

**²³¹Th -Comments on evaluation of decay data
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This evaluation was completed in 2007. Literature available by May 2007 was included.

1 Decay Scheme

²³¹Th disintegrates 100 % by β^- emission to levels in ²³¹Pa. ²³¹Th ground state has $J^\pi = 5/2^+$ (2001Br31).

The adopted $Q(\beta^-)$ value of 391.6 (15) keV from Audi(2003Au03) is good in agreement with the $Q(\beta^-)$ 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 ²³¹Th half-life values are listed in Table 1.

Table 1 Measured half-life values of ²³¹Th 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	4p β 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, $\chi^2=0.88$
25.52 (1)	recommended value	Weighted mean

A weighted half-life average has been calculated using the LWM program.

2.1 β^- transitions

The maximum energies of the β^- transitions in the decay of ²³¹Th 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 $I_{\beta^-}(\text{g.s.} + 9.2 \text{ keV}) = 0.022$ (7) and $I_{\beta^-}(58.6 \text{ keV}) < 0.33$ 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, $\delta = 0.14 (+12 -4)$ 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	$\alpha_T = 757$		$\alpha_{M3} > 9$
25.64	E1	$\alpha_T = 4.37, \alpha_L = 3.26, \alpha_M = 0.84$	$\alpha_T = 4.8\ 10$	$\alpha_{L3} = 1.6\ 3, \alpha_M = 0.96\ 9$
58.57	E2	$\alpha_T = 155.5, \alpha_L = 113.6, \alpha_M = 31.3$		$\alpha_L = 115.9, \alpha_M = 29.9\ 30$
63.86	M1+E2	$\alpha_T = 34\ 16, \alpha_L = 25, \alpha_M = 7$		$\alpha_{L1} = 9.1\ 16$
68.5	E2	$\alpha_T = 73.3, \alpha_L = 53.5, \alpha_M = 14.8$		$\alpha_L = 57\ 11$
81.228	M1(+E2)	$\alpha_T = 8.1, \alpha_L = 6.1, \alpha_M = 1.5$		$\alpha_{L1} = 4.7\ 8, \alpha_M = 1.3\ 3$
82.087	M1(+E2)	$\alpha_T = 7.9, \alpha_L = 5.9, \alpha_M = 1.4$		$\alpha_{L1+L3} = 5.7\ 11, \alpha_M = 1.6\ 4$
84.214	E1	$\alpha_T = 0.19, \alpha_L = 0.14$	$\alpha_T = 2.8\ 4$	$\alpha_T = 2.50\ 25, \alpha_M = 0.57\ 10$
99.278	M1+E2	$\alpha_T = 6, \alpha_L = 4.4, \alpha_M = 1.1$		$\alpha_M = 1.13\ 14, \alpha_N = 0.35\ 10$
135.664	M1(+E2)	$\alpha_T = 8, \alpha_K = 6.1, \alpha_L = 1.4$		$\alpha_K = 6.5\ 11, \alpha_L = 1.1\ 3$
145.94	M1+E2	$\alpha_T = 5.1, \alpha_K = 3.4, \alpha_L = 1.3$		$\alpha_K = 3.6\ 8, \alpha_L = 0.8\ 3$
163.101	M1(+E2)	$\alpha_T = 4.9, \alpha_K = 3.9, \alpha_L = 0.78$		$\alpha_K = 4.1\ 5, \alpha_L = 0.6\ 1$
217.94	E1	$\alpha_T = 0.079, \alpha_K = 0.062, \alpha_L = 0.01$		$\alpha_K < 0.12, \alpha_L < 0.09$
311	M1+E2	$\alpha_T = 0.6, \alpha_K = 0.5, \alpha_L = 0.1$		$\alpha_L = 0.11\ 3, \alpha_M = 0.04\ 1$
410.64	E2	$\alpha_T = 0.0548, \alpha_K = 0.0344\ 5$		

3. Atomic data

Atomic fluorescence yields ($\omega_K, \omega_L, \omega_M, \eta_{KL}$ 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)
$K_{\alpha 1}$	0.69 (8)	0.64 (4)	0.59 (7)
$K_{\alpha 2}$	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 γ -ray energy values

Measurements of γ -ray energy values from ²³¹Th 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 ²³¹Th

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)	236.1 (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 γ -ray intensities

Experimental γ -ray intensities from ²³¹Th 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 ^x								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: $I(\gamma+ce)$, from γ -ray transition intensity balance;

b: $I(\gamma+ce)$, 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 ²³¹Th 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 ²³¹Th

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), $\chi^2=1.07$
6.70 (7)		LWM (except 1960As03, 1971Ko48. 1973Br12), $\chi^2=1.1$
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).

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