^{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transitions well studied (1990Ak02), Singh and Tuli (2005Si15) list a large number of weak transitions and γ rays from unpublished work of de Bettencourt (1985DeZR), defining them as tentative.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$\rightarrow$^{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)	
$K\beta_1$	111,298		3,27 (15)	3,11 (15)			3,35 (5)	3,34 (8)	3,24 (6)	} 5,25 (18)
$K\beta_5$	111,964			0,15 (1)			0,1230 (17)	0,1239 (28)	0,139 (18)	
$K\beta_2$	114,407 (11)			0,52 (7)		} 1,59 (9)	1,293 (23)	1,34 (5)	} 1,317 (21)	} 1,49 (10)
$K\beta_4$	115,012	} 1,74 (8)	} 1,71 (8)	0,78 (7)	} 1,73 (8)		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)
$L\alpha$	13,93	15,7 (7)	12,7 (13)	21,5 (43)	16,9 (6)
$L\beta$	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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