^{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)·10^3	4,6·10^3
$\gamma_{2,0}$	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)·10^3	5,0·10^3
$\gamma_{5,1}$	87,99 (3)	340 (4)	333
$\gamma_{5,0}$	94,66 (5)	1,55 (2)·10^3	1,5·10^3
$\gamma_{9,6}$	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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