^{241}Pu – Comments on evaluation of decay data by V.P.Chechev and N.K. Kuzmenko

This evaluation was completed in November 2005 and corrected in September 2006. The literature available by September 2006 was included.

1. Decay Scheme

The decay scheme is based on the evaluation of 2006Ba41 (see also the evaluations of 1995Ak01 and 1978El02). It can be considered as basically completed though some very weak gamma transitions were not observed in ^{241}Pu alpha decay.

It should be noted there is an ambiguity in the placement of 121,2 keV γ–transition in ^{237}U level scheme due to doublet (7/2+, 11/2+) near 204 keV. Following 2006Ba41 we show the above γ–transition in Pu-241 α-decay as going from the level 7/2+ while Fotiades *et al.* (2004Fo01) observed this transition in (n,2n)-reaction as going from the level 11/2+.

The upper limit of SF decay is from 1985Dr09.

2. Nuclear Data

Q(α) value is from 2003Au03.

The evaluated ^{241}Pu half-life is based on the experimental data given in Table 1. A detailed review of half-life measurements up to 1985 can be found in 1987Ag03. References to earlier measurements are listed in 1978El02. Discrepancies in the measurements were examined by 1986Ha06 and 1987Ba84 in terms of chemical dependency of low-energy β^- decay. In 1986Ha06 a conclusion is drawn that chemical variations (~ 0,3 %) cannot be accountable completely for half-life discrepancies (≥ 1 %).

Table 1. Experimental values of the ^{241}Pu half-life (in years)

Reference [a]	Author(s)	Measurement method	Stated value	Revised value	Comments
1953Ma19	MacKenzie *et al.*	Ingrowth of ^{241}Am by α counting	13,0 (2)	14,1 (2)	Re-estimated for the ^{241}Am half-life of 432,6 (6) a
1956Ro26	Rose and Milstead	Ingrowth of ^{241}Am by 60-keV γ counting	12,77 (28)	13,87 (30)	Re-estimated for the ^{241}Am half-life of 432,6 (6) a. OMITTED: outlier
1960Br15	Brown *et al.*	Ingrowth of ^{241}Am by α counting	13,24 (24)	14,12 (26)	Re-estimated for the ^{241}Am half-life of 432,6 (6) a
1961Sm03	Smith	Ingrowth of ^{241}Am α-emission	13,0 (3)	14,1 (3) 13,3 (3)	Re-estimated for the ^{241}Am half-life of 432,6 (6) a
1966French	French *et al.*	Change in ^{241}Pu/Pu ratio by MS	13,59 (46)		Quoted in 1987Ag03 OMITTED: outlier
1966Stepan	Stepan and Nisle	Change in ^{241}Pu reactivity with time	13,63 (36)		OMITTED: updated in 1970Ni02
1967Shields	Shields	Change in ^{241}Pu/Pu ratio in a Pu isotopic standard in 2 years by MS	14,4 (2)		Quoted in 1967Oe01. Stated uncertainty at 0,95 C.L. OMITTED: updated in 1970Sh18

1968Ca19	Cabell	Change in ^{241}Pu/^{240,242}Pu ratios in 4,5 years by MS	14,98 (33)		OMITTED: updated in 1971Ca15, outlier
1970Ni02	Nisle and Stepan	Change in ^{241}Pu reactivity with time (in 2,5 yr)	14,63 (27)		
1970Sh18	Shields	Change in ^{241}Pu/Pu ratio in a Pu isotopic standard in 4 years by MS	14,6 (4)	14,6 (2)	Stated uncertainty at 0,95 C.L. For statistical analysis it has been multiplied by 0,5
1971Ca15	Cabel and Wilkins	Change in ^{241}Pu/^{240,242}Pu ratios in 6,65 years by MS	15,16 (19)		OMITTED: outlier
1972 Whitehead	Whitehead *et al.*	Ingrowth of ^{241}Am by 60-keV γ counting	14,91 (15)	14,96 (15)	Re-estimated for the ^{241}Am half-life of 432,6 (6) a OMITTED: updated in 1977Whitehead, outlier
1973JoYT	Jordan	Calorimetric determination of power decay	14,355 (7)		Quoted in 1974StYG
1973Ze02	Zeigler and Ferris	Change in ^{241}Pu/^{240}Pu ratio by MS	14,89 (11)		OMITTED: outlier
1975WiYM	Wilkins	Change in ^{241}Pu/^{240,242}Pu ratio by MS	15,02 (10)		OMITTED: outlier
1976McZB	McKean and Crouch	Change in ^{241}Pu/^{240,242}Pu ratio by MS	14,35 (6)		
1977Crouch	Crouch and McKean	Change in ^{241}Pu/^{240,242}Pu ratio by MS	14,41 (12)		Average of measurement results from 1976-1977 series of experiments
1977 Whitehead	Whitehead	Ingrowth of ^{241}Am 60-keV γ ray	14,56 (15)		
1978 Vaninbroukx	Vaninbroukx	Ingrowth of ^{241}Am by α and 60-keV γ ray counting	14,60 (10)		
1978 Vaninbroukx	Vaninbroukx	Change in ^{241}Pu/^{240}Pu ratio by MS	14,30 (14)		
1979Garner	Garner and Machlan	Change in ^{241}Pu/^{240,242}Pu ratio by MS	14,38 (7)		
1980Ag02	Aggarwal and Jane	Ingrowth of ^{241}Am by α spectrometry	14,42 (9)		80 α-spectrometric measurements in 457 days
1980Ma45	Marsch *et al.*	Change in ^{241}Pu/^{242}Pu ratio in 3,6 yr by MS	14,38 (6)	14,38 (3)	Stated uncertainty at 0,95 C.L. For statistical analysis it has been multiplied by 0,5
1981Ag01	Aggarwal *et al.*	Ingrowth of ^{241}Am by IDAS	14,52 (8)		
1981Ag07	Aggarwal *et al.*	Ingrowth of ^{241}Am by α spectrometry and APS	14,44 (6)		Average of the measurement results from two independent series of experiments
1982Ag01	Aggarwal *et al.*	Ingrowth of ^{241}Am by IDMS	14,32 (11)	14,32 (6)	Revised uncertainty, see 1989Ho24

1982Hiyama	Hiyama *et al.*	Change in $^{241}Pu/Pu$ ratio by MS	14,29 (15)		Quoted in 1989Ho24
1983DeZX	De Bievre *et al.*	Change in $^{241}Pu/^{240}Pu$ ratio in 6 years by MS	14,33 (2)		OMITTED: superseded in 1997DeZY
1985Ag02	Aggarwal *et al.*	Changes in $^{241}Pu/^{240}Pu$, $^{241}Pu/^{239}Pu$, $^{241}Pu/^{242}Pu$ ratios in 5 years by MS	14,38 (2)		In 1985Ag02 it is noted that values from 1980Ag02, 1981Ag01, 1981Ag07, 1982Ag01 were obtained in independent sets of experiments
1986Ti04	Timofeev *et al.*	Ingrowth of ^{241}Am by IDMS	14,57 (10)	14,57 (5)	Stated uncertainty at 0,95 C.L. For statistical analysis it has been multiplied by 0,5
1989Pa21	Parker *et al.*	Change in $^{241}Pu/^{239}Pu$ ratio by high resolution γ-spectrometry	14,355 (40)		156 sets of normalized spectral full energy peak-area ratios from 13 plutonium samples during 10 years
1997DeZY	De Bievre and Verbruggen	Change in $^{241}Pu/^{240}Pu$ ratio by precision MS	14,290 (6)	14,290 (3)	Stated uncertainty at 0,95 C.L. For statistical analysis it has been multiplied by 0,5

MS=Mass Spectrometry, IDMS=Isotope Dilution Mass Spectrometry, IDAS=Isotope Dilution Alpha Spectrometry

[a] In 1978El02 two more experimental values of are quoted from the private communications of 1977RGZZ and 1978RGZZ. These values are intermediate results of experiments and not discussed later on including the review of 1987Ag03.

After omitting the five superseded values from 1966Stepan, 1967Shields, 1968Ca19, 1972Whitehead and 1983DeZX the data set for statistical processing includes the 24 values. The LWEIGHT computer program using the LRSW analysis has identified the four outliers of 1971Ca15, 1975WiYM, 1973Ze02 and 1956Ro26 and increased the uncertainty of 1997DeZY by 2,04 times. The weighted average of the remaining twenty three values is 14,327, with an internal uncertainty of 0,037, a reduced χ^2 of 5,34, and an external uncertainty of 0,010. The unweighted average is 14,371 (34). The LWEIGHT program has chosen the weighted average and expanded the final uncertainty to 0,037 so range includes the most precise value of 14,290.

The adopted value of the ^{241}Pu half-life is 14,33 (4) years, or 5234 (15) days.

Possible chemical effects do not exceed or about the stated relative uncertainty of the half-life.

2.1. Beta Transition

^{241}Pu decays by β^- emission to the ground state of ^{241}Pu (Table 2).

Table 2. ^{241}Am level populated in the ^{241}Pu β^--decay

Level	Energy, (keV)	Spin and parity	Half-life	Probability (%)
0	20,8 (2)	$5/2^-$	432,6 (6) a	99,997 56 (2)

The experimental and evaluated values of the β^- transition energy are given in Table 3.

The value Q^- = 20,78 (20) keV from 1999YaZX was superseded by the same group in 1999Dr13 and 2000Dr02. Audi *et al.* (2003Au03) give Q^- = 20,78 (13) keV taking into account the value from 1999YaZX (see also 2005Ma88).

Table 3. Experimental values of the ^{241}Pu β^- transition energy (keV)

Level	1952Fr25	1956Sh31	1999Dr13 2000Dr02	Evaluated
0	20,5 (12)	20,8 (2)	20,7 (3)	20,8 (2)

The probability of the β^--transition was deduced from the evaluated α branching (Table 4).

Table 4. Experimental and evaluated values of α branching (α/β^-), per decay, in the ^{241}Pu decay

1961Sm03	1968Ah01	1976GuZN	1977VaYR	Evaluated
2,44 (10)$\cdot10^{-5}$	2,45 (8)$\cdot10^{-5}$	2,46 (1)$\cdot10^{-5}$	2,42 (2)$\cdot10^{-5}$	2,44 (2)$\cdot10^{-5}$

2.2. Alpha Transitions

The energies of the alpha transitions have been deduced from Q_α value and the level energies given in Table 5. The level energies were calculated from the gamma-ray energies except for the levels "8","9" and "10" the energies of which were taken from 1996FiZX.

Table 5. ^{237}U levels populated in the ^{241}Pu α decay

Level number	Energy, (keV)	Spin and parity	Half-life	Experimental probability of α transition (%) 1965Ba26	Experimental probability of α transition (%) 1968Ah01	Adopted probability of α transition (%)
0	0,0	1/2$^+$	6,752 (2) d	8,6$\cdot10^{-6}$		8,6 (10)$\cdot10^{-6}$
1	11,39 (2)	3/2$^+$		2,5$\cdot10^{-5}$		2,5 (2)$\cdot10^{-5}$
2	56,30 (12)	5/2$^+$		0,88$\cdot10^{-5}$	1,00 (12)$\cdot10^{-5}$	1,00 (12)$\cdot10^{-5}$
3	82,97 (13)	7/2$^+$		2,73$\cdot10^{-5}$	3,2 (3)$\cdot10^{-5}$	3,2 (3)$\cdot10^{-5}$
4	159,96 (2)	5/2$^+$	3,1 (1) ns	2,04$\cdot10^{-3}$	2,03 (4)$\cdot10^{-3}$	2,03 (4)$\cdot10^{-3}$
5	204,19 (14)	7/2$^+$		3,00$\cdot10^{-4}$	2,95 (8)$\cdot10^{-4}$	2,95 (8)$\cdot10^{-4}$
6	260,95 (17)	9/2$^+$	-	2,88$\cdot10^{-5}$		2,9 (3)$\cdot10^{-5}$
7	274,0 (10)	(7/2)$^-$	155 (6) ns		0,5 (2)$\cdot10^{-5}$	0,5 (2)$\cdot10^{-5}$
8	316 (5)	(9/2)$^-$	-		≈1,7$\cdot10^{-6}$	≈1,7$\cdot10^{-6}$
9	327 (3)	11/2$^+$	-	≈7$\cdot10^{-7}$		≈7$\cdot10^{-7}$
10	367 (3)	(11/2$^-$)			≈7$\cdot10^{-7}$	≈7$\cdot10^{-7}$

The absolute alpha transition probabilities, $P(\alpha_i)$, were calculated using the value of 2,44 (2)$\cdot10^{-5}$ for the ^{241}Pu alpha decay branching. The uncertainties of $P(\alpha_{0,0})$ and $P(\alpha_{0,1})$ have been estimated using the relative uncertainty of the sum of $P(\alpha_{0,0})$ and $P(\alpha_{0,1})$ (equal to 1/15) from 1968Ah01.

The probabilities of α-transitions (per 100 α decays) are from the measurements of 1965Ba26 and 1968Ah01. Other measurements: 1976BaZZ. The values of hindrance factors have been calculated using ALPHAD code and r_0 = 1,5156 (9) from 1998Ak04.

2.3. Gamma-ray Transitions and Internal Conversion Coefficients

The evaluated energies of gamma-ray transitions are virtually the same as the photon energies because nuclear recoil is negligible.

The gamma-ray transition probabilities, $P_{\gamma+ce}$, were deduced from the gamma-ray emission probabilities and the total internal conversion coefficients (ICC's) interpolated from the BrIcc package. The relative uncertainties of α_K, α_L, α_M, α_T for pure gamma ray multipolarities have been taken as 2 %.

$P_{\gamma+ce}$ ($\gamma_{1,0}$ 11,39-keV), $P_{\gamma+ce}$ ($\gamma_{3,2}$ 26,6-keV), $P_{\gamma+ce}$ ($\gamma_{5,4}$ 44,18-keV), $P_{\gamma+ce}$ ($\gamma_{2,1}$ 44,86-keV) and $P_{\gamma+ce}$ ($\gamma_{6,5}$ 56,76-keV) were derived from the intensity balances using the adopted probabilities of α-transitions to the corresponding levels. The E2/M1 mixing ratios for $\gamma_{5,4}$ (44,18-keV), $\gamma_{2,1}$ (44,86-keV) and $\gamma_{6,5}$ (56,76-keV) have been deduced from the calculated total conversion coefficients. The gamma transition multipolarities and the E2/M1 mixing ratios for the remaining gamma transitions have been adopted from the analysis of the ^{237}U level scheme in 1995Ak01.

The transition $\gamma_{6,4}$ (100,94 keV) was not observed experimentally; it is obscured by U KX-rays. This transition is given in 1995Ak01.

3. Atomic Data

3.1. Fluorescence yields

The fluorescence yield data are from 1996Sc06 (Schönfeld and Janßen).

3.2. X Radiations

The relative KX-ray emission probabilities are from 1999ScZX.

3.3. Auger Electrons

The ratios P(KLX)/P(KLL), P(KXY)/P(KLL) are from 1996Sc06.

4. Electron Emissions

The energies of the conversion electrons have been calculated from the gamma transition energies and the electron binding energies.

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

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

β^- average energy was adopted from the measurement of 1968Oe01. The calculated value is discrepant: 5,23(5) keV.

5. Alpha Emissions

In Table 6 the experimental and adopted energies of α particles (in keV) are given. The original values of 1965Ba26, 1968Ba25 were increased by 0,4 keV and the values of 1968Ah01 by 0,6 keV because of changes in calibration energies, as recommended by Rytz in 1991Ry01. Other measurements: 1953As40, 1964Dz03, 1976BaZZ, 1984Gl03.

The adopted energies of α particles have been obtained from Q_α value and the level energies given in Table 5 taking into account the relevant recoil energies.

Table 6. α - particle energies in the ^{241}Pu decay (keV)

	1965Ba26 1968Ba25	1968Ah01	Adopted (calculated from Q_α)
$\alpha_{0,10}$		4693 (6)	4694 (3)
$\alpha_{0,9}$	4732		4733 (3)
$\alpha_{0,8}$		4743 (5)	4744 (5)
$\alpha_{0,7}$		4784 (5)	4785,1 (11)
$\alpha_{0,6}$	4798	4798 (3)	4798,0 (5)
$\alpha_{0,5}$	4853,3 (12)	4853 (3)	4853,8 (5)
$\alpha_{0,4}$	4896,3 (12)	4896 (3)	4897,3 (5)
$\alpha_{0,3}$	4971	4973 (3)	4973,1 (5)
$\alpha_{0,2}$	4998	5000 (4)	4999,2 (5)
$\alpha_{0,1}$	5041	5043 (3)	5043,4 (5)
$\alpha_{0,0}$	5051	5056 (5)	5054,6 (5)

6. Photon Emissions

6.1. X-Ray Emissions

The absolute emission probabilities of U KX and LX-rays have been calculated using the EMISSION code.

		Energy, (keV)	Number of photons per 100 disintegrations
X_K	$K\alpha_2$ (U)	94,666	$3{,}00\ (7)\cdot 10^{-4}$
	$K\alpha_1$ (U)	98,440	$4{,}79\ (10)\cdot 10^{-4}$
	$K\beta_3$ (U)	110,421	}
	$K\beta_1$ (U)	111,298	} $1{,}79\ (5)\cdot 10^{-4}$
	$K\beta_5$ (U)	111,964	}
	$K\beta_{2,4}$ (U)	114,46	}$0{,}59\ (2)\cdot 10^{-4}$
	$KO_{2,3}$ (U)	115,377	}
X_L	Ll (U)	11,619	$0{,}336\ (12)\cdot 10^{-4}$
	$L\alpha_2$ (U)	13,438	$0{,}556\ (19)\cdot 10^{-4}$
	$L\alpha_1$ (U)	13,615	$4{,}87\ (17)\cdot 10^{-4}$
	$L\eta$ (U)	15,399	$0{,}0444\ (13)\cdot 10^{-4}$
	$L\beta$ (U)	15,727 – 18,206	$4{,}77\ (8)\cdot 10^{-4}$
	$L\gamma$ (U)	19,507 – 20,714	$1{,}09\ (2)\cdot 10^{-4}$

6.2. Gamma-Ray Emissions

In Table 7 the experimental and adopted energies of gamma-rays are given (see also the evaluation of 1988ChZL). Other measurements: 1952Fr25, 1965Ba35, 1976Um01, 1979Ce04, 1993Dr05.

The energies of $\gamma_{1,0}$ (11,39 keV), $\gamma_{3,2}$ (26,67 keV) and $\gamma_{6,4}$ (100,94 keV) have been calculated from the level scheme: $E\gamma_{1,0}$ (11,39 keV) = $E\gamma_{4,0}$ - $E\gamma_{4,1}$; $E\gamma_{3,2}$ (26,67 keV) = $E\gamma_{4,2}$ - $E\gamma_{4,3}$; $E\gamma_{6,4}$ (100,94 keV) = $E\gamma_{5,4}$ + $E\gamma_{6,5}$.

Table 7. Experimental and evaluated gamma-ray energies in the ^{241}Pu decay (keV)

	1968Ah01	1971GuZN 1976GuZN	1972Cline	Adopted
$\gamma_{1,0}$		11,39		11,39 (2)
$\gamma_{3,2}$				26,67 (4)
$\gamma_{5,4}$		44,19 (3)	44,175 (30)	44,18 (3)
$\gamma_{2,1}$	44,7 (3)	44,86 (10)		44,86 (10)
$\gamma_{2,0}$	56,6 (2)	56,30 (12)	56,412 (30)	56,30 (12)
$\gamma_{6,5}$		56,76 (10)		56,76 (10)
$\gamma_{3,1}$		71,60 (7)	71,672 (40)	71,64 (9)
$\gamma_{4,3}$	76,9 (2)	76,96 (10)	77,014 (40)	77,01 (4)
$\gamma_{6,4}$				100,94 (11)
$\gamma_{4,2}$	103,5 (2)	103,680 (5)	103,540 (40)	103,680 (5)
$\gamma_{7,4}$	114,0 (10)		115,342 (40)	114,0 (10)
$\gamma_{5,3}$	120,7 (5)	121,2 (10)	121,220 (30)	121,22 (5)
$\gamma_{4,1}$	148,5 (2)	148,567 (10)	148,560 (20)	148,567 (10)
$\gamma_{4,0}$	160,0 (2)	160,00 (4)	159,960 (20)	159,96 (2)

In Table 8 the experimental and evaluated absolute gamma-ray emission probabilities are given. The evaluated values have been obtained using the LWEIGHT computer program. The uncertainty assigned in this evaluation to the recommended value is always greater than or equal to the smallest uncertainty in any of the experimental values used in the statistical processing.

Table 8. Experimental and evaluated absolute emission probabilities of gamma rays in the ^{241}Pu decay per 10^6 disintegrations

Eγ (keV)	1968Ah01	1976GuZN	1976Um01	1978DiZU	1985He02	1985Wi04	1994Ba91	Evaluated
44,18		0,042 (2)						0,042 (2)
44,86		0,0084 (10)						0,0084 (10)
56,30		0,025 (2)						0,025 (2)
56,76		0,010 (1)						0,010 (1)
71,64		0,029 (2)						0,029 (2)
77,0	0,18 (2)	0,220 (8)			0,211 (5)	0,203 (4)		0,207 (4)
100,94		0,00072						0,00072
103,68	1,10 (12)	1,03 (3)		1,04 (5)	1,02 (3)	1,032 (12)		1,03 (2)
114,0		0,062 (12)						0,062 (12)
121,22		0,0070 (7)						0,0070 (7)
148,6	2,20 (22)	1,86 (3)	1,91 (4)	1,85 (7)	1,863 (17)	1,855 (16)	1,863 (8)	1,863 (8)
159,9	0,078 (8)	0,0671 (15)			0,0654 (19)	0,0651 (14)	0,06321 (40)	0,0645 (9)

The absolute emission probability of $\gamma_{6,4}$ (100,94 keV) has been deduced from the ratio of P_γ ($\gamma_{6,4}$; 100,94 keV) /P_γ ($\gamma_{6,5}$; 56,76 keV) = 5,87 which has been calculated in 1995Ak01 by using the Alaga rule.

The absolute emission probabilities of the remaining gamma rays have been adopted from 1976GuZN.

7. References

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1953As40	F. Asaro, Thesis, Univ.California (1953); UCRL-2180 (1953) (α-transition energies)
1953Ma19	D.R. MacKenzie, M. Lounsbury, A.W. Boyd, Phys. Rev. 90, 327 (1953) (Half-life)
1956Ro26	B. Rose and J. Milsted, J. Nuclear Energy 2, 264 (1956) (Half-life)
1956Sh31	K.N. Shliagin, Izvest. Akad. Nauk SSSR, Ser. Fiz. 20, 891 (1956); Columbia Tech. Transl. 20, 810 (1957) (β-transition energy)
1957Ha10	G.R. Hall, T.L. Markin, J. Inorg. Nuclear Chem. 4, 137 (1957). Quoted in 1969Hanna (Half-life)
1960Br15	F. Brown, G.G. George, D.E. Green, D.E.Watt, J. Inorg.Nuclear Chem. 13, 192 (1960) (Half-life)
1961Sm03	H.L. Smith, J. Inorg. Nuclear Chem. 17, 178 (1961) (Half-life, β-transition probability)
1964Dz03	B.S.Dzhelepov, R.B.Ivanov, V.G.Nedovesov, Zh.Eksperim.i Teor.Fiz. 46, 1517 (1964); Soviet Phys.JETP 19, 1027 (1964) (α-transition energies)
1965Ba26	S.A.Baranov, M.K.Gadzhiev, V.M.Kulakov, V.M.Matinskii, Yadern.Fiz. 1, 557 (1965); Soviet J.Nucl.Phys. 1, 397 (1965) (α-transition energies)
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1966French	R.J. French, F.L. Langford, Jr., W.D. Leggett, and R.J. Nodvik, Yankee Core Evaluation Program Quarterly Progress Report for the Period ending 30 September 1966. Quoted in 1987Ag03 (Half-life)
1966Stepan	I.E. Stepan and R.G. Niske, Trans. Am. Nucl. Soc. 9, 451 (1966) (Half-life)
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1968Ah01	I. Ahmad, A.M. Friedman, J.P. Unik, Nucl. Phys. A119, 27 (1968) (α- and gamma transition energies, α/β-branching)
1968Ba25	S.A. Baranov, V.M. Kulakov, V.M. Shatinskii, Yadern. Fiz. 7, 727 (1968); Soviet J. Nucl. Phys. 7, 442 (1968) (α-transition energies)
1968Ca19	M.J. Cabell, J. Inorg. Nucl. Chem. 30, 2583 (1968) (Half-life)
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1970Ni02	R.G. Nisle, I.E. Stephan, Nucl. Sci. Eng. 39, 257 (1970) (Half-life)
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1971Ca15	M.J. Cabell and M. Wilkins, J. Inorg. Nucl. Chem. 33, 903 (1971) (Half-life)
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1972Whitehead	C. Whitehead, A.C. Sherwood, and B. Rose, AERE-PR/NP 18 (1972) (Half-life)
1973JoYT	K.C. Jordan, Priv.Comm. (1973). Quoted in 1974StYG (Half-life)
1973Ze02	R.K. Zeigler, Y. Ferris, J. Inorg. Nucl. Chem. 35, 3417 (1973) (Half-life)
1974STYG	W.W. Strohm and K.C. Jordan, Trans. Amer. Nucl. Soc. 18, 185 (1974) (Half-life)
1975WiYM	M. Wilkins, UKNDC (75)-P71, p.56 (1975) (Half-life)
1976BaZZ	S.A. Baranov, A.G. Zelenkov, V.M. Kulakov, Proc. Advisory Group Meeting on Transactinium Nucl. Data, Karlsruhe, Vol.III, p.249 (1976); IAEA-186 (1976) (α-transition energies and probabilities)

1976GuZN	R. Gunnink, J.E .Evans, A.L. Prindle, UCRL-52139 (1976) (Gamma-ray energies and emission probabilities, α/β-branching)
1976McZB	I.E. McKean and E.A.C. Crouch, UKNDC (76)-P80, p.41 (1976) (Half-life)
1976Um01	H. Umezawa, T. Suzuki, S. Ichikawa, J. Nucl. Sci. Technol. 13, 327 (1976) (Gamma-ray energies and emission probabilities)
1977Crouch	E.A. Crouch and I.C. McKean, UKNDC (78)-P88, AERE Harwell, Oxfordshire, p.96 (1978) (Half-life)
1977RGZZ	Priv.Comm. (June 1977) Research Groups, Atlantic Richfield Hanford Lab., Savannah River Lab., Livermore Lab., Mound Lab., Rocky Flats Lab., LASL (1977) (Half-life)
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1978DiZU	J.K. Dickens, J.S. Emery, R.M. Freestone, T.A. Love, J.W. McConnell, K.J. Northcutt, R.W. Peelle, ORNL/NUREG/TM-223 (1978) (Gamma-ray emission probabilities)
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