						497,0				497,0 (5)
$\gamma_{27,5}$						526,4				526,4 (4)
$\gamma_{-1,10}$					538,9	538,8 (2)				538,8 (2)
$\gamma_{33,8}$					550,6	550,5 (2)				550,5 (2)
$\gamma_{-1,11}$					557,7	557,3 (5)				557,3 (5)
$\gamma_{36,10}$						579,4 (3)				579,4 (3)
$\gamma_{31,5}$						582,89	582,75 (8)			582,89 (10)
$\gamma_{29,4}$					586,4	586,3	586,940 (14)			586,3 (3)

	1965 Tr03	1966 Ah02	1966 Ho09	1968 Cl02	1971 GuZY	1976 GuZN	1979 Al03	1982 He02	1994 Mo36	Adopted
$\gamma_{43,12}$						596,0				596,0 (5)
$\gamma_{33,6}$					598,4	597,99 (5)				597,99 (5)
$\gamma_{36,8}$						599,6 (2)				599,6 (2)
$\gamma_{40,10}$					607,3	606,9 (2)				606,9 (2)
$\gamma_{-1,12}$						608,9 (2)				608,9 (2)
$\gamma_{31,4}$					612,9	612,83 (3)	612,838 (6)			612,83 (3)
$\gamma_{35,6}$					617,4	617,10 (10)	617,212 (7)			617,10 (10)
$\gamma_{31,3}$					618,9	618,28 (6)	618,335 (6)			618,28 (6)
$\gamma_{33,5}$						619,21 (6)				619,21 (6)
$\gamma_{29,2}$							624,75 (10)			624,78 (5)
$\gamma_{32,3}$					624,8	624,78 (5)				624,78 (3)
$\gamma_{28,0}$					633,19	633,15 (6)	633,088 (6)			633,15 (6)
$\gamma_{29,1}$										637,73 (5) [b]
$\gamma_{29,0}$			636,0 (30)		637,97	637,84 (6)	637,77 (1)			637,80 (5)
$\gamma_{38,7}$					640,15	640,075		639,99 (10)		639,99 (10)
$\gamma_{30,2}$			645,5 (30)		646,02	645,969	645,894 (5)	645,98 (3)		645,94 (4)
$\gamma_{33,4}$					649,5	649,32 (6)				649,32 (6)
$\gamma_{-1,13}$						650,529 (60)				650,529 (60)
$\gamma_{34,4}$					652,19	652,074	652,052 (5)	651,79 (10)		652,05 (2)
$\gamma_{33,3}$					654,86	654,88 (8)	654,80 (2)			654,88 (8)
$\gamma_{30,1}$					658,99	658,929	658,862 (5)	658,63 (15)		658,86 (6)
$\gamma_{31,0}$					664,67	664,58 (5)	664,520 (12)			664,58 (5)
$\gamma_{36,5}$						668,2 (5)				668,2 (5)
$\gamma_{43,4}$						670,8				670,8 (5)
$\gamma_{32,0}$										670,99 (4)
$\gamma_{40,6}$					674,2	674,05 (3)				674,05 (3)
$\gamma_{40,5}$										674,4 (5)
$\gamma_{-1,14}$					686,16	685,97 (11)	685,861 (6)			685,97 (11)
$\gamma_{-1,15}$						688,1 (3)				688,1 (3)
$\gamma_{34,2}$					690,85	690,81 (8)	690,730 (22)			690,81 (8)
$\gamma_{-1,16}$						693,2 (5)				693,2 (5)
$\gamma_{46,10}$							693,81 (1)			693,81 (1) [c]
$\gamma_{41,5}$						697,8				697,8 (5)
$\gamma_{-1,17}$						699,6 (5)				699,6 (5)
$\gamma_{33,0}$					701,00	701,1 (2)				701,1 (2)
$\gamma_{34,1}$					703,79	703,68 (5)	703,680 (22)			703,68 (5)
$\gamma_{-1,18}$						712,96 (5)				712,96 (5)
$\gamma_{44,7}$						714,71	714,57 (1)			714,71 (14)
$\gamma_{39,4}$					717,76	717,72	718,23 (1)	718,0 (5)		718,0 (5)
$\gamma_{35,0}$						720,3 (5)				720,3 (5)
$\gamma_{47,10}$							720,550 (25)			720,56 (3)
$\gamma_{41,4}$					727,81	727,9	727,860 (25)			727,9 (2)
$\gamma_{46,7}$						736,5	735,910 (15)			736,5 (5)
$\gamma_{-1,19}$						742,7 (5)				742,7 (5)

	1965 Tr03	1966 Ah02	1966 Ho09	1968 Cl02	1971 GuZY	1976 GuZN	1979 Al03	1982 He02	1994 Mo36	Adopted
$\gamma_{37,2}$						747,4	747,97 (1)			747,4 (5)
$\gamma_{38,2}$					}	}756,4 (2)	756,190 (35)			756,23 (6) [b]
$\gamma_{39,2}$			756,0 (30)		}756,40	}	756,87 (6)			756,4 (4)
$\gamma_{47,7}$							762,6 (2)			762,6 (2)
$\gamma_{45,5}$						763,7	763,60 (15)			763,60 (15) [c]
$\gamma_{41,2}$			766,8 (30)			766,6	766,53 (4)			766,47 (3)
$\gamma_{51,12}$							767,29 (4)			767,29 (4)
$\gamma_{38,1}$							769,15 (8)		769,19 (4) [a]	769,15 (8)
$\gamma_{39,1}$					769,38	769,4 (5)	769,59			769,4 (5)
$\gamma_{43,4}$							769,87 (2)			769,54 (4)
$\gamma_{-1,20}$						777,1				777,1 (3)
$\gamma_{41,1}$					779,5	779,61	779,42 (2)			779,43 (3) [b]
$\gamma_{-1,21}$					787,3	786,9 (2)	786,90 (2)			786,9 (2)
$\gamma_{-1,22}$					793,0	788,5 (3)				788,5 (3)
$\gamma_{42,2}$						792,9	792,58 (5)			792,68 (6) [b]
$\gamma_{-1,23}$					796,5	796,9 (3)				796,9 (3)
$\gamma_{-1,24}$					803,3	803,2 (2)				803,2 (2)
$\gamma_{42,1}$						805,9	805,65 (1)			805,65 (6) [b]
$\gamma_{43,2}$					808,2	808,4	808,19 (4)			808,21 (4) [b]
$\gamma_{46,4}$					813,9	813,7	813,510 (17)			813,7 (2)
$\gamma_{50,9}$						816,0 (2)				816,0 (2)
$\gamma_{43,0}$					821,1					821,25 (4) [b]
$\gamma_{51,10}$						821,3 (2)				821,3 (2)
$\gamma_{-1,25}$						826,8 (3)				826,8 (3)
$\gamma_{-1,26}$					828,8	828,9 (2)	828,82 (4)			828,9 (2)
$\gamma_{52,12}$					832,1	832,5				832,2 (2)
$\gamma_{-1,27}$						837,3 (2)				837,3 (2)
$\gamma_{47,4}$					839,0	840,4	840,26 (10)			840,4 (2)
$\gamma_{44,1}$					843,8	844,0	843,78 (1)			843,780 (10)
$\gamma_{47,2}$					879,0	879,2				879,2 (3)
$\gamma_{47,1}$						891,0				891,0 (3)
$\gamma_{-1,28}$						895,4 (3)				895,4 (3)
$\gamma_{-1,29}$						898,1 (3)				898,1 (3)
$\gamma_{-1,30}$						905,5 (3)				905,5 (3)
$\gamma_{-1,31}$						911,7 (3				911,7 (3)
$\gamma_{49,4}$						918,7 (3)				918,7 (3)
$\gamma_{-1,32}$						931,9 (3)				931,9 (3)
$\gamma_{50,3}$					940,1	940,3 (3)				940,3 (3)
$\gamma_{48,2}$					956,4	955,6	955,390 (21)			955,41 (2) [b]
$\gamma_{49,2}$						957,6 (3)				957,6 (3)
$\gamma_{48,1}$							968,390 (34)			968,37 (2)
$\gamma_{51,2}$					979,5	979,7				979,7 (3)
$\gamma_{-1,33}$						982,7 (3)				982,7 (3)
$\gamma_{53,7}$					986,7	986,9	986,920 (35)			986,92 (4) [c]

	1965 Tr03	1966 Ah02	1966 Ho09	1968 Cl02	1971 GuZY	1976 GuZN	1979 Al03	1982 He02	1994 Mo36	Adopted
$\gamma_{51,1}$					992,5	992,7	992,639 (33)			992,64 (3) [c]
$\gamma_{52,4}$					1005,5	1005,7				1005,7 (3)
$\gamma_{-1,34}$						1009,4 (3)				1009,4 (3)
$\gamma_{52,0}$					1057,3					1057,3 (2)

[a] Measured in 1980Despres
[b] Obtained as a level energy difference
[c] Adopted from 1979Al03

Table 10. Experimental and evaluated relative emission probabilities of gamma rays in decay of ^{239}Pu [&]

	Energy, keV	1966 Ah02	1976 GuZN	1980 Despres	1982 He02	1984 Iw02	1992 Bl07	1994 Mo36	Evaluated
$\gamma_{1,0}$	0,077								~0,00016 [a]
$\gamma_{2,1}$	12,98						540 (14)	540 (14)	540 (14)
$\gamma_{-1,1}$	14,22							87 (6)	87 (6) *
$\gamma_{5,4}$	30,04		3,47 (13)		15,4 (4)			4,4 (13)	3,47 (13)
$\gamma_{4,2}$	38,66	152 (15)	168 (4)		157,0 (4)		165,8 (24)	165,5 (21)	166 (3)
$\gamma_{-1,2}$	40,41		2,58 (26)						2,58 (26) *
$\gamma_{10,7}$	41,93		2,64 (10)		4,07 (10)			2,31 (24)	2,59 (12)
$\gamma_{3,0}$	46,21	16 (2)	11,8 (12)		14,6 (7)			11,43 (17)	11,5 (2)
$\gamma_{11,8}$	46,68		0,93 (6)		1,2 (1)			0,74 (4)	0,80 (9)
$\gamma_{7,5}$	47,60							0,99 (4)	0,99 (4)
$\gamma_{4,1}$	51,62	410 (40)	431 (9)		422 (3)		434 (6)	431 (4)	427 (3)
$\gamma_{12,10}$	54,04		3,19 (8)		3,01 (7)			3,08 (4)	3,08 (4)
$\gamma_{6,3}$	56,83	16 (2)	18,0 (4)		17,4 (4)			18,26 (21)	18,0 (2)
$\gamma_{14,12}$	65,71		0,72 (4)		0,72 (6)			0,82 (5)	0,75 (4)
$\gamma_{9,6}$	67,67		2,57 (7)		2,70 (11)			2,40 (4)	2,50 (8)
$\gamma_{5,2}$	68,70	}14 (2)	8,15 (18)		7,9 (2)			7,69 (10)	5,7 (16) [b]
$\gamma_{8,5}$	68,73	}							2,1 (10) [b]
$\gamma_{-1,3}$	74,96								0,60 (10) [c] *
$\gamma_{7,4}$	77,59	11,2	6,23 (13)		6,8 (2)			6,02 (8)	6,08 (9)
$\gamma_{13,9}$	78,43		2,43 (6)		2,1 (2)			2,44 (4)	2,43 (4)
$\gamma_{17,13}$	89,39								~0,03 [d]
$\gamma_{10,5}$	89,64				0,47 (8)			0,43 (3)	0,43 (3)
$\gamma_{12,7}$	96,14		0,36 (7)					0,60 (3)	0,60 (3)
$\gamma_{15,11}$	97,6								1,4 (10) [e, a]
$\gamma_{8,4}$	98,78		19,5 (7)					23,2 (11)	21,4 (18)
$\gamma_{6,0}$	103,06		3,47 (9)					3,42 (9)	3,44 (9)
$\gamma_{11,5}$	115,38		7,27 (18)						7,3 (8) [f]
$\gamma_{7,2}$	116,26		9,54 (24)					8,99 (17)	9,2 (3)
$\gamma_{10,4}$	119,70		}0,479 (14)		}0,53 (2)			0,479 (29)	0,33 (4) [g]
$\gamma_{14,10}$	119,76		}		{				0,15 (2) [g, i]
$\gamma_{12,6}$	122,35		0,05 (3)					0,015 (2)	0,015 (2) [i]
$\gamma_{37,29}$	123,23								0,000025 (6) [h]
$\gamma_{21,14}$	123,62		0,315 (20)					0,376 (14)	0,376 (14)
$\gamma_{9,3}$	124,51		0,98 (4)					1,08 (3)	1,08 (3)
$\gamma_{10,3}$	125,21		1,13 (3)					0,892 (24)	0,892 (24)
$\gamma_{7,0}$	129,30	100	100	100	100	100		100	100

	Energy, keV	1966 Ah02	1976 GuZN	1980 Despres	1982 He02	1984 Iw02	1992 Bl07	1994 Mo36	Evaluated
$\gamma_{19,12}$	141,66	0,6 (1)	0,511 (15)	0,45 (7)	0,46 (8)	0,63 (18)			0,509 (15)
$\gamma_{12,5}$	143,35		0,276 (12)	0,45	}4,80 (9)	}4,75 (13)			0,276 (12)
$\gamma_{15,8}$	144,20	5 (1)	4,52 (10)	4,75 (24)	}	}			4,52 (10)
$\gamma_{13,6}$	146,09	2,1 (2)	1,90 (4)	1,80 (18)	2,00 (10)	1,91 (10)			1,91 (4)
$\gamma_{10,2}$	158,1		0,0160 (16)						0,0160 (16)
$\gamma_{18,11}$	160,19		0,099 (20)						0,099 (20) [i]
$\gamma_{16,10}$	161,45		1,92 (4)	2,00 (12)	1,96 (4)	1,91 (10)			1,94 (10)
$\gamma_{17,9}$	167,81		0,047 (12)						0,047 (12)
$\gamma_{10,0}$	171,39	1,8 (2)	1,76 (5)	1,69 (10)	1,74 (4)	1,70 (9)			1,74 (4)
$\gamma_{42,28}$	172,56								~0,00005 [h]
$\gamma_{12,4}$	173,70		0,049 (12)						0,049 (12)
$\gamma_{12,3}$	179,22	1,2 (2)	1,05 (3)	1,04 (8)	1,04 (3)	1,00 (5)			1,04 (3)
$\gamma_{-1,4}$	184,55		0,034 (10)						0,034 (10) *
$\gamma_{14,6}$	188,23		0,174 (18)						0,174 (18)
$\gamma_{21,12}$	189,36	1,5 (2)	1,33 (4)	1,33 (12)	1,30 (2)	1,28 (3)			1,30 (2)
$\gamma_{-1,5}$	193,13		0,142 (15)						0,142 (15) *
$\gamma_{19,10}$	195,68	1,9 (2)	1,70 (4)	1,64 (11)	1,68 (3)	1,68 (4)			1,68 (3)
$\gamma_{-1,6}$	196,87		0,059 (7)						0,059 (7) *
$\gamma_{16,7}$	203,55	9 (1)	8,95 (18)	8,94 (42)	8,90 (13)	8,95 (14)			8,93 (13)
$\gamma_{21,11}$	218,0								0,019 (16) [i]
$\gamma_{12,0}$	225,42		0,249 (11)	0,22 (2)	0,23 (2)	0,23 (2)			0,238 (11)
$\gamma_{19,7}$	237,77		0,230 (10)	0,23 (2)		0,32 (2)			0,230 (10)
$\gamma_{26,14}$	242,08		0,117 (8)	}	}	}			0,117 (8)
$\gamma_{21,10}$	243,38		0,404 (11)	}0,41	}0,38 (3)	}0,61 (4)			0,404 (11)
$\gamma_{14,3}$	244,92		0,081 (8)	}	}	}			0,081 (8)
$\gamma_{24,12}$	248,95		0,115 (12)	0,112 (11)	0,11 (1)	0,106 (20)			0,111 (10)
$\gamma_{22,10}$	255,38	1,6 (2)	1,29 (4)	1,27 (10)	1,27 (3)	1,23 (3)			1,26 (3)
$\gamma_{20,7}$	263,95	0,6 (1)	0,417 (15)	0,40 (4)	0,42 (4)	0,39 (3)			0,411 (15)
$\gamma_{30,20}$	265,7		0,025 (6)						0,025 (6)
$\gamma_{16,4}$	281,2		0,035 (5)	0,033 (10)		0,025 (13)			0,034 (5)
$\gamma_{19,5}$	285,3		0,030 (6)	0,03					0,030 (6)
$\gamma_{22,7}$	297,46	0,9 (1)	0,802 (23)	0,77 (8)	0,78 (2)	0,77 (2)			0,78 (2)
$\gamma_{24,10}$	302,87		0,081 (7)	0,070 (12)	0,075 (10)	0,074 (12)			0,077 (7)
$\gamma_{26,12}$	307,85		0,088 (6)	0,076 (12)	0,08 (2)	0,073 (12)			0,083 (6)
$\gamma_{21,6}$	311,78	0,5 (1)	0,412 (12)	0,39 (4)	0,40 (3)	0,36 (8)			0,408 (12)
$\gamma_{23,7}$	316,41		0,217 (8)	0,21 (4)	0,20 (4)	0,196 (14)			0,211 (8)
$\gamma_{16,2}$	319,7		0,077 (8)			}0,85 (2)			0,077 (8)
$\gamma_{19,3}$	320,86	0,8 (1)	0,856 (19)	0,86 (8)	0,86 (3)	}			0,856 (19)
$\gamma_{24,8}$	323,84	0,9 (1)	0,866 (19)	0,82 (8)	0,84 (2)	0,81 (2)			0,84 (2)
$\gamma_{16,0}$	332,85	8 (1)	8,08 (16)	7,64 (32)	7,70 (11)	7,64 (11)			7,74 (11)
$\gamma_{26,11}$	336,11	1,8 (2)	1,81 (4)	1,72 (13)	1,73 (4)	1,75 (4)			1,76 (4)
$\gamma_{20,4}$	341,51	1,2 (1)	1,058 (22)	1,05 (10)	1,00 (4)	1,02 (2)			1,03 (2)
$\gamma_{24,7}$	345,00	}	}						<0,8 [i]
$\gamma_{22,5}$	345,013	}8,7 (9)	}8,93 (18)	8,75 (30)	8,67 (13)	8,61 (11)			8,69 (11)
$\gamma_{-1,7}$	350,8		0,028 (6)						0,028 (6) *
$\gamma_{19,2}$	354,0		0,012 (5)						0,012 (5)
$\gamma_{26,10}$	361,89		0,195 (11)	0,18 (2)	0,22 (2)	0,17 (1)			0,185 (11)

	Energy, keV	1966 Ah02	1976 GuZN	1980 Despres	1982 He02	1984 Iw02	1992 Bl07	1994 Mo36	Evaluated
$\gamma_{19,0}$	367,07	1,6 (2)	1,38 (3)	1,38 (6)	1,44 (3)	1,35 (2)			1,38 (3)
$\gamma_{21,3}$	368,55	1,4 (2)	1,44 (3)	1,39 (6)	1,37 (3)	1,38 (2)			1,39 (2)
$\gamma_{22,4}$	375,05	25 (3)	25,1 (5)	24,9 (8)	24,2 (3)	24,2 (3)			24,4 (3)
$\gamma_{20,2}$	380,19	5 (1)	4,87 (10)	4,78 (26)	4,75 (7)	4,77 (6)			4,78 (6)
$\gamma_{26,8}$	382,75	4 (1)	4,13 (8)	4,08 (32)	4,02 (6)	4,04 (5)			4,05 (5)
$\gamma_{24,5}$	392,53		}8,83 (18)	}8,72 (35)	}8,55 (13)	1,91 (25)			1,91 (25)
$\gamma_{20,1}$	393,14	10 (1)	}	}	}	6,64 (26)			6,64 (26)
$\gamma_{23,3}$	399,53		0,097 (4)		0,09 (1)	0,103 (17)			0,097 (4)
$\gamma_{25,6}$	406,8		0,010 (4)		0,046 (11)				0,010 (4)
$\gamma_{27,11}$	411,2		0,11 (5)						0,11 (5)
$\gamma_{42,20}$	412,49					}23,0 (3)			~0,00029 [j]
$\gamma_{22,2}$	413,71	25 (3)	23,8 (5)	23,8 (8)	23,0 (3)	}			23,2 (3)
$\gamma_{24,4}$	422,60	2,0 (3)	1,90 (4)	1,91 (14)	1,88 (4)	1,90 (3)			1,90 (3)
$\gamma_{22,1}$	426,68	0,3 (1)	0,372 (9)	0,36 (4)		0,42 (2)			0,379 (9)
$\gamma_{24,3}$	428,4		0,0160 (16)						0,0160 (16)
$\gamma_{26,6}$	430,1		0,069 (3)	0,068 (7)		0,065 (6)			0,068 (3)
$\gamma_{23,0}$	445,72		0,139 (4)	0,146 (15)		0,13 (11)			0,139 (4)
$\gamma_{-1,8}$	446,8		0,0135 (20)						0,0135 (20) *
$\gamma_{26,5}$	451,48	3,4 (5)	3,02 (7)	3,08 (19)	2,96 (4)	2,93 (4)			2,96 (4)
$\gamma_{27,8}$	457,61		0,0238 (5)	0,026 (3)		0,023 (6)			0,0239 (5)
$\gamma_{24,2}$	461,25		0,0363 (8)						0,0363 (8)
$\gamma_{25,3}$	463,9		0,0044 (5)						0,0044 (5)
$\gamma_{24,0}$	473,9		0,0009 (5)						0,0009 (5)
$\gamma_{26,4}$	481,7		0,0735 (15)	0,077 (8)		0,069 (4)			0,0731 (15)
$\gamma_{26,3}$	487,1		0,042 (3)						0,042 (3)
$\gamma_{31,10?}$	493,08		0,0139 (5)	0,014 (2)		0,013 (3)			0,0139 (5)
$\gamma_{-1,9}$	497,0		0,0007 (4)						0,0007 (4) *
$\gamma_{27,5}$	526,4		0,0009 (3)						0,0009 (3)
$\gamma_{-1,10}$	538,8		0,0049 (3)						0,0049 (3) *
$\gamma_{33,8}$	550,5		0,0067 (4)	0,0074 (8)		0,0079 (31)			0,0069 (4)
$\gamma_{-1,11}$	557,3		0,0006 (3)						0,0006 (3) *
$\gamma_{36,10}$	579,4		0,0014 (3)						0,0014 (3)
$\gamma_{31,5}$	582,9		0,0098 (4)						0,0098 (4)
$\gamma_{29,4}$	586,3		0,00244 (25)						0,00244 (25)
$\gamma_{43,12}$	596,0		0,00062 (19)						0,00062 (19)
$\gamma_{33,6}$	597,99		0,0267 (10)	0,032 (3)		0,030 (3)			0,0275 (10)
$\gamma_{36,8}$	599,6		0,0032 (4)						0,0032 (4)
$\gamma_{40,10}$	606,9		0,00192 (20)						0,00192 (20)
$\gamma_{-1,12}$	608,9		0,00185 (19)						0,00185 (19) *
$\gamma_{31,4}$	612,83		0,0151 (8)	0,025		0,016 (4)			0,0151 (8)
$\gamma_{35,6}$	617,10		0,0214 (12)	}0,08 (1)	}0,09 (1)	}0,069 (5)			0,0214 (12)
$\gamma_{31,3}$	618,28		0,0326 (12)	}	}	}			0,0326 (12)
$\gamma_{33,5}$	619,21		0,0193 (12)						0,0193 (12)
$\gamma_{29,2}$	624,78		0,0073 (3) }						0,0073 (3) [k]
$\gamma_{32,3}$	624,78		}						<0,0003 [k]
$\gamma_{28,0}$	633,15		0,0404 (9)	0,043 (4)		0,036 (3)			0,0404 (9)
$\gamma_{29,1}$	637,73		}0,0409 (10)	}0,047 (5)		}0,047 (4			0,0101 (10) [k]

	Energy, keV	1966 Ah02	1976 GuZN	1980 Despres	1982 He02	1984 Iw02	1992 Bl07	1994 Mo36	Evaluated
$\gamma_{29,0}$	637,80		}	}		}			0,0304 (30) [k]
$\gamma_{38,7}$	639,99		0,131 (3)	0,139 (14)	0,16 (2)	0,142 (5)			0,134 (3)
$\gamma_{30,2}$	645,94		0,238 (5)	0,25 (3)	0,21 (2)	0,236 (6)			0,236 (5)
$\gamma_{33,4}$	649,32		0,0114 (8)						0,0114 (8)
$\gamma_{-1,13}$	650,53		0,0043 (7)						0,0043 (7) *
$\gamma_{34,4}$	652,05		0,105 (3)	0,105 (11)	0,125 (15)	0,102 (5)			0,105 (3)
$\gamma_{33,3}$	654,88		0,0359 (8)	0,029 (7)		0,023 (5)			0,0359 (8)
$\gamma_{30,1}$	658,86		0,155 (4)	0,159 (16)	0,125 (14)	0,150 (5)			0,152 (4)
$\gamma_{31,0}$	664,58		0,0265 (6)	0,027 (3)		0,026 (3)			0, 0265 (6)
$\gamma_{36,5}$	668,2		0,00063 (19)						0,00063 (19)
$\gamma_{43,4}$?	670,8		}0,00014 (4)						<0,00014 (4) [l, i]
$\gamma_{32,0}$?	670,99		}						<0,00014 (4) [l, i]
$\gamma_{40,6}$	674,05		0,0082 (3)	}0,0096 (10)		0,0080 (3)			0,0080 (3) [k]
$\gamma_{40,5}$	674,4			}					0,0016 (2) [k]
$\gamma_{-1,14}$	685,97		0,0199 (5)	0,0158 (16)		0,023 (4)			0,0199 (5) *
$\gamma_{-1,15}$	688,1		0,00177 (18)						0,00177 (18) *
$\gamma_{34,2}$	690,81		0,0089 (5)	0,0104 (10)		0,014 (3)			0,0093 (7)
$\gamma_{-1,16}$	693,2		}0,00080 (24)						0,0005 (2) [g] *
$\gamma_{46,10}$	693,81		}						0,0003 (1) [g]
$\gamma_{41,5}$	697,8		0,00117 (24)						0,00117 (24)
$\gamma_{-1,17}$	699,6		0,00126 (25)						0,00126 (25) *
$\gamma_{33,0}$	701,1		0,0082 (3)	0,0095 (10)		0,0106 (34)			0,0083 (3)
$\gamma_{34,1}$	703,68		0,063 (2)	0,067 (7)		0,070 (4)			0,065 (2)
$\gamma_{-1,18}$	712,96		0,00082 (10)						0,00082 (10) *
$\gamma_{44,7}$	714,7		0,00125 (13)						0,00125 (13)
$\gamma_{39,4}$	718,0		0,0438 (9)	0,048 (5)		0,042 (3)			0,0438 (9)
$\gamma_{35,0}$	720,3		}0,00078 (8)						0,00046 (5) [g]
$\gamma_{47,10}$	720,56		}						0,00032 (3) [g]
$\gamma_{41,4}$	727,9		0,00198 (11)						0,00198 (11)
$\gamma_{46,7}$	736,5		0,00048 (14)						0,00048 (14)
$\gamma_{-1,19}$	742,7		0,00060 (18)						0,00060 (18) *
$\gamma_{37,2}$	747,4		0,00129 (26)						0,00129 (26)
$\gamma_{38,2}$	756,23		}0,0554 (11)	}0,061 (6)		}0,054 (4)			0,044 (8) [g]
$\gamma_{39,2}$	756,4		}	}		}			0,011 (3) [g]
$\gamma_{47,7}$	762,6								~0,00016 [g]
$\gamma_{45,5}$	763,60		0,00052 (26)						0,00035 [g]
$\gamma_{41,2}$	766,47		}0,00439 (24)						0,0021 (3) [g]
$\gamma_{51,12}$	767,29		}						0,0022 (5) [g,i]
$\gamma_{38,1}$	769,15		}0,179 (4)	}0,20 (2)		}0,187 (5)			0,081 (16) [g]
$\gamma_{39,1}$	769,4		}	}		}			0,108 (19) [g]
$\gamma_{43,4}$	769,54		}	}		}			- [m]
$\gamma_{-1,20}$	777,1		0,00044 (11)						0,00044 (11) *
$\gamma_{41,1}$	779,43		0,00217 (14)						0,00217 (14)
$\gamma_{-1,21}$	786,9		0,00138 (14)						0,00138 (14) *
$\gamma_{-1,22}$	788,5		0,00056 (11)						0,00056 (11)
$\gamma_{42,2}$	792,68		0,00032 (6)						0,00032 (6)
$\gamma_{-1,23}$	796,9		0,00024 (5)						0,00024 (5) *

	Energy, keV	1966 Ah02	1976 GuZN	1980 Despres	1982 He02	1984 Iw02	1992 Bl07	1994 Mo36	Evaluated
$\gamma_{-1,24}$	803,2		0,00102 (7)						0,00102 (7) *
$\gamma_{42,1}$	805,65		0,00044 (7)						0,00044 (7)
$\gamma_{43,2}$	808,21		0,00193 (10)						0,00193 (10)
$\gamma_{46,4}$	813,7		0,00072 (7)						0,00072 (7)
$\gamma_{50,9}$	816,0		0,00039 (6)						0,00039 (6)
$\gamma_{43,0}$	821,25		}0,00088 (9)						0,00079 (17) [n]
$\gamma_{51,10}$	821,3		}						~0,00009 [n]
$\gamma_{-1,25}$	826,8		0,00029 (10)						0,00029 (10) *
$\gamma_{-1,26}$	828,9		0,00212 (13)						0,00212 (13) *
$\gamma_{52,12}$	832,2		0,00047 (6)						0,00047 (6)
$\gamma_{-1,27}$	837,3		0,00031 (6)						0,00031 (6) *
$\gamma_{47,4}$	840,4		0,00077 (8)						0,00077 (8)
$\gamma_{44,1}$	843,78		0,00214 (12)						0,00214 (12)
$\gamma_{47,2}$	879,2		0,00058 (6)						0,00058 (6)
$\gamma_{47,1}$	891,0		0,00119 (13)						0,00119 (13)
$\gamma_{-1,28}$	895,4		0,00012 (4)						0,00012 (4) *
$\gamma_{-1,29}$	898,1		0,00028 (6)						0,00028 (6) *
$\gamma_{-1,30}$	905,5		0,00012 (4)						0,00012 (4) *
$\gamma_{-1,31}$	911,7		0,00022 (5)						0,00022 (5) *
$\gamma_{49,4}$	918,7		0,00014 (5)						0,00014 (5)
$\gamma_{-1,32}$	931,9		0,00020 (7)						0,00020 (7) *
$\gamma_{50,3}$	940,3		0,00079 (8)						0,00079 (8)
$\gamma_{48,2}$	955,41		0,00049 (5)						0,00049 (5)
$\gamma_{49,2}$	957,6		0,00051 (5)						0,00051 (5)
$\gamma_{48,1}$	968,37								~0,00044 [h]
$\gamma_{51,2}$	979,7		0,00044 (7)						0,00044 (7)
$\gamma_{-1,33}$	982,7		0,00017 (4)						0,00017 (4) *
$\gamma_{53,7}$	986,92		0,00033 (7)						0,00033 (7)
$\gamma_{51,1}$	992,64		0,00042 (6)						0,00042 (6)
$\gamma_{52,4}$	1005,7		0,00028 (4)						0,00028 (4)
$\gamma_{-1,34}$	1009,4		0,00022 (4)						0,00022 (4) *
$\gamma_{52,0}$	1057,3								0,00071 (11) [j]

[&]Other measurements for some γ rays: 1965Tr03, 1966Ho09, 1968Cl02, 1971GuZY, 1981UmZZ, 1992Ba08, 1992Co10, 1997Bu23, 1997Ko52.

* Unplaced in level scheme.

[a] Deduced from P(γ+ce) and total ICC.

[b] Intensity suitably divided for doublet in 2003Br12 (see comments therein).

[c] From 1971GuZY. Reported also in Coulomb excitation, see comments in 2003Br12.

[d] Intensity suitably divided for doublet in 2003Br12 using systematics.

[e] Seen in conversion electron spectrum only (1965Tr03).

[f] From 1976GuZN and corrected for X-ray component in 2003Br12.

[g]. Intensity suitably divided for doublet in 2003Br12 based on (n, γ) data (1979Al03).

[h] From (n, γ) data (1979Al03). See 2003Br12.

[i] Placement of this transition in the level scheme is uncertain (2003Br12).

[j] From 2003Br12.

[k] Intensity suitably divided for doublet in 1996Firestone.

[l] Multiply placed, undivided intensity given.

[m] E0-transition.

[n] Possible doublet (see 2003Br12); multiply placed.

Table 11. Energies, multipolarities, E2/M1 mixing ratios and ICC for soft gamma rays (< 120 keV) in decay of ^{239}Pu *

Energy (keV)	Multipolarity	δ-mixing ratio	K	L1	L2	L3	L	M	TOT
0,0765 (4)	E3								
12,975 (10)	M1+0,19 (2) %E2 [a]	0,0436 (23) [a]						451 (13)	607 (17) [a]
14,22 (3)									
30,04 (2)	(M1) [a]			104,9 (21)	12,42 (25)	0,687 (14)	118,0 (24)	28,7 (6)	157 (3)
38,661 (2)	M1+22,2 (16) %E2 [a]	0,534 (24) [a]		42,3 (8)	110 (7)	96 (7)	249 (14)	67 (4)	339 (19)
40,41 (5)									
41,93 (5)	(M1) [a]			39,3 (8)	4,66 (9)	0,249 (5)	44,2 (9)	10,71 (21)	58,6 (12)
46,21 (5)	M1+1,8 (5) %E2 [a]	0,134 (19) [a]		29,0 (6)	7,0 (11)	3,3 (9)	39,4 (19)	9,8 (5)	52,6 (27) [a]
46,68 (3)	M1+9 (5) %E2 [a]	0,32 (9) [a]		26,6 (12)	21 (10)	16 (9)	63 (17)	17 (5)	86 (24) [a]
47,60 (3)	(M1)			27,0 (5)	3,22 (6)	0,170 (3)	30,4 (6)	7,37 (15)	40,4 (8)
51,624 (1)	E2			4,20 (8)	120,4 (24)	101,8 (20)	226 (5)	62,6 (13)	310 (6)
54,039 (8)	M1 [a]			18,6 (4)	2,22 (4)	0,1154 (23)	21,0 (4)	5,08 (10)	27,8 (6)
56,828 (3)	M1+5,0 (8) %E2 [b]	0,23 (2) [b]		15,4 (3)	5,7 (7)	3,3 (5)	24,3 (11)	6,14 (30)	32,6 (15)
65,708 (30)	M1+4 (6) %E2 [a]	0,21 (16) [a]		10,1 (7)	2,8 (29)	1,35 (24)	14 (5)	3,,6 (13)	19 (6) [a]
67,674 (12)	M1+3,63 (11) %E2 [b]	0,194 (3) [b]		9,33 (19)	2,34 (5)	1,01 (3)	12,7 (4)	3,15 (9)	16,9 (5)
68,696 (6)	E2			1,19 (24)	31,6 (6)	24,5 (5)	57,3 (11)	15,9 (3)	78,6 (16)
68,73 (2)	(M1+20 %E2) [c]	0,5 [c]		7,6	7,2	4,9	20	5,2	27
74,96 (10)									

Energy (keV)	Multipolarity	δ-mixing ratio	K	L1	L2	L3	L	M	TOT
77,592 (14)	M1(+20 (32) %E2) [d]	0,5 (5) [d]		5,3 (2)	4 (5)	2,7 (40)	12 (7)	3,2 (21)	17 (10)
78,43 (2)	M1(+20 (32) %E2) [d]	0,5 (5) [d]		5,2 (17)	4 (5)	2,6 (40)	12 (7)	3,1 (20)	16 (10)
89,39 (6)	[M1]			4,28 (9)	0,519 (10)	0,0253 (5)	4,82 (10)	1,167 (23)	6,40 (13)
89,64 (3)	(M1+E2)						11 (6)	2,8 (17)	14 (8)
96,14 (3)	[E2]			0,318 (6)	6,72 (14)	4,63 (9)	11,67 (23)	3,24 (7)	16,0 (3)
97,6 (3)	M1+20 (19) %E2 [d]	0,5 (3) [d]		2,71 (6)	1,6 (11)	0,9 (8)	5,2 (14)	1,3 (4)	7,0 (19)
98,78 (2)	E2			0,289 (6)	5,94 (12)	4,05 (8)	10,28 (21)	2,85 (6)	14,1 (3)
103,06 (3)	E2			0,250 (5)	4,90 (10)	3,29 (7)	8,44 (17)	2,34 (5)	11,58 (23)
115,38 (5)	E2			0,172 (3)	2,95 (6)	1,88 (4)	5,00 (10)	1,39 (3)	6,87 (14)
116,26 (2)	M1(+24 (36) %E2) [d]	0,56 (56) [d]	8,4 (18)	1,5 (6)	0,9 (9)	0,5 (6)	2,9 (6)	0,74 (16)	12,2 (26)
119,70 (3)	(M1+E2)		5 (5)				3,1 (11)	0,8 (3)	9 (4)
119,76 (2)	[E2]		0,200 (4)	0,154 (3)	2,49 (5)	1,57 (3)	4,22 (8)	1,169 (23)	5,99 (12)

* For gamma rays with energies more than 120 keV the multipolarities are taken from 2003Br12 based on conversion electron data of 1965Tr03, experimental (n,γ) results of 1979Al03 or assigned from the decay scheme (in square brackets). The δ-mixing ratios are: 1,0 (10) for $\gamma_{26,5}$ (451,5 keV), < 1 for $\gamma_{40,10}$ (606,9 keV), < 0,5 for $\gamma_{28,0}$ (633,2 keV), 1,2 (2) for $\gamma_{46,7}$ (736,5 keV), 0,6 (2) for $\gamma_{46,7}$ (955,4 keV) and 0,6 (3) $\gamma_{46,7}$ (968,4 keV).

[a] Deduced from intensity balance.

[b] From muonic ^{235}U atom.

[c] From systematics.

[d] From conversion electron data of 1965Tr03.

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^{240}Pu – Comments on evaluation of decay data

by V. P. Chechev

This evaluation was done originally in 2004 (2004BeZQ, 2005ChZU) and then updated in June 2009 with a literature cut-off by the same date.

1. DECAY SCHEME

The decay scheme is based on 2006Br20. Some expected weak gamma-ray transitions were not observed directly in ^{240}Pu alpha decay but have been adopted from decay of ^{236}Pa and ^{236}Np and from data on nuclear reactions.

The alpha transitions to ^{236}U highly excited levels with energy of 958.960 and 967 keV were not observed. They are expected from data on level spins and gamma-rays de-excited these levels.

2. NUCLEAR DATA

Q(α) value is from 2003Au03.

The recommended half-life of ^{240}Pu is based on the experimental results given in Table 1. Re-estimated values were used for averaging where necessary.

Table 1. Experimental values of ^{240}Pu half-life (in years)

Reference	Author(s)	Original value	Re-estimated value	Measurement method
1951In03	Inghram et al.	6580 (40)	6500 (45) [b, c]	Mass-Spectrometry
1951We21	Westrum	6300 (600)		a-Particle Counting
1954Farwell	Farwell et al.	6760		a-Particle Counting
1956Bu92	Butler et al.	6600 (100)		a-Particle Counting
1959Dokuchaev	Dokuchaev	6620 (50)	6610 (55) [b]	a-Particle Counting
1968Oe02	Oetting	6524 (10)	6537 (15) [c]	Calorimetry
1978Ja11	Jaffey et al.	6569 (6)	6569 (7) [c]	a-Particle Counting
1984Be19	Beckmann et al.	6574 (6) [a]	6574 (7) [c]	Mass-Spectrometry
1984St06	Steinkruger et al.	6571 (9) [a]		a-Particle Counting
1984Lu04	Lucas and Noyce	6552.2 (20)	6552.2 (66) [c]	a-Particle Counting
1984Ru04	Rudy et al.	6552.4 (17)	6552.4 (66)	Calorimetry
2007Ah05	Ahmad et al.	6545 (19)		Ingrowth of ^{240}Pu in ^{244}Cm source, ^{240}Pu/^{244}Cm activity ratio measurement

[a] Quoted uncertainties, corresponding to 95 % confidence level, have been reduced by a factor 2.
[b] Re-estimated in 1978Ja11.
[c] Re-estimated in 1986LoZT.

With omitting the value of 1954Farwell reported without uncertainty the weighted average of the remaining 11 values is 6561 yr with the internal uncertainty 3.1 yr and external uncertainty 3.8 yr.

According to the criterion adopted by the members of the CRP (1986LoZT) a minimum uncertainty of the recommended ^{240}Pu half-life should be attributed as 7 years.

Therefore, the adopted value of the ^{240}Pu half-life is 6561(7) years.

The recommended of ^{240}Pu spontaneous fission half-life is based on the experimental results given in Table 2.

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

Reference	Author(s)	Measure-ment value	Measurement method	Used for final averaging
1953Ki72	Kinderman	1.314 (26)	Low geometry a-counting	No
1954Ba14	Barclay et al.	1.225 (30)	Low geometry a-counting	No
1954Ch74	Chamberlain et al.	1.20	Low geometry a-counting	No
1959Mi90	Mikheev et al.	1.20	Low geometry a-counting	No
1962Wa13	Watt et al.	1.340 (15)	Low geometry a-counting	No
1963Ma50	Malkin et al.	1.45 (2)	Low geometry a-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 a-counting	Yes
1991Iv01	Ivanov et al.	1.15 (2)	$?_{SF}$ /?a in ^{240}Pu standards	Yes

[a] Re-estimated in 2000Ho27. Original value is 1.170 (25).

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

The recommended value of the ^{240}Pu spontaneous fission is 1.15 (2)·10^{11} years where the uncertainty is the smallest quoted uncertainty.

2.1 Alpha Transitions

The energies of the alpha transitions have been obtained from the Q value and the level energies given in Table 3 from 2006Br20.

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

Level number	Energy, keV	Spin and parity	Half-life	Probability of α-transition (x100)
0	0,0	0^+	2.343 (6)·10^7 yr	72.74 (18)
1	45.2440 (20)	2^+	234 (6) ps	27.16 (19)
2	149.477 (6)	4^+	124 (7) ps	0.0863 (18)
3	309.785 (7)	6^+	58 (3) ps	0.001082 (18)
4	522.25 (5)	8^+	24 (2) ps	4.7 (5)·10^{-5}
5	687.59 (4)	1^-	3.78 (9) ns	1.93 (4)·10^{-5}
6	744.18 (7)	3^-	< 0.1 ns	
7	919.14 (17)	0^+		≈ 6.5·10^{-7}
8	957.90 (17)	(2^+)		< 1.7·10^{-7}
9	960.3 (3)	(2^+)		< 1.3·10^{-7}
10	966.62 (9)	1^-		< 1·10^{-7}

The probabilities of the most intense transitions $\alpha_{0,0}$ and $\alpha_{0,1}$ have been obtained by averaging experimental data (Table 4). The probabilities of all the remaining α-transitions have been deduced from the P(γ+ce) balances at relevant levels in ^{236}U. The $\alpha_{0,6}$-transition probability of 1.3 (7) 10^{-8} % has been taken from 2006Br20.

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

	a-particle energy keV	1956 Ko67	1956 Go43	1952 As28 1957 As83	1969 Le05	1977 Ba69	1984 Ah06	1990 An33	1992 Bl13	1994 Ra27	1994 Sa63	1996 Vi07	2004 Si03	Recommended
$a_{0,0}$	5168	75.5	75.5	76		73.51 (36)	72.8 (1)	73.0 (5)	72.55 (20)	73.1 (1)	72.5 (11)	74 (2)	72.56 (6)	72.74 (18) [a]
$a_{0,1}$	5124	24.4	24.5	24		26.39 (21)	27.1 (1)	27.0 (5)	27.35 (10)	26.8 (1)	27.5 (11)	26 (2)	27.35 (7)	27.16 (19) [b]
$a_{0,2}$	5021	0.091 (6)	0.085 (15)	0.1		0.096 (5)	0.090 (5)		0.10 (2)					0.0863 (18) [c]
$a_{0,3}$	4864	0.0032 (1)				0.001								0.001082 (18) [c]
$a_{0,4}$	4655													4.7 (5)·10^{-5} [c]
$a_{0,5}$	4492				2.1(4) 10^{-5}									1.93 (4)·10^{-5} [c]

[a] LWEIGHT computer program has increased the uncertainty of 2004Si03 to 0.0649 and recommended a weighted average (72.74) with the expanded uncertainty of 0.18 so range includes the most precise value of 72.56.
[b] LWEIGHT computer program has recommended a weighted average (27.16) with the expanded uncertainty of 0.19 so range includes the most precise value of 27.35.
[c] Deduced from (γ+ce)-intensity balance at relevant levels.

2.2. Gamma Transitions and Internal Conversion Coefficients

The recommended energies of gamma-ray transitions are virtually the same as the gamma-ray energies because nuclear recoil is negligible for ^{234}U.

The gamma-ray transition probabilities have been deduced from the gamma-ray emission probabilities and total internal conversion coefficients (ICCs). The ICCs have been interpolated using the BrIcc package with the so called "*Frozen Orbital*" approximation (2008Ki07). The uncertainties in the ICCs for pure multipolarities have been taken as 2 %. The multipolarities have been taken from 2006Br20.

The experimental values of ICC have been adopted for the E1 anomalously converted gamma-ray transitions $\gamma_{5,1}$ (642.4 keV) and $\gamma_{5,0}$ (687.6 keV).

3. ATOMIC DATA

3.1. Fluorescence yields

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

3.2. X-Rays

The energies of U LX-rays taken from the SAISINUC software supporting programs agree with the measurements of 1994Le28 and 1994Le37 where the fine structure of LX-radiation was measured in decays of ^{239}Pu and ^{240}Pu. Other measurements of U LX-rays can be found in 1983Ah02, 1984Bo41, 1992Ba08 and 1995Jo23.

The U KX-ray energies have been taken from 1999Schönfeld where the calculated values based on X-ray wavelengths from 1967Be65 (Bearden). In Table 5 the adopted values of U KX-ray energies are compared with experimental values.

The relative KX-ray emission probabilities have been taken from 1999Schönfeld.

Table 5. Experimental and recommended (calculated) values of U KX-ray energies (keV)

	1976GuZN	1982Ba56	1983Ah02	Adopted
$K\alpha_2$	94.655 (5)	94.656 (2)	94.67 (2)	94.666
$K\alpha_1$	98.442 (5)	98.435 (2)	98.45 (2)	98.440
$K\beta_3$	110.42	110.416 (3)	110.42 (3)	110.421
$K\beta_1$	111.30	111.300 (2)	111.31 (2)	111.298
$K\beta_5$	-	111.868 (5) - $K\beta_5''$ 112/043 (5) - $K\beta_5'$	112.01 (5)	111.964
$K\beta_{2,4}$	114.54	-	114.50 (3)	114.46
$KO_{2,3}$	115.40	-	115.40 (5)	115.377

3.3. Auger Electrons

The energies of Auger electrons are from the SAISINUC software supporting programs.

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

4. ALPHA EMISSIONS

The energy of alpha particles corresponding to the alpha transition to a ground state of ^{236}U, $E(\alpha_{0,0})$, has been adopted from the absolute measurement of 1972Go33 taking into account the correction of − 0.17 keV recommended by A.Rytz in 1991Ry01.

The energies of all other alpha particles have been deduced from $Q(\alpha)$, $E(\alpha_{0,0})$ and the level energies taking into account the ^{236}U recoil energies.

In Table 6 the deduced (recommended) values of α-particle energies are compared with the experimental results.

Table 6. Experimental and recommended α-particle energies in decay of ^{240}Pu, keV

	Measured [a]						Recommended
	1956 Ko67	1956 Go43	1952As28 1957As83	1962 Le11	1972 Go33	1977 Ba69	
$\alpha_{0,0}$	5166	5165	5168 (4)	5167.7 (7)	5168.13 (15) [b]	5168.13 (15) [b]	5168.13 (15) [b]
$\alpha_{0,1}$	5122	5121	5123 (5)	5123.3 (7)	5123.26 (23)	5123.45 (25)	5123.6 (2)
$\alpha_{0,2}$	5021 (2)	5020	5019			5021.3 (5)	5021.1 (2)
$\alpha_{0,3}$	4858 (5)	4856				4863.4 (5)	4863.5 (2)

[a] Original values have been adjusted taking into account changes in calibration energies as suggested in 1991Ry01.
[b] Absolute measurement; the value was adopted as recommended in 1991Ry01 and used in 2003Au03 for obtaining $Q(\alpha)$.

It should be noted that Sibbens and Romme (2004Si03) measured (using a 50 mm^2 high-resolution planar silicon detector) the energies of ^{240}Pu alpha particles relatively to reference peaks of ^{238}Pu and ^{239}Pu for a ^{238,239,240}Pu mixture. They obtained $E(a_{0,0})$ = 5168.54 (14) keV and $E(a_{0,1})$ = 5124.10 (15) keV discrepant with other published data.

5. ELECTRON EMISSIONS

The energies of the conversion electrons have been obtained from the gamma transition energies and the atomic-electron binding energies.

The emission probabilities of conversion electrons have been deduced from the evaluated P(γ) and ICC values. The experimental spectrum of the conversion electrons in decay of ^{240}Pu is given in 1958Sa21.

The absolute emission probabilities of K Auger electrons have been calculated using the EMISSION computer program (2000Schönfeld).

The total absolute emission probability of L Auger electrons has been deduced using the adopted total absolute emission probability of U LX–rays and fluorescence yield ϖ_L = 0.500 (19).

6. PHOTON EMISSIONS

6.1. X-Ray Emissions

The absolute emission probabilities of U LX–rays have been obtained as weighted averages of measurement results from 1994Le28 and 1994Le37. The uncertainties are the smallest quoted uncertainties.

The total absolute emission probability of U LX–rays P(XL) = 10.34 (15) %, adopted from measurements of 1994Le28, 1994Le37, agrees well with the value of P(XL) = 10.14 (23) %, calculated with using the EMISSION computer program (2000Schönfeld). The measurement result of 1970Swinth (11.5 (3) %) disagrees with the adopted and calculated values.

The absolute KX –ray emission probabilities have been calculated using the EMISSION computer program (2000Schönfeld).

6.2. Gamma-Ray Emissions

The energies of gamma-rays have been adopted from 2006Br20 based on the available experimental data from ^{240}Pu α-decay (Table 7) and data from decay of ^{236}Pa and ^{236}Np.

Table 7. Measured in ^{240}Pu α-decay [a] and recommended values of gamma-ray energies (keV)

	1969Le05	1971GuZY	1972Sc01	1974HeYW	1975OtZX	1976GuZN	1981He16	Recommended
$\gamma_{1,0}$		45.235 (20)	45.242 (6)			45.232 (5)	45.244 (3)	45.2440 (20)
$\gamma_{2,1}$		104.233 (10)	104.233 (5)	104.15 (2)		104.244 (5)	104.234 (6)	104.233 (5)
$\gamma_{3,2}$		160.35 (50)	160.310 (8)	160.27 (2)	160.312 (10)	160.280 (15)	160.308 (3)	160.308 (3)
$\gamma_{4,3}$			212.4 (1)		212.48 (5)			212.46 (5)
$\gamma_{5,2}$	538.05 (30)				538.09 (15)			538.10 (10)
$\gamma_{5,1}$	642.43 (10)			642.48 (15)	642.33 (10)	642.48		642.34 (5)
$\gamma_{5,0}$	687.77 (15)			688.01 (15)	687.57 (10)	687.7		687.56 (10)
$\gamma_{7,1}$	873.91 (20)				873.92 (15)			874.0 (2)

[a]. Other much more inaccurate measurements results see in 1958Sa21, 1959Tr37 and 1972CiZS.

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

Table 8. Experimental and recommended emission probabilities of gamma-rays in ^{240}Pu decay with energy less than 200 keV (per 10^4 α-decays)

	Energy (keV)	1971 GuZY	1972 Sc01	1975 OtZX	1976 GuZN	1976 Um01	1981 He16	1981 Morel	1994 Ba91	Recommended
$\gamma_{1,0}$	45.24	4.50 (10) [a]	4.50 [b]		4.53 (9) [d]	4.61 (14) [e]	4.35 (9)			4.62 (9) [f]
$\gamma_{2,1}$	104.23	0.700 (14) [a]	0.91 (5) [c]	0.70 [b]	0.698 (14) [d]		0.718 (7)			0.714 (7) [g]
$\gamma_{3,2}$	160.31	0.0420 (8) [a]	0.049 (12) [c]	0.0408 (10)	0.0402 (8) [d]		0.0402 (4)	0.0402 (7)	0.04065 (17)	0.04045 (22) [h]

[a] Omitted from averaging as the results of 1971GuZY were superseded in 1976GuZN.
[b] Omitted from averaging as an uncertainty is not quoted.
[c] Omitted on statistical considerations (using Chauvenet's criterion).
[d] The uncertainty quoted in 1976GuZN was re-estimated in 1986LoZT to include a 2 % detector efficiency uncertainty.
[e] The uncertainty quoted in 1976Um01 was re-estimated in 1986LoZT to include a 2 % detector efficiency uncertainty and 1 % from the sample isotopic composition.
[f] Deduced from intensity balance at level 45,24 keV using P($\alpha_{0,1}$) = 27,16 (19) % and total ICC $a_T(\gamma_{1,0})$ = 589 (12). The recommended value agrees with the measurement of 1976Um01and differs from the measurement result of 1981He16.
[g] Weighted average of 1976GuZN and 1981He16; the uncertainty is the smallest quoted uncertainty.
[h] LWEIGHT computer program identified an outlier (1972Sc01). With the five remained experimental values for processing the program increased the uncertainty of 1994Ba91 to 0.00030 and recommended a weighted average; the uncertainty is internal.

The emission probabilities of $\gamma_{4,3}$(212 keV) and $\gamma_{5,2}$(538 keV) have been adopted from absolute measurements of 1975OtZX. The emission probabilities of ?$_{5,1}$(642 keV) and ?$_{5,0}$(687 keV) have been obtained by averaging experimental data (Table 9).

Table 9. Experimental and recommended emission probabilities of gamma-rays de-exciting the ^{236}U level with energy of 687.6 keV in ^{240}Pu decay (per 10^8 a-decays)

	Energy, keV	1969Le05	1971GuZY	1975OtZX	1975Dr05	1976GuZN	Recommended
$\gamma_{5,2}$	538.1	≈ 0.23 [a]		0.147 (12)			0.147 (12)
$\gamma_{5,1}$	642.4	14.5 [a]	14.5 (5) [b]	12.6 (4)	13 (1)	12.45 (30)	12.6 (3) [c]
$\gamma_{5,0}$	687.6	3.77 (11)	3.70 (15) [b]	3.30 (13)		3.55 (9)	3.56 (9) [c]

[a] Omitted from averaging as an uncertainty is not quoted.
[b] Omitted from averaging as the results of 1971GuZY were superseded in 1976GuZN.
[c] Weighted average of 3 experimental values; the uncertainty is the smallest quoted uncertainty.

The emission probability of $\gamma_{7,1}$ (874 keV) has been obtained as a weighted average of measurement results from 1969Le05 and 1975OtZX.

The weak gamma-rays with energy more than 900 keV were reported in 1969Le05 and 1976GuZN. They are expected from the decay scheme but their emission probabilities ($<10^{-7}$ per 100 decays) were determined with a great inaccuracy.

7. CONSISTENCY OF RECOMMENDED DATA

The most accurate Q value, Q(M), is taken from the atomic mass adjustment table of Audi et al. (2003Au03). Comparison of Q(eff)(deduced as the sum of average energies per disintegration ($\sum E_i \times P_i$) for all emissions accompanying ^{240}Pu α- decay) with the tabulated decay energy Q(M) allows to check a consistency of the recommended decay-scheme parameters obtained in this evaluation.

Here E_i and P_i are the evaluated energies and emission probabilities of the i-th alpha particle, beta particle, gamma-ray, X-ray, etc. Consistency (percentage deviation) is determined by {[Q(M) – Q(eff))] / Q(M)} × 100. "Percentage deviations above 5 % would be regarded as high and imply a poorly defined decay scheme; a value of less than 5 % indicates the construction of a reasonably consistent decay scheme" (quoted from the article by A. L. Nichols in Appl. Rad. Isotopes 55(2001) 23-70).

For the above ^{240}Pu decay data evaluation we have Q(M) = 5255.75 (14) keV and Q(eff) = 5255 (9) keV. Thereafter, the percentage deviation is (0.00 ± 0.17) %, i.e. consistency is superior.

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

This evaluation was completed in November 2005 and corrected in September 2006. The literature available by September 2006 was included.

1. Decay Scheme

The decay scheme is based on the evaluation of 2006Ba41 (see also the evaluations of 1995Ak01 and 1978El02). It can be considered as basically completed though some very weak gamma transitions were not observed in ^{241}Pu alpha decay.

It should be noted there is an ambiguity in the placement of 121,2 keV γ–transition in ^{237}U level scheme due to doublet (7/2+, 11/2+) near 204 keV. Following 2006Ba41 we show the above γ–transition in Pu-241 α-decay as going from the level 7/2+ while Fotiades *et al.* (2004Fo01) observed this transition in (n,2n)-reaction as going from the level 11/2+.

The upper limit of SF decay is from 1985Dr09.

2. Nuclear Data

Q(α) value is from 2003Au03.

The evaluated ^{241}Pu half-life is based on the experimental data given in Table 1. A detailed review of half-life measurements up to 1985 can be found in 1987Ag03. References to earlier measurements are listed in 1978El02. Discrepancies in the measurements were examined by 1986Ha06 and 1987Ba84 in terms of chemical dependency of low-energy β^- decay. In 1986Ha06 a conclusion is drawn that chemical variations (~ 0,3 %) cannot be accountable completely for half-life discrepancies (≥ 1 %).

Table 1. Experimental values of the ^{241}Pu half-life (in years)

Reference [a]	Author(s)	Measurement method	Stated value	Revised value	Comments
1953Ma19	MacKenzie *et al.*	Ingrowth of ^{241}Am by α counting	13,0 (2)	14,1 (2)	Re-estimated for the ^{241}Am half-life of 432,6 (6) a
1956Ro26	Rose and Milstead	Ingrowth of ^{241}Am by 60-keV γ counting	12,77 (28)	13,87 (30)	Re-estimated for the ^{241}Am half-life of 432,6 (6) a. OMITTED: outlier
1960Br15	Brown *et al.*	Ingrowth of ^{241}Am by α counting	13,24 (24)	14,12 (26)	Re-estimated for the ^{241}Am half-life of 432,6 (6) a
1961Sm03	Smith	Ingrowth of ^{241}Am α-emission	13,0 (3)	14,1 (3) 13,3 (3)	Re-estimated for the ^{241}Am half-life of 432,6 (6) a
1966French	French *et al.*	Change in ^{241}Pu/Pu ratio by MS	13,59 (46)		Quoted in 1987Ag03 OMITTED: outlier
1966Stepan	Stepan and Nisle	Change in ^{241}Pu reactivity with time	13,63 (36)		OMITTED: updated in 1970Ni02
1967Shields	Shields	Change in ^{241}Pu/Pu ratio in a Pu isotopic standard in 2 years by MS	14,4 (2)		Quoted in 1967Oe01. Stated uncertainty at 0,95 C.L. OMITTED: updated in 1970Sh18

1968Ca19	Cabell	Change in $^{241}Pu/^{240,242}Pu$ ratios in 4,5 years by MS	14,98 (33)		OMITTED: updated in 1971Ca15, outlier
1970Ni02	Nisle and Stepan	Change in ^{241}Pu reactivity with time (in 2,5 yr)	14,63 (27)		
1970Sh18	Shields	Change in ^{241}Pu/Pu ratio in a Pu isotopic standard in 4 years by MS	14,6 (4)	14,6 (2)	Stated uncertainty at 0,95 C.L. For statistical analysis it has been multiplied by 0,5
1971Ca15	Cabel and Wilkins	Change in $^{241}Pu/^{240,242}Pu$ ratios in 6,65 years by MS	15,16 (19)		OMITTED: outlier
1972 Whitehead	Whitehead *et al.*	Ingrowth of ^{241}Am by 60-keV γ counting	14,91 (15)	14,96 (15)	Re-estimated for the ^{241}Am half-life of 432,6 (6) a OMITTED: updated in 1977Whitehead, outlier
1973JoYT	Jordan	Calorimetric determination of power decay	14,355 (7)		Quoted in 1974StYG
1973Ze02	Zeigler and Ferris	Change in $^{241}Pu/^{240}Pu$ ratio by MS	14,89 (11)		OMITTED: outlier
1975WiYM	Wilkins	Change in $^{241}Pu/^{240,242}Pu$ ratio by MS	15,02 (10)		OMITTED: outlier
1976McZB	McKean and Crouch	Change in $^{241}Pu/^{240,242}Pu$ ratio by MS	14,35 (6)		
1977Crouch	Crouch and McKean	Change in $^{241}Pu/^{240,242}Pu$ ratio by MS	14,41 (12)		Average of measurement results from 1976-1977 series of experiments
1977 Whitehead	Whitehead	Ingrowth of ^{241}Am 60-keV γ ray	14,56 (15)		
1978 Vaninbroukx	Vaninbroukx	Ingrowth of ^{241}Am by α and 60-keV γ ray counting	14,60 (10)		
1978 Vaninbroukx	Vaninbroukx	Change in $^{241}Pu/^{240}Pu$ ratio by MS	14,30 (14)		
1979Garner	Garner and Machlan	Change in $^{241}Pu/^{240,242}Pu$ ratio by MS	14,38 (7)		
1980Ag02	Aggarwal and Jane	Ingrowth of ^{241}Am by α spectrometry	14,42 (9)		80 α-spectrometric measurements in 457 days
1980Ma45	Marsch *et al.*	Change in $^{241}Pu/^{242}Pu$ ratio in 3,6 yr by MS	14,38 (6)	14,38 (3)	Stated uncertainty at 0,95 C.L. For statistical analysis it has been multiplied by 0,5
1981Ag01	Aggarwal *et al.*	Ingrowth of ^{241}Am by IDAS	14,52 (8)		
1981Ag07	Aggarwal *et al.*	Ingrowth of ^{241}Am by α spectrometry and APS	14,44 (6)		Average of the measurement results from two independent series of experiments
1982Ag01	Aggarwal *et al.*	Ingrowth of ^{241}Am by IDMS	14,32 (11)	14,32 (6)	Revised uncertainty, see 1989Ho24

1982Hiyama	Hiyama *et al.*	Change in ^{241}Pu/Pu ratio by MS	14,29 (15)		Quoted in 1989Ho24
1983DeZX	De Bievre *et al.*	Change in ^{241}Pu/^{240}Pu ratio in 6 years by MS	14,33 (2)		OMITTED: superseded in 1997DeZY
1985Ag02	Aggarwal *et al.*	Changes in ^{241}Pu/^{240}Pu, ^{241}Pu/^{239}Pu, ^{241}Pu/^{242}Pu ratios in 5 years by MS	14,38 (2)		In 1985Ag02 it is noted that values from 1980Ag02, 1981Ag01, 1981Ag07, 1982Ag01 were obtained in independent sets of experiments
1986Ti04	Timofeev *et al.*	Ingrowth of ^{241}Am by IDMS	14,57 (10)	14,57 (5)	Stated uncertainty at 0,95 C.L. For statistical analysis it has been multiplied by 0,5
1989Pa21	Parker *et al.*	Change in ^{241}Pu/^{239}Pu ratio by high resolution γ-spectrometry	14,355 (40)		156 sets of normalized spectral full energy peak-area ratios from 13 plutonium samples during 10 years
1997DeZY	De Bievre and Verbruggen	Change in ^{241}Pu/^{240}Pu ratio by precision MS	14,290 (6)	14,290 (3)	Stated uncertainty at 0,95 C.L. For statistical analysis it has been multiplied by 0,5

MS=Mass Spectrometry, IDMS=Isotope Dilution Mass Spectrometry, IDAS=Isotope Dilution Alpha Spectrometry
[a] In 1978El02 two more experimental values of are quoted from the private communications of 1977RGZZ and 1978RGZZ. These values are intermediate results of experiments and not discussed later on including the review of 1987Ag03.

After omitting the five superseded values from 1966Stepan, 1967Shields, 1968Ca19, 1972Whitehead and 1983DeZX the data set for statistical processing includes the 24 values. The LWEIGHT computer program using the LRSW analysis has identified the four outliers of 1971Ca15, 1975WiYM, 1973Ze02 and 1956Ro26 and increased the uncertainty of 1997DeZY by 2,04 times. The weighted average of the remaining twenty three values is 14,327, with an internal uncertainty of 0,037, a reduced χ^2 of 5,34, and an external uncertainty of 0,010. The unweighted average is 14,371 (34). The LWEIGHT program has chosen the weighted average and expanded the final uncertainty to 0,037 so range includes the most precise value of 14,290.

The adopted value of the ^{241}Pu half-life is 14,33 (4) years, or 5234 (15) days.

Possible chemical effects do not exceed or about the stated relative uncertainty of the half-life.

2.1. Beta Transition

^{241}Pu decays by β^- emission to the ground state of ^{241}Pu (Table 2).

Table 2. ^{241}Am level populated in the ^{241}Pu β^--decay

Level	Energy, (keV)	Spin and parity	Half-life	Probability (%)
0	20,8 (2)	$5/2^-$	432,6 (6) a	99,997 56 (2)

The experimental and evaluated values of the β^- transition energy are given in Table 3.

The value Q^- = 20,78 (20) keV from 1999YaZX was superseded by the same group in 1999Dr13 and 2000Dr02. Audi *et al.* (2003Au03) give Q^- = 20,78 (13) keV taking into account the value from 1999YaZX (see also 2005Ma88).

Table 3. Experimental values of the ^{241}Pu β^- transition energy (keV)

Level	1952Fr25	1956Sh31	1999Dr13 2000Dr02	Evaluated
0	20,5 (12)	20,8 (2)	20,7 (3)	20,8 (2)

The probability of the β^--transition was deduced from the evaluated α branching (Table 4).

Table 4. Experimental and evaluated values of α branching (α/β^-), per decay, in the ^{241}Pu decay

1961Sm03	1968Ah01	1976GuZN	1977VaYR	Evaluated
$2{,}44\ (10)\cdot10^{-5}$	$2{,}45\ (8)\cdot10^{-5}$	$2{,}46\ (1)\cdot10^{-5}$	$2{,}42\ (2)\cdot10^{-5}$	$2{,}44\ (2)\cdot10^{-5}$

2.2. Alpha Transitions

The energies of the alpha transitions have been deduced from Q_α value and the level energies given in Table 5. The level energies were calculated from the gamma-ray energies except for the levels “8”,”9” and “10” the energies of which were taken from 1996FiZX.

Table 5. ^{237}U levels populated in the ^{241}Pu α decay

Level number	Energy, (keV)	Spin and parity	Half-life	Experimental probability of α transition (%) 1965Ba26	Experimental probability of α transition (%) 1968Ah01	Adopted probability of α transition (%)
0	0,0	$1/2^+$	6,752 (2) d	$8{,}6\cdot10^{-6}$		$8{,}6\ (10)\cdot10^{-6}$
1	11,39 (2)	$3/2^+$		$2{,}5\cdot10^{-5}$		$2{,}5\ (2)\cdot10^{-5}$
2	56,30 (12)	$5/2^+$		$0{,}88\cdot10^{-5}$	$1{,}00\ (12)\cdot10^{-5}$	$1{,}00\ (12)\cdot10^{-5}$
3	82,97 (13)	$7/2^+$		$2{,}73\cdot10^{-5}$	$3{,}2\ (3)\cdot10^{-5}$	$3{,}2\ (3)\cdot10^{-5}$
4	159,96 (2)	$5/2^+$	3,1 (1) ns	$2{,}04\cdot10^{-3}$	$2{,}03\ (4)\cdot10^{-3}$	$2{,}03\ (4)\cdot10^{-3}$
5	204,19 (14)	$7/2^+$		$3{,}00\cdot10^{-4}$	$2{,}95\ (8)\cdot10^{-4}$	$2{,}95\ (8)\cdot10^{-4}$
6	260,95 (17)	$9/2^+$	-	$2{,}88\cdot10^{-5}$		$2{,}9\ (3)\cdot10^{-5}$
7	274,0 (10)	$(7/2)^-$	155 (6) ns		$0{,}5\ (2)\cdot10^{-5}$	$0{,}5\ (2)\cdot10^{-5}$
8	316 (5)	$(9/2)^-$	-		$\approx1{,}7\cdot10^{-6}$	$\approx1{,}7\cdot10^{-6}$
9	327 (3)	$11/2^+$	-	$\approx7\cdot10^{-7}$		$\approx7\cdot10^{-7}$
10	367 (3)	$(11/2^-)$			$\approx7\cdot10^{-7}$	$\approx7\cdot10^{-7}$

The absolute alpha transition probabilities, $P(\alpha_i)$, were calculated using the value of $2{,}44\ (2)\cdot10^{-5}$ for the ^{241}Pu alpha decay branching. The uncertainties of $P(\alpha_{0,0})$ and $P(\alpha_{0,1})$ have been estimated using the relative uncertainty of the sum of $P(\alpha_{0,0})$ and $P(\alpha_{0,1})$ (equal to 1/15) from 1968Ah01.

The probabilities of α-transitions (per 100 α decays) are from the measurements of 1965Ba26 and 1968Ah01. Other measurements: 1976BaZZ. The values of hindrance factors have been calculated using ALPHAD code and r_0 = 1,5156 (9) from 1998Ak04.

2.3. Gamma-ray Transitions and Internal Conversion Coefficients

The evaluated energies of gamma-ray transitions are virtually the same as the photon energies because nuclear recoil is negligible.

The gamma-ray transition probabilities, $P_{\gamma+ce}$, were deduced from the gamma-ray emission probabilities and the total internal conversion coefficients (ICC's) interpolated from the BrIcc package. The relative uncertainties of α_K, α_L, α_M, α_T for pure gamma ray multipolarities have been taken as 2 %.

$P_{\gamma+ce}$ ($\gamma_{1,0}$ 11,39-keV), $P_{\gamma+ce}$ ($\gamma_{3,2}$ 26,6-keV), $P_{\gamma+ce}$ ($\gamma_{5,4}$ 44,18-keV), $P_{\gamma+ce}$ ($\gamma_{2,1}$ 44,86-keV) and $P_{\gamma+ce}$ ($\gamma_{6,5}$ 56,76-keV) were derived from the intensity balances using the adopted probabilities of α-transitions to the corresponding levels. The E2/M1 mixing ratios for $\gamma_{5,4}$ (44,18-keV), $\gamma_{2,1}$ (44,86-keV) and $\gamma_{6,5}$ (56,76-keV) have been deduced from the calculated total conversion coefficients. The gamma transition multipolarities and the E2/M1 mixing ratios for the remaining gamma transitions have been adopted from the analysis of the ^{237}U level scheme in 1995Ak01.

The transition $\gamma_{6,4}$ (100,94 keV) was not observed experimentally; it is obscured by U KX-rays. This transition is given in 1995Ak01.

3. Atomic Data

3.1. Fluorescence yields

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

3.2. X Radiations

The relative KX-ray emission probabilities are from 1999ScZX.

3.3. Auger Electrons

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

4. Electron Emissions

The energies of the conversion electrons have been calculated from the gamma transition energies and the electron binding energies.

The emission probabilities of the conversion electrons have been calculated using the evaluated P_γ and ICC values.

The total absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program.

β^- average energy was adopted from the measurement of 1968Oe01. The calculated value is discrepant: 5,23(5) keV.

5. Alpha Emissions

In Table 6 the experimental and adopted energies of α particles (in keV) are given. The original values of 1965Ba26, 1968Ba25 were increased by 0,4 keV and the values of 1968Ah01 by 0,6 keV because of changes in calibration energies, as recommended by Rytz in 1991Ry01. Other measurements: 1953As40, 1964Dz03, 1976BaZZ, 1984Gl03.

The adopted energies of α particles have been obtained from Q_α value and the level energies given in Table 5 taking into account the relevant recoil energies.

Table 6. α - particle energies in the ^{241}Pu decay (keV)

	1965Ba26 1968Ba25	1968Ah01	Adopted (calculated from Q_α)
$\alpha_{0,10}$		4693 (6)	4694 (3)
$\alpha_{0,9}$	4732		4733 (3)
$\alpha_{0,8}$		4743 (5)	4744 (5)
$\alpha_{0,7}$		4784 (5)	4785,1 (11)
$\alpha_{0,6}$	4798	4798 (3)	4798,0 (5)
$\alpha_{0,5}$	4853,3 (12)	4853 (3)	4853,8 (5)
$\alpha_{0,4}$	4896,3 (12)	4896 (3)	4897,3 (5)
$\alpha_{0,3}$	4971	4973 (3)	4973,1 (5)
$\alpha_{0,2}$	4998	5000 (4)	4999,2 (5)
$\alpha_{0,1}$	5041	5043 (3)	5043,4 (5)
$\alpha_{0,0}$	5051	5056 (5)	5054,6 (5)

6. Photon Emissions

6.1. X-Ray Emissions

The absolute emission probabilities of U KX and LX-rays have been calculated using the EMISSION code.

		Energy, (keV)	Number of photons per 100 disintegrations
X_K	$K\alpha_2$ (U)	94,666	3,00 (7)·10^{-4}
	$K\alpha_1$ (U)	98,440	4,79 (10)·10^{-4}
	$K\beta_3$ (U)	110,421	}
	$K\beta_1$ (U)	111,298	} 1,79 (5)·10^{-4}
	$K\beta_5$ (U)	111,964	}
	$K\beta_{2,4}$ (U)	114,46	}0,59 (2)·10^{-4}
	$KO_{2,3}$ (U)	115,377	}
X_L	Ll (U)	11,619	0,336 (12)·10^{-4}
	$L\alpha_2$ (U)	13,438	0,556 (19)·10^{-4}
	$L\alpha_1$ (U)	13,615	4,87 (17)·10^{-4}
	Lη (U)	15,399	0,0444 (13)·10^{-4}
	Lβ (U)	15,727 – 18,206	4,77 (8)·10^{-4}
	Lγ (U)	19,507 – 20,714	1,09 (2)·10^{-4}

6.2. Gamma-Ray Emissions

In Table 7 the experimental and adopted energies of gamma-rays are given (see also the evaluation of 1988ChZL). Other measurements: 1952Fr25, 1965Ba35, 1976Um01, 1979Ce04, 1993Dr05.

The energies of $\gamma_{1,0}$ (11,39 keV), $\gamma_{3,2}$ (26,67 keV) and $\gamma_{6,4}$ (100,94 keV) have been calculated from the level scheme: $E\gamma_{1,0}$ (11,39 keV) = $E\gamma_{4,0}$ - $E\gamma_{4,1}$; $E\gamma_{3,2}$ (26,67 keV) = $E\gamma_{4,2}$ - $E\gamma_{4,3}$; $E\gamma_{6,4}$ (100,94 keV) = $E\gamma_{5,4}$ + $E\gamma_{6,5}$.

Table 7. Experimental and evaluated gamma-ray energies in the ^{241}Pu decay (keV)

	1968Ah01	1971GuZN 1976GuZN	1972Cline	Adopted
$\gamma_{1,0}$		11,39		11,39 (2)
$\gamma_{3,2}$				26,67 (4)
$\gamma_{5,4}$		44,19 (3)	44,175 (30)	44,18 (3)
$\gamma_{2,1}$	44,7 (3)	44,86 (10)		44,86 (10)
$\gamma_{2,0}$	56,6 (2)	56,30 (12)	56,412 (30)	56,30 (12)
$\gamma_{6,5}$		56,76 (10)		56,76 (10)
$\gamma_{3,1}$		71,60 (7)	71,672 (40)	71,64 (9)
$\gamma_{4,3}$	76,9 (2)	76,96 (10)	77,014 (40)	77,01 (4)
$\gamma_{6,4}$				100,94 (11)
$\gamma_{4,2}$	103,5 (2)	103,680 (5)	103,540 (40)	103,680 (5)
$\gamma_{7,4}$	114,0 (10)		115,342 (40)	114,0 (10)
$\gamma_{5,3}$	120,7 (5)	121,2 (10)	121,220 (30)	121,22 (5)
$\gamma_{4,1}$	148,5 (2)	148,567 (10)	148,560 (20)	148,567 (10)
$\gamma_{4,0}$	160,0 (2)	160,00 (4)	159,960 (20)	159,96 (2)

In Table 8 the experimental and evaluated absolute gamma-ray emission probabilities are given. The evaluated values have been obtained using the LWEIGHT computer program. The uncertainty assigned in this evaluation to the recommended value is always greater than or equal to the smallest uncertainty in any of the experimental values used in the statistical processing.

Table 8. Experimental and evaluated absolute emission probabilities of gamma rays in the ^{241}Pu decay per 10^6 disintegrations

Eγ (keV)	1968Ah01	1976GuZN	1976Um01	1978DiZU	1985He02	1985Wi04	1994Ba91	Evaluated
44,18		0,042 (2)						0,042 (2)
44,86		0,0084 (10)						0,0084 (10)
56,30		0,025 (2)						0,025 (2)
56,76		0,010 (1)						0,010 (1)
71,64		0,029 (2)						0,029 (2)
77,0	0,18 (2)	0,220 (8)			0,211 (5)	0,203 (4)		0,207 (4)
100,94		0,00072						0,00072
103,68	1,10 (12)	1,03 (3)		1,04 (5)	1,02 (3)	1,032 (12)		1,03 (2)
114,0		0,062 (12)						0,062 (12)
121,22		0,0070 (7)						0,0070 (7)
148,6	2,20 (22)	1,86 (3)	1,91 (4)	1,85 (7)	1,863 (17)	1,855 (16)	1,863 (8)	1,863 (8)
159,9	0,078 (8)	0,0671 (15)			0,0654 (19)	0,0651 (14)	0,06321 (40)	0,0645 (9)

The absolute emission probability of $\gamma_{6,4}$ (100,94 keV) has been deduced from the ratio of P_γ ($\gamma_{6,4}$; 100,94 keV) /P_γ ($\gamma_{6,5}$; 56,76 keV) = 5,87 which has been calculated in 1995Ak01 by using the Alaga rule.

The absolute emission probabilities of the remaining gamma rays have been adopted from 1976GuZN.

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

This evaluation was done originally in 2004 (2004BeZQ, 2005ChZU) and then updated in June 2009 with a literature cut-off by the same date.

1 Decay Scheme

The decay scheme can be basically considered completed though weak alpha transitions to some highly excited ^{238}U levels (with energy more than 307 keV, see 2002Ch52) are possible but have not been observed yet. They are expected from data on level spins and Q(α) value and cannot appreciably influence intensity balances at the four lower levels well established.

2 Nuclear Data

Q(α) value is from 2003Au03.

The recommended half-life of ^{242}Pu is based on the experimental results given in Table 1. Re-estimated values were used for averaging where necessary.

Table 1. Experimental values of ^{242}Pu half-life (in 10^5 years).

Reference	Author(s)	Original value	Re-estimated value	Measurement method
1956Bu64	Butler et al.	3.73 (5)	3.65 (5) [a]	^{242}Pu/^{238}Pu, mass- and α-spectrometry
1956Bu92	Butler et al.	3.79 (5)		Specific activity, ionization chamber
1956Me37	Metch et al.	3.88 (10)	3.85 (10) [a]	^{242}Pu/^{240}Pu, mass- and α-spectrometry
1969Be06	Bemis et al.	3.869 (16)	3.82 (3) [b]	^{242}Pu/^{239}Pu, mass- and α-spectrometry
1970Du02	Durham and Molson	3.66 (7)	3.67 (7) [a]	^{242}Pu/^{238}Pu, mass- and α-spectrometry
1976Bu23	Bulaynitsa et al.	3.702 (7) [c]		Specific activity, 4πα-X coincidences
1976Os05	Osborne and Flotov	3.763 (9)		Calorimetry
1978MeZL	Meadows	3.736 (25)	3.708 (29) [a]	^{242}Pu/^{239}Pu, mass- and α-spectrometry
1979Ag03	Aggarwal et al.	3.742 (24)		^{242}Pu/^{239}Pu, mass- and α-spectrometry
1979Ag03	Aggarwal et al.	3.766 (25)		^{242}Pu/^{238}Pu, mass- and α-spectrometry

[a] Re-estimated in 1979Ag03 using the values of 87.74 yr for ^{238}Pu half-life and 24110 yr for ^{239}Pu half-life.
[b] Re-estimated in 1976Bu23 as a result of analysis of systematic uncertainties in 1969Be06 and using better values of auxiliary half-lives (see also 1979Ag03).
[c] Quoted uncertainty, corresponding to 95 % confidence level, has been reduced by a factor 2.

The weighted average of the ten values is 3.7304 with the internal uncertainty 0.0051 and external uncertainty 0.0116 and $\chi^2/\nu = 3.16$. The uncertainty of 1976Bulaynitsa was increased to 0.00724 to adjust weights according to the Limitation of Relative Statistical Weight method.

The LWEIGHT computer program has used the weighted average and expanded the uncertainty to 0.0284 so range includes the most precise value of 3.702 (1976Bu23).

The recommended value of ^{242}Pu half-life is 3.73 (3)·10^5 years.

The recommended spontaneous fission half-life of ^{242}Pu is based on the experimental results given in Table 2.

Table 2. Experimental values of the spontaneous fission ^{242}Pu half-life (in 10^{10}years).

Reference	Author(s)	Original value	Re-estimated value [a]	Measurement method
1956Studier	Studier and Hirsch	6.7 (7)		Quoted by Mech et al.(1956); no details available
1956Me37	Mech et al.	7.06 (19)	6.79 (19)	α/SF; low geometry α-counting and Ar-CH_3 counter for SF
1956Bu92	Butler et al.	6.64 (10)	6.65 (10)	α/SF; ionization chamber
1961Dr04	Druin et al.	6.6 (7)		Gas scintillator; relative to α half-life of ^{238}Pu
1963Ma50	Malkin et al.	7.45 (17)		Gas scintillator; specific activity
1978MeZL	Meadows	6.80 (5)	6.74 (5)	α/SF; relative to half-life of ^{239}Pu
1980Kh05	Khan et al.	7.43		Mica fission track detector
1988SeZY	Selickij et al.	6.86 (26)		Fission fragment detection in 2π geometry

[a] Re-estimated in 2000Ho27.

Omitting the value of 1980Kh05 reported without uncertainty, the weighted average of the seven remaining values is 6.79 with the internal uncertainty 0.032 and external uncertainty 0.090 and $\chi^2/\nu = 2.94$.

The adopted value of the ^{242}Pu spontaneous fission is 6.79 (10)·10^{10} years where the uncertainty is the smallest quoted experimental uncertainty.

2.1 α Transitions

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

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

Level number	Energy, keV	Spin and parity	Half-life	Probability of α-transition (x100)
0	0,0	0^+	4.468 (5)·10^9 yr	76.53 (17)
1	44.915 (13)	2^+	206 (3) ps	23.44 (17)
2	148.39 (3)	4^+		0.030 4 (13)
3	307.19 (8)	6^+		0.000 84 (6)

The probabilities of the transitions of $\alpha_{0,0}$, $\alpha_{0,1}$and $\alpha_{0,2}$ have been obtained by averaging the direct alpha-emission measurement results (the most accurate of them are from 1986Va33) and the values deduced from the gamma-ray transition probability (P(γ+ce)) balances at the corresponding ^{238}U levels. The deduced values are based on the measurements of absolute gamma-ray emission probabilities (P(γ)) from 1986Va33 (see Table 6) and adopted total internal conversion coefficients (ICCs).

Such averaging is possible as in 1986Va33 the independent measurements were carried out for alpha-emission intensities (with Si(Au) detector) and gamma-ray intensities (with two Ge detectors). The correlation between these measurements can be only due to the same sources used but it is negligible taking into account a large difference between the methods and detectors. Determination of the ^{242}Pu disintegration rates for six sources required for the absolute gamma intensity measurements was made in 1986Va33 using absolute alpha particle counting under well-defined low solid angles, i.e. out of connection with the alpha - emission intensity measurements with Si(Au) detector.

The probability of the $\alpha_{0,3}$-transition has been deduced from the P(γ+ce) balance at the ^{238}U level of 307.19 keV (Table 4).

Table 4. Experimental, deduced and recommended values of α-transition probabilities ($\times$100) in ^{242}Pu decay.

	α-particle energy (keV)	1953Asaro	1956Hu96	1976Baranov	1986Va33	Deduced from P(γ) measured in 1986Va33	Recommended
$\alpha_{0,0}$	4902	80 (6) [a]	74 (4) [a]	79.7 (20) [b]	76.45 (17)	77.3 (6)	76.53 (17) [c]
$\alpha_{0,1}$	4858	20 (6) [a]	26 (4) [a]	20.2 (20) [b]	23.52 (17)	22.7 (6)	23.44 (17)[c]
$\alpha_{0,2}$	4756	-	-	-	0.0290 (14)	0.031 7 (13)	0.030 4 (13)
$\alpha_{0,3}$	4600	-	-	-	-	0.000 84 (6)	0.000 84 (6)

[a] No uncertainties were quoted by the authors. The uncertainties adopted here were estimated by R. Vaninbroukx from the spectra shown in the papers (1986LoZT).
[b] The uncertainties of 2.7 for 79.7 and 1.1 for 20.2 quoted by the authors were re-estimated by R. Vaninbroukx (1986LoZT).
[c] Weighted average of the five values including direct measurement results and deduced value, uncertainty is the smallest quoted one.
[d] Weighted average of the two values including direct $\alpha_{0,2}$-transition measurement result and deduced value, uncertainty is the smallest quoted one.

2.2 γ Transitions

The recommended energies of gamma-ray transitions are virtually the same as the gamma-ray energies because nuclear recoil is negligible for ^{234}U.

The gamma-ray transition probabilities have been deduced from the gamma-ray emission probabilities and total internal conversion coefficients (ICCs). The ICCs have been interpolated using the BrIcc package with the so called "*Frozen Orbital*" approximation (2008Ki07). The uncertainties in the ICCs for pure multipolarities have been taken as 2 %. The multipolarities have been taken from 2002Ch52.

3 Atomic Data

3.1. Fluorescence yields

The fluorescence yield data are from 1996Sc06 (Schönfeld and Janβen).

3.2 X-rays and Auger electrons

The energies of U LX-rays taken from the SAISINUC software supporting programs agree with the measurements of 1994Le37 where the fine structure of LX radiation was measured in decay of ^{240}Pu.

The U KX-ray energies have been taken from 1999Schönfeld where the calculated values based on X-ray wavelengths from 1967Be65.

The relative KX-ray emission probabilities have been taken from 1999Schönfeld.

The energies of Auger electrons are from the SAISINUC software supporting programs. The ratios P(KLX)/P(KLL), P(KXY)/P(KLL) are taken from 1996Sc06.

4 Alpha Emissions

The α-emission energies have been obtained from Q value and ^{238}U level energies taking into account the ^{238}U recoil energies. In Table 5 the recommended values of α-emission energies are compared with the experimental results from alpha-spectrometric measurements and also with the evaluated data by A. Rytz (1991Ry01).

Table 5. Experimental and recommended α-emission energies in decay of ^{242}Pu (keV).

	Measured [a]				1991Ry01	Recommended
	1953Asaro	1956Hu96	1956Ko67	1968Ba25		
$\alpha_{0,0}$	4904.6 (20)	4903.7 (30)	4907.2 (30)	4900.4 (12)	4902.3 (14)	4902.3 (10)
$\alpha_{0,1}$	4860.6 (20)	4859.7 (30)	4863.2 (30)	4856.1 (12)	4858.1 (15)	4858.2 (10)
$\alpha_{0,2}$	-	-	-	-	-	4756.2 (10)
$\alpha_{0,3}$	-	-	-	-	-	4600.1 (10)

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

5 Electron Emissions

The energies of conversion electrons have been obtained from the gamma-ray transition energies and the atomic-electron binding energies. The emission probabilities of the conversion electrons have been deduced from the evaluated P(γ) and ICC values.

The absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program (2000Schönfeld).

6 Photon emissions

6.1 X-ray Emissions

The absolute emission probability of U MX–rays (αβ) in decay of ^{242}Pu has been deduced from the relative intensity P(XMαβ)/P(XLηβ) = 0.41 (4) measured in 1990Po14.

The absolute emission probabilities of U KX- and U LX-rays in decay of ^{242}Pu have been calculated using the EMISSION computer program (2000Schönfeld).

6.2 Gamma-ray Emissions

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

The absolute emission probabilities of the gamma-rays $\gamma_{1,0}$ (44.915 keV) and $\gamma_{2,1}$ (103.50 keV) have been deduced from the recommended P(α) values (Table 4) and the adopted total ICCs on the basis of intensity balances at the corresponding ^{238}U levels. The absolute emission probability of the gamma-ray $\gamma_{3,2}$ (158.80 keV) has been adopted from the direct measurement of 1986Va33 (Table 6).

Table 6. Experimental and recommended absolute emission probabilities of gamma-rays (×100) in ^{242}Pu decay.

	Energy (keV)	1972Sc01	1986Va33	Recommended
$\gamma_{1,0}$	44.915	-	0.0372 (7)	0.0384 (8)
$\gamma_{2,1}$	103.50	0.0081 (9) [a]	0.00263 (9)	0.00253 (12)
$\gamma_{3,2}$	158.80	0.005 (2) [a]	0.000298 (20)	0.000298 (20)

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

7 Consistency of recommended data

The most accurate Q value, Q(M), is taken from the atomic mass adjustment table of Audi et al. (2003Au03). Comparison of Q(eff)(deduced as the sum of average energies per disintegration ($\sum E_i \times P_i$) for all emissions accompanying ^{242}Pu α- decay) with the tabulated decay energy Q(M) allows to check a consistency of the recommended decay-scheme parameters obtained in this evaluation.

Here E_i and P_i are the evaluated energies and emission probabilities of the i-th alpha-particle, beta particle, gamma-ray, X-ray, etc. Consistency (percentage deviation) is determined by {[Q(M)− Q(eff))]/ Q(M)} ×100. "Percentage deviations above 5 % would be regarded as high and imply a poorly defined decay scheme; a value of less than 5 % indicates the construction of a reasonably consistent decay scheme" (quoted from the article by A.L. Nichols in Appl. Rad. Isotopes 55 (2001) 23-70).

For the above ^{242}Pu decay data evaluation we have Q(M) = 4984.5 (10) keV and Q(eff) = 4984 (13) keV. Thereafter, the percentage deviation is (0.01 ± 0.26) %, i.e. consistency is superior.

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

This evaluation was done originally in October 2002, revised in January 2004 and then updated in September 2009 with a literature cut-off by the same date.

1 Decay Scheme

The scheme of ^{241}Am decay is rather complex. It contains more than forty excited levels in ^{237}Np populated by alpha- and gamma-ray transitions (2006Ba41, 1995Ak01). The intense population takes place only for lower levels with the energy less than 230 keV (8 excited levels and ground state in ^{237}Np) and in this part the decay scheme is mainly defined. Nevertheless here there are some gamma-ray transitions scarcely studied and expected but not certainly observed such as 27-keV, 54-keV, 97-keV that leads to not so good intensity balance for some levels. Additional difficulties are due to anomalous internal conversion of the 26-keV and 59-keV gamma ray transitions because of "penetration effects" (1996Jo28, 2008Go10).

For high levels the decay scheme has not been completed yet since many observed gamma-ray transitions were not placed and some expected gamma transitions were not observed. The population of these levels does not exceed 0,1 %.

The unplaced gamma rays carry ≤ 0,6 % of the total intensity of all the gamma rays placed in the decay scheme.

2 Nuclear Data

Q value is from Audi et al. (2003Au03).

The recommended ^{241}Am half-life is based on the experimental results given in Table 1.

Table 1. Experimental values of ^{241}Am half-life (in years).

Reference	Author(s)	Original value	Measurement method
1967Oe01	Oetting and Gunn	432,7 (7)	Calorimetry
1968Br22	Brown and Propst	433 (7)	Specific Activity Determination
1968St02	Stone and Hulet	436,6 (30)	Specific Activity Determination
1972Jo07	Jove and Robert	426,3 (21)	Calorimetry
1974StYG	Strohm and Jordan	432,5 (7)	Calorimetry
1974StYZ		435,0 (7)	Specific Activity Determination
1974Po16	Polyukhov et al.	432,8 (16)	Specific Activity Determination
1975Ra35	Ramthun and Muller	432,0 (2)	Calorimetry

The values before 1967 have been omitted due to their large systematic uncertainties (those values lead to the ^{241}Am half-life of 458 years).

The eight values were used for statistical processing. The uncertainty of 1975Ra35 was increased to 0,38 a to adjust weights according to the LRSW method.

Statistical processing of the final data set with the reduced χ^2 of 3,58 gives the unweighted mean of

432,6 (11) years and of 432,6 with an internal uncertainty of 0,27 and an external uncertainty of 0,51.

The LWEIGHT computer program has used the weighted mean and expanded the uncertainty to 0,6 so range includes the most precise value of 432,0 (1975Ra35). Therefore, the recommended value of ^{241}Am half-life is 432,6 (6) years.

The value of 1,2 (3) 10^{14} years has been adopted for ^{241}Am spontaneous fission half-life as recommended in 2000Ho27.

2.1 α Transitions

The energies of the alpha transitions have been deduced from the Q value and ^{237}Np level energies given in Table 2 from 2006Ba41 where they were deduced from a least-squares fit to gamma ray energies.

Table 2. ^{237}Np levels populated in ^{241}Am α-decay.

Level number	Energy, keV	Spin and parity	Half-life	Probability of α-transition (×100)
0	0,0	$5/2^+$	2,144 (7) 10^6 yr	0,38 (1)
1	33,19629 (22)	$7/2^+$	54 (24) ps	0,23 (1)
2	59,54092 (10)	$5/2^-$	67 (2) ns	84,45 (10)
3	75,899 (5)	$9/2^+$	~ 56 ps	< 0,04
4	102,959 (3)	$7/2^-$	80 (40) ps	13,23 (10)
5	129,99 (3)	$11/2^+$		~ 0,01
6	158,497 (11)	$9/2^-$		1,66 (3)
7	191,53 (6)	$13/2^+$		
8	225,957 (16)	$11/2^-$		0,014 (3)
9	267,556 (17)	$3/2^-$	5,2 (2) ns	5 10^{-4}
10	281,356 (20)	$1/2^-$		
11	305,05 (3)	$13/2^-$		0,0022 (3)
12	316,8 (2) ?			
13	324,420 (23)	$(7/2^-)$		0,0013
14	332,376 (16)	$1/2^+$	≤ 1 ns	
15	359,7 (1)	$(5/2^-)$		6 10^{-4}
16	368,602 (20)	$5/2^+$		9 10^{-4}
17	370,928 (23)	$3/2^+$		3 10^{-4}
18	395,53 (4)	$15/2^-$		7 10^{-4}
19	418,2 (1) ?			
20	434,12 (5)	$(11/2^-)$		4 10^{-4}
21	444,78 (10) ?			
22	452,545 (22)	$9/2^+$		~ 4 10^{-4}
23	459,693 (24)	$7/2^+$		~ 4 10^{-4}
24	486,21 (9)	$(9/2^-)$		1,1 10^{-4}
25	497,01 (5)	$17/2^-$		
26	514,19 (4)	$(3/2^-)$		
27	546,12 (6)	$(5/2^-)$		1 10^{-4}
28	590,09 (4)	$(7/2^-)$		
29	592,33 (7)	$13/2^+$		
30	597,99 (9)	$11/2^+$		
31	646,03 (17)	$(9/2^-)$		
32	666,19 (10)	$(5/2^+, 7/2^-)$		
33	721,961 (13)	$5/2^-$		7 10^{-4}

Level number	Energy, keV	Spin and parity	Half-life	Probability of α-transition (×100)
34	755,685 (19)	$7/2^-$		$8,6\ 10^{-5}$
35	770,57 (5)			
36	799,82 (4)	$9/2^-$		$4\ (3)\ 10^{-5}$
37	805,77 (12)	$(7/2^+, 9/2^+)$		
38	853,36 (15)	$11/2^-$		
39	861,65 (19)	$(5/2^+, 7/2)$		
40	920,88 (20)			
41	946 (2)			
42	962 (3) ?			
43	1014 (3) ?			

The probabilities of the alpha transitions $\alpha_{0,0}$, $\alpha_{0,1}$, $\alpha_{0,2}$, $\alpha_{0,4}$ and $\alpha_{0,6}$ have been obtained by averaging experimental values from the spectrometric measurements carried out for the last twenty five years (Table 3). Earlier measurements for these alpha transitions see in 2006Ba41.

Table 3. Experimental and recommended probabilities (%) of the most intense alpha transitions.

	α-particle energy, keV	1984Ah06 1993Ahmad	1987Bo25	1994Bl12	1996 Bueno	1996 Sanchez	1998Ya17	Recommended
$\alpha_{0,0}$	5544	0,36 (1)	0,34 (5)	0,36 (5)	0,5 (2)	0,36 (3)	0,394 (9)	0,38 (1)
$\alpha_{0,1}$	5511	0,23 (1)	0,22 (3)	0,22 (6)	-	0,28 (3)	0,224 (7)	0,23 (1)
$\alpha_{0,2}$	5486	84,6 (2) [a]	84,7 (9)	84,69 (28)	84,5 (8)	84,5 (3)	84,30 (7)	84,45 (10)
$\alpha_{0,4}$	5443	13,1 (1) [a]	13,0 (3)	13,08 (24)	12,5 (3)	13,2 (3)	13,40 (8)	13,23 (10)
$\alpha_{0,6}$	5388	1,65 (8)	1,6 (1)	1,66 (6)	1,6 (2)	1,65 (7)	1,67 (2)	1,66 (3)

[a] The $\alpha_{0,2}$ and $\alpha_{0,4}$ probabilities from 1984Ah06 were superseded by the same author in 1993Ahmad. The latter values are given in Table 3.

The probabilities of the alpha transitions $\alpha_{0,3}$, $\alpha_{0,5}$, $\alpha_{0,9}$, $\alpha_{0,13}$, $\alpha_{0,15}$, $\alpha_{0,33}$ have been adopted from the magnetic spectrometer measurements of 1964Ba26. The probabilities of the $\alpha_{0,8}$ and $\alpha_{0,11}$ transitions have been obtained from measurements of 1955Go57, 1964Ba26 and 1965Mi06. The probabilities of the $\alpha_{0,34}$ and $\alpha_{0,36}$ transitions have been deduced from the intensity balance of gamma transitions.

2.2 γ Transitions

The recommended energies of the gamma-ray transitions are virtually the same as the gamma-ray energies because nuclear recoil is negligible for ^{237}Np.

The gamma-ray transition probabilities have been deduced from their gamma-ray emission probabilities and the evaluated total ICC's.

ICC's for the intense E1 anomalously converted gamma-ray transitions $\gamma_{2,1}$ (26,3 keV) and $\gamma_{2,0}$ (59,5 keV) have been obtained from a joint analysis of the gamma ray and L-, M- conversion electron probabilities measured in ^{241}Am α decay and ^{237}U β^-decay (1996Jo28, 2006Ba41). Experimental conversion electron data are given in 1959Sa10, 1964Wo03, 1966Ko06, 1966Le13, 1966Ya05, and 1998Ko61. For discussion of anomalous electric dipole gamma-ray transitions see 1960As02, 1966Ya05, 1967Pa23, 1970Gr36, 1996Jo28, and 2008Go10. In 2008Go10 an assessment of ICCs for a number of such transitions was made. In particular, the total ICCs for gamma-ray transitions $\gamma_{2,1}$ (26,3 keV) and $\gamma_{2,0}$ (59,5 keV) in ^{237}Np have been assessed as 7,9 (8) and 0,99 (9), respectively.

ICC's for other gamma transitions have been interpolated using the BrIcc computer program, version v2.2a, data set BriccFO (2008Ki07). Multipolarities of the gamma-ray transitions and E2/M1 mixing ratios have been adopted from 2006Ba41 based on the measurements of 1959Sa10, 1964Wo03, 1966Ko06, 1966Ya05, 1998Ko61.

The E2 admixture of 16,6 (25) % for M1+E2 gamma-ray transition $\gamma_{4,2}$(43,4-keV) has been obtained by averaging the four measurement results from 1964Wo03 (17,6 (19) %), 1966Ko06 (13 (2) %), 1966Ya05 (11 (4) %), and 1998Ko61 (21,2 (22) %).

3 Atomic Data

The atomic data (fluorescence yields, X-ray energies and relative probabilities, and Auger electrons energies and relative probabilities) were deduced by using the Saisinuc software (2002Be). The fluorescence yield ϖ_M is from 1989Hubbell.

The XL -ray energies are taken from 2001Sc08.

The XK -ray energies are taken from 1999Schönfeld. Below these calculated (adopted) values are compared with the experimental results of 1982Ba56 and 1983Ah02:

	Calculated (1999Schönfeld)	Measured in 1982Ba56	Measured in 1983Ah02
$K\alpha_2$	97,069	97,069 (3)	97,08 (2)
$K\alpha_1$	101,059	101,057 (3)	101,07 (2)
$K\beta_3$	113,303	113,308 (4)	113,30 (2)
$K\beta_1$	114,234	114,244 (3)	114,24 (2)
$K\beta_5$	114,912	-	114,95 (2)
$K\beta_2$	117,463		}
$K\beta_4$	117,876		} 117,51 (3)
$KO_{2,3}$	118,429	-	118,45 (5)

4 α Emissions

The recommended energies of alpha particles have been deduced from the energies of alpha transitions taking info account the recoil energies for ^{237}Np.

The experimental values of the alpha particle energies from spectrometric measurements are given in 1971Gr17, 1968Ba25, 1968Ka09, 1965Mi06, 1964Ba26, 1962Le11, 1957Ro20, 1955Go57 (see also 2006Ba41). Most of them have lesser accuracy in comparison with the recommended values.

5 Electron emissions

The energies of the conversion electrons have been obtained from the gamma-ray transition energies and the atomic electron binding energies.

The emission probabilities of the conversion electrons have been deduced using the evaluated P_γ and ICC values. The total absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program.

6 Photon emissions

6.1 X-ray emissions

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

The recommended absolute emission probabilities of Np LX - rays have been obtained by averaging of experimental results (per 100 disintegrations) shown in Table 4.

Table 4. Experimental and recommended absolute Np LX-ray emission probabilities (%) [a].

	1971 Ge11	1971 Wa28	1974 Ca16	1976 GuZN	1980 Cohen	1988 Co07	1992 Bl07	1994 Le37	2008 Le07	**Recommended**	2001Sc08 (calculated)
Ll	0,81 (7)	0,87 (6)	0,86 (2)	0,806 (40)	0,87 (3)	0,83 (3)	0,837 (10)	0,864 (12)	0,837 (9)	**0,844 (9)** [b]	0,842 (27)
Lα	12,6 (9)	13,5 (12)	13,20 (25)	13,2 (7)	13,2 (3)	12,7 (4)	13,01 (10)	13,03 (13)	13,00 (12)	**13,02 (10)** [b]	13,3 (4)
Lη	} 19,1 (14)	19,1 (14)	19,25 (40)	19,2 (10)	19,78 (36)	0,368 (5)	0,377 (15)	0,369 (12)	0,404 (5)	**0,384 (20)** [c]	0,383 (16)
Lβ						18,3 (6)	18,61 (15)	18,39 (19)	18,65 (13)	**18,58 (13)** [b]	20,0 (6)
Lγ	4,75 (35)	4,75 (35)	4,85 (15)	4,94 (25)	4,96 (20)	4,8 (2)	4,815 (38)	4,74 (8)	4,84 (3)	**4,83 (3)** [b]	5,17 (14)

[a] In addition to given references the value of 19,46 (16) for Lη+Lβ was obtained in 1974Ga40.
[b] The smallest uncertainty of the experimental results.
[c] The LWEIGHT computer program has used the weighted mean of 0,3843 and expanded the uncertainty so range includes the most precise value of 2008Le07.

The experimental results of 1993Lépy (per 100 disintegrations) are quoted in 2001Sc08: Ll - 0,875 (18), Lα - 13,10 (21), Lη - 0,354 (8), Lβ - 18,5 (4), Lγ - 4,84 (8). These results were superseded in 1994Le37 and were not used by the evaluators for statistical processing.

The evaluated total absolute emission probability of LX - rays P(XL) = 37,66 (17) % can be compared with the value of 36,8 (21) % calculated using the EMISSION computer program.

The absolute emission probabilities of Np XK -rays have been calculated using the EMISSION computer program. The recommended value of the total absolute emission probability P(XK) = 0,003 82 (10) % can be compared with measurements of 1976GuZN which give P(XK) = 0,004 01 (10) %.

Below the experimental data of 1976GuZN are compared with the calculated values of absolute emission probability for KX-ray components:

	1976GuZN (measured) [a]	Recommended (calculated)
$K\alpha_2$	0,001 18 (4)	0,001 134 (30)
$K\alpha_1$	0,001 89 (6)	0,001 81 (5)
$K\beta_1'$	7,1 (3) 10^{-4}	6,58 (21) 10^{-4}
$K\beta_2'$	2,29 (15) 10^{-4}	2,26 (8) 10^{-4}

[a] The uncertainties quoted in 1976GuZN have been increased by 2 % to allow for the uncertainty of the detector calibration.

6.2 Gamma-ray emissions

6.2.1 Gamma-ray energies

The gamma ray energies have been taken mainly from 2006Ba41 (see also the evaluation of 1988ChZL). Some gamma ray energies have been deduced directly from the adopted ^{237}Np level energies.

The recommended gamma ray energy values are based on measurements of 1955Da02, 1959Sa10, 1964Wo03, 1966Ko06, 1966Ya05, 1968Je01, 1968Ka09, 1970Ne11, 1976GuZN, 1978Ge06, 1978Ge17, 1978Ov01, 1979Ar11, 1984Ov02, and 1998Ab43.

The energies of gamma rays $\gamma_{2,1}$ (26,3 keV) and $\gamma_{2,0}$ (59,5 keV) have been adopted from 2000He14. The energy of gamma ray $\gamma_{1,0}$ (33,2 keV) has been deduced as the difference of $E\gamma_{2,0}$ - $E\gamma_{2,1}$. The energies of gamma rays $\gamma_{3,1}$ (42,7 keV), $\gamma_{4,2}$ (43,4 keV), and $\gamma_{8,4}$ (123,0 keV) have been taken from 1998Ko61. The gamma ray with energy of 32,183 keV has been adopted from 1976GuZN and was not reported by others.

The energies of gamma rays $\gamma_{27,26}$ (31,9 keV), $\gamma_{17,14}$ (38,5 keV), $\gamma_{14,10}$ (51,0 keV), $\gamma_{5,3}$ (54,1 keV), $\gamma_{13,9}$ (56,9 keV), $\gamma_{7,5}$ (61,6 keV), $\gamma_{14,9}$ (64,8 keV), $\gamma_{36,33}$ (77,9 keV), $\gamma_{11,8}$ (79,0 keV), $\gamma_{15,9}$ (92,4 keV) and $\gamma_{5,1}$ (96,8 keV) have been deduced from the adopted ^{237}Np level energies. These gamma ray transitions were not observed in the ^{241}Am α-decay; they are expected from the decay scheme (see 2006Ba41).

The gamma rays $\gamma_{20,11}$ (129,1 keV), $\gamma_{23,13}$ (135,3 keV), $\gamma_{30,23}$ (138,3 keV) and unplaced in decay scheme gamma rays with energies of 128,05 keV and 136,7 keV have been adopted from 1979Ar11 and were not observed by others.

Many unplaced gamma rays are reported only in 1998Ab43.

6.2.2 Gamma-ray emission probabilities

The recommended absolute emission probabilities (Pγ) of the most intense gamma rays $\gamma_{1,0}$ (26,3 keV), $\gamma_{2,1}$(33,2 keV), $\gamma_{4,2}$ (43,4 keV) and $\gamma_{2,0}$(59,5 keV) have been deduced from the available experimental data (Table 5).

Table 5. Experimental and recommended values of the most intense gamma rays in ^{241}Am α-decay.

Reference	$P\gamma_{1,0}$ (26,3 keV) ×100	$P\gamma_{2,1}$ (33,2 keV) ×100	$P\gamma_{4,2}$ (43,4 keV) ×100	$P\gamma_{2,0}$ (59,5 keV) ×100
1952Be24	2,8 (3)			40,0 (15)
1957Ma17	2,5 (2)		0,073 (7)	35,9 (6)
1964Mc12				34,6 (7)
1965Mi06				38,0 (6)
1969Pe17				35,3 (6)
1971Ge11	2,23 (18)	0,104 (11)	0,057 (18)	
1974Ca16	2,4 (1)			
1975Le09				36,3(4)
1976GuZN	2,45 (5)			
1976Pl05				35,5 (3)
1978Ge06	2,54 (26)	0,106 (11)	0,073 (7)	
1983Ah02		0,125 (8)		
1983De11	2,41 (5)			
1983Hu04				35,82 (17) [d]
1984Ov02		0,12 (1)	0,066 (5)	
1987De22				36,36 (17)
1992Bl07	2,395 (19)	0,1233 (28)	0,0654 (29)	36,03 (25)
1992Ma16				35,6 (2)
2005Iw01	2,06 (3)			35,87 (17)
Recommended	**2,31 (8)** [a]	**0,1215 (28)** [b]	**0,0669 (29)** [c]	**35,92 (17)** [e]

[a] The LWEIGHT computer program has used the weighted mean of 2,31 and expanded the uncertainty so range includes the most precise value of 1992Bl07.

[b] The LWEIGHT computer program has used the weighted mean of 0,12148 and external uncertainty of 0,0028. The smallest value of experimental uncertainties is also 0,0028.

[c] The LWEIGHT computer program has used the weighted mean of 0,0669 and internal uncertainty of 0,0022. The smallest value of experimental uncertainties is 0,0029.

[d] Uncertainty quoted by authors (0,12) has been increased to 0,17 by the evaluators to include possible systematic errors in correction factors to 59,5-keV-peak counting rate.

[e] The LWEIGHT computer program has identified one by one the three outliers of 1952Be24, 1965Mi06 and 1964Mc12 and used the weighted mean of 35,92 (8). The smallest value of experimental uncertainties of 0,17 has been adopted as the uncertainty.

The absolute emission probabilities of gamma rays $\gamma_{3,1}$ (42,7 keV), $\gamma_{6,4}$ (55,6 keV), γ(57,8 keV), $\gamma_{8,6}$ (67,5 keV), and $\gamma_{4,1}$ (69,8 keV) have been adopted from the measurements of 1978Ge06.

The absolute emission probabilities of gamma rays $\gamma_{6,2}$ (99,0 keV), $\gamma_{4,0}$ (103,0 keV), $\gamma_{8,4}$ (123,0 keV), and $\gamma_{6,1}$ (125,3 keV) have been adopted from the measurements of 1976GuZN.

The remaining weak gamma ray emission probabilities (Pγ < 10^{-5}) have been adopted from the evaluations of 2006Ba41 and 1988ChZL, based mainly on the measurements of 1976GuZN and 1978Ge17 with Ge(Li) detectors, and (for gamma rays with energy more than 200 keV) from the measurements of 1998Ab43 with 40 % HPGe detector and intense purified sources. The uncertainties quoted in 1998Ab43 have been increased by 1 % to allow for the uncertainty of the detector calibration.

Other measurements of Pγ are given in 19840v02, 1983Hu04, 1983De11, 1983Ah02, 1979Ce04, 1978Ge06, 1976Pl05, 1975Le09, 1974Ca16, 1974HeYW, 1971Ge11, 1971Cl03, 1967Gu08, 1967Br26, 1966Ko06, 1965Mc12, 1965Be38, 1957Ro20, 1957Ma17, 1956Ho38, 1955Tu13, 1955Ja01, 1955Da02, 1955Ba31, and 1952Be24.

The gamma ray emission probabilities quoted in 1976GuZN and also in 19840v02, 1978Ge06, 1974Ca16, 1971Ge11, 1967Gu08 have been normalized to Pγ (59,54 keV) = 0,3592. The gamma ray emission probabilities from 1971Cl03, 1978Ge17 have been normalized to Pγ (208,00 keV) = 7,86 10^{-6}.

7 Consistency of recommended data

The most accurate Q value, Q(M), is taken from the atomic mass adjustment table of Audi et al. (2003Au03). Comparison of Q(eff) (deduced as the sum of average energies per disintegration ($\sum E_i \times P_i$) for all emissions accompanying ^{241}Am α- decay) with the tabulated decay energy Q(M) allows to check a consistency of the recommended decay-scheme parameters obtained in this evaluation.

Here E_i and P_i are the evaluated energies and emission probabilities of the i-th alpha particle, gamma ray, X-ray, etc. Consistency (percentage deviation) is determined by $\{[Q(M)- Q(eff))]/ Q(M)\} \times 100$. “Percentage deviations above 5 % would be regarded as high and imply a poorly defined decay scheme; a value of less than 5 % indicates the construction of a reasonably consistent decay scheme” (quoted from the article by A.L. Nichols in Appl. Rad. Isotopes 55 (2001) 23-70).

For the above ^{241}Am decay data evaluation we have Q(M) = 5637,82 (12) keV and Q(eff) = 5638 (8) keV, i.e. consistency is better than 0,15 %.

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^{242}Am - Comments on evaluation of decay data

by A. L. Nichols

Evaluated: March 2007/September 2008 – Updated comments December 2010

Evaluation Procedure

Limitation of Relative Statistical Weight Method (LWM) was applied to average the decay data when appropriate.

Decay Scheme

A relatively simple decay scheme was constructed from the β^-/EC ratio and branching fraction measurements of Hoff *et al.* (1955Ho67, 1959Ho02), Baranov and Shlyagin (1955Ba31), Asaro *et al.* (1960As05), Gasteiger *et al.* (1969Ga17), Aleksandrov *et al.* (1969Al20) and Gabeskiriya (1972Ga35). There are no known well-defined gamma-ray spectroscopic studies.

Some confusion arose during the course of the 1950s as to the correct identity of the ground and metastable states of ^{242}Am. This problem was resolved in 1960 by Asaro *et al.* (1960As05) when the 16-hour half-life activity was shown to be the ground state. The possible existence of an alpha branch has been extensively considered by Barnes *et al.* (1959Ba22) and Aleksandrov *et al.* (1969Al20). While Barnes *et al.* found such a branch (BF_α = 0.004 76 (14)), subsequent studies have shown no evidence for this particular decay mode, and Aleksandrov *et al.* were only able to set a limit of less than 10^{-7} of the total ^{242}Am decay.

Nuclear Data

^{242}Am needs to be better characterised for improved quantification of the production and decay heat contributions of ^{242}Cm and ^{244}Cm.

Half-life

The recommended half-life of 16.01 (2) hours has been adopted from three known sets of measurements (1953Ke38, 1969Al20, 1982Wi05). Five independent half-life measurements were individually reported by Aleksandrov *et al.* (1969Al20) from which a value of 16.07 (14) hours was calculated (LWM). A limited data set of effectively three studies is rather unsatisfactory, and further measurements are required to determine the half-life with much greater confidence.

Half-life measurements

Reference	Half-life (hours)
1953Ke38	16.01 ± 0.02
1969Al20	16.07 ± 0.14
1982Wi05	16.1 ± 0.1
Recommended value	16.01 ± 0.02

Gamma Rays

Energies

All gamma-ray transition energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of Akovali were adopted (2002Ak06), and used to determine the energies and associated uncertainties of the gamma-ray transitions that depopulate the first excited states of ^{242}Pu and ^{242}Cm.

Emission Probabilities

There are no known dedicated measurements of the gamma-ray emission probabilities. Under these unsatisfactory circumstances, the proposed gamma-ray decay data were derived from the tabulated P_{ce}/P_{β} data of Baranov and Shlyagin (1955Ba31) and the BF_{β} measurements (1959Ba22, 1959Ho02, 1969Al20, 1969Ga17, 1972Ga35). A BF_{β} of 0.831 (3) was derived in terms of LWM, with the uncertainty extended to the minimum value measured (± 0.003); this parameter was adopted in preference to the equivalent LWM calculation for the β^-/EC ratio (i.e. 4.88 (8) compared with a value of 4.92 (9) calculated from the weighted mean BF_{β}).

β^-/EC ratio and BF_{β}.

Reference	BF_{β}	β^-/EC
1955Ba31	0.82	4.6
1955Ho67	0.81	4.2
1959Ba22	0.836 ± 0.008*	5.1 ± 0.2
1959Ho02	0.836 ± 0.003	5.1 ± 0.1*
1960As05	0.836*	5.1
1969Al20	0.82 ± 0.01*	4.6 ± 0.3
1969Ga17	0.828 ± 0.004	4.8 ± 0.1*
1972Ga35	0.827 ± 0.003*	4.78 ± 0.08
Recommended value	0.831 ± 0.003	[4.88 ± 0.08]

* Emphasis of the publication, and assumed to be the primary measurement.

Baranov and Shlyagin determined the conversion-electron emission intensities separately for both the electron-capture and beta decay processes, along with the β^- decay in equivalent units (1955Ba31) to furnish the following ratios:

P_{ce}(EC component)/$P_{\beta-}$ = 153.5/1200, and

P_{ce}(β^- component)/$P_{\beta-}$ = 661/1200.

One problem involves the assignment of uncertainties to the $P_{ce}/P_{\beta-}$ values as determined by Baranov and Shlyagin. Both parameters are the ratios of two equivalent measurements, and the resulting uncertainty for each of these ratios was assumed to be approximately 5 %:

P_{ce}(EC component)/$P_{\beta-}$ = 153.5/1200 = 0.128 (6)

P_{ce}(β^- component)/$P_{\beta-}$ = 661/1200 = 0.551 (28).

Using these data and BF_{β} of 0.831 (3):

$P_{ce}(\beta^-)$ = 0.551 (28) × 0.831 (3) = 0.458 (23) for the 42.13-keV gamma-ray,
and P_{ce}(EC) = 0.128 (6) × 0.831 (3) = 0.106 (5) for the 44.54-keV gamma-ray.

These values were then used in conjunction with the theoretical internal conversion coefficients to calculate the absolute gamma-ray emission probabilities.

Quite remarkably, the resulting gamma-ray emission probabilities are in good agreement with the tabulated spectroscopic data of Vylov *et al.* (1980VyZZ) which are listed as 42.129 (7) keV and 0.039 (5) %, and 44.542 (25) keV and 0.015 (3) %. Accurate, high-resolution gamma-ray measurements are required to confirm the validity of the proposed decay scheme.

Gamma-ray emissions: recommended energies, emission probabilities, multipolarities and theoretical internal conversion coefficients (frozen orbital approximation).

	E_γ (keV)	P_γ^{abs}	Multi	α_K	α_L	α_{M+}	α_{tot}	
$\gamma_{1,0}$ (Cm)	42.13 (5)	0.040 ± 0.002	E2	-	836 (12)	319 (5)	1155 (17)	β^-
$\gamma_{1,0}$ (Pu)	44.54 (2)	0.014 ± 0.001	E2	-	544 (8)	204 (3)	748 (11)	EC

Multipolarities and Internal Conversion Coefficients

The nuclear level scheme specified by Akovali has been used to define the multipolarities of the gamma transitions on the basis of known spins and parities (2002Ak06). Recommended internal conversion coefficients have been determined from the frozen orbital approximation of Kibédi *et al*. (2008Ki07), based on the theoretical model of Band *et al*. (2002Ba85, 2002Ra45).

Beta Particles

Energies and emission probabilities

Beta-particle energies were calculated from the nuclear level energies of Akovali (2002Ak06) and a Q_{β^-} value of (664.5 ± 0.4) keV taken from Audi *et al.* (2003Au03).

Assuming virtually full internal conversion of the 42.13-keV gamma transition, the beta-particle emission probabilities were calculated from BF_β of 0.831 (3) and $P_{ce}(\beta^-)$ of 0.458 (23):

Beta-particle Emission Probabilities per 100 Disintegrations of ^{242}Am.

	E_β (keV)	av. E_β (keV)	P_β	Transition type	log *ft*
$\beta^-_{0,1}$	622.4 ± 0.4	185.92 ± 0.14	45.8 ± 2.3	1st forbidden non-unique	6.84
$\beta^-_{0,0}$	664.5 ± 0.4	200.17 ± 0.14	37.3 ± 2.3	1st forbidden non-unique	7.03

EC Transitions

Energies and transition probabilities

EC transition energies were calculated from the nuclear level energies of Akovali (2002Ak06) and a Q_{EC} value of (751.3 ± 0.7) keV from Audi *et al.* (2003Au03).

Assuming virtually full internal conversion of the 44.54-keV gamma transition, the EC transition probabilities were calculated from BF_{EC} of 0.169 (3) and $P_{ce}(EC)$ of 0.106 (5):

EC Transition Probabilities per 100 Disintegrations of ^{242}Am.

	E_{EC} (keV)	P_{EC}	Transition type	log *ft*	P_K	P_L	P_M
$EC_{0,1}$	706.8 ± 0.7	10.6 ± 0.5	1st forbidden non-unique	7.26	0.7261 (23)	0.2016 (15)	0.0532 (10)
$EC_{0,0}$	751.3 ± 0.7	6.3 ± 0.6	1st forbidden non-unique	7.55	0.7303 (22)	0.1987 (15)	0.0522 (10)

Atomic Data

The x-ray and Auger-electron data have been calculated using the evaluated gamma-ray data, and atomic data from 1996Sc06, 1998ScZM and 1999ScZX. Both the x-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.01, 28 January 2003, with the emission.101 database extended to Z = 96 to calculate component L x-ray data of daughter Cm). This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

K and L X-ray Emission Probabilities per 100 Disintegrations of ^{242}Am.

			Energy keV	Photons per 100 disint.
XL		(Pu)	12.124 – 22.153	10.8 (5)
	XL_l	(Pu)	12.124	0.293 (11)
	XL_α	(Pu)	14.087 – 14.282	4.56 (16)
	XL_η	(Pu)	16.333	0.084 (4)
	XL_β	(Pu)	16.498 – 18.541	4.64 (15)
	XL_γ	(Pu)	21.420 – 22.153	1.03 (4)
XK_α	$XK_{\alpha2}$	(Pu)	99.525	3.55 (17)
	$XK_{\alpha1}$	(Pu)	103.734	5.6 (3)
$XK'_{\beta1}$	$XK_{\beta3}$	(Pu)	116.244	)
	$XK_{\beta1}$	(Pu)	117.228	) 2.06 (11)
	$XK''_{\beta5}$	(Pu)	117.918	)
$XK'_{\beta2}$	$XK_{\beta2}$	(Pu)	120.540	)
	$XK_{\beta4}$	(Pu)	120.969	) 0.72 (4)
	$XKO_{2,3}$	(Pu)	121.543	)
XL		(Cm)	12.633 – 23.527	18.0 (11)
	XL_l	(Cm)	12.633	0.451 (22)
	XL_α	(Cm)	14.746 – 14.961	6.8 (3)
	XL_η	(Cm)	17.314	0.194 (11)
	XL_β	(Cm)	17.286 – 19.688	8.7 (4)
	XL_γ	(Cm)	22.735 – 23.527	2.09 (10)

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

Data Consistency

An effective Q-value of 679.2 (4) keV has been adopted from the atomic mass evaluation of Audi *et al*. (2003Au03) while in the course of formulating the decay scheme of ^{242}Am. This value has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{242}Am beta- and EC-decay processes (i.e. β^-, conversion electrons, γ, etc.):

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 679\ (22)\ \text{keV}$$

Percentage deviation from the effective Q-value of Audi *et al*. is (0 ± 3) %, which supports the derivation of a highly consistent decay scheme with a large variant.

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$^{242}Am^m$ - Comments on evaluation of decay data

by A. L. Nichols

Evaluated: April 2007/April 2010

Evaluation Procedure

Limitation of Relative Statistical Weight Method (LWM) was applied to average the decay data when appropriate.

Decay Scheme

A simple IT-decay mode dominates the decay scheme of $^{242}Am^m$. The small α branch is complex, and many features of this decay mode remain unresolved despite the extensive study of Hoff *et al.* (1990Ho02).

Some confusion arose during the course of the 1950s as to the correct identity of the ground and metastable states of ^{242}Am. This problem was resolved in 1960 by Asaro *et al.* (1960As05) when the 16-hour half-life activity was shown to be the ground state and the longer-lived 140-year isomer was defined as the metastable state. The α branch has been determined by Barnes *et al.* (1959Ba22) and Zelenkov *et al.* (1979Ze05) to be 0.46 (1) %. Hoff *et al.* have studied the emissions from the α-decay mode in considerable detail (1990Ho02), and the more modest measurements of Baranov *et al.* (1979Ba67) and Vylov *et al.* (1980VyZZ) show reasonable agreement with this extensive data set. A small spontaneous fission branch of 1.5 (6) × 10^{-8} % has been quantified by Caldwell *et al.* (1967Ca04), while an upper limit of 4.8 × 10^{-9} % has been specified by Zelenko *et al*. (1986Ze06).

Nuclear Data

The decay characteristics of $^{242}Am^m$ need to be better defined for improved quantification of the production and decay heat contributions of ^{242}Cm and ^{244}Cm.

Half-life

A recommended half-life of 143 (2) years has been adopted from the two known measurements (1959Ba22, 1979Ze05). This limited data set is unsatisfactory, and further studies are required to determine the half-life with much greater confidence.

Half-life measurements

Reference	Half-life (years)
1959Ba22	152 ± 7
1979Ze05	141.9 ± 1.7
Recommended value	143 ± 2

Branching Fractions

Barnes *et al.* and Zelenkov *et al.* have determined the α branching fraction for $^{242}Am^m$ (1959Ba22, 1979Ze05), and these data were used to derive an α branch of 0.46 (1) % and IT branch of 99.54 (1) %.

Reference	$BF_α$
1959Ba22	0.004 76 ± 0.000 14
1979Ze05	0.004 5 ± 0.000 1
Recommended value	0.004 6 ± 0.000 1
α branch	(0.46 ± 0.01) %

A spontaneous fission branch of 1.5 (6) × 10^{-8} % can be determined from the recommended total half-life of 143 (2) years and measured spontaneous fission half-life of 9.5 (35) × 10^{11} years (1967Ca04). Similarly, an upper limit of 4.8 × 10^{-9} % for the spontaneous fission branch can be derived from equivalent studies of the spontaneous fission half-life of > 3 × 10^{12} years (1986Ze06). Under these uncertain circumstances, a recommended value of < 4.8 × 10^{-9} % has been adopted for the spontaneous fission branch of ^{242}Am^{m}.

Q values

Q_{IT} of 48.60 (5) keV and Q_{α} of 5637.10 (25) keV were adopted from the evaluated tabulations of Audi *et al.* (2003Au03).

Alpha Particles

Alpha-particle measurements reveal a relatively complex α-decay mode (1979Ba67, 1980VyZZ, 1990Ho02). The Q_{α} of 5637.10 (25) keV (2003Au03) and nuclear level energies as defined by Chukreev *et al.* (2002Ch52) were used to calculated the alpha-particle energies, while the alpha-particle emission probabilities were primarily adopted from the measurements of Hoff *et al.* (1990Ho02) and fortified by the introduction of a number of minor transitions observed by Baranov *et al.* (1979Ba67), all expressed in terms of decay per 100 alphas. Small adjustments were made to some of the low-intensity alpha-particle emission probabilities after consideration of the observed differences between the two sets of measurements (i.e., 5091.9-, 5248.15/5248.21- and 5272.96-keV alpha-particle emission probabilities). Some of the proposed daughter nuclear levels of comparable energy were also judged to be populated by alpha-particle transitions that were not experimentally resolved (i.e., alpha-particle transitions to nuclear levels with energies of 297.03/299.23, 300.68/300.743 and 374.7/376.7 keV). Under these circumstances, the observed alpha-particle emission was arbitrarily shared between the two nuclear levels of relevance. An unweighted mean value of 1.508 (5) was adopted for the radius parameter $r_0(^{238}Np)$ as derived from the equivalent data for neighboring doubly-even nuclei (1998Ak04), and used in the calculation of α-hindrance factors (HF):

$$r_0(^{238}Np) = [r_0(^{240}Pu) + r_0(^{242}Pu) + r_0(^{242}Cm) + r_0(^{244}Cm)] / 4$$

$$= [1.5168 (3) + 1.5143 (9) + 1.5013 (10) + 1.4979 (7)] / 4 = 1.508 (5)$$

All of the available alpha-particle decay data were assessed in conjunction with the gamma-ray measurements of Hoff *et al.* These extremely significant gamma-ray studies do not furnish gamma-ray energy and emission probability data that can be adopted to depopulate the major alpha-populating nuclear levels of ^{238}Np in a consistent and satisfactory manner (i.e., nuclear levels at 407.59 keV and 342.439 keV populated by alpha particles with emission probabilities of 5.6 (2) % and 89.0 (7) % per 100 alphas, respectively). These two seriously incomplete features within the decay scheme are also observed to impact in various ways throughout the gamma-ray decay to the ground state of ^{238}Np. While the recommended alpha-particle emissions are believed to be reasonably sound, the related gamma-ray data remain significantly incomplete.

Alpha-particle emissions: energies, emission probabilities and hindrance factors.

1979Ba67		1980VyZZ		1990Ho02		Recommended		
E$_{\alpha}$ *(keV)*	*P*$_{\alpha}$ *(x100α)*	*E*$_{\alpha}$ *(keV)*	*P*$_{\alpha}$ *(x100α)*	*E*$_{\alpha}$ *(keV)*	*P*$_{\alpha}$ *(x100α)*	*E*$_{\alpha}$ *(keV)*	*P*$_{\alpha}$ *(x100α)*	*HF*
4974.9	~ 0.002	-	-	-	-	4975 (3)	0.002 (1)	2400
5027.1	0.02	-	-	5031 (5)	0.02 (1)	5027.3 (15)	0.02 (1)	540
5064.2	0.22	5065 (5)	0.23	5072 (3)	0.25 (7)	5068 (3)	0.25 (7)	81
5082	0.03	5082 (5)	) 0.34	-	-	5082.6 (12)	0.03 (1)	840
5088.4	0.19		)	5093 (4)	0.21 (7)	5091.9 (7)	0.20 (7)	146
5141.6 (5)	5.82	5142.35 (104)	6.601 (163)	5144.4 (9)	5.6 (2)	5143.07 (26)	5.6 (2)	11.2

1979Ba67		1980VyZZ		1990Ho02		Recommended		
E$_α$ (keV)	*P$_α$ (x100α)*	*E$_α$ (keV)*	*P$_α$ (x100α)*	*E$_α$ (keV)*	*P$_α$ (x100α)*	*E$_α$ (keV)*	*P$_α$ (x100α)*	*HF*
5153.3	0.02	-	-	-	-	5153.2 (15)	0.02 (1)	3600
~ 5173	) 0.04	-	-	-	-	5173.45 (26)	0.02 (1)	4900
5173.7	)	-	-	-	-	5175.4 (10)	0.02 (1)	5000
5206.8 (5)	89.84	5205.92 (72)	100.00 (167)	5208.4 (8)	89.0 (7)	5207.15 (25)	89.0 (7)	1.80
5214.7 ?	0.03	-	-	-	-	5215.4 (7)	0.03 (1)	6000
5248.2	~ 0.11	5248 (5)	0.67	5248.4 (22)	1.0 (1)	) 5248.15 (25)	0.4 (1)	730
						) 5248.21 (26)	0.4 (1)	730
5250.0	0.04	-	-	-	-	) 5249.64 (26)	0.02 (1)	14800
						) 5251.80 (25)	0.02 (1)	15300
~ 5273	0.86	5284	~ 0.34	5271 (3)	1.1 (1)	5272.96 (25)	1.0 (1)	414
5313.5	0.69	5312 (5)	0.90	5316 (3)	0.6 (1)	5314.95 (25)	0.6 (1)	1250
-	-	-	-	5331 (5)	0.15 (10)	5331.97 (25)	0.15 (10)	6400
5367.2	1.17	5364 (5)	1.67	5369.1 (18)	1.1 (2)	5367.73 (25)	1.1 (2)	1430
5409.3	1.04	5408 (5)	1.35	5412.4 (21)	1.0 (2)	5410.13 (25)	1.0 (2)	2820
5458.2	0.14	-	-	-	-	5458.68 (25)	0.14 (4)	39000
5517.3	0.006	-	-	-	-	5517.93 (25)	0.003 (3)	4000000
							Σ 100.025	

Gamma Rays

Energies

All gamma-ray transition energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of Akovali and Chukreev *et al.* were adopted (2002Ak06, 2002Ch52), and used to determine the energies and associated uncertainties of the gamma-ray transitions that populate and depopulate the excited nuclear levels of ^{238}Np and ^{242}Am^{m}.

Emission Probabilities

Dedicated measurements of the gamma-ray emission probabilities of ^{242}Am^{m} are limited to the significant studies of Hoff *et al*. (1990Ho02). Under these rather unsatisfactory circumstances, these gamma-ray decay data were adopted wholesale, although some comparison could be made with the limited data set of Vylov *et al*. (1980VyZZ). Hoff *et al.* have directly identified over 60 gamma-rays with the α-decay mode which has a branch of only 0.46 (1) %, while the major IT decay mode involves only one highly-converted gamma transition (48.60 keV).

Hoff *et al*. report the emission probabilities of a number of unresolved gamma rays in terms of what is believed to be the upper limit for each: 4.0 (3) per 100 α for both 109.61 (1) and 109.618 (3) keV; 0.024 (7) per 100 α for both 139.05 (3) and 139.11 (2) keV; 0.150 (8) per 100 α for both 152.70 (2) and 152.73 (1) keV; 3.50 (10) per 100 α for both 163.1 (5) and 163.29 (1) keV; and 0.122 (10) per 100 α for both 250.33 (3) and 250.37 (2) keV. These data have been adopted and both entries carried forward as values less or equal (≤) to the specified emission probability, as well as being incorporated into the database of recommended emission probabilities and transition probabilities.

The 26.427-keV gamma transition is particularly problematic, with a measured emission probability of 1.36 (1) per 100 α (1990Ho02). Combining this value with the internal conversion coefficients for an E2 transition generates an unrealistic absolute transition probability for this single gamma from the

26.427-keV nuclear level to the ground state of 2.12 %. There is a good possibility that this particular γ line arises partially from the alpha decay of ^{241}Am (isotopic content of 0.79 %, and γ-ray emission energy of 26.345 keV), and/or consists of a number of unresolved transitions that could not be identified nor located elsewhere within the incomplete decay scheme of ^{242}Am^{m}. Therefore, the emission probability per 100 α of the 26.427-keV gamma transition has been significantly reduced to < 0.154, and is primarily based on α and γ transition probabilities per 100 α that are known to populate the 26.427-keV nuclear level.

Np K X-rays complicate the interpretation of the gamma-ray emission probability data over the energy ranges from 97 to 101 keV (Kα) and 113.3 to 118.5 keV (Kβ). Hoff *et al.* observed gamma rays with energies in the vicinity of 97 keV and between 113.7 and 118 keV. While many of these particular emissions can be incorporated into the proposed decay scheme, their emission probabilities and existence in this form are doubtful.

A limited number of the gamma rays observed by Hoff *et al.* could not be placed in the proposed and incomplete alpha-decay scheme: 89.60 (5) keV with P_γ per 100 α of 0.29 (7), 160.61 (2) keV with P_γ per 100 α of 0.09 (4), 165.97 (15) keV with P_γ per 100 α of 0.010 (5), and 233.69 (10) keV with P_γ per 100 α of 0.028 (7).

Gamma-ray emissions: measured and recommended energies and emission probabilities.

1980VyZZ			1990Ho02				**Adopted**	
E_γ (keV)	P_γ^{rel}	*P_γ per 100α*	*E_γ (keV) α decay*	*P_γ per 100α*	*E_γ (keV) (n,γ)*	*P_γ per 100n*	***E_γ (keV)***	***P_γ per 100α***
-	-	-	-	-	24.37 (2)	0.0064 (10)	24.34 (1)	-
-	-	-	26.32 (3)	1.36 (10)	26.43 (2)	0.104 (15)	26.427 (2)	< 0.154*
-	-	-	-	-	32.67 (3)	0.026 (4)	32.64 (1)	-
-	-	-	-	-	34.97 (3)	0.082 (11)	34.97 (1)	-
-	-	-	-	-	35.90 (2)	0.0109 (15)	35.90 (1)	-
-	-	-	-	-	43.11 (3)	0.044 (7)	43.11 (1)	-
-	-	-	-	-	43.32 (3)	0.0046 (7)	43.33 (1)	-
-	-	-	-	-	43.84 (3)	0.075 (11)	43.83 (2)	-
-	-	-	-	-	43.98 (4)	0.058 (8)	43.89 (2)	-
-	-	-	-	-	46.84 (3)	0.111 (17)	46.833 (3)	-
-	-	-	-	-	-	-	48.60 (5)	IT decay
49.367 (4)	100	[29.1]	49.35 (2)	29.1 (9)	49.372 (2)	8.57 (14)	49.371 (3)	29.1 (9)
-	-	-	-	-	52.98 (7)	0.029 (4)	53.2 (6)	-
-	-	-	53.69 (3)	0.45 (6)	53.70 (7)	0.038 (6)	53.67 (1)	0.45 (6)
-	-	-	-	-	53.88 (4)	0.017 (3)	53.85 (2)	-
-	-	-	57.54 (6)	0.21 (5)	-	-	57.51 (1)	0.21 (5)
-	-	-	-	-	59.31 (4)	0.0082 (13)	59.32 (1)	-
-	-	-	60.13 (6)	1.19 (11)	60.243 (4)	0.68 (5)	60.247 (3)	1.19 (11)
-	-	-	-	-	62.33 (3)	0.0100 (15)	62.330 (4)	-
66.808 (20)	11.2	3.26	66.89 (2)	3.25 (10)	66.919 (5)	0.23 (3)	66.92 (1)	3.25 (10)
67.9	3.9	1.1	67.93 (3)	0.87 (7)	-	-	67.92 (2)	0.87 (7)
73.3	3.2	0.93	73.66 (2)	1.71 (12)	73.715 (4)	0.49 (15)	73.72 (1)	1.71 (12)
-	-	-	-	-	75.97 (7)	0.0051 (8)	75.98 (1)	-
-	-	-	-	-	79.483 (17)	0.17 (3)	79.48 (1)	-
-	-	-	-	-	79.74 (3)	0.019 (3)	79.73 (2)	-
-	-	-	84.9 (2)	0.21 (7)	-	-	85.16 (7)	0.21 (7)
86.680 (36)	19.5	5.67	86.65 (2)	4.97 (15)	86.676 (2)	2.3 (4)	86.674 (2)	4.97 (15)
-	-	-	89.60 (5)	0.29 (7)	-	-	89.60 (5)	0.29 (7)#
92.5	2.2	0.64	92.52 (3)	0.61 (7)	92.486 (7)	0.19 (4)	92.48 (1)	0.61 (7)
-	-	-	93.82 (3)	0.79 (9)	93.67 (5)	0.19 (4)	93.88 (1)	0.79 (9)
-	-	-	-	-	95.22 (2)	0.046 (6)	95.22 (1)	-
-	-	-	95.7 (6)	-	-	-	96.204 (3)	-
-	-	-		-	96.82 (5)	0.025 (4)	96.78 (1)	-
97.077	$K_{\alpha2}$ (Np)	-	-	-	-	-	-	-
-	-	-	98.0 (6)	-	97.22 (5)	0.046 (6)	97.18 (2)	-
101.068	$K_{\alpha1}$ (Np)	-	-	-	-	-	-	-

1980VyZZ			1990Ho02				**Adopted**	
E_γ (keV)	P_γ^{rel}	P_γ per 100α	E_γ (keV) α decay	P_γ per 100α	E_γ (keV) (n,γ)	P_γ per 100n	**E_γ (keV)**	**P_γ per 100α**
109.6	12.9	3.75	109.61 (2)	4.0 (3)	109.614 (4)	1.09 (24)	109.61 (1)	≤ 4.0 (3)
			109.62 (2)	4.0 (3)	109.614 (4)	1.09 (24)	109.618 (3)	≤ 4.0 (3)
111.1	1.5	0.44	111.16 (5)	0.55 (9)	111.197 (15)	0.19 (4)	111.18 (1)	0.55 (9)
113.3-114.9	K_β (Np)	-	-	-	-	-	-	-
-	-	-	113.7 (6)	-	-	-	113.9 (5)	-
			114.3 (6)	-	-	-	-	-
117.5-118.4	K_β (Np)	-	-	-	-	-	-	-
-	-	-	117.2 (6)	-	-	-	117.2 (6)	-
-	-	-	117.8 (6)	-	-	-	117.80 (7)	-
-	-	-	117.85 (60)	-	-	-	117.85 (7)	-
-	-	-	121.3 (6)	-	-	-	121.59 (2)	-
-	-	-	-	-	121.69 (4)	0.076 (11)	121.645 (9)	-
-	-	-	122.5 (6)	-	122.76 (7)	0.019 (8)	122.81 (1)	-
-	-	-	126.83 (5)	0.028 (14)	-	-	126.92 (1)	0.028 (14)
-	-	-	131.49 (8)	0.059 (14)	-	-	131.50 (5)	0.059 (14)
-	-	-	132.6 (6)	-	-	-	132.07 (6)	-
135.17 (6)	5.6	1.63	135.19 (2)	1.47 (8)	-	-	135.21 (2)	1.47 (8)
137.02 (6)	5.1	1.48	136.03 (2)	2.05 (6)	136.045 (10)	0.68 (11)	136.045 (2)	2.05 (6)
-	-	-	139.05 (2)	0.024 (7)	-	-	139.05 (3)	≤ 0.024 (7)
-	-	-	139.05 (2)	0.024 (7)	-	-	139.11 (2)	≤ 0.024 (7)
-	-	-	151.07 (5)	0.018 (4)	-	-	151.01 (3)	0.018 (4)
152.75 (6)	0.7	0.2	152.70 (2)	0.150 (8)	152.69 (3)	0.29 (4)	152.70 (2)	≤ 0.150 (8)
-	-	-	152.73 (2)	0.150 (8)	152.69 (3)	0.29 (4)	152.73 (1)	≤ 0.150 (8)
			-	-	153.192 (12)	0.43 (5)	153.19 (1)	-
153.84 (6)	2.4	0.70	153.85 (2)	0.721 (22)	153.870 (9)	0.45 (10)	153.87 (1)	0.721 (22)
-	-	-	156.46 (2)	0.059 (10)	156.452 (2)	4.23 (22)	156.451 (3)	0.059 (10)
-	-	-	160.61 (2)	0.09 (4)	-	-	160.61 (2)	0.09 (4)#
163.24 (4)	12.7	3.70	163.25 (2)	3.50 (10)	163.29 (5)	0.28 (4)	163.1 (5)	≤ 3.50 (10)
-	-	-	163.25 (2)	3.50 (10)	-	-	163.29 (1)	≤ 3.50 (10)
-	-	-	164.67 (7)	-	-	-	164.64 (7)	-
-	-	-	165.97 (15)	0.010 (5)	-	-	165.97 (15)	0.010 (5)#
-	-	-	170.50 (1)	0.136 (10)	-	-	170.7 (8)	0.136 (10)
-	-	-	174.76 (6)	0.038 (10)	-	-	174.76 (6)	0.038 (10)
-	-	-	176.68 (15)	0.006 (3)	176.62 (5)	0.17 (3)	176.66 (2)	0.006 (3)
-	-	-	182.86 (2)	0.199 (7)	182.876 (2)	13.9 (16)	182.878 (2)	0.199 (7)
-	-	-	189.01 (3)	0.059 (10)	189.099 (6)	0.44 (4)	189.10 (1)	0.059 (10)
-	-	-	190.88 (5)	0.023 (5)	-	-	190.88 (5)	0.023 (5)
194.63 (5)	-	-	194.61 (2)	0.308 (10)	-	-	194.59 (2)	0.308 (10)
-	-	-	196.46 (10)	0.021 (10)	-	-	196.52 (1)	0.021 (10)
206.34 (5)	2.0	0.58	206.37 (2)	0.34 (4)	-	-	206.39 (1)	0.34 (4)
-	-	-	213.20 (14)	0.012 (4)	-	-	213.19 (1)	0.012 (4)
-	-	-	215.52 (2)	0129 (21)	215.517 (5)	0.81 (4)	215.522 (4)	0.129 (21)
-	-	-	232.40 (3)	0.122 (7)	232.433 (8)	0.29 (5)	232.43 (1)	0.122 (7)
-	-	-	233.69 (10)	0.028 (7)	233.650 (6)	0.243 (22)	233.69 (10)	0.028 (7)#
-	-	-	237.02 (10)	0.010 (5)	-	-	236.90 (6)	0.010 (5)
-	-	-	238.53 (5)	0.0035 (18)	-	-	238.35 (7)	0.0035 (18)
-	-	-	250.33 (3)	0.122 (10)	-	-	250.33 (3)	≤ 0.122 (10)
-	-	-	250.33 (3)	0.122 (10)	250.40 (4)	0.35 (6)	250.37 (2)	≤ 0.122 (10)
-	-	-	270.55 (6)	0.0063 (18)	-	-	270.55 (7)	0.0063 (18)
-	-	-	272.75 (7)	0.0081 (18)	-	-	272.80 (6)	0.0081 (18)
-	-	-	280.04 (5)	0.0130 (14)	-	-	280.11 (1)	0.0130 (14)
-	-	-	299.20 (14)	0.006 (3)	-	-	299.23 (6)	0.006 (3)

* emission probability per 100 α has been significantly reduced to < 0.154, based on the α branching fraction and γ transition probabilities per 100 α of the γ transitions populating the 26.427-keV nuclear level.

not placed in the proposed partial decay scheme.

Placements of gamma-ray transitions.

Adopted E_γ (keV)	Proposed location in decay scheme (^{238}Np nuclear levels)	Adopted E_γ (keV)	Proposed location in decay scheme (^{238}Np nuclear levels)
24.34 (1)	86.674 (2) – 62.330 (4)	121.645 (9)	121.645 (9) – 0
26.427 (2)	26.427 (2) – 0	122.81 (1)	258.853 (8) – 136.045 (2)
32.64 (1)	215.522 (4) – 182.878 (2)	126.92 (1)	342.439 (8) – 215.522 (4)
34.97 (1)	121.645 (9) – 86.674 (2)	131.50 (5)	297.03 (5) – 165.532 (15)
35.90 (1)	62.330 (4) – 26.427 (2)	132.07 (6)	407.59 (6) – 275.519 (9)
43.11 (1)	179.154 (7) – 136.045 (2)	135.21 (2)	300.743 (16) – 165.532 (15)
43.33 (1)	258.853 (8) – 215.522 (4)	136.045 (2)	136.045 (2) – 0
43.83 (2)	106.155 (15) – 62.330 (4)	139.05 (3)	300.743 (16) – 161.69 (2)?
43.89 (2)	165.532 (15) – 121.645 (9)	139.11 (2)	165.532 (15) – 26.427 (2)
46.833 (3)	182.878 (2) – 136.045 (2)	151.01 (3)	312.70 (2) – 161.69 (2)?
49.371 (3)	136.045 (2) – 86.674 (2)	152.70 (2)	258.853 (8) – 106.155 (15)
53.2 (6)	218.7 (6) – 165.532 (15)	152.73 (1)	179.154 (7) – 26.427 (2)
53.67 (1)	232.828 (8) – 179.154 (7)	153.19 (1)	215.522 (4) – 62.330 (4)
53.85 (2)	312.70 (2) – 258.853 (8)	153.87 (1)	275.519 (9) – 121.645 (9)
57.51 (1)	179.154 (7) – 121.645 (9)	156.451 (3)	182.878 (2) – 26.427 (2)
59.32 (1)	121.645 (9) – 62.330 (4)	160.61 (2)	not placed in decay scheme
60.247 (3)	86.674 (2) – 26.427 (2)	163.1 (5)	328.6 (5) – 165.532 (15)
62.330 (4)	62.330 (4) – 0	163.29 (1)	342.439 (8) – 179.154 (7)
66.92 (1)	342.439 (8) – 275.519 (9)	164.64 (7)	300.68 (7) – 136.045 (2)
67.92 (2)	300.743 (16) – 232.828 (8)	165.97 (15)	not placed in decay scheme
73.72 (1)	136.045 (2) – 62.330 (4)	170.7 (8)	389.4 (5) – 218.7 (6)
75.98 (1)	258.853 (8) – 182.878 (2)	174.76 (6)	407.59 (6)– 232.828 (8)
79.48 (1)	215.522 (4) – 136.045 (2)	176.66 (2)	312.70 (2) – 136.045 (2)
79.73 (2)	106.155 (15) – 26.427 (2)	182.878 (2)	182.878 (2) – 0
85.16 (7)	300.68 (7) – 215.522 (4)	189.10 (1)	215.522 (4) – 26.427 (2)
86.674 (2)	86.674 (2) – 0	190.88 (5)	297.03 (5) – 106.155 (15)
89.60 (5)	not placed in decay scheme	194.59 (2)	300.743 (16) – 106.155 (15)
92.48 (1)	179.154 (7) – 86.674 (2)	196.52 (1)	258.853 (8) – 62.330 (4)
93.88 (1)	215.522 (4) – 121.645 (9)	206.39 (1)	342.439 (8) – 136.045 (2)
95.22 (1)	121.645 (9) – 26.427 (2)	213.19 (1)	275.519 (9) – 62.330 (4)
96.204 (3)	182.878 (2) – 86.674 (2)	215.522 (4)	215.522 (4) – 0
96.78 (1)	232.828 (8) – 136.045 (2)	232.43 (1)	258.853 (8) – 26.427 (2)
97.18 (2)	312.70 (2) – 215.522 (4)? X-ray?	233.69 (10)	not placed in decay scheme
109.61 (1)	342.439 (8) – 232.828 (8)	236.90 (6)	299.23 (6) – 62.330 (4)
109.618 (3)	136.045 (2) – 26.427 (2)	238.35 (7)	300.68 (7) – 62.330 (4)
111.18 (1)	232.828 (8) – 121.645 (9)	250.33 (3)	250.33 (3) – 0
113.9 (5)	389.4 (5) – 275.519 (9); X-ray?	250.37 (2)	312.70 (2) – 62.330 (4)
114.3 (6)	not placed in decay scheme; X-ray?	270.55 (7)	376.70 (7) – 106.155 (15)
117.2 (6)	459.6 (6) – 342.439 (8); X-ray?	272.80 (6)	299.23 (6) – 26.427 (2)
117.80 (7)	300.68 (7) – 182.878 (2)? X-ray?	280.11 (1)	342.439 (8) – 62.330 (4)
117.85 (7)	376.70 (7) – 258.853 (8)? X-ray?	299.23 (6)	299.23 (6) – 0
121.59 (2)	300.743 (16) – 179.154 (7)		

Measurements have also been carried out by Hoff *et al*. on the gamma-ray emissions following thermal-neutron capture on ^{237}Np – when judged appropriate, some of these (n,γ) data have been used to develop the proposed decay scheme of $^{242}Am^{m}$. The (n,γ) data were inspected in detail, and the opportunity taken to utilize these gamma-ray emission probabilities in a relative sense if their equivalent gamma-ray data had also been detected and quantified in the ^{242}Am^{m} studies. For example, consider the depopulation of the 258.853-keV nuclear level:

Proposed depopulating γ-ray transition (keV)	P_γ per 100n (1990Ho02)	P_γ per 100α (1990Ho02)	P_γ per 100α calculated	P_γ per 100α adopted
43.33	0.0046 (7)	–	0.0019 (3)	0.0019 (3)
75.98	0.0051 (8)	–	0.0021 (3)	0.0021 (3)
122.81	0.019 (8)	–	0.008 (4)	0.008 (4)
152.70	≤ 0.29	≤ 0.150	–	≤ 0.150
196.52	–	0.021 (10)	–	0.021 (10)
232.43	0.29 (5)	0.122 (7)	–	0.122 (7)

Unobserved P_γ per 100 α data can be calculated on the reasonable assumption that the relative emission probabilities of these six depopulating gamma rays would be the same irrespective of the mode of feeding to that nuclear level. The emission probability of the 232.43-keV gamma ray has been measured for both the ^{237}Np(n,γ) reaction and the α decay of ^{242}Am^{m}, and this ratio can be used to determine the equivalent relative emission probabilities of the 43.33-, 75.98- and 122.81-keV gamma-ray transitions in the α-decay mode. Thus, P_γ per 100 α for the 75.98-keV gamma ray can be calculated:

$$(0.122/0.29) \times 0.0051\ (8) = 0.0021\ (3)$$

This approach was adopted for a number of specific gamma transitions, as noted in the relevant footnote of the table below.

Despite the introduction of gamma-ray data as outlined above, additional gamma transitions are required to create a more comprehensive and consistent decay scheme for the ^{242}Am^{m} alpha-decay mode. While some of these possibilities can be gleaned from the ^{237}Np(n,γ) reaction data, they cannot be quantified in terms of P_γ per 100 α because of commensurate limitations in the (n,γ) measurements – these particular gamma rays are denoted by a dash (–) within the column entitled "Adopted P_γ per 100 α" in the table below.

Gamma-ray emissions: multipolarities and theoretical internal conversion coefficients (frozen orbital approximation).

Adopted E_γ (keV)	Adopted P_γ per 100 α*	Multipolarity	α_K	α_L	α_{M+}	α_{total}	
24.34 (1)	0.014 (2)#	M1+0.01%E2 δ = 0.01	–	242 (4)	80	322 (5)	α
26.427 (2)	< 0.154‡	M1+1%E2 δ = 0.10	–	252 (4)	86	338 (5)	α
32.64 (1)	0.0041 (6)#	M1+0.02%E2 δ = 0.014	–	102.6 (15)	33.8	136.4 (20)	α
34.97 (1)	–	M1+1%E2 δ = 0.10	–	98.7 (14)	33.2	131.9 (19)	α
35.90 (1)	–	M1+1.8%E2 δ = 0.135	–	101.5 (15)	34.5	136.0 (19)	α
43.11 (1)	0.014 (3)#	M1+0.2%E2 δ = 0.045	–	46.1 (7)	15.2	61.3 (9)	α
43.33 (1)	0.0019 (3)#	M1+9.1%E2 δ = 0.32	–	93.5 (14)	33.2	126.7 (18)	α
43.83 (2)	–	M1+0.9%E2 δ = 0.095	–	47.3 (7)	15.8	63.1 (9)	α
43.89 (2)	–	M1+1.3%E2 δ = 0.115	–	49.2 (7)	16.5	65.7 (10)	α
46.833 (3)	0.0016 (3)#	M1+0.4%E2 δ = 0.063	–	36.7 (6)	12.1	48.8 (7)	α
48.60 (5)	IT decay	E4	–	$3.33\ (5) \times 10^5$	$3.71\ (6) \times 10^5$	$7.04\ (8) \times 10^5$	IT
49.371 (3)	29.1 (9)	E1	–	0.615 (9)	0.206	0.821 (12)	α
53.2 (6)	–	(M1+E2)	–	–	–	–	α

Adopted E_γ (keV)	Adopted P_γ per 100 α*	Multipolarity	α_K	α_L	α_{M+}	α_{total}	
53.67 (1)	0.45 (6)	M1+5.9%E2 δ = 0.25	–	34.2 (5)	11.8	46.0 (7)	α
53.85 (2)	0.0006 (3)#	M1+2.4%E2 δ = 0.16	–	27.8 (4)	9.4	37.2 (6)	α
57.51 (1)	0.21 (5)	E1	–	0.412 (6)	0.137	0.549 (8)	α
59.32 (1)	–	M1+E2	–	–	–	–	α
60.247 (3)	1.19 (11)	M1+0.5%E2 δ = 0.07	–	17.34 (25)	5.76	23.1 (4)	α
62.330 (4)	–	E2	–	98.9 (14)	37.1	136.0 (19)	α
66.92 (1)	3.25 (10)	E1	–	0.277 (4)	0.091	0.368 (6)	α
67.92 (2)	0.87 (7)	M1+11%E2 δ = 0.35 (6)	–	18 (2)	6	24 (3)	α
73.72 (1)	1.71 (12)	E1	–	0.214 (3)	0.071	0.285 (4)	α
75.98 (1)	0.0021 (3)#	E2	–	38.4 (6)	14.4	52.8 (8)	α
79.48 (1)	0.027 (5)#	M1+50%E2 δ = 1.0 (2)	–	19 (3)	7	26 (4)	α
79.73 (2)	–	E2	–	30.6 (5)	11.5	42.1 (6)	α
85.16 (7)	0.21 (7)	M1+50%E2 δ = 1.0 (2)	–	14 (2)	5	19 (3)	α
86.674 (2)	4.97 (15)	M1+1%E2 δ = 0.10	–	5.98 (9)	1.97	7.95 (12)	α
89.60 (5)	0.29 (7)	–	–	–	–	–	α
92.48 (1)	0.61 (7)	E1	–	0.1184 (17)	0.0390	0.1574 (22)	α
93.88 (1)	0.79 (9)	E1	–	0.1138 (16)	0.0375	0.1513 (22)	α
95.22 (1)	–	M1+E2	–	–	–	–	α
96.204 (3)	–	E1	–	0.1068 (15)	0.0352	0.1420 (20)	α
96.78 (1)	0.072 (12)#	E2	–	12.28 (18)	4.62	16.90 (24)	α
97.18 (2)	0.0016 (8)#	E2	–	12.05 (17)	4.53	16.58 (24)	α
109.61 (1)	≤ 4.0 (3)	M1+50%E2 δ = 1.0 (2)	–	4.9 (5)	1.8	6.7 (7)	α
109.618 (3)	≤ 4.0 (3)	E1	–	0.0760 (11)	0.0250	0.1010 (15)	α
111.18 (1)	0.55 (9)	E1	–	0.0733 (11)	0.0241	0.0974 (14)	α
113.9 (5)	–	E2	–	5.77 (15)	2.17	7.94 (20)	α
114.3 (6)	–	–	–	–	–	–	α
117.2 (6)	–	E1	–	0.0639 (13)	0.0211	0.0850 (17)	α
117.80 (7)	–	(M1+E2)	–	–	–	–	α
117.85 (7)	–	E2	–	4.93 (7)	1.85	6.78 (10)	α
121.59 (2)	–	E2	0.178 (3)	4.27 (6)	1.612	6.06 (9)	α
121.645 (9)	–	E2	0.179 (3)	4.27 (6)	1.601	6.05 (9)	α
122.81 (1)	0.008 (4)#	M1+50%E2 δ = 1.0 (2)	5.4 (12)	3.11 (22)	1.09	9.6 (9)	α
126.92 (1)	0.028 (14)	E2	0.196 (3)	3.51 (5)	1.324	5.03 (7)	α
131.50 (5)	0.059 (14)	E1	0.205 (3)	0.0475 (7)	0.0155	0.268 (4)	α
132.07 (6)	–	E1	0.203 (3)	0.0470 (7)	0.0150	0.265 (4)	α
135.21 (2)	1.47 (8)	E1	0.192 (3)	0.0443 (7)	0.0147	0.251 (4)	α
136.045 (2)	2.05 (6)	E1	0.190 (3)	0.0436 (6)	0.0137	0.247 (4)	α
139.05 (3)	≤ 0.024 (7)	E1	0.180 (3)	0.0412 (6)	0.0135	0.235 (4)	α
139.11 (2)	≤ 0.024 (7)	E2	0.211 (3)	2.32 (4)	0.869	3.40 (5)	α
151.01 (3)	0.018 (4)	E1	0.1495 (21)	0.0334 (5)	0.0111	0.194 (3)	α
152.70 (2)	≤ 0.150 (8)	E1	0.1458 (21)	0.0325 (5)	0.0107	0.189 (3)	α
152.73 (1)	≤ 0.150 (8)	E1	0.1457 (21)	0.0324 (5)	0.0107	0.189 (3)	α
153.19 (1)	0.068 (8)#	E1	0.1447 (21)	0.0322 (5)	0.0101	0.187 (3)	α
153.87 (1)	0.721 (22)	M1+1.9%E2 δ = 0.14	5.53 (8)	1.123 (16)	0.367	7.02 (10)	α
156.451 (3)	0.059 (10)	E1	0.1379 (20)	0.0305 (5)	0.0100	0.1784 (25)	α
160.61 (2)	0.09 (4)	–	–	–	–	–	α
163.1 (5)	≤ 3.50 (10)	M1+50%E2 δ = 1.0 (2)	2.5 (5)	1.04 (3)	0.36	3.9 (5)	α

Adopted E_γ (keV)	Adopted P_γ per 100 α*	Multipolarity	α_K	α_L	α_{M+}	α_{total}	
163.29 (1)	≤ 3.50 (10)	M1+50%E2 δ = 1.0 (2)	2.5 (5)	1.04 (3)	0.36	3.9 (5)	α
164.64 (7)	–	(M1 + E2)	–	–	–	–	α
165.97 (15)	0.010 (5)	–	–	–	–	–	α
170.7 (8)	0.136 (10)	(M1+50%E2) δ = 1.0 (2)	2.2 (5)	0.882 (23)	0.318	3.4 (5)	α
174.76 (6)	0.038 (10)	M1+50%E2 δ = 1.0 (2)	2.1 (5)	0.809 (17)	0.191	3.1 (4)	α
176.66 (2)	0.006 (3)	E2	0.181 (3)	0.804 (12)	0.300	1.285 (18)	α
182.878 (2)	0.199 (7)	E1	0.0965 (14)	0.0206 (3)	0.0067	0.1238 (18)	α
189.10 (1)	0.059 (10)	E1	0.0894 (13)	0.0190 (3)	0.0062	0.1146 (16)	α
190.88 (5)	0.023 (5)	E1	0.0875 (13)	0.0185 (3)	0.0061	0.1121 (16)	α
194.59 (2)	0.308 (10)	E1	0.0837 (12)	0.01768 (25)	0.00582	0.1072 (15)	α
196.52 (1)	0.021 (10)	E1	0.0819 (12)	0.01725 (25)	0.00565	0.1048 (15)	α
206.39 (1)	0.34 (4)	E2	0.1454 (21)	0.412 (6)	0.1536	0.711 (10)	α
213.19 (1)	0.012 (4)	M1+50%E2 δ = 1.0 (2)	1.19 (24)	0.401 (11)	0.139	1.73 (25)	α
215.522 (4)	0.129 (21)	E1	0.0664 (10)	0.01376 (20)	0.00454	0.0847 (12)	α
232.43 (1)	0.122 (7)	E1	0.0560 (8)	0.01145 (16)	0.00375	0.0712 (10)	α
233.69 (10)	0.028 (7)	–	–	–	–	–	α
236.90 (6)	0.010 (5)	M1+50%E2 δ = 1.0 (2)	0.89 (18)	0.280 (12)	0.100	1.27 (19)	α
238.35 (7)	0.0035 (18)	E1	0.0530 (8)	0.01078 (16)	0.00352	0.0673 (10)	α
250.33 (3)	≤ 0.122 (10)	(M1+50% E2) δ = 1.0 (2)	0.77 (15)	0.233 (12)	0.077	1.08 (16)	α
250.37 (2)	≤ 0.122 (10)	E1	0.0475 (7)	0.00958 (14)	0.00312	0.0602 (9)	α
270.55 (7)	0.0063 (18)	E1	0.0400 (6)	0.00798 (12)	0.00262	0.0506 (7)	α
272.80 (6)	0.0081 (18)	M1+50%E2 δ = 1.0 (2)	0.61 (12)	0.176 (11)	0.064	0.85 (13)	α
280.11 (1)	0.0130 (14)	E1	0.0371 (6)	0.00735 (11)	0.00235	0.0468 (7)	α
299.23 (6)	0.006 (3)	M1+50%E2 δ = 1.0 (2)	0.48 (9)	0.131 (9)	0.039	0.65 (10)	α

* gamma rays with emission probabilities denoted by a dash (–) are believed to be relevant to the α-decay scheme, but could not be quantified in terms of P_γ per 100 α, and are omitted from the final recommendations.

\# not observed in γ-ray measurements of the α-decay mode of $^{242}Am^m$ – derived from equivalent (n,γ) studies (1990Ho02).

‡ reported emission probability of 1.36 (10) per 100 α decays exceeds expectations considerably from the point of view of the proposed decay scheme and the internal conversion coefficients of this (M1 + 1 % E2) transition – value was reduced to < 0.154 to maintain a satisfactory balance for depopulation of the 26.427(2)-keV nuclear level and population to the ground state of ^{238}Np.

Multipolarities and Internal Conversion Coefficients

The nuclear level schemes specified by Akovali and Chukreev *et al*. have been used to define the multipolarities of the gamma transitions on the basis of known spins and parities (2002Ak06, 2002Ch52). Mixing ratios for many of the (M1 + E2) transitions up to gamma-ray energies of 153.87-keV are the assignments proposed by Hoff *et al.* (1990Ho02), while others were arbitrarily assigned mixing ratios of 1.0 with an uncertainty of 20 %. Others were derived from consideration of population-depopulation of the relevant nuclear levels. Recommended internal conversion coefficients have been determined from the frozen orbital approximation of Kibédi *et al*. (2008Ki07), based on the theoretical model of Band *et al*. (2002Ba85, 2002Ra45).

Significant conflict and inconsistencies remain in the proposed decay scheme for the rather small α branch, despite the impressive work of Hoff *et al*. (1990Ho02). Emphasis has been placed on the validity and comprehensive nature of the α-spectroscopy studies of Baranov *et al*. and Hoff *et al*. (1979Ba67, 1990Ho02) that may be of questionable merit. There are also very strong indications that the known gamma-ray data are unable to support the significant γ depopulation of the 407.59- and 342.439-keV nuclear levels of ^{238}Np. Arguably, further accurate high-resolution gamma-ray spectroscopy studies are required to develop and complete the rather complex α-decay mode with much greater confidence.

Atomic Data

The x-ray and Auger-electron data have been calculated using the evaluated gamma-ray data, and atomic data from 1996Sc06, 1998ScZM and 1999ScZX. Both the x-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.01, 28 January 2003, with the emission.101 database extended to Z = 96 to calculate component L x-ray data for IT decay to ^{242}Am). This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data. A number of the gamma-ray emission probabilities can only be quantified in terms of recommended upper limits (≤ and <) – EMISSION calculations have been undertaken with these values reduced by a factor of approximately two and assigned uncertainties of the same magnitude.

K and L X-ray emission probabilities per 100 disintegrations of ^{242}Am^{m}.

			Energy (keV)	Photons per 100 disint.
XL		(Np)	11.871 – 21.491	0.37 (4)
	XL_l	(Np)	11.871	0.0090 (9)
	XL_α	(Np)	13.761 – 13.946	0.143 (13)
	XL_η	(Np)	15.861	0.0022 (4)
	XL_β	(Np)	16.109 – 17.992	0.164 (13)
	XL_γ	(Np)	20.784 – 21.491	0.040 (3)
XK_α	$XK_{\alpha2}$	(Np)	97.069	0.019 (9)
	$XK_{\alpha1}$	(Np)	101.059	0.030 (14)
$XK'_{\beta1}$	$XK_{\beta3}$	(Np)	113.303	)
	$XK_{\beta1}$	(Np)	114.234	) 0.011 (5)
	$XK''_{\beta5}$	(Np)	114.912	)
$XK'_{\beta2}$	$XK_{\beta2}$	(Np)	117.463	)
	$XK_{\beta4}$	(Np)	117.876	) 0.0037 (17)
	$XKO_{2,3}$	(Np)	118.429	)
XL		(Am)	12.377 – 22.836	25.0 (11)
	XL_l	(Am)	12.377	0.608 (18)
	XL_α	(Am)	14.414 – 14.620	9.33 (24)
	XL_η	(Am)	16.819	0.274 (9)
	XL_β	(Am)	16.890 – 19.110	12.2 (3)
	XL_γ	(Am)	22.072 – 22.836	2.90 (8)

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

Data Consistency

An effective Q-value of 74.31 (5) keV has been adopted from the atomic mass evaluation of Audi *et al*. (2003Au03) while in the course of formulating the decay scheme of ^{242}Am^{m}. This value has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{242}Am^{m} alpha- and IT-decay processes (i.e. α, conversion electrons, γ, etc.):

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 72.9\ (12)\ \text{keV}$$

Percentage deviation from the effective Q-value of Audi *et al.* is (1.9 ± 1.6) %, which supports the derivation of a reasonably consistent decay scheme with a large variant. Much of this deviation can be attributed to the incompleteness of the recommended alpha- and gamma-transition data within the small alpha-decay mode.

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^{243}Am - Comments on evaluation of decay data by E. Browne, M.-M. Bé, R.G. Helmer

This evaluation was completed in September 2004 and reviewed in 2009. The literature available by April 2009 was included. Half-life and conversion coefficients have been updated.

Several measurements of the α emission intensities were carried out and, their results are in good agreement. However, the available experimental γ-ray emission intensities are mostly imprecise and in poor agreement with each other.
The decay scheme overall consistency is supported by the agreement between Q(eff)=5439.6 (40) keV, deduced from average radiation energies and intensities, and $Q(\beta^-)$=5438.8 (10) keV, from the atomic mass adjustment (2003Au03).

Evaluation Procedures

The *Limitation of Relative Statistical Weight* (LWM) [1985ZiZY] method, used for averaging numbers throughout this evaluation, provided a uniform approach for the analysis of discrepant data. The uncertainty assigned in this evaluation to the recommended value is always greater than or equal to the smallest uncertainty in any of the experimental values used in the calculation.

1 Decay Scheme

^{243}Am decays 100 % by emission of α particles, with a minute branch of 3.8 (7) $\times 10^{-9}$ % (2002Sa53) by spontaneous fission. Other value: 3.7 (9) $\times 10^{-9}$ % (1966Gv01). The α-particle intensities (in percent) to individual levels presented in the decay scheme are experimental values from α-spectroscopic measurements. α-hindrance factors given in the decay scheme have been calculated by using a radius parameter r_0 (^{239}Np) = 1.505, average of r_0 (^{238}U) = 1.5143 (9), r_0 (^{240}U) = 1.5062 (10), r_0 (^{238}Pu) = 1.5013 (10), and r_0 (^{240}Pu) = 1.4979 (7) (1998Ak04). The level energies, spins, parities, as well as γ-ray multipolarities shown in the decay scheme are recommended values from the evaluation 2003Br12.

Levels at 71- and 122 keV are based on α-γ coincidence experiments with γ rays (169-, 50.6-, and 195 keV) that feed such levels. The de-excitations of these two levels, however, have not been observed. The expected γ rays may have been masked by more intense ones, which de-excite other levels.

2 Nuclear Data

The recommended half-life of ^{243}Am is 7367 *a*, a weighted average of the values given in Table 1, the most accurate value (from 2007Ag02) contributes 54 % to the statistical weight. The calculated internal uncertainty is 17 *a*. However, the recommended uncertainty is the smallest uncertainty in the input values, i.e., 23 *a*. This half-life compares well with other recommended values such as 7370 (40) *a* (1992Ak06), 7366 (20) *a* (1991BaZS), and 7370 (15) *a* (1986LoZT).

Q_α= 5438.8 (10) keV is from the atomic mass adjustment 2003Au03.

Table 1. ^{243}Am measured half-life values

Reference	Method	$T_{1/2}(^{243}Am)/T_{1/2}(^{241}Am)$	$T_{1/2}(^{243}Am)$ (*a*)	u_c	Remarks
1959Ba22	Relative activity	16.85 (35)	7289.3 *	151.7	
1960Be10	Relative activity	16.70 (10)	7224.4 *	100.0	An uncertainty of 1.4% (100 *a*) from 1960Be10 is mostly systematic. Thus, dividing this value by the square root of the number of measurements (5) is questionable and was not done in the evaluation of 1986LOZT. Omitted from analysis.
1968Br22	Relative activity	16.96 (13)	7336.9 *	57.2	
	Specific activity		7390	50	
1974Po17			7380	34	This value is the weighted mean result from specific $T_{1/2}(^{243}Am)$ determination and from measurements relative to $T_{1/2}(^{241}Am)$
1980Ag05	Relative activity	17.010 (95)	7359 *	42	Superseded by 2007Ag02
2007Ag02	Relative activity	17.022 (27)	7363.7 *	23	
	LWM		7367	17	χ^2 /n-1 = 0.2 , χ^2 crit = 3.3, int. uc = 17
		Recommended value	7367 (23)		Weighted average. Some results depend on the $T_{1/2}(^{241}Am)$ and then are not independent so the uncertainty is the minimum value from input.

* Relative to $T_{1/2}(^{241}Am)$=432.6 (6) *a* (Chechev in 2004BeZQ).

3 Atomic Data

X-ray and Auger (relative and absolute) electron emission probabilities given in Sections 3 and 5, respectively, have been calculated by means of the computer code EMISSION (version 3,01, Nov. 3, 1999) [1], which makes use of the atomic data from 1996Sc06, from reference [2], and from the evaluated γ-ray data given in Sections 2.1 and 4.2. In addition, internal conversion electron energies and absolute emission probabilities for the strongest lines are presented in Section 5. Electron energies have been calculated using electron binding energies from 1977La19, and γ-ray energies from Section 2.1. Absolute electron emission probabilities have been calculated using absolute γ-ray emission probabilities given in Section 4.2 and conversion coefficients from Section 2.1.

4 Alpha Particles

a -Particle Energies

Most of the recommended α-particle energies in this evaluation are weighted averages (*Limited Relative Statistical Weight* method, LWM) of values from 1964Ba26 and 1968Ba25 (magnetic spectrograph), and from 1996Sa24 and 2002Da21 (semiconductor detectors). Values reported by 2002Da21 are from the analysis of an α-particle spectrum measured by 1992Ga01.

A. Rytz (1991Ry01) has critically evaluated the α-particle groups at 5233, 5275, and 5379 keV. His energies, also recommended in this evaluation, are virtually the same as the weighted average energies given in Table 2. This table shows the results of various measurements as well as the values recommended in this evaluation.

Table 2. ^{243}Am Alpha-Particle Energies

1964Ba26	1968Ba25	1996Sa24	2002Da21&	W. Average	Rec. Values
4695 (3)			[4697]#		4695 (3)
4919 (3)					4919 (3)
4930 (3)			[4936]#		4930 (3)
4946 (3)			[4951]#		4946 (3)
4997 (3)			[5001]#		4997 (3)
5008 (3)		5002(5)	5012 (5)	5008 (3)	5008 (3)
5029 (3)		5030 (5)		5029 (3)	5029 (3)
5035 (3)			5037 (5)	5035 (3)	5035 (3)
5088 (3)		5083 (5)	5091 (5)	5088 (5)	5088 (5)
5113 (1)		5109 (5)	5113 (5)	5113 (1)	5113 (1)
5181 (1)		5177 (5)	5178 (5)	5181 (1)	5181 (1)
5234 (1)	5232.9 (10)	5232 (5)	5233 (5)	5233.4 (10)	5233.3 (10)*
5276 (1)	5274.8 (10)	5275 (5)	5275 (5)	5275.3 (10)	5275.3 (10)*
5321 (1)		5319 (5)	5318 (5)	5321 (1)	5321 (1)
5350 (1)		5350 (5)	5349 (5)	5350 (1)	5349.4 (23)*

2002Da21 did not measure the alpha spectrum of 243Am. The alpha spectrum used was from 1992Ga01, who had not identified these very weak peaks. 2002Da21 reported for these peaks, intensities ranging from 2 to 13 times those given by 1964Ba26. Evaluators have interpreted this discrepancy as possibly caused by *spurious peaks* produced in the spectral peak-shape analysis of 2002Da21. Thus, they did not use these α-particle energies in the averaging process.

* From 1991Ry01.

& Rounded values. Uncertainties assigned by evaluators are typical values for spectra measured with semiconductor detectors.

α-Particle Emission Intensities

Table 3 shows the emission intensities measured by various authors. The uncertainties given by all of them (except one, 1996Sa24) are statistical values deduced from spectral peak-shape analysis. Such uncertainties do not include a constraint imposed by normalizing the sum of the emission probabilities to 100, that is, to absolute emission intensities (p_i(%)) per 100 α-particle disintegrations of the parent nuclide. The following formula (1988Br07) may be used to convert uncertainties (dI_i) in relative α-particle emission intensities (I_i) to values in the absolute emission intensities (dp_i(%)):

$$dp_i(\%)/p_i(\%) = [(dI_i/I_i)^2 (1 - 2 I_i/\Sigma I_k) + \Sigma dI_k^2/(\Sigma I_k)^2]^{1/2} \qquad (1)$$

The uncertainties given by 1996Sa24 (see Table 3) are those in the absolute α-emission intensities (dp_i(%)), whereas the other authors give uncertainties only in the relative α-emission intensities (dI_i). This situation significantly affects only the two most intense α-particle groups for which 1996Sa24 give the same uncertainty of 0.03.

The energies and absolute emission intensities recommended in this evaluation are given in Section 2.2. The following description shows the procedure used here for determining these recommended absolute emission intensities:

1. Changing the uncertainty in the 5275-keV α-particle group before averaging from its absolute value of dp (%) = 0.03 (1996Sa24) to a relative value (estimated by evaluators) of dI = 0.06.

2. Averaging (i.e., weighted averages, LWM) the relative emission intensities given by various authors (1955St98, 1956Hu96, 1964Ba26, 1966Le13, 1992Ga01, 1996Sa24, 2002Da21) and depicted in Table 3. Relative emission probabilities from 1998Ya17 (also shown in Table 3) are in disagreement with those from these authors, thus significantly increasing χ^2/ν for most averages. Their uncertainties include a "non-statistical component." Unfortunately, 1998Ya17 give neither their values for these components nor the criteria used for estimating them. Therefore, data from 1998Ya17 have not been used for averaging.

3. Converting uncertainties in the recommended emission intensities (Table 3, column 9) to uncertainties in the absolute α-particle emission intensities by using formula (1). It should be noticed that only the uncertainties in the two most intense α-particle groups have been affected by this procedure.

Table 3. ^{243}Am Alpha particle emission intensities

Eα(keV)	1955St98	1956Hu96	1964Ba26	1966Le13	1992Ga01	1998Ya17	1996Sa24##	2002Da21$	Iα(avg)&&	χ^2/ν	Rec. Iα &&&
4695			0.0006	0.0017 (5)***				0.0038 (4)^^			0.0017 (5)
4919			0.000085								0.000085
4930			0.00018					0.0026 (3)^^			0.00018
4946			0.00034					0.0028 (3)^^			0.00034
4997			0.0016#		0.0016 (5)#		0.0020 (4)#	0.0031 (4)^^	0.0018 (3)	0.39	0.0018 (4)#
5008								0.0052 (4)^^			
5029			0.0022^		0.0033 (5)^		0.0044 (5)^	0.0082 (5)^^	0.0039 (4)	2.4	0.0039 (6)^
5035											
5088			0.004		0.0056 (7)		0.0055 (6)	0.0112 (6)^^	0.0055 (5)	0.01	0.0055 (6)
5113			0.0054		0.010 (1)		0.0101 (10)	0.019 (1)^^	0.0100 (7)	0	0.010 (1)
5181	1.1 (3)&	1.3 (2)	1.1		1.36 (1)	0.98 (2)	1.388 (8)	1.391 (7)	1.383 (5)	2.0	1.383 (7)
5233	11.5 (3)*	11.5 (3)	10.6 (2)**		11.46 (3)	11.04 (7)	11.37 (3)	11.52 (2)	11.46 (6)	7.1	11.46 (5)$$
5275	87.1 (4)*	86.9 (4)	87.9 (3)**		86.74 (6)	87.42 (8)	86.79 (3)	86.60 (7)	86.74 (4)	4.1	86.74 (5)$$
5321	0.16	0.16	0.12		0.190 (7)	0.270 (6)	0.194 (3)	0.190 (3)	0.192 (2)	0.48	0.192 (3)
5349	0.17	0.17	0.16		0.230 (7)	0.298 (8)	0.243 (3)	0.240 (3)	0.240 (2)	1.5	0.240 (3)

$ 2002Da21 analyzed an α spectrum of 1992Ga01.

& Uncertainty assumed by evaluator.

* From 1955St98, quoted in 1991Ry01; uncertainties are from 1991Ry01.

4997α + 5008α

^ 5029α + 5035α

** From 1964Ba26, quoted in 1991Ry01; uncertainties are from 1991Ry01.

Uncertainties include the effect of covariances when normalizing ΣIα = 100.

^^ α-particle intensities are at least about twice those found by other authors, which suggest a possible systematic bias in the analysis of the spectrum. These values were not used for averaging.

*** Agrees well with Iα=0.00148 3% from γ-ray transition intensity balance.

&& Weighted average using the Limitation of Relative Statistical Weights method. Data from 1998Ya17 have not been included. See text.

$$ Normalization of Iα to ΣIa=100 requires same values for these uncertainties. See text.

&&& Uncertainty is always greater than or equal to the smallest uncertainty in any of the experimental values used in the calculation

5 Gamma Rays

Energies

The recommended γ-ray energies given in Sections 2.1 and 4.2 are weighted averages (LWM) of values given in 1982Ah04 and 1975Pa04, complemented with values from 1996Sa23, 1969En02, and 1968Va09 (See table 4).

Table 4. ^{243}Am Gamma-ray Energies							
E_g (keV)	E_g (keV)	E_g (keV)	E_g (keV)	E_g (keV)	E_g (keV)		E_g (keV)
1996Sa23	1982Ah04	1975Pa04	1969En02	1968Va09	**W. Avg.***	c**2/**n	**Rec. E**g
31.13	31.14 (3)	31.10 (15)		31.2	31.14 (3)	0.068	31.14 (3)
		43.1	43.1				43.1#
43.53	43.53 (2)	43.53 (15)		43.6	43.53 (2)		43.53 (2)
50.6				50.6			50.6&$
55.18			55.4	55.4			55.18&
74.66	74.66 (2)	74.67 (15)	74.7	74.8	74.66 (2)	0.004	74.66 (2)
86.71	86.71 (2)	86.79 (15)	86.7	86.7	86.71 (2)	0.27	86.71 (2)
98.5			98.5				98.5^
117.84		117.60 (15)	117.8	117.8			117.60 (15)#
141.89	141.89 (3)	142.18 (15)	142	142	141.90 (3)	3.6	141.90 (6)
169				169			169$
195				195			195$
* Weighted average of values in 1982Ah04 and 1975Pa04.							
# From 1975Pa04							
& From 1996Sa23							
$ From 1968Va09							
^ From 1969En02							

The recommended absolute γ-ray emission (photons) and transition (photons + electrons) intensities given in Sections 4.2 and 2.2, respectively, are weighted averages (LWM) of values in 1996Sa23, 1996Wo05, 1984Va41, 1982Ah04, 1979Po20, 1977St35, 1975Pa04, 1972Ah02, 1969Al14 and 1960As02 (see Table 5).

The conversion coefficients used for deducing absolute transition probabilities (see section 2.2) are theoretical values interpolated from the Band's tables (2002Ba85) by using the computer code BrIcc (2008Ki07) with the so called "Frozen orbital" approximation.

The M1/E2 mixing ratio for $\gamma_{3,0}$ (31,1 keV) $\delta = 0{,}17$ was deduced from probability balance in ^{243}Am α- decay and in ^{239}U β^- -decay

The M1/E2 mixing ratios for $\gamma_{4,3}$ (43,1 keV) $\delta = 0{,}38\ (4)$ and $\gamma_{6,4}$ (55,2 keV) $\delta = 0{,}75\ (10)$ have been taken from Engelkemeir (1969En02).
The remaining M1/E2 mixing ratios are from 2003Br12 based on measurements of 1957Ho07, 1964Bl11, 1969En02.

Table 5. ^{243}Am γ-ray Absolute Emission Probabilities

E_γ (keV) Rec. Value*	I_γ 1960As02	I_γ@ 1968Va09	I_γ 1969Al14	I_γ 1972Ah02	I_γ 1975Pa04	I_γ 1977St35	I_γ 1979Po20	I_γ 1982Ah04	I_γ 1984Va41	I_γ 1996Wo05	I_γ 1996Sa23	W. Avg.	χ^2/ν	I_γ [a] Rec. Value
31.14 (3)								0.069 (7)			0.0477 (13)	0.0484 (13)	9	0.048 (4)
43.1		0.03												0.065^
43.53 (2)	4 (1)	5.3	5 (1)	5.5 (3)			5.3 (12)	6.20 (30)	6.04 (13)	5.93 (10)	5.72 (17)	5.89 (7)	1.4	5.89 (10)
50.6		0.0027									0.0062 (10)			0.0062 (10)#
55.18		0.0094									0.0168 (11)			0.0168 (11)#
74.66 (2)	69 (3)	61		66 (3)		59.1 (40)	60 (4)	68.0 (20)	68.5 (15)	66.7 (12)	68.4 (13)	67.2 (7)	1.4	67.2 (12)
86.71 (2)		0.37						0.340 (15)	0.35 (1)	0.342 (15)	0.344 (9)	0.346 (6)	0.2	0.346 (9)
98.5											0.0151 (21)			0.0151 (21)#
117.60 (15)		0.75			0.56 (8)						0.57 (5)			0.57 (5)#
141.90 (6)		0.13						0.128 (6)	0.13 (1)	0.117 (5)	0.1068 (26)	0.115 (2)	3.8	0.115 (8)
169		0.0012												0.0012[&]
195		0.00085												0.00085[&]

a Recommended absolute emission probabilities are weighted averages (LWM) of experimental values, unless otherwise noted.
Uncertainty is always greater than or equal to the smallest uncertainty in any of the experimental values used in the calculation.

***** From Table 4

From 1996Sa23

& From 1968Va09

^ Estimated by 2003Br12 from α_M (43.1γ, exp.) = 31, I_M (ce, 43.1γ) / Iγ(117) = 3.56 (1969En02), and Iγ(117) = 0.57.

@ Uncertainties are at least 10%.

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^{244}Am - Comments on evaluation of decay data by A. L. Nichols

Evaluated: January 2007/February 2009 – Updated comments Dec. 2010

Evaluation Procedure

Limitation of Relative Statistical Weight Method (LWM) was applied to average the decay data when appropriate (but see below).

Decay Scheme

A relatively simple decay scheme was constructed from the gamma-ray studies of 1962Va08, 1963Ha29, 1967Sc34 and 1984Ho02. Only the gamma-ray measurements of Hoff *et al*. provide any estimates of the uncertainties in the gamma-ray probabilities expressed in terms of their relative intensity per 100 neutron captures in a high-flux reactor (1984Ho02). All other studies contained no information with respect to their overall uncertainties. Thus, no weighted mean data could be derived, and the data of 1984Ho02 were adopted wholesale and re-adjusted when deemed necessary (expressed in terms of the 743.977-keV gamma-ray emission probability (100 %)). Further measurements are merited to quantify the gamma-ray emission probabilities and decay scheme with greater certainty.

Nuclear Data

^{244}Am is an important actinide for high burn-up fuel within the reactor core, and needs to be better characterised for improved assessments of accelerator-driven systems (ADS) and ^{244}Cm decay heat contribution.

Half-life

The recommended half-life has been adopted from the single known measurement of Vandenbosch and Day (1962Va08). Further measurements are required to determine this half-life with much greater confidence.

Half-life measurement

Reference	Half-life (hours)
1962Va08	10.1 ± 0.1

Gamma Rays

Energies

All gamma-ray transition energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of Akovali were adopted (2003Ak04), and used to determine the energies and associated uncertainties of the gamma-ray transitions between the various populated-depopulated levels. However, Akovali recommended the gamma-ray energies determined by Hoff *et al.* (1984Ho02) by means of two curved-crystal spectrometers – minor differences do occur between the calculated energies of the higher energy transitions (538.402 (16), 743.977 (5) and 897.840 (7) keV) and those observed by Hoff *et al.*

<u>Emission Probabilities</u>

Relative emission probabilities and their uncertainties were determined from measurements of Hoff *et al*. (1984Ho02). These data were estimated to be in reasonably good agreement with the earlier measurements of Vandenbosch and Day, and Schuman (1962Va08, 1967Sc34), although these latter two sets of data possessed no uncertainties. Under these unsatisfactory circumstances, the data of Hoff *et al.* had to be adopted wholesale as the only suitable starting point in the attempted construction of a consistent decay scheme. Adjustments were made to the relative emission probabilities of the 99.383-, 153.863- and 205.575-keV gamma-rays (adjusted from 7.0 (12) to 7.5 (13), 25 (5) to 28.6 (60), and 0.52 (12) to 0.53 (12), respectively) to conform with respect to the expected population-depopulation balance for the 501.79-, 296.21- and 142.35-keV nuclear levels of ^{244}Cm. Furthermore, a relative emission probability had to be calculated for the 42.96-keV gamma-ray for which there were no data at all (from a population-depopulation balance of the 42.96-keV nuclear level of ^{244}Cm (populated by the 99.38-keV gamma ray and depopulated by the 42.96-keV gamma ray)). Downward adjustments were made to the uncertainties of specific gamma-ray transitions and emissions through consideration of these and other data that are judged to be heavily correlated (99.383- and 153.863-keV gamma rays compared with 743.977-keV gamma-ray and each other).

Measured relative gamma-ray emission probabilities

	E_γ (keV)	P_γ^{rel}		
		1962Va08	**1967Sc34**	**1984Ho02**
$\gamma_{1,0}$ (Cm)	42.965 (10)	-	-	-
$\gamma_{2,1}$ (Cm)	99.383 (4)	-	-	0.23 (4) → 7.0 (12)
$\gamma_{3,2}$ (Cm)	153.863 (2)	72 → 100	-	0.82 (16) → 25 (5)
$\gamma_{4,3}$ (Cm)	205.575 (4)	0.4 → 0.6	-	0.017 (4) → 0.52 (12)
$\gamma_{9,4}$ (Cm)	538.402 (16)	0.4 → 0.6	-	0.033 (7) → 1.0 (2)
$\gamma_{9,3}$ (Cm)	743.977 (5)	72 → 100	66.2 → 100	3.3 (9) → 100 (27)
$\gamma_{9,2}$ (Cm)	897.840 (7)	28 → 39	27.6 → 42	1.4 (4) → 42 (12)

Gamma-ray emissions: recommended energies, relative emission probabilities, multipolarities and theoretical internal conversion coefficients (frozen orbital approximation)

E_γ (keV)	P_γ^{rel}	Multipolarity	α_K	α_L	α_{M+}	α_{tot}	
42.965 (10)	0.145 (12)*	E2	-	760 (11)	290 (4)	1050 (15)	β^-
99.383 (4)	7.5 (13)§	E2	-	13.9 (2)	5.4 (1)	19.3 (3)	β^-
153.863 (2)	28.6 (60)§	E2	0.174 (3)	1.90 (3)	0.74 (1)	2.81 (4)	β^-
205.575 (4)	0.53 (12)§	E2	0.141 (2)	0.541 (8)	0.205 (3)	0.887 (13)	β^-
538.402 (16)	1.0 (2)	E2	0.0292 (4)	0.0149 (2)	0.0054 (1)	0.0495 (7)	β^-
743.977 (5)	100 (27)	M1 + E2 $\delta = -0.92$ (8)	0.059 (4)	0.0130 (7)	0.0050 (3)	0.077 (5)	β^-
897.840 (7)	42 (12)	E2	0.0122 (2)	0.00358 (5)	0.00124 (2)	0.0170 (3)	β^-

* Determined from the calculated theoretical internal conversion coefficients and the transition probability of the 99.383-keV gamma ray feeding the 42.965-keV nuclear level of ^{244}Cm.

§ Adjusted to conform with respect to the expected population-depopulation balances for the 501.79-, 296.21- and 142.35-keV nuclear levels of ^{244}Cm.

A normalisation factor of 0.66 (14) was calculated from the relative emission probabilities of the three gamma rays that depopulate the 1040.188-keV nuclear level:

$$\sum^{3} P_\gamma (1+\alpha_{tot}) \times F \quad = \quad 100\%$$

$$[P^{rel}(897.84\,keV)(1+\alpha_{tot}) + P^{rel}(743.97keV)(1+\alpha_{tot}) + P^{rel}(538.40keV)(1+\alpha_{tot})] \times F \; = 100$$

$$F = 100/151\ (32) = 0.66 \pm 0.14$$

Multipolarities and Internal Conversion Coefficients

The nuclear level scheme specified by Akovali has been used to define the multipolarities of the gamma transitions on the basis of known spins and parities (2003Ak04). Hansen *et al.* undertook angular correlation measurements to confirm the assignment of the 1040.2-keV nuclear level as the only ^{244}Cm nuclear level populated directly by β^- decay (1963Ha29), in which the depopulating 743.977-keV gamma ray was defined as (46 ± 4) % quadrupole [E2] and (54 ± 4) % dipole [M1] to give a mixing ratio (δ) of – 0.92 (8) for this transition. Recommended internal conversion coefficients have been determined from the frozen orbital approximation of Kibédi *et al*. (2008Ki07), based on the theoretical model of Band *et al*. (2002Ba85, 2002Ra45).

Beta Particle

Energy and emission probability

The single beta-particle energy was calculated from the structural detail of the proposed decay scheme. A nuclear level energy of 1040.188 (12) keV from Akovali (2003Ak04) and a Q_{β^-} value of (1427.3 ± 1.0) keV from Audi *et al.* (2003Au03) were used to determine the energy and uncertainty of the beta-particle transition. By definition, this single beta transition was assigned an emission probability of 100 %.

Beta-particle Emission Probability per 100 Disintegrations of ^{244}Am.

	E_β (keV)	P_β	Transition type	log *ft*
$\beta^-_{0,9}$	387.1 ± 1.0	100	(1st forbidden non-unique)	5.63

Atomic Data

The x-ray and Auger-electron data have been calculated using the evaluated gamma-ray data, and atomic data from 1996Sc06, 1998ScZM and 1999ScZX. Both the x-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.01, 28 January 2003, with the emission.101 database extended to Z = 96 to calculate component L x-ray data of daughter Cm). This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

K and L X-ray Emission Probabilities per 100 Disintegrations of ^{244}Am.

			Energy keV	Photons per 100 disint.
XL		(Cm)	12.633 – 23.527	100 (10)
	XL_l	(Cm)	12.633	2.36 (24)
	XL_{α}	(Cm)	14.746 – 14.961	36 (4)
	XL_{η}	(Cm)	17.314	1.15 (15)
	XL_{β}	(Cm)	17.286 – 19.688	51 (5)
	XL_{γ}	(Cm)	22.735 – 23.527	12.5 (13)
XK_{α}	$XK_{\alpha2}$	(Cm)	104.590	2.2 (3)
	$XK_{\alpha1}$	(Cm)	109.271	3.4 (4)
$XK'_{\beta1}$	$XK_{\beta3}$	(Cm)	122.304	)
	$XK_{\beta1}$	(Cm)	123.403	) 1.29 (16)
	$XK''_{\beta5}$	(Cm)	124.124	)
$XK'_{\beta2}$	$XK_{\beta2}$	(Cm)	126.889	)
	$XK_{\beta4}$	(Cm)	127.352	) 0.45 (6)
	$XKO_{2,3}$	(Cm)	127.970	)

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

Data Consistency

A Q_{β}-value of 1427.3 (1) keV has been adopted from the atomic mass evaluation of Audi *et al.* (2003Au03) while in the course of formulating the decay scheme of ^{244}Am. This value has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{244}Am beta-decay process (i.e. β^-, conversion electrons, γ, etc.):

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 1431\ (90)\ \text{keV}$$

Percentage deviation from the Q-value of Audi *et al.* is (0 ± 6) %, which supports the derivation of a highly consistent decay scheme with a large variant.

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$^{244}Am^{m}$ - Comments on evaluation of decay data

by A. L. Nichols

Evaluated: January 2007/February 2009 – Updated comments 2010

Evaluation Procedure

Limitation of Relative Statistical Weight Method (LWM) was applied to average the decay data when appropriate (but see below).

Decay Scheme
A relatively simple decay scheme was constructed from the branching fraction measurements of Fields *et al*. and Gabeskipiya *et al*. (1955Fi36, 1976Ga31) and the gamma-ray studies of Hoff *et al*. (1984Ho02). Only the gamma-ray studies of Hoff *et al*. provide estimates of the gamma-ray emission probabilities and their uncertainties per 100 neutron captures. Thus, no weighted mean data could be derived, and the data of 1984Ho02 were adopted as published.

Nuclear Data

$^{244}Am^{m}$ is an important actinide for high burn-up fuel within the reactor core, and needs to be better characterised for assessments of accelerator-driven systems (ADS) and ^{244}Cm production and decay heat contribution.

Half-life
The recommended half-life has been adopted from two known measurements that did not quantify the uncertainties (1950St61, 1954Gh24). Thus, the assigned uncertainty is a crude estimate of ~ 10 %. This situation is extremely unsatisfactory, and further measurements are required to determine the half-life and uncertainty with much greater confidence.

Half-life measurements.

Reference	Half-life (min)
1950St61	~ 25
1954Gh24	26
Recommended value	26 ± 3

Branching Fractions
Fields *et al.* and Gabeskipiya *et al.* have determined the EC/β⁻ ratio (1955Fi36, 1976Ga31).

Reference	EC/β⁻
1955Fi36	0.000 38 ± 0.000 03*
1976Ga31	0.000 361 ± 0.000 013
Recommended value	0.000 36 ± 0.000 01

* Adjusted from 0.000 39 (3) on consideration of ^{244}Cm half-life (18.11 (3) years).

Recommended EC/β⁻ ratio was used to derive $BF_{\beta-}$ of 0.999 64 (1) and BF_{EC} of 0.000 36 (1).

Gamma Rays

Energies

All gamma-ray transition energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 2003Ak04 were adopted, and used to determine the energies and associated uncertainties of the gamma-ray transitions between the various populated-depopulated levels.

Emission Probabilities

Relative emission probabilities and their uncertainties were determined from the studies of Hoff *et al.* (1984Ho02). There are no other known measurements of these important decay characteristics. Under such unsatisfactory circumstances, the data of Hoff *et al.* had to be adopted wholesale, and further measurements are required to confirm the validity of the proposed decay scheme.

Measured gamma-ray emission probabilities per 100 neutron captures.

	E$_\gamma$ (keV)	P_γ	**Multipolarity**
		1984Ho02	
$\gamma_{1,0}$ (Cm)	42.965 (10)	(0.029)*	E2
$\gamma_{6,1}$ (Cm)	941.95 (3)	0.33 (11)	E2
$\gamma_{7,1}$ (Cm)	977.80 (4)	not detected	E0 (+ M1 + E2)
$\gamma_{6,0}$ (Cm)	984.91 (2)	not detected	E0
$\gamma_{10,1}$ (Cm)	1041.22 (3)	0.18 (6)	(M1 + E2)
$\gamma_{11,1}$ (Cm)	1062.95 (3)	0.26 (8)	E1
$\gamma_{10,0}$ (Cm)	1084.181 (14)	0.34 (11)	(E2)
$\gamma_{11,0}$ (Cm)	1105.91 (2)	0.04 (2)	(E1)

* Calculated from experimental electron emission probabilities and theoretical internal conversion coefficients

Vandenbosch *et al.* have measured the ^{243}Am*(n,γ)* cross-section ratio for ^{244}Am^{m} and ^{244}Am production (1964Va04), and this value has been used to convert the P$_\gamma$ per 100 neutron captures to P$_\gamma$ per 100 disintegrations of ^{244}Am^{m}:

$$\frac{\sigma(^{243}Am(n,\gamma)^{244}Am^{m})}{\sigma(^{243}Am(n,\gamma)^{244}Am)} \quad = \quad 18.6(19)$$

$$^{244}Am^{m} \quad = \quad 18.6(19) \times {}^{244}Am \qquad (1)$$

Consider *(n,γ)* reaction to produce ^{244}Am, and expressing the generation of ^{244}Am and ^{244}Am^{m} in the following manner:

$$\sum(^{244}Am + {}^{244}Am^{m}) \quad = \quad 100\% \qquad (2)$$

Substituting Eqn. (1) in (2):

$$^{244}Am \quad = \quad 100/19.6(19) \quad = \quad (5.1 \pm 0.5)\%$$

$$\text{and} \quad {}^{244}Am^{m} \quad = \quad (94.9 \pm 0.5)\%$$

Absolute Pγ per 100 disintegrations of ^{244}Am^{m} were obtained by multiplying the Pγ per 100 neutron capture data of Hoff *et al.* by a factor of 1/0.949 (5).

There is considerable ambivalence in the quantification of the transition probabilities of the E0 977.80- and 984.91-keV gammas that cannot be satisfactorily resolved on the basis of the available measurements. While Hoff *et al.* found no evidence for any gamma-ray emissions with these particular energies (1984Ho02), von Egidy *et al.* observed a 977.92-keV gamma ray in their neutron capture studies with the following emission probability ratio (1984Vo07):

$$\frac{P_{\gamma}(977.92\,keV)}{P_{\gamma}(1084.18\,keV)} \quad = \quad \frac{0.12(4)}{0.52(16)} \,.$$

Substituting $P_{\gamma}(1084.18\,keV) = 0.36(12)$ in this equation from the β^{-} decay of ^{244}Am^{m},

$$P_{\gamma}(977.92\,keV) \quad = \quad \frac{0.12(4)}{0.52(16)} \times 0.36(12) \quad = \quad 0.083(28),$$

with the recommended uncertainty reflecting only the uncertainty in $P_{\gamma}(1084.18\,keV)$. This value is in good agreement with equivalent calculations involving the 1041.22- and 1062.95-keV gamma rays (0.084 (27) and 0.081 (24), respectively) that were also observed by von Egidy *et al* (1984Vo07).

Gamma-ray emissions: recommended energies, absolute emission probabilities, multipolarities and theoretical internal conversion coefficients (frozen orbital approximation).

E_{γ} (keV)	P_{γ}^{abs}	Multipolarity	α_K	α_L	α_{M+}	α_{tot}	
42.965 (10)	0.030 (9)*	E2	-	760 (11)	290 (4)	1050 (15)	β^{-}
941.95 (3)	0.35 (12)	E2	0.011 20 (16)	0.003 18 (5)	0.001 09	0.015 47 (22)	β^{-}
977.80 (4)	-	E0 (+ M1 + E2)	-	-	-	-	β^{-}
984.91 (2)	-	E0	-	-	-	-	β^{-}
1041.22 (3)	0.19 (6)	(M1 + E2)	-	-	-	-	β^{-}
1062.95 (3)	0.27 (8)	anomalous E1‡	0.09 (3)	0.015 (4)	0.005	0.11 (3)	β^{-}
1084.181 (14)	0.36 (12)	anomalous (E2)‡	0.030 (8)	0.008 (2)	0.003	0.041 (11)	β^{-}
1105.91 (2)	0.04 (2)	anomalous (E1)‡	0.14 (3)	0.024 (6)	0.006	0.17 (4)	β^{-}

* Uncertainty of 30 % assigned on the basis of TP(total) of 30 (9), as defined by Hoff *et al*. (1984Ho02).

‡ Anomalous internal conversion coefficients derived from the measurements of Hoff *et al.* (1984Ho02), with the components adjusted to match theoretical data on a relative basis.

Hoff *et al.* used a beta spectrometer to study the conversion electrons and determine the internal conversion coefficients of the various gamma transitions (1984Ho02). Total transition probabilities per 100 neutron captures were also derived by Hoff *et al*. for the two E0 gamma transitions: 977.80-keV TP_{γ} per 100 disintegrations of ^{244}Am^{m} approximated to 0.08 (2), and 984.91-keV TP_{γ} per 100 disintegrations of ^{244}Am^{m} approximated to 1.0 (1). Anomalous internal conversion coefficients were observed for the 1062.95-, 1084.181- and 1105.91-keV gamma rays.

A combination of the P_γ and P_{total} measurements of Hoff *et al.* and von Egidy *et al.* were adopted (1984Ho02, 1984Vo07), while complete sets of anomalous internal conversion coefficients were determined on the basis of the theoretical data derived from Kibedi *et al.* (2008Ki07) and adjusted in terms of the studies of Hoff *et al.* (1984Ho02). The emission probability of the 42.965-keV gamma ray was estimated by Hoff *et al.* to be 0.029 per 100 neutron captures from P_{total} of 30 (9) and theoretical internal conversion coefficients. This transition probability of 30 (9) was corrected for the ^{244}Am contribution to derive a TP of 31.6 (95) and P_γ(42.96 keV) of 0.030 (9) per 100 disintegrations of $^{244}Am^{m}$.

<u>Multipolarities and Internal Conversion Coefficients</u>

The nuclear level scheme specified by Akovali has been used to define the multipolarities of the gamma transitions on the basis of known spins and parities (2003Ak04). Recommended internal conversion coefficients have been determined from the frozen orbital approximation of Kibedi *et al*. (2008Ki07), based on the theoretical model of Band *et al*. (2002Ba85, 2002Ra45). Some of these data were judged to be anomalous from the studies of Hoff *et al.* (1984Ho02), and were adjusted accordingly (ICC data for the 1062.95-, 1084.181- and 1105.91-keV gamma transitions).

Beta Particles

<u>Energies and emission probabilities</u>

The $^{244}Am^{m}$ nuclear level was estimated to have an energy of (89 ± 2) keV from S(n) of 5366.5 (17) keV (2003Au03) and a gamma-ray energy of 5277.6 (4) keV from the neutron capture state to $^{244}Am^{m}$ (1984Vo07). Energies of the ^{244}Cm nuclear levels adopted from Akovali (2003Ak04), Q_{β^-} value of (1427.3 ± 1.0) keV from Audi *et al.* (2003Au03), and $^{244}Am^{m}$ nuclear level energy of (89 ± 2) keV were used to determine the energies and uncertainties of the beta-particle transitions.

Adopted Nuclear Levels of ^{244}Cm: J^π and Origins (2003Ak04).

Nuclear level number	Nuclear level energy (keV)	J^π	Origins
0	0.0	0+	^{244}Bk EC decay, ^{244}Am β^- decay, **$^{244}Am^{m}$ β^- decay**, ^{248}Cf α decay, Coulomb excitation
1	42.965 ± 0.010	2+	^{244}Am β^- decay, **$^{244}Am^{m}$ β^- decay**, ^{248}Cf α decay, Coulomb excitation
2	142.348 ± 0.011	4+	^{244}Am β^- decay, ^{248}Cf α decay, Coulomb excitation
3	296.211 ± 0.011	6+	^{244}Am β^- decay
4	501.786 ± 0.012	8+	^{244}Am β^- decay
5	970 ± 4	(2+, 3–)	Coulomb excitation
6	984.914 ± 0.021	0+	**$^{244}Am^{m}$ β^- decay**
7	1020.76 ± 0.03	(2+)	**$^{244}Am^{m}$ β^- decay**
8	1038 ± 6	(2+, 3–)	Coulomb excitation
9	1040.188 ± 0.012	6+	^{244}Am β^- decay
10	1084.181 ± 0.014	1, 2+	**$^{244}Am^{m}$ β^- decay**
11	1105.91 ± 0.02	(1, 2–)	**$^{244}Am^{m}$ β^- decay**

Beta-particle emission probabilities were determined by balancing the proposed decay scheme through consideration of the βγ-population and γ-depopulation of the nuclear levels of daughter ^{244}Cm. The recommended absolute gamma-ray emission probabilities and theoretical internal conversion coefficients derived from Kibédi *et al.* (2008Ki07) were used in this process, with the theoretical internal conversion coefficients adjusted if identified as anomalous on the basis of the measurements by Hoff *et al*.

Beta-particle Emission Probabilities per 100 Disintegrations of $^{244}Am^m$.

	^{244}Cm level energy (keV)	E_β (keV)	P_β	Transition type	log *ft*
$\beta^-_{0,11}$	1105.91 ± 0.02	410 ± 3	0.35 ± 0.09	(1st forbidden non-unique)	6.80
$\beta^-_{0,10}$	1084.181 ± 0.014	432 ± 3	0.56 ± 0.13	(allowed)	6.67
$\beta^-_{0,7}$	1020.76 ± 0.03	496 ± 3	0.08 ± 0.02	(allowed)	7.7
$\beta^-_{0,6}$	984.914 ± 0.021	531 ± 3	1.36 ± 0.16	allowed	6.58
$\beta^-_{0,1}$	42.965 ± 0.010	1473 ± 3	31 ± 9	allowed	6.74
$\beta^-_{0,0}$	0.0	1516 ± 3	67 ± 9	allowed	6.45

Σ 100.35

EC Transition

Energy and transition probability

The EC transition energy was assigned a value of (164 ± 9) keV commensurate with Q_{EC} calculated from Audi *et al.* (2003Au03), while the transition probability was adopted from the recommended BF_{EC} of 0.00036 (1).

EC Transition Probability per 100 Disintegrations of $^{244}Am^m$.

	E_{EC} (keV)	P_{EC}	Transition type	log *ft*	P_K	P_L	P_M
$EC_{0,0}$	164 ± 9	0.036 ± 0.001	allowed	6.37	0.24 (5)	0.53 (4)	0.168 (12)

Atomic Data

K and L X-ray Emission Probabilities per 100 Disintegrations of $^{244}Am^m$.

			Energy keV	Photons per 100 disint.
XL		(Cm)	12.633 – 23.527	12.3 (27)
	XL_l	(Cm)	12.633	0.43 (8)
	XL_α	(Cm)	14.746 – 14.961	4.6 (11)
	XL_η	(Cm)	17.314	0.13 (4)
	XL_β	(Cm)	17.286 – 19.688	6.0 (14)
	XL_γ	(Cm)	22.735 – 23.527	1.4 (4)
XK_α	$XK_{\alpha2}$	(Cm)	104.590	0.013 (4)
	$XK_{\alpha1}$	(Cm)	109.271	0.020 (6)
$XK'_{\beta1}$	$XK_{\beta3}$	(Cm)	122.304	)
	$XK_{\beta1}$	(Cm)	123.403	) 0.0076 (21)
	$XK''_{\beta5}$	(Cm)	124.124	)
$XK'_{\beta2}$	$XK_{\beta2}$	(Cm)	126.889	)
	$XK_{\beta4}$	(Cm)	127.352	) 0.0027 (8)
	$XKO_{2,3}$	(Cm)	127.970	)

The x-ray and Auger-electron data have been calculated using the evaluated gamma-ray data, and atomic data from 1996Sc06, 1998ScZM and 1999ScZX. Both the x-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.01, 28 January 2003, with the emission.101 database extended to Z = 96 to calculate component L x-ray data of daughter Cm). This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

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

Data Consistency

An effective Q-value of 1515.5 (30) keV has been adopted from the atomic mass evaluation of Audi *et al*. (2003Au03) while in the course of formulating the decay scheme of ^{244}Am^{m}. This value has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{244}Am^{m} beta- and EC-decay processes (i.e. β^-, conversion electrons, γ, etc.):

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 1510\ (190)\ \text{keV}$$

Percentage deviation from the effective Q-value of Audi *et al*. is (0 ± 13) %, which supports the derivation of a highly consistent decay scheme with a very large variant.

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^{242}Cm - Comments on evaluation of decay data by V.P. Chechev

This evaluation was completed in February 2005 (see 2006Ch34) and then corrected in October 2009 with a literature cut-off by the same date.

1 Decay Scheme

The decay scheme is based on the evaluation of Chukreev et al. (2002Ch52) and can be considered essentially complete although some weak gamma-ray transitions have not been observed in ^{242}Cm alpha decay. Such gamma rays were taken from ^{238}Am→^{238}Pu, ^{238}Np→^{238}Pu decays and have been included in the decay scheme.

2 Nuclear Data

Q(α) is from 2003Au03.

The evaluated half-life of ^{242}Cm is based on the experimental results given in Table 1. Re-estimated values were used for averaging when needed.

Table 1. Experimental values of the ^{242}Cm half-life (in days)

Reference	Author(s)	Original value	Re-estimated value	Measurement method
1950Ha14	Hanna et al.	162.5 (20)	-	α-counting with low geometry counter
1954Gl37	Glover and Milsted	162.46 (14) [a]	162.46 (32) [c]	α-counting with low geometry counter
1954Hu32	Hutchinson and White	163.0 (18)	-	Calorimetry
1957Treiman	Treiman et al.	162.7 (1)	-	Calorimetry
1965Fl02	Flynn et al.	164.4 (4)	163.1 (4) [d]	2π α counting
1975Ke02	Kerrigan and Banick	163.2 (2) [b]	-	Calorimetry
1977Di04	Diamond et al.	162.76 (4)	162.76 (8) [c]	Intermediate geometry α-counting
1979Ch41	Chang et al.	163.02 (11)	163.02 (18) [c]	α-counting with low geometry counter
1980Jadhav	Jadhav et al.	162.13 (215)	162.13 (225)	α-spectrometry with solid state detector
1981Us03	Usuda and Umezawa	161.35 (20)	161.35 (30) [c]	α-counting with 2π proportional counter
1982Ag02	Aggarwal et al.	163.17 (6)	163.17 (11) [c]	α-counting with proportional counter
1982Ag02	Aggarwal et al.	162.82 (21)	162.82 (26) [c]	α-spectrometry with solid state detector
1984Wi14	Wiltshire et al.	163.0 (2)	-	α-counting with low geometry counter

[a] The uncertainty of 0.27 quoted by authors, which corresponds to 95 % confidence level, has been reduced by a factor 2.

[b] The uncertainty of 0.04 quoted by authors, which corresponds to 95 % confidence level, has been reduced by a factor 2.

[c] Quoted uncertainties have been re-estimated in 1986LoZT.

[d] The value has been recalculated in 1977Di04.

The LWEIGHT and EV1NEW computer programs identified two outliers in the above data set. These are the values from 1981Us03 and 1980Jadhav. Omitting these values in the calculation and using the remaining 11 results produced a weighted mean of 162.86 with an internal uncertainty of 0.05 and an external uncertainty of 0.06 ($\chi^2/\nu = 1.6$). The EV1NEW program has chosen the smallest experimental uncertainty of 0.08 as the uncertainty of the weighted average.

Thus the recommended value of the ^{242}Cm half-life is 162.86 (8) days.

The evaluated spontaneous fission partial half-life of ^{242}Cm is based on the experimental results given in Table 2. Re-estimated values were used for averaging when needed.

Table 2. Experimental values of the ^{242}Cm spontaneous fission half-life (in 10^6 years)

Reference	Author(s)	Original value	Re-estimated value [a]	Measurement method
1951Ha87	Hanna et al.	7.2 (2)	-	Fission fragment counting, ionization chamber
1967Ar09	Armani and Gold	6.09 (18)	6.82 (18)	Fission neutron counting, LiI detector
1979Ch41	Chang et al.	7.46 (6)	-	Mica fission track detector
1982Ra33	Raghuraman et al.	7.15 (15)	-	Solid state detector
1982UmZZ	Umezawa et al.	6.89 (17)	-	Mica fission track detector
1986Ze06	Zelenkov et al.	6.9 (3)	6.98 (33)	α/SF, Si(Au) detectors
1989Us04	Usuda et al.	6.96 (18)	-	Absolute fission track counting

[a] Recalculated in 2000Ho27

Omitting the value of 1979Ch41 (outlier) the weighted mean of the six remaining values becomes 7.005 with an internal uncertainty of 0.076 and an external uncertainty of 0.063 ($\chi^2/\nu = 0.69$).

The recommended value of the ^{242}Cm spontaneous fission half-life is 7.01 (15) 10^6 years, where the uncertainty is the smallest quoted uncertainty of 6 experimental results.

2.1 α Transitions

The energies of the alpha-particle transitions given in Section 2.1 have been deduced from the Q value and the level energies given in Table 3 from 2002Ch52.

Table 3. ^{238}Pu levels populated in the ^{242}Cm α-decay

Level number	Energy (keV)	Spin and parity	Half-life	Probability of α-transition (%)
0	0.0	0^+	87,74 (3) a	74.06 (7)
1	44.08 (3)	2^+	177 (5) ps	25.94 (7)
2	146.00 (5)	4^+		0.034 (2)
3	303.42 (7)	6^+		0.0046 (5)
4	513.62 (16)	8^+		2×10^{-5}
5	605.08 (7)	1^-		$2.5 (5)\times10^{-4}$
6	661.28 (11)	3^-		$1.3 (3)\times10^{-5}$
7	763.22 (12)	5^-		$\leq 2.2\times10^{-7}$
8	941.44 (9)	0^+		$3.5 (7)\times10^{-5}$
9	962.72 (8)	1^-		$1.13 (21)\times10^{-6}$
10	983.00 (9)	2^+		$1.7 (5)\times10^{-6}$
11	1018.6 (3)	1^-		$\leq 2\times10^{-7}$
12	1028.62 (5)	2^+		$3.7 (10)\times10^{-6}$
13	1125.79 (17)	(4^+)		$3.1 (10)\times10^{-7}$
14	1228.69 (22)	0^+		$5.5 (15)\times10^{-7}$
15	1264.29 (22)	2^+		$5.2 (14)\times10^{-7}$

The emission probabilities of the most intensive transitions $\alpha_{0,i}$ (i = 0 to 4) have been obtained by averaging experimental data (Table 4). The emission probabilities of the remaining α-particle transitions have been deduced either from the P(γ+ce) decay-scheme balances or by averaging experimental and deduced values (for example, $\alpha_{0,5}$).

Table 4. Experimental, calculated and recommended α-transition probabilities (%) in the ^{242}Cm decay

	α-particle energy (keV)	1953As14	1958Ko87	1963Dz07	1966Ba07	1998Ya17	Deduced from decay-scheme balance c	Recommended
$\alpha_{0,0}$	6113	73.7 (5)	73.5 (5)	74 (2)	74.2 (5) [a]	74.08 (7)		74.06 (7) [d]
$\alpha_{0,1}$	6069	26.3 (5)	26.5 (5)	26.0 (9)	25.8 (5) [a]	25.92 (6)		25.94 (7) [d]
$\alpha_{0,2}$	5969	0.035 (2) [a]	0.030 (2) [b]	0.035 (2)	0.036 (2) [a]			0.034 (2) [e]
$\alpha_{0,3}$	5816		0.0046 (5)		0.0046			0.0046 (5) [f]
$\alpha_{0,4}$	5608			1963Bj01	$2·10^{-5}$			$2·10^{-5}$ [g]
$\alpha_{0,5}$	5518			$2.8 (5)·10^{-4}$	$2.5 (6)·10^{-4}$		$2.6 (7)·10^{-4}$	$2.5 (5)·10^{-4}$ [e]
$\alpha_{0,6}$	5462						$1.3 (3)·10^{-5}$	$1.3 (3)·10^{-5}$ [c]
$\alpha_{0,7}$	5366						$2.2·10^{-7}$	$2.2·10^{-7}$ [c]
$\alpha_{0,8}$	5187			$3.4 (8)·10^{-5}$	$2.5 (8)·10^{-5}$		$3.5 (7)·10^{-5}$	$3.5 (7)·10^{-5}$ [c]
$\alpha_{0,9}$	5166						$1.13 (21)·10^{-6}$	$1.13 (21)·10^{-6}$ [c]
$\alpha_{0,10}$ [h]	5146				$\le 5·10^{-6}$		$1.7 (5)·10^{-6}$	$1.7 (5)·10^{-6}$ [c]

[a] No uncertainties are quoted by the authors. The uncertainties have been adopted by the evaluator based on the similarity of the spectra measured with magnetic spectrometers in 1953As14, 1958Ko87 and 1966Ba07.
[b] The uncertainty of 0.001 quoted by authors has been increased by a factor of 2 by the evaluator (see [a]).
[c] Deduced from P(γ+ce) decay-scheme balances for corresponding ^{238}Pu levels.
[d] Weighted average of experimental values The experimental data of 1998Ya17 have been obtained by the most accurate method (using a semiconductor detector).
[e] Weighted average of experimental and deduced values.
[f] Adopted experimental value from 1958Ko87.
[g] Adopted experimental value from 1966Ba07.
[h] The probabilities of remaining alpha-transitions ($\alpha_{0,11}$ and $\alpha_{0,15}$) have been deduced from P(γ+ce) decay-scheme balances.

2.2 γ Transitions and Internal Conversion Coefficients

The recommended energies of gamma-ray transitions are essentially the same as the gamma-ray energies because nuclear recoil is negligible.

The probabilities, P(γ+ce), for gamma-ray transitions of 44-($\gamma_{1,0}$), 102- ($\gamma_{2,1}$), 157-($\gamma_{3,2}$), and 210-keV ($\gamma_{4,3}$) have been deduced from transition- intensity balances, using the emission probabilities of α-transitions directly measured.

For E0- gamma transitions 941-($\gamma_{8,0}$) and 1229-keV ($\gamma_{14,0}$) the P(γ+ce) values have been taken from data on the electron capture decay ^{238}Am → ^{238}Pu (see 2002Ch52 and references therein).

The remaining P(γ+ce) values have been obtained from the gamma-ray emission probabilities and the total internal conversion coefficients (ICC's). The experimental values of ICC's have been adopted for (E0+E2) gamma-ray transitions 939-($\gamma_{10,1}$) and 1220-keV ($\gamma_{15,1}$). The remaining ICC's have been interpolated using the BrIcc package with the so called "*Frozen Orbital*" approximation (2008Ki07). The relative uncertainties of α_K, α_L, α_M, α_T for pure multipolarities have been taken as 2 %.

The multipolarities and E2/M1, M2/E1 mixing ratios have been taken from 2002Ch52. These are based on conversion electron measurements of 1952Du12, 1956Ba95, 1956Sm18, 1960As10, and 1965Ak02 made in the ^{242}Cm α-decay.

3 Atomic Data

3.1 Fluorescence yields

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

3.1.1 X rays

The Pu KX-ray energies and relative emission probabilities have been taken from 1999Schönfeld, where the calculated energy values are based on X-ray wavelengths from 1967Be65 (Bearden). In Table 5 the recommended values of Pu KX-ray energies are compared with experimental results.

Table 5. Experimental and recommended values of Pu KX-ray energies (keV)

	1980Di13	1982Ba56	Recommended
$K\alpha_2$	99.55 (3)	99.530 (2)	99.525
$K\alpha_1$	103.76 (3)	103.741 (2)	103.734
$K\beta_3$	116.27	116.242 (2)	116.244
$K\beta_1$	117.26	117.233 (2)	117.228
$K\beta_{2,4}$	120.60 (15)	-	120.553
$KO_{2,3}$	121.55 (6)	-	121.543

The Pu KX-ray energies in 1980Di13 were measured in the alpha decay of ^{245}Cm. The relative emission probabilities of KX-rays were given as: $K\alpha_2$:$K\alpha_1$:$K\beta_3$:$K\beta_1$:$K\beta_{2,4}$ = 64.7 (23) : 100.0 (33) : 12.9 (7) : 23.1 (10) : 8.9 (5).

3.1.2 Auger Electrons

The energies of Auger electrons have been calculated from atomic electron binding energies.

The P(KLX)/P(KLL), P(KXY)/P(KLL) ratios have been taken from 1996Sc06.

4 α Emissions

The energy of the alpha-particle group to the ground state of ^{238}Pu, $E(\alpha_{0,0})$ is from the absolute measurement of 1971Gr17, with a correction of –0.20 keV recommended by A. Rytz in 1991Ry01.

The energies of all other α particles have been deduced from Q_α and the ^{238}Pu level energies including the recoil energy corrections (see 2002Ch52).

In Table 6 the recommended values of α-particle energies are compared with the experimental results obtained with magnetic alpha spectrometers.

Table 6. Experimental[a] and recommended α-emission energies in the decay of ^{242}Cm (keV)

	1953As14	1958Ko87	1963Dz07	1966Ba07 1971Bb10	1971Gr17	Recommended
$\alpha_{0,0}$	6113	6114	6113 (1)	6112.9 (3)	6112.72 (8)	6112.72 (8)
$\alpha_{0,1}$	6069	6070	6069 (1)	6069.5 (5)	6069.43 (12)	6069.37 (9)
$\alpha_{0,2}$	5968	5968 (2)	5969 (3)	5970		5969.24 (9)
$\alpha_{0,3}$	-	5816 (2)	-	5817		5816.39 (11)
$\alpha_{0,4}$	-	-	-	5609		5607.76 (16)
$\alpha_{0,5}$	-	-	-	5514		5517.75 (11)
$\alpha_{0,8}$	-	-	-	5189		5186.95 (12)
$\alpha_{0,10}$	-	-	-	5146		5146.07 (12)

[a] Authors' values have been adjusted for changes in calibration energies (see 1991Ry01)

5 Electron emissions

The energies of conversion electrons have been obtained using gamma-ray transition energies and electron binding energies. The emission probabilities of conversion electrons have been deduced from the evaluated P(γ) and ICC values.

The absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program (2000Schönfeld).

6 Photon emissions

6.1. X-Ray emissions

The absolute emission probabilities of U KX- and U LX-rays in decay of ^{242}Pu have been calculated using the EMISSION computer program (2000Schönfeld).

The calculated total absolute emission probability of LX-rays P(XL)= 9.92 (23) % agrees well with the experimental value of 9.70 (14) % from 1970By01 and disagrees with the value of 11.7 (3) % measured in 1971Swinth.

The relative Pu LX-ray emission probabilities in ^{242}Cm α-decay measured in 1990Po14 [4.9 (8)-Ll; 66 (7)-Lα; 100-Lηβ; 23 (3)-Lγ] agree well with the values calculated using the EMISSION computer program with the exception of $L\alpha/L\eta\beta^{calc.}$ = 79 (4)/100. The latter agrees well with the experimental result from 1995Jo23, Lα/Lηβ (Pu) = 80.9 (9)/100, obtained for LX-rays in the decay of other even-even curium isotope – ^{244}Cm.

6.2 Gamma emission

6.2.1. Gamma-ray energies

The energy of the 44-keV gamma ray ($\gamma_{1,0}$) is from ^{238}Np→^{238}Pu β^-decay (1972Wi22); it agrees with the less accurate measurements in ^{242}Cm α-decay (44.11 (5) keV - 1956Sm18) and in ^{238}Am ε-decay (44.1 (1) keV - 1972Ah04).

The energies of the 102-($\gamma_{2,1}$), 157-($\gamma_{3,2}$), 336-($\gamma_{8,5}$), 358-($\gamma_{9,5}$), 605-($\gamma_{5,0}$), 940-($\gamma_{10,1}$), and 941-($\gamma_{8,0}$) keV gamma rays have been obtained from the available experimental data of 1981Le15 (^{242}Cm α-decay and ^{238}Np β^--decay), 1972Wi22, 1972Ah04, 1956Sm18, and 1971Po09 (^{238}Am ε-decay) using the adopted ^{238}Pu level energies.

The energies of the 210-($\gamma_{4,3}$), 617-($\gamma_{7,2}$), and 883-($\gamma_{12,2}$) keV gamma rays, which were not observed in the ^{242}Cm α-decay, have been deduced from the adopted level energies. The energies of the remaining gamma rays have been taken from the measurements of 1981Le15 (^{242}Cm α-decay).

6.2.2. Gamma-ray emission probabilities

The absolute emission probabilities for gamma-rays of 44-($\gamma_{1,0}$), 102- ($\gamma_{2,1}$), 157-($\gamma_{3,2}$), and 210-($\gamma_{4,3}$) keV have been deduced from decay-scheme intensity balances using the probabilities of α-transitions evaluated directly from experimental data.

The absolute emission probabilities of > 300 keV gamma-rays (except for 883- and 1229-keV γ-rays) have been obtained from relative gamma-ray emission probabilities P(γ)/P(γ 561keV) measured in 1981Le15. The normalization factor P(γ 561keV) = $1.5 \cdot 10^{-4}$ per 100 disintegrations, which was used here, was estimated in 1981Le15 using a previous αγ coincidence measurement of the sum of the absolute emission probabilities of the 515-, 561-, 605-, and 617-keV gamma-rays (1963Le17).

P(γ 883keV) and P(γ 1229keV) are from 2002Ch52, using the experimental data on ^{238}Np β^--decay and ^{238}Am ε-decay, respectively.

7. Consistency of recommended data

The most accurate Q value, Q(M), is taken from the atomic mass adjustment table of Audi et al. (2003Au03). Comparison of Q(eff)(deduced as the sum of average energies per disintegration ($\sum E_i \times P_i$) for all emissions accompanying ^{242}Cm α- decay) with the tabulated decay energy Q(M) allows to check a consistency of the recommended decay-scheme parameters obtained in this evaluation.

Here E_i and P_i are the evaluated energies and emission probabilities of the i-th alpha particle, beta particle, gamma ray, X-ray, etc. Consistency (percentage deviation) is determined by {[Q(M) − Q(eff))]/ Q(M)} ×100. "Percentage deviations above 5 % would be regarded as high and imply a poorly defined decay scheme; a value of less than 5 % indicates the construction of a reasonably consistent decay scheme" (quoted from the article by A.L. Nichols in Appl. Rad. Isotopes 55 (2001) 23-70).

For the above ^{242}Cm decay data evaluation we have Q(M) = 6215.56 (8) keV and Q(eff) = 6217 (6) keV, i.e. consistency is better than 0.12 %.

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^{243}Cm -Comments on evaluation of decay data
by V.P. Chechev

This evaluation was done in October 2010 with a literature cut-off by the same date.

1. DECAY SCHEME

The structure of the adopted scheme of ^{243}Cm decay is based on the evaluations by E. Browne (2003Br12) and Y.A. Akovali (2004Ak21). The decay scheme includes two decay modes: α decay to ^{239}Pu (99.71 (3) %) and electron capture decay (EC) to ^{243}Am (0.29 (3) %).

EC branching was obtained from the EC decay half-life of 1.0 (1) × 10^4 y, as determined in 1958Ch38 from a ratio of ^{243}Am and ^{243}Cm α activities (correction for the half-lives of ^{243}Am and ^{243}Cm adopted by DDEP does not change this value), and from the total ^{243}Cm half-life of 29.1 (1) y (correction for the recommended below value of the ^{243}Cm half-life does not change the EC branching). The EC decay occurs 100 % to the ground state 5/2- of ^{243}Am (1958Ch38, 2004Ak21).

In the ^{243}Cm α decay to ^{239}Pu the intense population takes place only to levels in ^{239}Pu with the energy less than 400 keV (8 excited levels and ground state) and in this part the decay scheme is well defined. Nevertheless, a number of gamma-ray transitions with energy less than 200 keV were not observed in the ^{243}Cm α decay, such as 7.86-keV, 49.4-keV, 61.5-keV, 67.8-keV, 88.1-keV, 102.0-keV, 106.1-keV, 106.5-keV, and 166.4-keV. These transitions, included in the ^{243}Cm decay scheme, have been derived from measurements of ^{239}Np and ^{239}Am decays.

For levels with higher energy, the decay scheme has not been completed since many gamma-ray transitions have not been observed yet. In addition, many levels were placed in the ^{243}Cm α decay scheme based only on questionable weak α transitions. Therefore, further measurements are needed to determine the γ transitions and ^{243}Cm α decay scheme with greater precision.

2. NUCLEAR DATA

Q(α) and Q(EC) values are from Audi et al. (2003Au03).

The recommended ^{243}Cm half-life is based on the experimental results given in Table 1.

Table 1. Experimental values of ^{243}Cm half-life (in years)

Reference	Author(s)	Original value	Re-estimated value	Comments
1950Th52	Thompson et al.	Roughly 100		Not used
1953As40	Asaro	35		Not used
1958Ch38	Choppin and Thompson	29.0 (8)	28.5 (2) [a]	Relative activity to ^{244}Cm
1986Ti03	Timofeev et al.	29.20 (12)	29.20 (13) [a]	Relative activity to ^{244}Cm

[a] Re-estimated by the evaluator to the ^{244}Cm half-life of 18.11 (3) y

The weighted average of 29.0 for this two re-estimated discrepant experimental data set is dominated by the accurate value of 1986Ti03. The LWEIGHT computer program, which uses a *Limitation of Relative Statistical Weights* (LRSW method), has expanded the 1986Ti03 uncertainty from 0.13 to 0.20 and used a weighted mean (28.85) and an external uncertainty (0.35) for the average of the adjusted data set ($\chi^2/\nu = 6.13$).

The recommended value of the ^{243}Cm half-life is **28.9 (4) years**.

The value of 5.5 (9) × 10^{11} years was adopted for ^{243}Cm spontaneous fission (SF) half-life from the measurement of 1987Po19. SF branching of 5.3 (9) ×10^{-9} % has been obtained using the adopted values of SF half-life and total half-life of 28.9 (4) y.

2.1. Alpha Transitions

The energies of the alpha transitions have been obtained from the Q(α) value and ^{239}Pu level energies given in Table 2 from 2003Br12 where they were deduced from a least-squares fit to gamma ray energies.

Table 2. ^{239}Pu levels populated in ^{243}Cm α-decay

Level	Energy (keV)	Spin and parity	Half-life	Probability of α-transition (×100)
0	0	1/2+	24100 (11) y	1.3 (2)
1	7.861 (2)	3/2+	36 (3) ps	4.4 (2)
2	57.275 (2)	5/2+	101 (5) ps	1.05 (12)
3	75.705 (3)	7/2+	83 (8) ps	5.7 (2)
4	163.76 (3)	9/2+	73 (4) ps	0.1
5	192.8 (10)	11/2+		0.7
6	285.460 (2)	5/2+	1.12 (5) ns	73.4 (4)
7	330.124 (4)	7/2+		11.3 (2)
8	387.42 (2)	9/2+		1.6 (1)
9	391.584 (3)	7/2-	193 (4) ns	0.2
10	427 (3) ?			0.03
11	434 (3)	(9/2-)		0.14
12	451 (5) ?			0.06
13	462 (3)	(11/2+)		0.03
14	469.8 (4)	(1/2-)		≤ 0.01
15	481 (3) ?			0.01
16	487 (3)	(11/2-)		0.02
17	492.1 (3)	3/2-		0.009
18	499 (3)			0.007
19	505.6 (2)	(5/2-)		0.007
20	538 (3)			0.002
21	543 (3) ?			0.006
22	556.2 (5)	(7/2-)		0.002
23	746 (3)			0.003
24	756 (3)			0.003
25	763 (3)			0.001
26	813 (3)			0.0015
27	850 (15)			0.00039

The probabilities of the most intense α-transitions (I_α > 1 %) have been obtained by averaging experimental values from the spectrometric measurements (Table 3). Probabilities of the rest of alpha transitions have been adopted from the magnetic spectrometer measurements of 1966Ba07. The probability of the $\alpha_{0,9}$ transition (0.2 %) from 1966Ba07 disagrees with the value deduced from the gamma-ray transition intensity balance (> 0.4 %).

The α-decay hindrance factors have been calculated using the ALPHAD computer program from the ENSDF evaluation package with r_0 (^{239}Pu) = 1.4996 fm (see 2003Br12).

Table 3. Experimental (per 100 α decays) and recommended probabilities (per 100 decays) of the most intense α-transitions (I_α > 1 %) observed in ^{243}Cm α decay *

	α-part. energy	1957 As83	1963 Dz07	1966Ba07	1973 Ah04	2009 KoZV	Evaluated from α measurement results (per 100 α decays)	Deduced from P(γ+ce) balance	Recommended(per 100 (α+ EC) decays)
$\alpha_{0,0}$	6066	1.0 (2) [a]		1.5 (2) [a]			1.3 (2) [a]		1.3 (2)
$\alpha_{0,1}$	6058	5		4.7 (3) [a]	4.3 (2)	4.5 (3)	4.4 (2) [a]		4.4 (2)
$\alpha_{0,2}$	6010		0.95		1.05 (5)	1.1 (2)	1.05 (12) [b]		1.05 (12)
$\alpha_{0,3}$	5992	6.0 (2) [a]	5.4 (2)	5.63 (20) [a]	5.6 (2)	5.8 (2)	5.7 (2) [a]		5.7 (2)
$\alpha_{0,6}$	5785	73 (4) [a]	73 (4)	73.54 (40) [a]	74.2 (8)	72.9 (12)	73.6 (4) [a]	73.8 (26)	73.4 (4)
$\alpha_{0,7}$	5742	11.5 (6) [a]	12.3 (6)	10.65 (60) [a]	11.1 (2)	11.6 (4)	11.3 (2) [a]	11	11.3 (2)
$\alpha_{0,8}$	5686		1.7	1.6	1.52 (5)	1.8 (1)	1.6 (1) [a]		1.6 (1)

[a] Weighted average, uncertainty is the smallest experimental one.
[b] Weighted average, uncertainty is external.

2.2. Gamma Transitions and Internal Conversion Coefficients

The recommended energies of the gamma-ray transitions are virtually the same as those of the gamma-ray energies because the nuclear recoil is negligible for ^{239}Pu.

The probabilities of gamma-ray transitions $\gamma_{1,0}$ (7.86 keV), $\gamma_{3,2}$ (18.43 keV), $\gamma_{2,0}$ (57.27 keV), $\gamma_{3,1}$ (67.84 keV), $\gamma_{4,2}$ (106.47 keV), and $\gamma_{5,3}$ (117.1 keV) have been deduced from intensity balances at the ^{239}Pu levels “0” (0 keV), “3” (75.7 keV), “2” (57.3 keV), “1” (7.86 keV), “4” (163.8 keV), and “5” (192.8 keV), respectively.

The rest of gamma-ray transition probabilities (P_γ) have been deduced from their evaluated gamma-ray emission probabilities and total internal conversion coefficients (ICCs).

ICCs have been interpolated using the BrIcc computer program, version v2.2a, data set BrIccFO (2008Ki07). Multipolarities of the gamma-ray transitions and E2/M1 mixing ratios (δ) are based on the measurements of conversion electrons (ce) in ^{239}Am, ^{239}Np and ^{243}Cm decays and γ(θ) measurements by 1972Kr07, 1990Si12 from polarized ^{239}Np. The multipolarities have been taken from 2003Br12. The δ values have been adopted mainly from 2003Br12, except as noted below.

The δ values for $\gamma_{6,3}$ (209.75 keV), $\gamma_{6,2}$ (228.18 keV), and $\gamma_{6,1}$ (277.60 keV) have been taken from γ(θ) measurements of 1972Kr07, 1990Si12. Asymmetric uncertainties of 1972Kr07, 1990Si12 were symmetrized by transformation to equivalent symmetric normal distribution using a method described in 2003Au03 (p. 21): for $\gamma_{6,3}$ δ = -0.004 (+1 -24) → δ = -0.019(15) and for $\gamma_{6,2}$ δ = + 0.004 (+9 -1) → δ = +0.009 (6). The value of δ = 0.24 (4) has been adopted for $\gamma_{7,6}$ (44.66 keV) to provide more accurate intensity balances at the levels “6” (285.46 keV) and “7” (330.12 keV).

ICCs for the E1(+M2) anomalously converted 106.1-keV gamma-ray transition are from conversion electron measurements of 1959Ew90.

3. ATOMIC DATA

The fluorescence yields, X-ray energies and relative probabilities, and Auger electrons energies and relative probabilities are from the SAISINUC software.

4. ALPHA EMISSIONS

The recommended energies of alpha particles have been deduced from the energies of alpha transitions taking into account the recoil energies for ^{239}Pu.

In Table 4 the deduced (recommended) values of α-particle energies for the four intense α-transitions are compared with the experimental results from spectrometric measurements of 1957As83, 1963Dz07 and 1966Ba07. Other measurement results can be found in 1953As14, 1957As70, 1962Iv01, 1963Le17, 1970By01, 1971Bb10, 1976BaZZ, and 1977VaZW. Most of them have lesser accuracy in comparison with the recommended values.

Table 4. Experimental and recommended values of α -particle energies (keV) in the decay of ^{243}Cm

	Measured [a]			Evaluated in 1991Ry01	Recommended
	1957As83	1963Dz07	1966Ba07		
$\alpha_{0,0}$	6061 (3) [b]		6067 (2) [b]	6066.2 (17)	6067.2 (10)
$\alpha_{0,3}$	5987 (3) [b]	5992 (3)	5993 (2) [b]	5991.8 (15)	5992.7 (10)
$\alpha_{0,6}$	5780 (3) [b]	5785 (3)	5784.5 (10)	5785.2 (9)	5786.4 (10)
$\alpha_{0,7}$	5736 (3) [b]	5740 (3)	5741.6 (10)	5742.1 (9)	5742.5 (10)

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

[b] Uncertainty deduced or guessed by A. Rytz.

5. ELECTRON EMISSIONS

The energies of the conversion electrons have been obtained from the gamma-ray transition energies and the atomic electron binding energies.

The emission probabilities of the conversion electrons were deduced using the evaluated P_γ and ICC values. The total absolute emission probabilities of K and L Auger electrons were calculated using the EMISSION computer program.

6. PHOTON EMISSIONS

6.1 X - Ray emissions

The absolute emission probabilities of Pu KX- and LX-rays were calculated using the EMISSION computer program (Table 5).

Table 5. Measured (1972Ah02) and calculated absolute Pu KX-ray emission probabilities (%).

	1972Ah02	Calculated
$K\alpha_2$ (Pu)	13.5 (5)	13.34 (28)
$K\alpha_1$ (Pu)	20.8 (8)	21.1 (5)
$K\beta'_1$ (Pu)	7.6 (3)	7.75 (21)
$K\beta'_2$ (Pu)	2.6 (1)	2.69 (8)

The good agreement between measured and calculated KX-ray emission probabilities supports the recommended γ-ray emission probabilities and assigned multipolarities.

6.2. Gamma emissions

6.2.1. Gamma ray energies

The gamma ray energies have been taken mainly from 2003Br12. They are based on measurements of γ-ray transitions observed in ^{239}Np and ^{239}Am decays by 1959Ew90, 1964Ba31, 1965Ma17, 1972Po04, 1979Bo30, and 1982Ah04. The energies of gamma rays $\gamma_{9,8}$ (4.16 keV), $\gamma_{1,0}$ (7.86 keV), $\gamma_{3,2}$ (18.43 keV), $\gamma_{2,1}$ (49.41 keV), $\gamma_{8,7}$ (57.30 keV), $\gamma_{5,3}$ (117.1 keV), and $\gamma_{22,2}$ (498.9 keV) have been deduced directly from the adopted ^{239}Pu level energies.

Earlier measurement results can be found in 1953As14, 1955Sc08, and 1956Ne17.

The gamma rays reported in 1963Le17 only, have not been placed in the decay scheme.

6.2.2. Gamma ray emission probabilities

The absolute gamma ray emission probabilities (Pγ) were adopted from the experimental values given by 1972Ah02 multiplied by 0.9971 (3), except when noted below.

Pγ of gamma rays $\gamma_{1,0}$ (7.86 keV), $\gamma_{3,2}$ (18.43 keV), $\gamma_{2,0}$ (57.27 keV), $\gamma_{3,1}$ (67.84 keV), $\gamma_{4,2}$ (106.47 keV), and $\gamma_{5,3}$ (117.1 keV) have been obtained from P(γ+ce) values deduced from intensity balances (see section 2.2).

Pγ of gamma ray $\gamma_{7,6}$ (44.66 keV) has been deduced using the ratio Iγ(44.66 keV) / Iγ(254.4 keV) = 0.13 (1) / 0.1091 (22) in ^{239}Np β^- decay (2005Tr08, 2008BeZV) and $P\gamma_{7,3}$ (254.4 keV) = 0.11 (1) % measured in 1972Ah02.

Pγ of gamma ray $\gamma_{8,7}$ (57.30 keV) has been deduced from the total intensity of doublet $P\gamma_{2,0}$ (57.27 keV) + $P\gamma_{8,7}$ (57.30 keV) = 0.14 (1) % measured in 1972Ah02 and $P\gamma_{2,0}$ (57.27 keV) = 0.06 % from transition probability balance at the 57 keV level.

Pγ of gamma ray $\gamma_{9,7}$ (61.46 keV) has been deduced using the ratio Iγ(61.46 keV) / Iγ(334.31 keV) = 1.29 (2) / 2.05 (2) in ^{239}Np β^- decay (2005Tr08, 2008BeZV) and $P\gamma_{9,2}$ (334.31 keV) = 0.024 (2) % measured in 1972Ah02.

Pγ of gamma ray $\gamma_{4,3}$ (88.06 keV) has been deduced using from the ratio Iγ(88.06 keV) / Iγ(106.47 keV) = 0.006 (2) / 0.049 (2) in ^{239}Np β^- decay (2005Tr08, 2008BeZV) and P$\gamma_{4,2}$ (106.47 keV) = 0.015 %.

Pγ of gamma ray $\gamma_{8,6}$ (101.96 keV) has been deduced using data from ^{239}Am ε decay (1972Po04).

Pγ of gamma ray $\gamma_{9,6}$ (106.12 keV) has been deduced using data from ^{239}Np β^- decay of the relative intensity Iγ(106.12 keV) / Iγ(334.31 keV) = 25.32 (17) / 2.055 (13) as measured in 2005Tr08 and P$\gamma_{9,2}$ (334.31 keV) = 0.024 (2) % measured in 1972Ah02.

Pγ of gamma ray $\gamma_{7,4}$ (166.39 keV) has been deduced using the ratio Iγ(166.39 keV) / Iγ(254.4 keV) = 0.016 (7) / 0.1091 (22) in^{239}Np β^- decay (2005Tr08, 2008BeZV) and P$\gamma_{7,3}$ (254.4 keV) = 0.11 (1) % measured in 1972Ah02.

7. CONSISTENCY OF RECOMMENDED DATA

The most accurate Q(α) value, Q_α (M), is taken from the atomic mass adjustment table of Audi et al. (2003Au03). Comparison of Q_α (eff) (deduced as the sum of average energies per disintegration ($\sum E_i \times P_i$) for all emissions accompanying ^{243}Cm α- decay) with the tabulated decay energy Q_α (M) × 0.9971 allows to check a consistency of the recommended decay-scheme parameters obtained in this evaluation.

Here E_i and P_i are the evaluated energies and emission probabilities of the i-th alpha particle, γ- ray, X-ray, etc. Consistency (percentage deviation) is determined by $\{[Q_\alpha (M) \times 0.9971 - Q(eff))] / Q_\alpha (M) \times 0.9971 \} \times 100$. "Percentage deviations above 5 % would be regarded as high and imply a poorly defined decay scheme; a value of less than 5 % indicates the construction of a reasonably consistent decay scheme" (quoted from the article by A.L. Nichols in Appl. Rad. Isotopes 55 (2001) 23-70).

For the current ^{243}Cm decay data evaluation we have Q_α (M) × 0.9971 = 6150.9 (10) keV and Q(eff) = 6171 (35) keV, i.e. consistency is better than 1.0 %.

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^{244}Cm - Comments on evaluation of decay data by V. P. Chechev

This evaluation was completed in February 2005 (see 2006Ch34) and then corrected in October 2009 with a literature cut-off by the same date.

1 Decay Scheme

The decay scheme is based on the evaluation of 2004Ch64. It can be considered essentially complete although some weak gamma-ray transitions have not been observed in ^{244}Cm alpha decay. Such gamma-rays were taken from the ^{240}Np β^--decay and the ^{240}Am electron capture and have been included in the decay scheme.

2 Nuclear Data

Q(α) value is from 2003Au03.

The evaluated half-life of ^{244}Cm is based on the experimental values given in Table 1.

Table 1. Experimental values of the ^{244}Cm half-life (in years).

Reference	Author(s)	Value	Measurement method
1954Fr19	Friedman et al.	17.9 (5)	α-activity relative to ^{242}Cm
1954St33	Stevens et al.	19.2 (6)	α-activity relative to ^{242}Cm
1961Cao1	Carnall et al.	17.59 (6)	Specific activity
1968Be26	Bentley	18.099 (32) [a]	2π α-counting
1972Ke29	Kerrigan and Dorsett	18.13 (4)	Calorimetry
1982Po14	Polyukhov et al.	18.24 (25)	Specific activity

[a] Revised value, recalculated in 2000Ho27.

The EV1NEW program has led to successive rejections of values from 1961Ca01 and 1954St33 due to their too large contribution to χ^2-value (more than 80 %). The LRSW method has increased 1.03 times the uncertainty of the value from 1968Be26. The weighted mean of the data set including only the four remaining values is 18.115, with the internal uncertainty 0.028 and $\chi^2/\nu = 0.25$. The smallest experimental uncertainty is 0.032, thus the recommended value of ^{244}Cm half-life is **18.11 (3) a**.

The recommended spontaneous fission partial half-life of ^{244}Cm is based on the experimental values given in Table 2.

Table 2. Experimental values of the ^{244}Cm spontaneous fission half-life (in 10^7 years).

Reference	Author(s)	Value	Measurement method
1952Gh27	Ghiorso et al.	1.4 (2) [a]	Ionization chamber
1963Ma56	Malkin et al.	1.46 (6)	Gas scintillator
1965Me02	Metta et al.	1.345 (8) [a]	α/SF counting, α with low geometry counter, SF with 2π parallel plate chamber
1967Ar09	Armani and Gold	1.33 (3)	Fission neutron counting, LiI detector
1970Ba11	Barton and Koontz	1.250 (7)	Low geometry fission fragment counting
1972Ha80	Hastings and Strohm	1.343 (6) [a]	α/SF counting, Si(Au) detector
1993Pa29	Pandey et al.	1.263 (5)	α/SF counting by sequential etching of alpha and fission tracks

[a] Revised value, recalculated in 2000Ho27.

The data set in Table 2 is discrepant. The LWEIGHT computer program has chosen the unweighted mean of 1.342 and expanded the uncertainty to 0.079 so its range includes the most precise value of 1993Pa29.

The recommended value of ^{244}Cm spontaneous fission half-life is 1.34 (8) × 10^7 years.

2.1 α Transitions

The energies of the alpha transitions have been obtained from the Q value and the ^{240}Pu level energies given in Table 3 from 2004Ch64.

Table 3. ^{240}Pu levels populated in the ^{244}Cm α-decay.

Level number	Energy (keV)	Spin and parity	Half-life	Probability of α-transition (%)
0	0.0	0^+	6561 (7) a	76.7 (4)
1	42.824 (8)	2^+	164 (5) ps	23.3 (4)
2	141.690 (15)	4^+		0.0204 (15)
3	294.319 (24)	6^+		0.00352 (18)
4	497.6 [a]	8^+		4 × 10^{-5}
5	597.34 (4)	1^-		5.5 (9) × 10^{-5}
6	648.85 (4)	3^-		4.2 (30) × 10^{-6} [b]
7	860.71(7)	0^+		1.49 (16) × 10^{-4}
8	900.32 (4)	2^+		5.0 (5) × 10^{-5}
9	938.06 (6)	(1^-)		4.7 (11) × 10^{-6} [b]

[a] Energy has been taken from ^{238}U(α, 2n γ)-reaction measurements of 1972Sp06.
[b] Deduced from P(γ+ce) decay-scheme probability balances.

The probabilities of the transitions $α_{0,i}$ (i = 0, 1, 2, 3, 7) have been obtained by averaging experimental data (Table 4). The experimental results from 1998Ga19 agree well with the evaluated probabilities of the most intense alpha-transitions. The probabilities of the remaining α-transitions have been deduced using the experimental values and the values obtained from P(γ+ce) decay-scheme balances (see footnotes).

Table 4. Experimental and recommended α-transition probabilities (%) in the ^{244}Cm decay.

	α-energy (keV)	1956 Hu96	1960 As11, 1984 Asaro	1963 Dz07	1966 Ba07	1984 BuZJ	1996 Bu50	1996 Sa24	1997 Ka59	1998 Ga19	1998 Ya17	2002 Da21	Recommended
$α_{0,0}$	5805	76.7 (6)	-	76.2 (20)	76.4 (20) [a]	76.98 (5)	76.8 (7)	76.9 (5)	-	76.63 (18)	76.31 (5)	77.16 (11)	76.7 (4) [b]
$α_{0,1}$	5763	23.3 (6)	-	23.8 (9)	23.6 (9) [a]	23.00 (5)	23.2 (5)	23.1 (5)	-	23.34 (18)	23.69 (6)	22.80 (5)	23.3 (4) [c]
$α_{0,2}$	5664	0.017 (3)	0.023 (2)	0.021 (2)	0.02	0.0163 (7)	-	0.0135 (2)	-	0.0205 (15)	-	0.020 (1)	0.0204 (15) [d]
$α_{0,3}$	5515	-	0.0036 (3)	0.003 (1)	0.0034	-	-	-	0.003 42 (9)	0.0038 (5)	-	0.012 (1)	0.003 52 (18) [e]
$α_{0,4}$	5315		~ 1.5 10^{-4}		~ 4 10^{-5}								4 10^{-5} [f]
$α_{0,5}$	5215	-	1.5 10^{-4}	-	1 10^{-4}	-	-	-	4.2 (9) 10^{-5}	-	-	-	5.5 (9) 10^{-5} [g]
$α_{0,7}$	4960	-	1.55 (16) 10^{-4}	-	3 10^{-4}	-	-	-	1.42 (16) 10^{-4}	-	-		1.49 (16) 10^{-4} [h]
$α_{0,8}$	4920	-	5.0 (5) 10^{-5}	-	1.3 10^{-4}	-	-	-	4.9 (8) 10^{-5}	-	-	-	5.0 (5) 10^{-5} [i]

[a] No uncertainties are quoted by the authors. The uncertainties have been adopted by the evaluator based on the analogy of the spectra obtained with magnetic spectrometers in 1963Dz07and 1966Ba07.
[b] This set of experimental values is discrepant. The LWEIGHT computer program has recommended a weighted average and expanded the uncertainty so the range includes the most precise value from 1998Ya17.
[c] Obtained from the relation P($α_{0,1}$) = 100 – P($α_{0,0}$) per 100 disintegrations. An unweighted average of the discrepant set of the experimental values is 23.31, a weighted average is 23.11.
[d] Weighted average of the values from 1956Hu96, 1960As11, 1963Dz07, 1998Ga19 and 2002Da21. The lower values from 1984BuZJ and 1996Sa24 have been omitted as outliers. These values conflict greatly with the ratio P($γ_{2,1}$)/ P($γ_{1,0}$) = 0.067 (7) measured in 1972Sc01. The uncertainty of the evaluated $α_{0,2}$ probability has been adopted from the experimental result of 1998Ga19.
[e] Average of values from 1960As11, 1963Dz07, 1997Ka59 and 1998Ga19. The EV1NEW computer program using a limitation of relative statistical weights of 0.5 has expanded the uncertainty from 1997Ka59 to 0.00025 and recommended a weighted average and an internal uncertainty.

[f] Adopted from 1966Ba07.
[g] Deduced from the P(γ+ce)-probability balance at the 597-keV level ("5").
[h] Weighted average of values from 1960As11, 1997Ka59.
[i] Weighted average of values from 1960As11, 1997Ka59 and a value of 5.2 (7) × 10^{-5}, calculated from P(γ+ce)-probability balance at the 900-keV level ("8"). The uncertainty is the smallest experimental one.

2.2 γ Transitions

The evaluated energies of gamma-ray transitions are virtually the same as the photon energies because nuclear recoil is negligible.

The probabilities, P(γ+ce), for gamma-ray transitions of 42.8-keV ($\gamma_{1,0}$), 98.9-keV ($\gamma_{2,1}$), 152.6-keV ($\gamma_{3,2}$), and 202-keV ($\gamma_{4,3}$) have been deduced from intensity balances, using the probabilities of α-particle transitions evaluated directly from experimental data.

For the 861-keV ($\gamma_{7,0}$) E0 transition its P(ce) value has been obtained from the (α–ce)-coincidence measurement of 1963Bj03: P(ce $\gamma_{7,0}$) + P(ce $\gamma_{7,1}$) = 9.5 (20) × 10^{-6} per 100 disintegrations.

The remaining P(γ+ce) values have been calculated from the gamma-ray emission probabilities and the total internal conversion coefficients (ICC's). The ICC's have been interpolated using the BrIcc package with the so called "*Frozen Orbital*" approximation (2008Ki07). The fractional uncertainties of α_K, α_L, α_M, α_T for pure multipolarities have been taken as 2 %.

Multipolarities are from 2004Ch64. These are based on conversion electron measurements of 1956Sm18, 1963Bj03, 1968Du06 and 1990Pe03.

3 Atomic Data

3.1. Fluorescence yields

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

3.2 X radiations

The Pu KX-ray energies and relative emission probabilities are from 1999Schönfeld, where the calculated energy values are based on X-ray wavelengths from 1967Be65 (Bearden). In Table 5 the recommended values of U KX-ray energies are compared with experimental values.

Table 5. Experimental and recommend values of Pu KX-ray energies (keV).

	1980Di13	1982Ba56	Recommended
$K\alpha_2$	99.55 (3)	99.530 (2)	99.525
$K\alpha_1$	103.76 (3)	103.741 (2)	103.734
$K\beta_3$	116.27	116.242 (2)	116.244
$K\beta_1$	117.26	117.233 (2)	117.228
$K\beta_{2,4}$	120.60 (15)	-	120.553
$KO_{2,3}$	121.55 (6)	-	121.543

In 1980Di13 the Pu KX-ray energies were measured in the alpha decay of ^{245}Cm. The relative emission probabilities of KX-rays were obtained as:

$K\alpha_2 : K\alpha_1 : K\beta_3 : K\beta_1 : K\beta_{2,4}$ = 64.7 (23) : 100.0 (33) : 12.9 (7) : 23.1 (10) : 8.9 (5).

3.3. Auger Electrons

The energies of Auger electrons have been calculated from atomic electron binding energies.

The P(KLX)/P(KLL), P(KXY)/P(KLL) ratios have been taken from 1996Sc06.

4 α Emissions

The energy of alpha particles to the ground state of ^{240}Pu, E($\alpha_{0,0}$), are from the absolute measurement of 1971Gr17 but including the correction of −0.19 keV recommended by A. Rytz in 1991Ry01.

The energies of all other α-particles have been deduced from Q_α and ^{240}Pu level energies including the recoil energy corrections.

In Table 6 the recommended values of α-particle energies are compared with experimental results obtained with magnetic alpha spectrometers.

Table 6. Experimental [a] and evaluated α-particle energies in the decay of ^{244}Cm (keV).

	1960 As11	1963 Dz07	1966 Ba07	1971 Gr17	1992 Fr04	1998 Ga19	Recommended
$\alpha_{0,0}$	5805	5805 (3)	5805 (1)	5804.77 (5)	5803.6 (22)	-	5804.77 (5)
$\alpha_{0,1}$	5763	5762	5763 (1)	5762.16 (3)	-	-	5762.65 (5)
$\alpha_{0,2}$	5666	5665	5664 (3)	-	-	5664 (2)	5665.41 (5)
$\alpha_{0,3}$	5514	5514	5513 (3)	-	-	5515 (3)	5515.29 (6)
$\alpha_{0,4}$	5316	-	5313	-	-	-	5315.3
$\alpha_{0,5}$	5215	-	5215 (3)	-	-	-	5217.24 (7)
$\alpha_{0,7}$	4956	-	4960 (3)	-	-	-	4958.20 (9)
$\alpha_{0,8}$	4916	-	4920 (3)	-	-	-	4919.24 (7)

[a] Authors' values have been adjusted for changes in calibration energies (see 1991Ry01).

5 Electron emissions

The energies of conversion electrons have been obtained from gamma transition energies and relevant electron binding energies. The emission probabilities of conversion electrons have been deduced from the evaluated P(γ) and ICC values.

The absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program (2000Schönfeld).

6 Photon emissions

6.1 X-ray emissions

The absolute emission probabilities of U KX- and U LX-rays in decay of ^{242}Pu have been calculated using the EMISSION computer program (2000Schönfeld).

The calculated total absolute emission probability of LX-rays P(XL)= 8.92 (23) % agrees with the experimental value of 8.77 (6) % from 1995Jo23.

In 1990Po14 the relative LX-ray emission probabilities in ^{244}Cm α-decay were measured:
[5.3 (8) : Ll; 72 (7) : Lα; 100: Lηβ; 22.4 (23) : Lγ].

These values agree with the recommended ones with the exception of the (Lα/Lηβ)-ratio.

6.2 Gamma-ray emissions

6.2.1. Gamma-ray energies

The energies of the 43-keV ($\gamma_{1,0}$), 99-keV ($\gamma_{2,1}$), and 153-keV ($\gamma_{3,2}$) gamma rays are from ^{244}Cm α-decay (1972Sc01). Other, less accurate measurements of ^{244}Cm α-decay (1956Sm18), ^{240}Np β^--decay (1981Hs02) and ^{240}Am ε-decay (1972Ah07) agree with data from 1972Sc01.

The energies of remaining gamma rays have been obtained from the adopted ^{240}Pu level energies. In Table 7 the recommended gamma ray energies are compared with the available experimental data.

Table 7. Experimental and recommended gamma-ray energies (keV).

	1967Lederer (1978LeZA)	1972Ah07	1972Sc01	1981Hs02	Recommended
$\gamma_{1,0}$		42.9 (1)	42.824 (8)	-	42.824 (8)
$\gamma_{2,1}$	-	98.9 (1)	98.860 (13)	-	98.860 (13)
$\gamma_{3,2}$	-	-	152.630 (20)	-	152.630 (20)
$\gamma_{8,6}$	251.20 (20)	-	-	251.5 (1)	251.47 (6)
$\gamma_{7,5}$	263.34 (15)	-	-	263.4 (1)	263.37 (8)
$\gamma_{8,5}$	302.99 (15)	-	-	303.0 (1)	302.98 (6)
$\gamma_{6,2}$	506.9 (3)	-	-	507.2 (1)	507.16 (5)
$\gamma_{5,1}$	554.5 (2)	-	-	554.6 (1)	554.52 (4)
$\gamma_{5,0}$	597,2 (2)	-	-	597.4 (1)	597.34 (4)
$\gamma_{6,1}$	605.8 (2)	-	-	606.1 (1)	606.03 (4)
$\gamma_{8,2}$	758.6 (2)	-	-	758.6 (1)	758.63 (5)
$\gamma_{7,1}$	817.8 (2)	-	-	817.9 (1)	817.89 (7)
$\gamma_{8,1}$	857.5 (2)	-	-	857.5 (1)	857.50 (4)
$\gamma_{9,1}$	894.7 (5)	-	-	895.3 (1)	895.24 (6)
$\gamma_{8,0}$	900.1 (5)	-	-	900.3 (1)	900.32 (4)
$\gamma_{9,0}$	937.6 (10)	-	-	938.0 (1)	938.06 (6)

6.2.2. Gamma-Ray Emission Probabilities

The absolute emission probabilities for gamma rays of 43-keV ($\gamma_{1,0}$), 99-keV ($\gamma_{2,1}$), 153-keV ($\gamma_{3,2}$) and 202-keV ($\gamma_{4,3}$) have been deduced from intensity balances, using the experimental α-particle probabilities. The relative emission probabilities for the first three gamma rays were measured in 1972Sc01 as [100 - $\gamma_{1,0}$, 6.7 (7) - $\gamma_{2,1}$,and 4.1 (1) - $\gamma_{3,2}$]. The measured $P(\gamma_{2,1})/P(\gamma_{1,0})\times100$ ratio disagrees with the evaluated 5.3 (4), and the measured $P(\gamma_{3,2})/P(\gamma_{1,0})\times100$ ratio agrees with the evaluated 3.95 (23).

The recommended relative emission probabilities of gamma rays with energies greater than 150-keV, obtained by averaging the experimental data from 1967Lederer (1978LeZA) and 1969Sc18 (1970Sc39), are given in Table 8.

Table 8. Experimental and recommended relative emission probabilities of > 150-keV gamma rays from the decay of ^{244}Cm.

	Energy (keV)	1967Lederer 1978LeZA	1969Sc18 1970Sc39	Recommended
$\gamma_{3,2}$	152.6	-	1240 (150)	1170 (160) [a]
$\gamma_{8,6}$	251.5	14 (3)	12.7 (20)	13.1 (20) [b]
$\gamma_{7,5}$	263.4	73 (5)	68 (6)	71 (5) [b]
$\gamma_{8,5}$	303.0	23 (4)	21.0 (20)	21.4 (20) [b]
$\gamma_{6,2}$	507.2	10 (3)	-	10 (3) [c]
$\gamma_{5,1}$	554.5	100	100	100
$\gamma_{5,0}$	597.3	61 (2)	62 (4)	61 (2) [b]
$\gamma_{6,1}$	606.0	10 (2)	9.1 (11)	9.3 (20) [b]
$\gamma_{8,2}$	758.6	15.6 (8)	18.3 (21)	15.9 (8) [b]
$\gamma_{7,1}$	817.9	75 (4)	91 (8)	78 (4) [b]
$\gamma_{8,1}$	857.5	6.6 (4)	< 7.5	6.6 (4) [c]
$\gamma_{9,1}$	895.2	2.1 (6)	< 1.3	2.1 (6) [c]
$\gamma_{8,0}$	900.3	1.5 (6)	< 0.4	1.5 (6) [c]
$\gamma_{9,0}$	938.1	0.5 (5)	< 0.75	0.5 (5) [c]

[a] Deduced from the evaluated absolute emission probabilities P(γ 153 keV) and P(γ 555 keV).
[b] Weighted average, uncertainty is the smallest experimental value reported.
[c] Adopted from 1967Lederer (1978LeZA).

The deduced absolute emission probabilities of gamma-rays with energies greater than 250 keV are based on our recommended relative gamma-ray emission probabilities P(γ)/P(γ 555 keV) in Table 8 and a normalization factor obtained from decay scheme.

The absolute gamma-ray emission probability $P^{(1)}$(γ 555 keV) = 9.1 (11) × 10^{-5} per 100 disintegrations (used for decay-scheme normalization) has been obtained from the intensity balance at the 861-keV level ("7") using the alpha-transition probability $P(\alpha_{0,7})$ = 1.49 (16) × 10^{-4} per 100 disintegrations, deduced from the experimental data of 1960As11 and 1997Ka59:

$$P(\gamma\ 555\ keV) = [P(\alpha_{0,7}) - P(ce\ 861\ keV)] / [P'(\gamma\ 263\ keV)\times(1+\alpha_T^{263}) + P'(\gamma\ 818\ keV)\times(1+\alpha_T^{818}],$$

where P'(γ) is a gamma-ray emission probability relative to that of the 555-keV transition (i.e., P(γ)/P(γ 555 keV)).

Another way of deducing a normalization factor is by using the relative gamma-ray emission probability P(γ 153 keV)/P(γ 555 keV) = 12.4 (15) measured in 1969Sc18 (1970Sc39) and the absolute probability P(γ 153 keV) obtained from the intensity balance for the level 294-keV level ("3"):

$P^{(2)}$(γ 555 keV) = 8.2 (11) × 10^{-5} per 100 disintegrations.

The average of the two P(γ 555 keV) values, 8.7 (11) × 10^{-5} per 100 disintegrations, was used as a normalization factor for calculating absolute emission probabilities of gamma-rays with energy greater than 250 keV.

The absolute emission probabilities for the 289-keV ($\gamma_{9,6}$) and 341-keV ($\gamma_{9,5}$) gamma rays have been deduced using the ratios P(γ 895 keV)/P(γ 289 keV) = 3.6 (15) and P(γ 895 keV)/P(γ 341 keV) = 1.0 (3) measured in ^{240}Np β^--decay (1981Hs02, 2004Ch64).

The absolute emission probability of the 202-keV ($\gamma_{4,3}$) gamma ray has been obtained using the adopted $\alpha_{0,4}$-transition probability. The 202-keV E2-gamma-ray transition was not observed in the ^{244}Cm alpha decay; however, it is expected from theoretical considerations and by analogy with the ^{242}Cm decay scheme.

7 Consistency of recommended data

The most accurate Q value, Q(M), is taken from the atomic mass adjustment table of Audi et al. (2003Au03). Comparison of Q(eff)(deduced as the sum of average energies per disintegration ($\sum E_i \times P_i$) for all emissions accompanying ^{244}Cm α- decay) with the tabulated decay energy Q(M) allows to check a consistency of the recommended decay-scheme parameters obtained in this evaluation.

Here E_i and P_i are the evaluated energies and emission probabilities of the i-th alpha particle, beta particle, gamma ray, X-ray, etc. Consistency (percentage deviation) is determined by $\{[Q(M) - Q(eff)]\} / Q(M)\} \times 100$. "Percentage deviations above 5 % would be regarded as high and imply a poorly defined decay scheme; a value of less than 5 % indicates the construction of a reasonably consistent decay scheme" (quoted from the article by A.L. Nichols in Appl. Rad. Isotopes 55 (2001) 23-70).

For the above ^{244}Cm decay data evaluation we have Q(M) = 5901.74 (5) keV and Q(eff) = 5903 (33) keV, i.e. consistency of (0.02 ± 0.56) % is not superior, but better than 0.6 %.

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^{245}Cm -Comments on evaluation of decay data by V.P. Chechev

Evaluated in November 2010 with a literature cut-off by the same date.

1. DECAY SCHEME

^{245}Cm decays 100 % to levels of ^{241}Pu by emission of α particles and, with a very small branch of 5.9 (9) × 10^{-7} % by spontaneous fission. The adopted ^{241}Pu levels populated in the ^{245}Cm α decay are based generally on the evaluation by Martin (2005Ma88). Questionable ^{241}Pu levels with energies of 260.5 and ≈ 376 keV as reported from α spectrometric measurements of 1975Ba65 were not included into the current evaluation. The 260.5-keV nuclear level was judged in 1975Ba65 as belonging possibly to ^{243}Am α decay, while the 376-keV nuclear level was not identified by 1975Ba65 and may belong to ^{239}Pu α decay along with the ≈ 384-keV energy level. However, the latter has been identified as $13/2^{+}$ belonging to the ^{241}Pu 7/2 [624] rotational band populated in the ^{245}Cm α decay (1975Ba65), and therefore has been included in the proposed decay scheme.

The decay scheme overall consistency is supported by the agreement between Q(calc) = 5640 (30) keV, deduced from the evaluated average energies and intensities of all emissions, and Q(α) = 5622.3 (5) keV, deduced from measured α-particle energies. Percentage deviation of Q(calc) from the adopted Q(α) and the Q(α) value of Audi *et al*. (2003Au03) is –(0.3 ± 0.5) %.

2. NUCLEAR DATA

Q(α) value has been deduced from the five alpha transition energies obtained from the α particle energies measured in 1975Ba65 and adjusted for changes in calibration energies by Rytz (1991Ry01). This approach (Table 1) similar to the evaluation by Martin (2005Ma88) is due to absence of an adjusted Q(α) value for ^{245}Cm in 2003Au03. Audi *et al.* (2003) chose Q(α) = 5623 (1) keV reported in 1975Ba65.

Table 1. ^{245}Cm Q(α) values deduced from α-transition energies

Energy of ^{241}Pu level (keV)	Energy of α particles (keV) (experimental)	Energy of α-transition (keV)	Deduced Q(α) value (keV)
41.9722 (9)	$\alpha_{0,1}$ 5488.5 (5)	5579.7 (5)	5621.7 (5)
95.7795 (12)	$\alpha_{0,2}$ 5436.1 (5)	5526.4 (5)	5622.2 (5)
175.0523 (14)	$\alpha_{0,5}$ 5361.8 (12)	5450.9 (12)	5625.9 (12)
231.935 (9)	$\alpha_{0,6}$ 5303.6 (12)	5391.7 (12)	5623.6 (12)
301.172 (16)	$\alpha_{0,7}$ 5234.4 (12)	5321.4 (12)	5622.5 (12)

The weighted average of the deduced Q(α) data set is 5622.3 keV, the internal uncertainty is 0.31, the external uncertainty is 0.55, χ^2/ν = 3.05, χ^2/ν (critical) = 3.30. The smallest value of experimental uncertainties is ± 0.5 keV. The recommended **Q(α)** value is **5622.3 (5) keV**.

The ^{245}Cm half-life is based on the experimental results given in Table 2.

Table 2. Experimental values of ^{245}Cm half-life (in 10^3 years)

Reference	Author(s)	Original value	Re-estimated value	Comments
1954Hu50	Hulet *et al.*	≈ 20		Not used
1954Fr19	Friedman *et al.*	11.5 (50)	11.3 (50) [a]	Relative specific activity to ^{244}Cm - not used.
1955Br02	Browne *et al.*	14.3 (29)		α counting - not used.
1957Hu76	Huizenga *et al.*	7.5 (19)		H. Diamond, Priv. Com. no details - outlier.
1961Ca01	Carnall *et al.*	9.32 (28)	9.60 (29) [a]	Relative specific activity to ^{244}Cm - outlier.
1969Me01	Metta *et al.*	8.265 (180)	8.270 (180) [a]	Relative specific activity to ^{244}Cm
1971Ma32	MacMurdo *et al.*	8.532 (53)	8.537 (71) [a,b]	Relative specific activity to ^{244}Cm
1982Po14	Polyukhov *et al.*	8.445 (100)	8.450 (100) [a]	Relative specific activity to ^{244}Cm
2009KoZV	Kondev *et al.*	8.245 (70)		Daughter in-growth from ^{249}Cf sample

[a] Re-estimated by the evaluator on the basis of the recommended ^{244}Cm half-life of 18.11 (3) years.
[b] Uncertainty has been revised in 1989Ho24.

Of the six values adopted in the data analysis, the LWEIGHT computer program identified two outliers (1957Hu76 and 1961Ca01), and indicated that the four remaining experimental values are discrepant: there are two separate groups of measured values at 8.5×10^3 and 8.25×10^3 years. A similar situation for measurements of ^{239}Pu half-life by the specific activity method (24 400 and 24 100 years) was resolved to the benefit of the lower value on the basis of the detected presence of impurities leading to overestimations of half-life. This method involves the determination of the number of atoms and disintegration rate of the radionuclide with good accuracy, and thereby requires absolute efficiencies (2009KoZV). Daughter growth in a sample in which the parent is shorter lived does not require such efficiencies, and has been successfully adopted recently to determine the ^{240}Pu half-life (2008KoZP). Therefore, for statistical processing the evaluator has chosen two consistent experimental results obtained with different methods: 1969Me01 (re-estimated) and 2009KoZV, and omitted the other two measurements. The weighted average for this limited set of only two measurements is 8.25×10^3 years with an internal uncertainty of 0.065 and external uncertainty of 0.0084 (χ^2/ν = 0.02).

The recommended value for the ^{245}**Cm half-life** is **8.25 (7) × 10^3 years**.

A value of 1.4 (2) × 10^{12} years was adopted for ^{245}Cm spontaneous fission (SF) half-life from the measurement of 1985Dr10. SF branching of 5.9 (9) × 10^{-7} % has been derived from the adopted SF half-life and total half-life of 8.25 (7) × 10^3 years.

2.1. Alpha Transitions

The energies of alpha transitions $\alpha_{0,1}$, $\alpha_{0,2}$, $\alpha_{0,5}$, $\alpha_{0,6}$ and $\alpha_{0,7}$ have been obtained from the experimental α particle energies taking into account the recoil energies for ^{241}Pu (Table 1). The energies of the remaining alpha transitions have been obtained from Q(α) value and ^{241}Pu level energies given in Table 3 from the Adopted Levels, Gammas of 2005Ma88 where they were deduced from a least-squares fit to gamma-ray energies.

Table 3. ^{241}Pu levels populated in ^{245}Cm α-decay

Level	Energy (keV)	Spin and parity	Half-life	Probability of α- transition (%)
0	0.0	5/2+	14.33 (4) y	0.58
1	41.9722 (9)	7/2+		0.83
2	95.7795 (12)	9/2+		0.04
3	161.314 (4)	11/2+		0.39 (22)
4	161.6852 (9)	1/2+	0.88 (5) μs	0.0210 (9)
5	175.0523 (14)	7/2+		93.2 (5)
6	231.935 (9)	9/2+		5.0 (1)
7	301.172 (16)	11/2+		0.32
8	385 (3)	(13/2+)		≤0.005

The experimental values for the α-transition probabilities of ^{245}Cm from spectrometric measurements are presented in Table 4. Uncertainties were not reported in the cited references, but these for the most intense α-transitions $\alpha_{0,5}$ (5362 keV) and $\alpha_{0,6}$ (5304 keV) observed in 1975Ba65 were estimated in 1976BaZZ. The data of 1966Ba07 for ^{245}Cm are not given in Table 4 as those were superseded in 1975Ba65 by the same group. The probabilities of the α-transitions $\alpha_{0,3}$ and $\alpha_{0,4}$ (observed as a doublet with an energy of ~5370 keV) have been deduced from intensity balances at the ^{241}Pu levels "3" (161.3 keV) and "4" (161.7 keV), respectively. Probabilities of the remaining alpha transitions have been adopted from the magnetic spectrometer measurements of 1975Ba65.

Table 4. Experimental and recommended probabilities (per 100 decays) of alpha transitions observed in ^{245}Cm α decay

	α-particle energy	1960As11	1963Dz07	1966Fr03	1975Ba65	Deduced from P(γ+ce) balance	Recommended
$\alpha_{0,0}$	5529			1.1	0.58		0.58
$\alpha_{0,1}$	5488			0.9	0.83		0.83
$\alpha_{0,2}$	5436			0.2	0.04		0.04
$\alpha_{0,3}$	5372					0.39 (22)	0.39 (22)
$\alpha_{0,4}$	5371					0.0210 (9)	0.0210 (9)
$\alpha_{0,5}$	5362	93	90	91	93.2 (5)	95.3 (21)	93.2 (5)
$\alpha_{0,6}$	5303	7	7	6.2	5.0 (1)		5.0 (1)
$\alpha_{0,7}$	5234		2	0.5	0.32		0.32
$\alpha_{0,8}$	5152				≤ 0.005		≤ 0.005

The α decay hindrance factors have been calculated using the ALPHAD computer program from the ENSDF evaluation package with $r_0(^{241}Pu)$ = 1.4969 (12) fm (2005Ma88).

2.2. Gamma Transitions and Internal Conversion Coefficients

The recommended energies of the gamma-ray transitions are the same as those of the gamma-ray energies with correction to the minor nuclear recoil for ^{241}Pu.

The gamma-ray transition probabilities ($P_{\gamma+ce}$) have been deduced from their evaluated gamma-ray emission probabilities (P_γ) and total internal conversion coefficients (ICCs), apart from $P_{\gamma+ce}$ values for the gamma-ray transitions $\gamma_{6,5}$ (56.9 keV) and $\gamma_{7,6}$ (69.2 keV). The latter values have been deduced directly from intensity balances at the ^{241}Pu levels "6" (231.9 keV) and "7" (301.2 keV), respectively.

ICCs have been interpolated using the BrIcc computer program, version v2.2a, data set BrIccFO (2008Ki07). Multipolarities of the gamma-ray transitions and E2/M1 mixing ratios (δ) are based on the measurements of conversion electrons (ce) in the ^{240}Pu (n,γ)-reaction and have been taken from 2005Ma88, except as noted below.

The δ values for $\gamma_{6,5}$ (56.9 keV) and $\gamma_{7,6}$ (69.2 keV) have been obtained from the total ICC deduced using the expression $1+ \alpha_T = P_{\gamma+ce} / P_\gamma$.

3. ATOMIC DATA

The fluorescence yields, X-ray energies and relative probabilities, and Auger electrons energies and relative probabilities are from the SAISINUC software.

4. ALPHA EMISSIONS

The recommended energies of alpha particles for the five transitions ($\alpha_{0,1}$, $\alpha_{0,2}$, $\alpha_{0,5}$, $\alpha_{0,6}$, $\alpha_{0,7}$) used for obtaining Q(α) have been adopted from the most precise measurements of 1975Ba65. The remaining α particle energies have been deduced from the Q(α) value, taking into account the recoil energies for ^{241}Pu.

The recommended α-particle energies are compared in Table 5 with the experimental results from spectrometric measurements (1960As11, 1963Dz07, 1966Fr03 and 1975Ba65).

Table 5. Experimental and recommended α-particle energies (keV) in the decay of ^{245}Cm [a]

	1960As11	1963Dz07	1966Fr03	1975Ba65	Recommended
$\alpha_{0,0}$			5530 (3)	5529.0 (5)	5530.4 (5)
$\alpha_{0,1}$			5497 (5)	5488.5 (5)	5488.5 (5)
$\alpha_{0,2}$			5447 (5)	5436.1 (5)	5436.1 (5)
$\alpha_{0,3}$				5370	5371.7 (5)
$\alpha_{0,4}$				5370	5371.4 (5)
$\alpha_{0,5}$	5360	5361	5359 (2)	5361.8 (12)	5361.8 (12)
$\alpha_{0,6}$	5305	5305	5306 (2)	5303.6 (12)	5303.6 (12)
$\alpha_{0,7}$		5245	5239 (3)	5234.4 (12)	5234.4 (12)
$\alpha_{0,8}$				≈ 5151	5152 (3)

[a] Authors' experimental values have been adjusted for changes in calibration energies, as suggested in 1991Ry01.

5. ELECTRON EMISSIONS

The energies of the conversion electrons have been obtained from the gamma-ray transition energies and the atomic electron binding energies from 1977La19.

The emission probabilities of the conversion electrons have been deduced using the evaluated P_γ and ICC values. Measurements of the ^{241}Pu conversion electrons following thermal neutron capture in ^{240}Pu were carried out by 1998Wh01.

The total absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program (1996Sc06, 2000Sc47).

6. PHOTON EMISSIONS

6.1 X - Ray emissions

The absolute emission probabilities of Pu KX- and LX-rays were calculated using the EMISSION computer program (Table 6). In 1980Di13 the emission probabilities of Pu KX-rays were measured relatively to P_γ ($\gamma_{5,0}$ 175.0 keV). The experimental absolute P(KX) values are given in Table 6 using the evaluated P_γ ($\gamma_{5,0}$ 175.0 keV) = 9.83 (22) %.

Table 6. Experimental (1980Di13) and calculated absolute Pu KX-ray emission probabilities (%)

	1980Di13	Calculated
$K\alpha_2$ (Pu)	20.0 (7)	19.1 (5)
$K\alpha_1$ (Pu)	30.9 (11)	30.2 (7)
$K\beta'_1$ (Pu)	11.1 (5)	11.1 (3)
$K\beta'_2$ (Pu)	3.7 (2)	3.84 (12)

The good agreement between measured and calculated KX-ray emission probabilities supports the recommended γ-ray emission probabilities and assigned multipolarities.

6.2. Gamma emissions

6.2.1. Gamma-ray energies

The gamma-ray energies (E_γ) have been taken from 2005Ma88 (^{241}Pu, Adopted Levels, Gammas). They are based mainly on measurements of γ rays from ^{245}Cm α decay by 1980Di13, 1992Daniels, 1994Sh31, 1998Wh01 and γ rays from thermal neutron capture in ^{240}Pu by 1998Wh01 (Table 7). The gamma-ray energies for $\gamma_{7,6}$ (69.2 keV), $\gamma_{5,2}$ (79.3 keV), $\gamma_{2,0}$ (95.8 keV), $\gamma_{6,2}$ (136.1 keV), $\gamma_{7,2}$ (205.4 keV), and $\gamma_{6,0}$ (231.9 keV) have been deduced directly from the adopted ^{241}Pu level energies. Other, less accurate measurements of E_γ can be found in 1955Pe32, 1966Ba07, 1991Po17.

6.2.2. Gamma-ray emission probabilities

The relative gamma-ray emission probabilities (I_γ) are weighted averages of the experimental values from 1980Di13 and 1992Daniels, except as noted otherwise in Table 7. The LWEIGHT computer program was used for statistical processing, with the uncertainty assigned to the average value always greater than or equal to the smallest uncertainty of the values used to calculate the average.

The normalization factor (N) was obtained from the intensity balance to the ground state of ^{241}Pu:

$$\Sigma(1+\alpha_T)I_\gamma\,(\gamma_{1,0}, \gamma_{2,0}, \gamma_{4,0}, \gamma_{5,0}, \gamma_{6,0}) + P(\alpha_{0,0}) = 1$$

assuming $P(\alpha_{0,0}) = 0.006$ (1) (1975Ba65, 2005Ma88),

$N = P_\gamma(175.0 \text{ keV}) = 0.0983$ (22).

This adopted value agrees with the directly measured P_γ (175.0 keV) of 0.095 (7) (1980Di13) and 0.101 (1) (1992Daniels).

The absolute gamma-ray emission probabilities (P_γ) have been deduced from the evaluated relative gamma-ray emission probabilities (Table 7) using the derived normalization factor of 0.0983 (22).

Table 7. Experimental (E_γ^{exp}) and recommended gamma-ray energies and experimental and evaluated relative emission probabilities (I_γ^{exp}) in the decay of ^{245}Cm

	E_γ^{exp} from ^{245}Cm decay	**Recommended E_γ (keV)**	I_γ^{exp} (1980Di13)	I_γ^{exp} (1992Daniels)	I_γ^{exp} (1998Wh01)	**Evaluated I_γ**
$\gamma_{1,0}$	41.93 (3) [a]	**41.972 (1)**	3.68 (18)	4.10 (39)		**3.75 (18)** [a]
$\gamma_{2,1}$	53.72 (4) [a]	**53.807 (1)**	0.70 (4)	0.77 (4)		**0.74 (4)** [a]
$\gamma_{6,5}$	56.89 (3) [b]	**56.89 (3)**	0.38 (2)	0.325 (32)		**0.365 (20)** [a]
$\gamma_{3,2}$	65.44 (8) [a]	**65.535 (3)**	0.12 (4)	0.20 (2)		**0.18 (2)** [a]
$\gamma_{7,6}$	69.17 (6) [c]	**69.237 (18)**	0.07 (3)	-		**0.07 (3)**
$\gamma_{5,2}$	79.27 (4) [a]	**79.2728 (18)**	1.58 (9)	1.22 (7)		**1.22 (7)** [d]
$\gamma_{2,0}$	95.786 (3) [b, d]	**95.7795 (12)**				**0.111 (23)** [e]
$\gamma_{7,5}$	126.09 (4) [b]	**126.09 (4)**			0.07 (2)	**0.07 (2)** [b]
$\gamma_{5,1}$	133.05 (8) [a]	**133.081 (2)**	29.2 (15)	28.6 (4)		**28.6 (4)** [a]
$\gamma_{6,2}$	136.127 (20) [b]	**136.156 (9)**	1.18 (7)	1.15 (3)		**1.15 (3)** [a]
$\gamma_{7,3}$	139.87 (4) [b]	**139.858 (16)**	0.06 (2)	0.06 (3)	0.09 (1)	**0.08 (9)** [f]
$\gamma_{4,0}$	161.72 (8) [a]	**161.685 (1)**	0.09 (4)	0.067 (2)		**0.072 (2)** [a]
$\gamma_{5,0}$	175.01 (9) [a]	**175.0523 (14)**	100	100	100	**100**
$\gamma_{6,1}$	189.965 (10) [b]	**189.965 (10)**	2.03 (13)	2.07 (4)		**2.07 (4)** [a]
$\gamma_{7,2}$	205.404 (20) [a]	**205.393 (16)**	-	0.115 (19)	0.08 (1)	**0.09 (1)** [g]
$\gamma_{6,0}$	231.96 (3) [b]	**231.935 (9)**	0.16 (4)	0.117 (18)	0.11 (2)	**0.119 (18)** [h]
$\gamma_{-1,1}$	388.16 (5) [b]	**388.16 (5)**			0.19 (1)	**0.19 (1)** [b]

[a] Weighted averages of experimental values from 1980Di13 and 1992Daniels (see also1994Sh31, 2005Ma88).
[b] Experimental value from 1998Wh01.
[c] Reported only in 1980Di13, but also adopted in the level scheme of 1994Sh31.
[d] From 1992Daniels; higher value leads to a large intensity imbalance at the 96-keV and 175-keV levels
[e] Obscured by the Pu $K\alpha_2$ X-ray; I_γ is from I_γ/I_γ(53.8 keV) = 0.15 (3) in Adopted Gammas (2005Ma88).
[f] Weighted averages of experimental values from 1980Di13, 1992Daniels and 1998Wh01.
[g] Weighted averages of experimental values from 1992Daniels and 1998Wh01.
[h] Weighted averages of experimental values from 1980Di13, 1992Daniels and 1998Wh01.

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^{246}Cm - Comments on evaluation of decay data by F.G. Kondev

This evaluation was completed in December 2006 with a literature cut off by the same date. The Saisinuc software (2002BeXX) and associated supporting programs were used in assembling the data following the established protocol within the DDEP collaboration.

1. Decay Scheme

The deformed ^{246}Cm nucleus disintegrates by α emissions and spontaneous fission. The strongest α–decay branch populates the ground state of the daughter nuclide ^{242}Pu, which is also deformed. The level schemes of ^{242}Pu and ^{246}Cm are based on the evaluations of Akovali (2002Ak06) and Artna-Cohen (1998Ar12), respectively. The recent experimental work of Kondev *et al.* (2007Ko01) reported a weak α–decay branch to the 4^+ level of the ground-state band of ^{242}Pu.

2. Nuclear Data

Q(α) value is obtained from the adopted $\alpha_{0,0}$ energy (see section 2.1 for details) and by taking into account the relevant recoil energy. This value differs from that of 5475.1 (9) keV (2003Au03), deduced as a weighted mean of Q(α)=5475.2 (10) keV and 5474.9 (20) keV, which were determined from the $\alpha_{0,0}$ energies of 1984Sh31 and 1966Ba07, respectively. It should be noted that no uncertainty to the $E_{\alpha 0,0}$ value was reported in the original publication of 1966Ba07, but it was assigned by 2003Au03.

The experimental data on α/SF and $T_{1/2\ SF}$, together with results from the earlier evaluation of Holden (2000Ho27), are presented in Table 1.

Table 1. Experimental and evaluated data for the α/SF ratio and the SF half-life of ^{246}Cm

Author	a/**SF**	$\mathbf{T_{1/2SF}}$**, (10^7 a)**	**Method**	**Used in the evaluation**
1956Fi11	2740 (140)	> 1.24	From α/SF	No
1956FrXX		2.0 (8)	relative to ^{246}Pu weight and the α–counting technique	No
1965Me02	0.139 (9) 10^6 [a)]	1.66 (10)	relative to ^{244}Cm α–decay data [b)]	No
1969Me01	3822 (10)	1.80 (1)	From α/SF	Yes
1971Ma32	3833 (32)	1.85 (2)	From α/SF	Yes
2000Ho27		1.81 (2)	Evaluated value	No

[a)] Net (^{246}Cm fissions)/(^{244}Cm α–disintegrations).
[b)] Using $T_{1/2,\alpha}$ (^{244}Cm) = 18.11 (7) a, mole ratio (^{244}Cm/^{246}Cm) = 7.82 (9) and (^{246}Cm fissions)/(^{244}Cm α–disintegrations) = 0.139 (9) 10^6.

The %α and %SF values were deduced using α/SF = 3823 (10), a weighted mean of 3822 (10) (1969Me01) and 3833 (32) (1971Ma32):

$$\%SF = \frac{1}{1 + a/SF} \times 100 \text{, with } \%a = 100 - \%SF \qquad (1)$$

Then %SF = 0.02615 (7) % and %α = 99.97385 (7) %
The mean number of neutrons emitted by spontaneous fission is: 2.948 (from ENDF/B-VII)

The recommended partial SF half-life of $T_{1/2\ SF}$ = 1.81 (2) 10^7 a, was determined as a weighted mean of 1.80 (1) 10^7 a (1969Me01) and 1.85 (2) 10^7 a (1971Ma32).

The experimental data for the partial α–decay half-life of ^{246}Cm are presented in Table 2.

Table 2. Experimental data for the partial α–decay half-life of ^{246}Cm

Author	Method [a)]	$T_{1/2\ a}$, (a) [b)]	$T_{1/2\ a}$, (a) [c)]	$T_{1/2\ a}$, (a) [d)]	Used in the evaluation
1954Fr19	RSA to ^{244}Cm	4000 (600)	18.44 (5)	3928 (589)	No
1955Br02	IA to ^{246}Pu	2300 (460)			No
1956Bu91	IA to ^{250}Cf	6620 (320)	9.3 (9)	9311 (623)	No
1961Ca01	RSA to ^{244}Cm	5480 (170)	17.59 (6)	5642 (175)	No
1969Me01	RSA to ^{244}Cm	4711 (22)	18.099 (15)	4714 (22)	Yes
1971Mc19	ASA	4654 (40)			Yes
1971Ma32	RSA to ^{244}Cm	4820 (20)	18.099 (15)	4823 (20)	Yes
1977Po20	RSA to ^{244}Cm	4852 (76)	18.099 (15)	4855 (76)	Yes
2007Ko01	IA to ^{250}Cf	4706 (40)	13.08 (9)		Yes

[a)] RSA-relative specific activity method; ASA – absolute specific activity method; IA in-growth activity method.
[b)] Value reported in the original publication.
[c)] Half-life value for the reference ^{244}Cm or ^{250}Cf nuclide used in the original publication.
[d)] Corrected ^{246}Cm half-life values using $T_{1/2}$(^{244}Cm) = 18.11 (3) a (2005ChXX) and $T_{1/2}$(^{250}Cf) = 13.08 (9) a (2001Ak11))

Since in all cases, except 1971Mc19, relative methods were used to deduce $T_{1/2\ \alpha}$, the values reported in the original publications were corrected using the most recently adopted $T_{1/2\ \alpha}$ of the reference nuclides ^{244}Cm and ^{250}Cf, as summarized in Table 2. Results from the early work of 1954Fr19, 1955Br02, 1956Bu91 and 1961Ca01 are inaccurate and discrepant (with half-life values spanning between 2300 (460) a and 9311 (623) a), and hence, these data were excluded from the present analysis.

Although the remaining five $T_{1/2\ \alpha}$ values have better accuracy, these data are also discrepant. For example, while the data of 1969Me01, 1971Mc19 and 2007Ko01 give a weighted mean of $T_{1/2\ \alpha}$ = 4701 (17) a, the results of 1971Ma32 and 1977Po20 are clustered around the weighted mean value of $T_{1/2\ \alpha}$ = 4825 (19) a. In the present work, detailed evaluations of $T_{1/2\ \alpha}$ were carried out using specially developed techniques that deal with discrepant data (see references 1992Ra08, 1994Ka08 and 2004MaXX for example) and the results are presented in Table 3. The weighted mean (WM) value (external uncertainty) is $T_{1/2\ \alpha}$ = 4756 (32) a, but χ^2_ν = 6.16 (where $\chi^2_\nu = \chi^2/N-1$) is larger than the critical value of $\chi^2_{\nu\ crit}$ = 3.32 (99 % confidence level) because the data are discrepant.

The Limitation of Relative Statistical Weight (LRSW) method adopts $T_{1/2\ \alpha}$ = 4756 (67) a, which is the WM value, but the uncertainty is extended in order to include “the most precise” value of 4823 (20) a (1971Ma32) (uncertainty of 0.41 %). It should be noted, however, that the determined by the LRSW method “the most precise” value is as accurate as that of 4714 (22) a (1969Me01) (uncertainty of 0.47 %). Hence, if the value from 1969Me01 is adopted as “the most precise” one, then the LRSW would give $T_{1/2\ \alpha}$ = 4756 (42) a. In the LRSW case, χ^2_ν is also larger than $\chi^2_{\nu\ crit}$. The Normalized Residual Method (NRM) evaluates a value of $T_{1/2\ \alpha}$ = 4723 (27) a, while the Rajeval method (RM) adopts $T_{1/2\ \alpha}$ = 4713 (17) a. In both cases χ^2_ν is smaller than $\chi^2_{\nu\ crit}$.

Table 3. Evaluated values of the half-life of ^{246}Cm.

Method/Author [a)]	**Evaluated $T_{1/2}$, (a)**	**c^2/N-1**	
UWM	4750 (38)	6.21	
WM (external)	4756 (32)	6.16	
LRSW	4756 (67)	6.16	
NRM	4723 (27)	2.78	Adopted
RM	4713 (17)	1.24	
1989Ho24	4760 (40)	7.48	
1998Ar12	4760 (40) [b)]		

[a)] UWM – Unweighted Mean; WM – Weighted Mean; LRSW – Limitation of Relative Statistical Weight; NRM – Normalized Residual; RM – Rajeval.
[b)] Value adopted from 1989Ho24

The NRM value is recommended in the present evaluation since the relative statistical weights of the uncertainties (note that only the uncertainty reported in 1971Ma32 has been adjusted by the this method) are less than 50 %, while the RM value (uncertainties of 1971Ma32, 1971Mc19 and 1977Po20 were adjusted by this method) is biased towards that of $T_{1/2\,\alpha}$ = 4714 (22) a (1969Me01) (with a relative statistical weight of 62 %).

2.1 Alpha Transitions

The ^{242}Pu level energies were deduced by a least-square fit to the adopted γ–ray energies (see section 2.2 and Table 7 for details) using the computer program GTOL from the ENSDF evaluation package. The $\alpha_{0,0}$ energy was taken from the evaluation of Rytz (1991Ry01), while the $\alpha_{0,1}$ and $\alpha_{0,2}$ energies were obtained from the adopted $E_{\alpha 0,0}$ = 5387.5 (9) keV, the 2^+ and 4^+ level energies of ^{242}Pu, respectively, and by taking into account the relevant recoil energies.

Table 4. Experimental and evaluated values of the α–particle energies in decay of ^{246}Cm

Authors	**$E_{a0,0}$, (keV)**	**$E_{a0,1}$, (keV)**	**$E_{a0,2}$, (keV)**	**Comment** [a)]
1963Be48	5387	5345		MS
1963Dz07	5387 (4)	5345 (4)		MS
1966Ba07	5385	5342		MS
1984Sh31	5386.5 (10)	5343.5 (10)		MS
2007Ko01	5386 (3)	5342 (3)	5242 (3)	SD
1991Ry01	5387.5 (9)	5342.7 (9)		evaluated
Adopted	**5387.5 (9)**	**5343.7 (9)**	**5242.5 (10)**	**Evaluated**

a) MS – magnetic α–spectrometer; SD – semiconductor detector

The experimental values for the α–transition probabilities of ^{246}Cm are presented in Table 5. It should be noted that uncertainties were not reported in the work of 1963Be48 and 1966Ba07, but these were estimated by Rytz (1991Ry01).

Table 6 contains the evaluated $P_{\alpha 0,0}$ values using two different data sets, one that excludes values reported without uncertainty in the original publications ("limited data") and the second that includes all experimental values with uncertainties estimated by Rytz (1991Ry01) in cases where those were missing in the original publications ("all data"). The evaluated values deduced using both data sets are consisted and the WM value from the so-called "all data" set is recommended (χ^2_ν = 1.69 is smaller than the critical value of $\chi^2_{\nu\ crit}$ = 3.32 (99 % confidence level)). The recommended $P_{\alpha 0,2}$ value was deduced using the branching ratios of 2007Ko01 and the adopted here $P_{\alpha 0,0}$ = 79.17 (22) %. The $P_{\alpha 0,1}$ value was determined as:

$$P_{a\,0,1} = 100 - P_{a\,0,0} - P_{a\,0,2} \qquad (2)$$

Table 5. Experimental and evaluated α–transition probabilities in decay of ^{246}Cm.

Authors	**P**$_{a0,0}$**, (%)**	**P**$_{a0,1}$**, (%)**	**P**$_{a0,2}$**, (%)**	**Comment** [a)]
1963Be48	78	22		MS
1963Dz07	78 (5)	22 (5)		MS
1966Ba07	79	21		MS
1984Sh31	82.2 (12)	17.8 (12)		MS
2007Ko01	79.08 (22)	20.9 (4)	0.020 (2)	SD
1991Ry01	80.7 (11) [b)]	19.3 (11) [b)]		evaluated
Adopted	**79.17 (22)**	**20.81 (22)**	**0.020 (2)**	**Evaluated**

[a)] MS – magnetic α–spectrometer; SD – semiconductor detector

[b)] Rytz (1991Ry01) assigned uncertainties to the original 1963Be48 and 1966Ba07 values as follow: $P_{\alpha 0,0}$ = 78 (3) and $P_{\alpha 0,1}$ = 22 (3) (1963Be48) and $P_{\alpha 0,0}$ = 79 (2) and $P_{\alpha 0,1}$ = 21 (2) (1966Ba07).

The α–decay hindrance factors were calculated using the computer program ALPHAD from the ENSDF evaluation package with r_0 = 1.4954 (10) fm.

Table 6. Evaluated $P_{\alpha 0,0}$ values in the α–decay of ^{246}Cm

Method/Author [a)]	**"limited data"**		**"all data"**	
	P$_{a0,0}$**, (keV)**	c^2**/N-1**	**P**$_{a0,0}$**, (keV)**	c^2**/N-1**
UWM	79.8 (13)		79.26 (78)	
WM	79.18 (22)	3.30	79.17 (22)	1.69
LRSW	79.18 (22)	3.30	79.17 (22)	1.69
NRM	79.15 (22)	2.31	79.17 (22)	1.69
RM	79.10 (22)		79.10 (22)	
1991Ry01			80.7 (11)	

[a)] UWM – Unweighted Mean; WM – Weighted Mean; LRSW – Limitation of Relative Statistical Weight; NRM – Normalized Residual; RM – Rajeval.

2.2 Gamma-Ray Transitions and Electron Internal Conversion Coefficients

The energy of the $2^+ \rightarrow 0^+$ ground state band γ–ray transition of ^{242}Pu was taken from 1972Sc01. The $4^+ \rightarrow 2^+$ γ–ray transition was not observed in the α–decay of ^{246}Cm and its energy was taken from the Coulomb excitation data of 1983Sp03 (note that the uncertainty in this value comes from the work of 1971EiZS). Gamma-ray transition multipolarities were taken from the ENSDF evaluation of 1998Ar12. Since absolute γ–ray emission probabilities were not measured directly for any of the γ–ray transitions that follow α–decay of ^{246}Cm, the absolute transition probabilities, $P_{\gamma+ce}$, were deduced from the relative α–transition probabilities, presented in Table 5, after a correction for the α–decay branching was applied:

$$P_{g+ce}(g_{2,0}) = \frac{\%a}{100} \times P_{a\,0,2} \text{ and } P_{g+ce}(g_{1,0}) = \frac{\%a}{100} \times (P_{a\,0,1} + P_{a\,0,2}) \qquad (3)$$

The electron internal conversion coefficients were calculated by a program supplied with the Saisinuc software (2002BeXX) that uses interpolated values of Band *et al.* (2002Ba85) with the hole being taken into account.

Table 7. Energies, multipolarities and electron internal conversion coefficients for γ–ray transitions following α–decay of ^{246}Cm

	Energy, (keV)	Multipolarity	α_K	α_L	α_M	α_N	α_O	α_T
$\gamma_{1,0}$	44.545 (9)	E2	-	542 (16)	152 (5)	41.6 (12)	9.8 (3)	746 (22)
$\gamma_{2,1}$	102.8 (1)	E2	-	10.1 (3)	2.82 (8)	0.775 (23)	0.183 (5)	13.9 (4)

3. Atomic Data

The Atomic data (Fluorescence yields, X-Ray energies and Relative probabilities, and Auger electrons energies and Relative probabilities) were provided by the Saisinuc software (2002BeXX). Details regarding the origin of these data can be found in 1996Sc06, 1998ScZM, 1999ScZX, 2000ScXX and 2003DeXX.

4. Alpha Emissions

Details are given is section 2.1. The number of alphas per 100 disintegrations was obtained by multiplying the corresponding α–transition probabilities that are presented in Table 5 by the α–decay branching ratio of 0.999 738 5 (7).

5. Photon Emissions

5.1 X-Ray Emissions

The X-ray emissions per 100 disintegrations were calculated using the computer program EMISSION (2000ScXX).

	Energy, (keV)	(%)
Ll	12.125	0.195 (8)
Lα	14.083 – 14.279	3.03 (11)
Lη	16.334	0.082 (4)
Lβ	16.499 – 19.331	3.76 (14)
Lγ	20.708 – 21.984	0.87 (4)

5.2 Gamma-Ray Emissions

The number of γ rays per 100 disintegrations was obtained from the $P_{\gamma+ce}(\gamma_{i,k})$ values, described in section 2.2, and the total electron internal conversion coefficients, $\alpha_T(\gamma_{i,k})$ that are presented in Table 7:

$$P_{\gamma}(\gamma_{i,k}) = \frac{P_{\gamma+ce}(\gamma_{i,k})}{1+\alpha_T(\gamma_{i,k})} \qquad (4)$$

6. Electron Emissions

The energies of the conversion electrons have been calculated from the γ–ray transition energies presented in Table 7 and the corresponding electron shell binding energies (1977La19). The number of conversion electrons of type x=T,L,M,N and O, where T stands for total, L for L-shell electrons, etc., per 100 disintegrations have been determined from the evaluated numbers of photons per 100 disintegrations, $P_{\gamma}(\gamma_{i,k})$, and the corresponding electron internal conversion coefficients, $\alpha_x(\gamma_{i,k})$

$$ec_{i,kx} = P_{\gamma}(\gamma_{i,k}) \times \alpha_x(\gamma_{i,k}) \qquad (5)$$

The number of L Auger electrons per 100 disintegrations was obtained from the computer program EMISSION (2000ScXX).

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^{252}Cf - Comments on evaluation of decay data by M.M. Bé and V. Chisté

This evaluation was completed in November 2007. The literature available by October 2007 was included.

1 Decay Scheme

^{252}Cf disintegrates by α emissions mainly to the ^{248}Cm ground state level, and by spontaneous fission for 3,086 (8) %.
In the Tables part, the data are then normalized to 96,914 (3) alpha decays (see §2.2).
The calculated Q value of 6217 (26) keV deduced from the decay scheme data, for the α decay, is in agreement with the value of 6216,87 (4) keV from Audi *et al.* (2003Au03).

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).
The level energies, spins and parities are based on the evaluation of Y.A. Akovali (1999Ak02).

2.1 Total half-life

A theoretical calculation of the α-decay half-life of Cf-252, by M. Balasubramaniam *et al.* (1999Ba03) leads to a value of 2,592 *a*.

The measured half-life are, in years:

Reference	half-life	Uc	Comments
Mehta (1965Me02)	2,646	0,004	
De Volpi (1969De23)	2,621	0,006	Rejected by Chauvenet criterion
Mijnheer (1973Mi05)	2,659	0,010	Rejected by Chauvenet criterion
V.Spiegel (1974Sp02)	2,638	0,007	
V.T. Shchebolev (1974Sh15)	2,628	0,010	Superseded by 1992Sh33
Mozhaev (1976Mo30)	2,637	0,005	
Lagoutine (1982La25)	2,639	0,007	
J.R.Smith (1984SmZW)	2,651	0,003	
W.G.Alberts (1983Al**)	2,648	0,002	
E.J. Axton (1985Ax**)	2,6503	0,0031	
Chen Keliang (1988Ke**)	2,64	0,13	
V.T. Shchebolev (1992Sh33)	2,645	0,003	
Weighted mean	2,6470	0,0014	χ^2 = 1,3 ; χ^2 crit = 2,5

(See also 1994Ka08, 1994KhZWfor previous evaluated values.)
In the set of data listed above, two values were rejected in application of the Chauvenet's criterion. A value from 1974Sh15 has been superseded by a more recent one by the same author (1992Sh33). The remaining set of 9 values is consistent with a reduced χ^2 of 1,3. Then the weighted mean is 2,6470 with an external uncertainty of 0,0014. The largest contribution to the statistical weight (35 %) is from Alberts ; Axton,

Shchebolev and Smith give about 15 % each.
However, in the references listed above the uncertainty budget, in most cases, was not given. Some of them include the statistical part of the uncertainty only and did not take into account the systematic components as the associated presence of Cf-250 for example. So, as recommended in the study of Kharitonov (1994KhZW) an uncertainty of 0,1 % has been applied on the final result.

The adopted value is *2,6470 (26) a*.

2.2 Spontaneous fission half-life

The spontaneous fission decay constant λ_{sf} is determined by :

$\lambda_{sf} = \lambda / [(N\alpha/N_{sf}) + 1]$

where $(N\alpha / N_{sf})$ is the ratio between the number of α-decays and N_{sf} the number of spontaneous fission events and, λ is the total ^{252}Cf decay constant.

Measured values of the ratio $N\alpha/N_{sf}$:

Reference	Value	Uc
D.Mehta (1965Me02)	31,3	0,2
B.M.Aleksandrov (1970Al23)	31,39	0,26
J.D.Hastings (1971Ha**)	31,5	0,2
A.K. Pandey (1993Pa29)	31,56	0,35
Y.S.Popov (1990Po24)	31,38	0,12
Weighted mean	31,40	0,08

The 5 data sets given above are consistent (reduced χ^2 =0,2).

From this value and the total half-life above (§ 2.1), a **spontaneous fission half-life of *85,76 (23) a*** is deduced.

From $N\alpha/N_{sf}$ = 31,40 (8) and $N\alpha + N_{sf}$ = 100 Cf-252 decays, the **percentage of spontaneous fissions in the decay of Cf-252 is *3,086 (8) %*.**

Then the percentage of alpha transitions is: 96,914 (8) %.

2.3 Average number of neutrons

The average number of neutrons $\overline{\nu}$ emitted by spontaneous fission is:
$\overline{\nu}$ = 3,7675 (40)
as evaluated in the study of M. Divadeenam *et al.* (1984Di08) where relevant experimental data are taken into account and a least-squares fitting program was used to obtain an overall fit.

The average number of neutrons emitted per 100 disintegrations is:
n = 3,086 (8) × 3,7675 (40) = 11,627 (33) %

2.4 a Transitions

See Alpha-particle emissions (§ 4)

2.5 g Transitions

Multipolarities of these γ-ray transitions are from 1999Ak02.

The internal conversion coefficients for the 43- and 100-keV gamma transitions were calculated with the BrIcc code for the Frozen Orbital approximation (2005KiZW).

3 Atomic Data

Atomic values, ω_K, ϖ_L and n_K, are from Schönfeld and Janβen (1996Sc33).

4 a-Particle Emissions

4.1 a-Particle Energies

From the measured values of Rytz (1986Ry04) and Baranov (1976BaZZ, 1971Ba10, 1970Ba18), Rytz (1991Ry01) made some adjustments taking into account variations in the energies used as calibration standards. This leads, for the two main groups, to the recommended values of :
6118,10 (10) keV and 6075,64 (11) keV

The other energies : 5976,6 ; 5826,3 and 5615,6-keV are from Baranov (1970Ba18 and 1971Ba10)

Recorded spectra are also shown in Glover (1984Gl03) and Wiltshire (1985Wi14).

4.2 a-Particle Intensities

Measured alpha intensities, per 100 alpha decays :

Energy (keV)	Reference	Intensity (%)	Uc	Comments
6118,10	Asaro (1955As42)	84,5		
	Baranov (1976BaZZ)	84,1	0,4	See also 1970Ba18
	Adopted	84,3	0,3	Unweighted mean
6075,64	Asaro (1955As42)	15,5		
	Baranov (1976BaZZ)	15,8	0,1	See also 1970Ba18
	Adopted	15,6	0,3	Unweighted mean
5976,6	Baranov (1970Ba18)	0,2		See also 1985Wi14
	Asaro (1958As64)	0,28		
	Adopted	0,24	0,04	Unweighted mean
5826,3	Baranov (1970Ba18)	$2\ 10^{-3}$		
5616	Baranov (1970Ba18)	$\sim 6\ 10^{-5}$		

The number of measurements is very scarce moreover the results given by Asaro are without uncertainties. To try to make the most of this limited data, the unweighted mean is adopted, for the 6118-, 6075-, 5976-keV groups, with uncertainty covering the two existing values.
The intensity of the 5826-keV group is from Baranov (1970Ba18).
The weak group with energy 5615-keV, possibly feeding a 505-keV level, is not adopted, because no photons depopulating this level have been observed in the Cf-252 decay.

In the Tables part, these data are normalized to 96,914 (8) alpha decays (see §2.2).

5 Photon Emissions

5.1 γ-Ray Emissions

Measured gamma-ray intensities, per 100 alpha decays :

Energy (keV)	Reference	Intensity (%)	Uc	Comments
42	Asaro (1955As42)	0,014		
43,399 (25)	Watson (1971Wa28)	0,0153	0,0009	
	Adopted	0,0157	0,0004	From decay scheme
100,2 (4)	Asaro (1955As42)	0,013		Adopted Eγ (1999Ak02)
	Adopted	0,0123	0,0021	From decay scheme
154,5 (2)	Piercey (1993Pi07)			Adopted Eγ (1993Pi07)
	Adopted	0,00053	0,00001	From decay scheme

The gamma ray intensities were deduced from the gamma-ray transition probabilities (see §2.5) and the theoretical ICC values.

In the Tables, these data are normalized to 100 decays of Cf-252 (see §2.2).

5.2 X-ray emissions

Asaro (1955As42) measured a K X-ray intensity of 0,007 %. This value disagrees with an expected KX-ray intensity of 0,000 086 % from the internal conversion electrons of the 154,5-keV gamma ray.

Relative intensities were measured by Popov *et al.* (1990Po14).

Total L X-ray intensity following the Cf-252 decay to Cm-248 was measured by Watson (1971Wa28) as 7,83 (40) % per 100 alpha decays.

The L X-ray total intensity calculated from the decay scheme data is 6,26 (14) % per 100 alpha decays. This result is in reasonable agreement with the measured value of Watson.

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