^{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
Kα_2	87.768	0.715 (23)
Kα_1	90.885	1.16 (4)
Kβ_1’	102.10 – 103.46	0.410 (15)
Kβ_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 $\alpha_L = 3.3$ (4) is $\delta = 0.007$.

$\gamma_{2,0}$: 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 $\delta = 0.41$ (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.

6. References

1932Grosse A.V. Grosse, Naturwiss., 20 (1932) 505. [half-life]

1949Va02 Q. Van Winkle, R.G. Larson, L.I. Katzin, J. Am. Chem. Soc. 71 (1949) 2585. [half-life]

1953Fa08 P. Falk-Vairant, M. Riou, J. Phys. Radium 14 (1953) 65. [gamma-ray emission probabilities and energies]

1956Hu96 J.P. Hummel, Thesis, Univ. California (1956); UCRL-3456 (1956). [alpha-particle emission probabilities]

1960As02 F. Asaro, F.S. Stephens, J.M. Hollander, I. Perlman, Phys. Rev. 117 (1960) 492. [L- and M-shell conversion coefficients]

1960Fo05 R. Foucher, C. R. Acad. Sci., Paris. 250 (1960) 1249. [gamma-ray emission probabilities]

1961Ba42 S.A. Baranov, V.M. Kulakov, P.S. Samoilov, A.G. Zelenkov, Yu.F. Rodionov, S.V. Pirozhkov, Zhur. Eksptl. i Teoret. Fiz. 41 (1961) 1475; Soviet Phys. JETP 14 (1962) 1053. [alpha-particle emission energies and probabilities, experimental conversions]

1961Br32 F. Bragança Gil, G.Y. Petit, J. Phys. Radium 22 (1961) 680. [half-life first excited level]

1961Ki05 H.W. Kirby, J. Inorg. Nucl. Chem. 18 (1961) 8. [half-life]

1963Ab04 H. Abou-Leila, R. Foucher, A.G. De Pinho, N. Perrin, M. Valadares, J. Phys. 24 (1963) 857. [spin and parity, multipolarity]

1963Su10 V.B. Subrahmanyam, Thesis, Univ. California (1963); UCRL-11082 (1963). [alpha-particle emission probabilities]

1966Ba14 G. Bastin, C.F. Leang, R.J. Walen, C. R. Acad. Sci., Paris. 262B (1966) 89. [alpha-particle emission energies]

1968Ba25 S.A. Baranov, V.M. Kulakov, V.M. Shatinskii, Yadern. Fiz. 7 (1968) 727; Sov. J. Nucl. Phys. 7 (1968) 442. [alpha-particle emission energies]

1968Br04 D. Brown, S.N. Nixon, K.M. Glover, F.J.G. Rogers, J. Inorg. Nucl. Chem. 30 (1968) 19. [half-life]

1968Ha22 G.R. Hagee, R.C. Lange, A.G. Barnett, A.R. Campbell, C.R. Cothern, D.F. Griffing, H.J. Hennecke, Nucl. Phys. A115 (1968) 157. [spin and parity, conversion electron emission probabilities]

1969Ba20 A.G. Barnett, A.R. Campbell, G.R. Hagee, J. Inorg. Nucl. Chem. 31 (1969) 1553. [multipolarity, mixing ratio, conversion electron emission probabilities]

1969La04 R.C. Lange, G.R. Hagee, Nucl. Phys. A124 (1969) 412. [gamma-ray emission energies and probabilities]

1969Ro33 J. Robert, C.F. Miranda, R. Muxart, Radiochim. Acta 11 (1969) 104 [half-life]

1970De19 A.G. De Pinho, E.F. da Silveira, N.L. da Costa, Phys. Rev. C2 (1970) 572. [gamma-ray emission energies and probabilities, ICC]

1970Le11 C.F. Leang, J. Phys. Paris, 31 (1970) 269. [gamma-ray emission energies and probabilities]

1971Le10 C.F. Leang , J. Phys. Paris, 32 (1971), 95. [spin and parity]

1972Ga39 R.K. Garg, S.D. Chauhan, S. Sanyal, S.C. Pancholi, S.L. Gupta, N.K. Saha, Z. Phys. 257 (1972) 124. [half-life first excited level]

1974De11 A.G. De Pinho, L.T. Auler, A.G. da Silva, Phys. Rev. C9 (1974) 2056. [gamma-ray and X-ray emission probabilities, ICC]

1976Baranov S.A. Baranov, A.G. Zelenkov, V.M. Kulakov, At. Energy (Sov. J. At. Energy) 41 (1976) 342. [alpha-particle emission energies and probabilities]

1976BaZZ S.A. Baranov, A.G. Zelenkov, V.M. Kulakov, Proc. Advisory Group Meeting on Transactinium Nucl. Data, Karlsruhe, IAEA-186, Vol. III (1976) p.249. [alpha-particle emission energies and probabilities]

1979Bo30 H.G. Borner, G. Barreau, W.F. Davidson, P. Jeuch, T. von Egidy, J. Almeida, D.H. White, Nucl. Instrum. Methods 166 (1979) 251. [gamma-ray emission energies]

1979Te02 W. Teoh, R.D. Connor, R.H. Betts, Nucl. Phys. A319 (1979) 122. [gamma-ray emission energies and probabilities, ICC, multipolarity]

1982An02 I. Anicin, I. Bikit, C. Girit, H. Guven, W.D. Hamilton, A.A. Yousif, J. Phys.(London) G8 (1982) 369. [gamma-ray emission probabilities]

1983Banham M.F. Banham, R. Jones, Int. J. Appl. Radiat. Isot.34 (1983) 1225. [gamma-ray emission probabilities]

1984BAYS M.F. Banham, private communication quoted by 1986LoZT (1984) [gamma-ray emission probabilities]

1985Is03 T. Ishii, I. Ahmad, J.E. Gindler, A.M. Friedman, R.R. Chasman, S.B. Kaufman, Nucl. Phys. A444 (1985) 237. [half-life first excited level]

1986LoZT IAEA Technical Reports Series No.261 (1986). [evaluated gamma-ray emission energies and probabilities and alpha-particle emission energies and probabilities]

1990Ho28 N.E. Holden, Pure Appl. Chem. 62 (1990) 941. [half-life evaluation]

1991Ry01 A. Rytz, At. Data Nucl. Data Tables 47 (1991) 205. [alpha-particle probability and energy evaluation]

1996Sc06 E. Schönfeld, H. Janssen, Nucl. Instrum. Methods Phys. Res. A369 (1996) 527. [atomic data]

1998Ak04 Y.A. Akovali, Nucl. Data Sheets 84 (1998) 1. [r_0 radius parameter]

2002Ba85 I.M. Band, M.B. Trzhaskovskaya, C.W. Nestor Jr., P.O. Tikkanen, S. Raman, At. Data Nucl. Data Tables 81 (2002) 1. [ICC]

2001Br31 E. Browne, Nucl. Data Sheets 93 (2001) 763. [spin, parity, energy level, multipolarity]

2003Au03 G. Audi, A.H. Wapstra, C. Thibault, Nucl. Phys. A729 (2003) 337. [Q value]

2008Ki07 T. Kibédi, T.W. Burrows, M.B. Trzhaskovskaya, P.M. Davidson, C.W. Nestor Jr., Nucl. Instrum. Methods Phys. Res. A589 (2008) 202. [theoretical ICC]

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.

		P_γ^{rel}					
	E_γ(keV)	**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)

		P_γ^{rel}						
	E_γ(keV)	**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)	294 (8)	149.6 (75)	143.2 (55)	146.3 (13)	146.2 (13)
$\gamma_{15,1}$	302.670 (14)	148 (8)	144 (13)		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.