^{242}Cm - Comments on evaluation of decay data by V.P. Chechev

This evaluation was completed in February 2005 (see 2006Ch34) and then corrected in October 2009 with a literature cut-off by the same date.

1 Decay Scheme

The decay scheme is based on the evaluation of Chukreev et al. (2002Ch52) and can be considered essentially complete although some weak gamma-ray transitions have not been observed in ^{242}Cm alpha decay. Such gamma rays were taken from $^{238}Am \rightarrow ^{238}Pu$, $^{238}Np \rightarrow ^{238}Pu$ decays and have been included in the decay scheme.

2 Nuclear Data

Q(α) is from 2003Au03.

The evaluated half-life of ^{242}Cm is based on the experimental results given in Table 1. Re-estimated values were used for averaging when needed.

Table 1. Experimental values of the ^{242}Cm half-life (in days)

Reference	Author(s)	Original value	Re-estimated value	Measurement method
1950Ha14	Hanna et al.	162.5 (20)	-	α-counting with low geometry counter
1954Gl37	Glover and Milsted	162.46 (14) [a]	162.46 (32) [c]	α-counting with low geometry counter
1954Hu32	Hutchinson and White	163.0 (18)	-	Calorimetry
1957Treiman	Treiman et al.	162.7 (1)	-	Calorimetry
1965Fl02	Flynn et al.	164.4 (4)	163.1 (4) [d]	2π α counting
1975Ke02	Kerrigan and Banick	163.2 (2) [b]	-	Calorimetry
1977Di04	Diamond et al.	162.76 (4)	162.76 (8) [c]	Intermediate geometry α-counting
1979Ch41	Chang et al.	163.02 (11)	163.02 (18) [c]	α-counting with low geometry counter
1980Jadhav	Jadhav et al.	162.13 (215)	162.13 (225)	α-spectrometry with solid state detector
1981Us03	Usuda and Umezawa	161.35 (20)	161.35 (30) [c]	α-counting with 2π proportional counter
1982Ag02	Aggarwal et al.	163.17 (6)	163.17 (11) [c]	α-counting with proportional counter
1982Ag02	Aggarwal et al.	162.82 (21)	162.82 (26) [c]	α-spectrometry with solid state detector
1984Wi14	Wiltshire et al.	163.0 (2)	-	α-counting with low geometry counter

[a] The uncertainty of 0.27 quoted by authors, which corresponds to 95 % confidence level, has been reduced by a factor 2.

[b] The uncertainty of 0.04 quoted by authors, which corresponds to 95 % confidence level, has been reduced by a factor 2.

[c] Quoted uncertainties have been re-estimated in 1986LoZT.

[d] The value has been recalculated in 1977Di04.

The LWEIGHT and EV1NEW computer programs identified two outliers in the above data set. These are the values from 1981Us03 and 1980Jadhav. Omitting these values in the calculation and using the remaining 11 results produced a weighted mean of 162.86 with an internal uncertainty of 0.05 and an external uncertainty of 0.06 ($\chi^2/\nu = 1.6$). The EV1NEW program has chosen the smallest experimental uncertainty of 0.08 as the uncertainty of the weighted average.

Thus the recommended value of the ^{242}Cm half-life is 162.86 (8) days.

The evaluated spontaneous fission partial half-life of ^{242}Cm is based on the experimental results given in Table 2. Re-estimated values were used for averaging when needed.

Table 2. Experimental values of the ^{242}Cm spontaneous fission half-life (in 10^6 years)

Reference	Author(s)	Original value	Re-estimated value [a]	Measurement method
1951Ha87	Hanna et al.	7.2 (2)	-	Fission fragment counting, ionization chamber
1967Ar09	Armani and Gold	6.09 (18)	6.82 (18)	Fission neutron counting, LiI detector
1979Ch41	Chang et al.	7.46 (6)	-	Mica fission track detector
1982Ra33	Raghuraman et al.	7.15 (15)	-	Solid state detector
1982UmZZ	Umezawa et al.	6.89 (17)	-	Mica fission track detector
1986Ze06	Zelenkov et al.	6.9 (3)	6.98 (33)	α/SF, Si(Au) detectors
1989Us04	Usuda et al.	6.96 (18)	-	Absolute fission track counting

[a] Recalculated in 2000Ho27

Omitting the value of 1979Ch41 (outlier) the weighted mean of the six remaining values becomes 7.005 with an internal uncertainty of 0.076 and an external uncertainty of 0.063 ($\chi^2/\nu = 0.69$).

The recommended value of the ^{242}Cm spontaneous fission half-life is 7.01 (15) 10^6 years, where the uncertainty is the smallest quoted uncertainty of 6 experimental results.

2.1 α Transitions

The energies of the alpha-particle transitions given in Section 2.1 have been deduced from the Q value and the level energies given in Table 3 from 2002Ch52.

Table 3. ^{238}Pu levels populated in the ^{242}Cm α-decay

Level number	Energy (keV)	Spin and parity	Half-life	Probability of α-transition (%)
0	0.0	0^+	87,74 (3) a	74.06 (7)
1	44.08 (3)	2^+	177 (5) ps	25.94 (7)
2	146.00 (5)	4^+		0.034 (2)
3	303.42 (7)	6^+		0.0046 (5)
4	513.62 (16)	8^+		2×10^{-5}
5	605.08 (7)	1^-		$2.5 (5)\times10^{-4}$
6	661.28 (11)	3^-		$1.3 (3)\times10^{-5}$
7	763.22 (12)	5^-		$\leq 2.2\times10^{-7}$
8	941.44 (9)	0^+		$3.5 (7)\times10^{-5}$
9	962.72 (8)	1^-		$1.13 (21)\times10^{-6}$
10	983.00 (9)	2^+		$1.7 (5)\times10^{-6}$
11	1018.6 (3)	1^-		$\leq 2\times10^{-7}$
12	1028.62 (5)	2^+		$3.7 (10)\times10^{-6}$
13	1125.79 (17)	(4^+)		$3.1 (10)\times10^{-7}$
14	1228.69 (22)	0^+		$5.5 (15)\times10^{-7}$
15	1264.29 (22)	2^+		$5.2 (14)\times10^{-7}$

The emission probabilities of the most intensive transitions $\alpha_{0,i}$ (i = 0 to 4) have been obtained by averaging experimental data (Table 4). The emission probabilities of the remaining α-particle transitions have been deduced either from the P(γ+ce) decay-scheme balances or by averaging experimental and deduced values (for example, $\alpha_{0,5}$).

Table 4. Experimental, calculated and recommended α-transition probabilities (%) in the ^{242}Cm decay

	α-particle energy (keV)	1953As14	1958Ko87	1963Dz07	1966Ba07	1998Ya17	Deduced from decay-scheme balance c	Recommended
$\alpha_{0,0}$	6113	73.7 (5)	73.5 (5)	74 (2)	74.2 (5) [a]	74.08 (7)		74.06 (7) [d]
$\alpha_{0,1}$	6069	26.3 (5)	26.5 (5)	26.0 (9)	25.8 (5) [a]	25.92 (6)		25.94 (7) [d]
$\alpha_{0,2}$	5969	0.035 (2)[a]	0.030 (2) [b]	0.035 (2)	0.036 (2) [a]			0.034 (2) [e]
$\alpha_{0,3}$	5816		0.0046 (5)		0.0046			0.0046 (5) [f]
$\alpha_{0,4}$	5608			1963Bj01	$2\cdot10^{-5}$			$2\cdot10^{-5}$ [g]
$\alpha_{0,5}$	5518			$2.8 (5)\cdot10^{-4}$	$2.5 (6)\cdot10^{-4}$		$2.6 (7)\cdot10^{-4}$	$2.5 (5)\cdot10^{-4}$ [e]
$\alpha_{0,6}$	5462						$1.3 (3)\cdot10^{-5}$	$1.3 (3)\cdot10^{-5}$ [c]
$\alpha_{0,7}$	5366						$2.2\cdot10^{-7}$	$2.2\cdot10^{-7}$ [c]
$\alpha_{0,8}$	5187			$3.4 (8)\cdot10^{-5}$	$2.5 (8)\cdot10^{-5}$		$3.5 (7)\cdot10^{-5}$	$3.5 (7)\cdot10^{-5}$ [c]
$\alpha_{0,9}$	5166						$1.13 (21)\cdot10^{-6}$	$1.13 (21)\cdot10^{-6}$ [c]
$\alpha_{0,10}$ [h]	5146				$\le 5\cdot10^{-6}$		$1.7 (5)\cdot10^{-6}$	$1.7 (5)\cdot10^{-6}$ [c]

[a] No uncertainties are quoted by the authors. The uncertainties have been adopted by the evaluator based on the similarity of the spectra measured with magnetic spectrometers in 1953As14, 1958Ko87 and 1966Ba07.
[b] The uncertainty of 0.001 quoted by authors has been increased by a factor of 2 by the evaluator (see [a]).
[c] Deduced from P(γ+ce) decay-scheme balances for corresponding ^{238}Pu levels.
[d] Weighted average of experimental values The experimental data of 1998Ya17 have been obtained by the most accurate method (using a semiconductor detector).
[e] Weighted average of experimental and deduced values.
[f] Adopted experimental value from 1958Ko87.
[g] Adopted experimental value from 1966Ba07.
[h] The probabilities of remaining alpha-transitions ($\alpha_{0,11}$ and $\alpha_{0,15}$) have been deduced from P(γ+ce) decay-scheme balances.

2.2 γ Transitions and Internal Conversion Coefficients

The recommended energies of gamma-ray transitions are essentially the same as the gamma-ray energies because nuclear recoil is negligible.

The probabilities, P(γ+ce), for gamma-ray transitions of 44-($\gamma_{1,0}$), 102- ($\gamma_{2,1}$), 157-($\gamma_{3,2}$), and 210-keV ($\gamma_{4,3}$) have been deduced from transition- intensity balances, using the emission probabilities of α-transitions directly measured.

For E0- gamma transitions 941-($\gamma_{8,0}$) and 1229-keV ($\gamma_{14,0}$) the P(γ+ce) values have been taken from data on the electron capture decay ^{238}Am → ^{238}Pu (see 2002Ch52 and references therein).

The remaining P(γ+ce) values have been obtained from the gamma-ray emission probabilities and the total internal conversion coefficients (ICC's). The experimental values of ICC's have been adopted for (E0+E2) gamma-ray transitions 939-($\gamma_{10,1}$) and 1220-keV ($\gamma_{15,1}$). The remaining ICC's have been interpolated using the BrIcc package with the so called "*Frozen Orbital*" approximation (2008Ki07). The relative uncertainties of α_K, α_L, α_M, α_T for pure multipolarities have been taken as 2 %.

The multipolarities and E2/M1, M2/E1 mixing ratios have been taken from 2002Ch52. These are based on conversion electron measurements of 1952Du12, 1956Ba95, 1956Sm18, 1960As10, and 1965Ak02 made in the ^{242}Cm α-decay.

3 Atomic Data

3.1 Fluorescence yields

Fluorescence yield data are from 1996Sc06 (Schönfeld and Janβen).

3.1.1 X rays

The Pu KX-ray energies and relative emission probabilities have been taken from 1999Schönfeld, where the calculated energy values are based on X-ray wavelengths from 1967Be65 (Bearden). In Table 5 the recommended values of Pu KX-ray energies are compared with experimental results.

Table 5. Experimental and recommended values of Pu KX-ray energies (keV)

	1980Di13	1982Ba56	Recommended
$K\alpha_2$	99.55 (3)	99.530 (2)	99.525
$K\alpha_1$	103.76 (3)	103.741 (2)	103.734
$K\beta_3$	116.27	116.242 (2)	116.244
$K\beta_1$	117.26	117.233 (2)	117.228
$K\beta_{2,4}$	120.60 (15)	-	120.553
$KO_{2,3}$	121.55 (6)	-	121.543

The Pu KX-ray energies in 1980Di13 were measured in the alpha decay of ^{245}Cm. The relative emission probabilities of KX-rays were given as: $K\alpha_2$:$K\alpha_1$:$K\beta_3$:$K\beta_1$:$K\beta_{2,4}$ = 64.7 (23) : 100.0 (33) : 12.9 (7) : 23.1 (10) : 8.9 (5).

3.1.2 Auger Electrons

The energies of Auger electrons have been calculated from atomic electron binding energies.

The P(KLX)/P(KLL), P(KXY)/P(KLL) ratios have been taken from 1996Sc06.

4 α Emissions

The energy of the alpha-particle group to the ground state of ^{238}Pu, $E(\alpha_{0,0})$ is from the absolute measurement of 1971Gr17, with a correction of –0.20 keV recommended by A. Rytz in 1991Ry01.

The energies of all other α particles have been deduced from Q_α and the ^{238}Pu level energies including the recoil energy corrections (see 2002Ch52).

In Table 6 the recommended values of α-particle energies are compared with the experimental results obtained with magnetic alpha spectrometers.

Table 6. Experimental[a] and recommended α-emission energies in the decay of ^{242}Cm (keV)

	1953As14	1958Ko87	1963Dz07	1966Ba07 1971Bb10	1971Gr17	Recommended
$\alpha_{0,0}$	6113	6114	6113 (1)	6112.9 (3)	6112.72 (8)	6112.72 (8)
$\alpha_{0,1}$	6069	6070	6069 (1)	6069.5 (5)	6069.43 (12)	6069.37 (9)
$\alpha_{0,2}$	5968	5968 (2)	5969 (3)	5970		5969.24 (9)
$\alpha_{0,3}$	-	5816 (2)	-	5817		5816.39 (11)
$\alpha_{0,4}$	-	-	-	5609		5607.76 (16)
$\alpha_{0,5}$	-	-	-	5514		5517.75 (11)
$\alpha_{0,8}$	-	-	-	5189		5186.95 (12)
$\alpha_{0,10}$	-	-	-	5146		5146.07 (12)

[a] Authors' values have been adjusted for changes in calibration energies (see 1991Ry01)

5 Electron emissions

The energies of conversion electrons have been obtained using gamma-ray transition energies and electron binding energies. The emission probabilities of conversion electrons have been deduced from the evaluated P(γ) and ICC values.

The absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program (2000Schönfeld).

6 Photon emissions

6.1. X-Ray emissions

The absolute emission probabilities of U KX- and U LX-rays in decay of ^{242}Pu have been calculated using the EMISSION computer program (2000Schönfeld).

The calculated total absolute emission probability of LX-rays P(XL)= 9.92 (23) % agrees well with the experimental value of 9.70 (14) % from 1970By01 and disagrees with the value of 11.7 (3) % measured in 1971Swinth.

The relative Pu LX-ray emission probabilities in ^{242}Cm α-decay measured in 1990Po14 [4.9 (8)-Ll; 66 (7)-Lα; 100-Lηβ; 23 (3)-Lγ] agree well with the values calculated using the EMISSION computer program with the exception of $L\alpha/L\eta\beta^{calc.}$ = 79 (4)/100. The latter agrees well with the experimental result from 1995Jo23, Lα/Lηβ (Pu) = 80.9 (9)/100, obtained for LX-rays in the decay of other even-even curium isotope – ^{244}Cm.

6.2 Gamma emission

6.2.1. Gamma-ray energies

The energy of the 44-keV gamma ray ($\gamma_{1,0}$) is from ^{238}Np→^{238}Pu β^-decay (1972Wi22); it agrees with the less accurate measurements in ^{242}Cm α-decay (44.11 (5) keV - 1956Sm18) and in ^{238}Am ε-decay (44.1 (1) keV - 1972Ah04).

The energies of the 102-($\gamma_{2,1}$), 157-($\gamma_{3,2}$), 336-($\gamma_{8,5}$), 358-($\gamma_{9,5}$), 605-($\gamma_{5,0}$), 940-($\gamma_{10,1}$), and 941-($\gamma_{8,0}$) keV gamma rays have been obtained from the available experimental data of 1981Le15 (^{242}Cm α-decay and ^{238}Np β^--decay), 1972Wi22, 1972Ah04, 1956Sm18, and 1971Po09 (^{238}Am ε-decay) using the adopted ^{238}Pu level energies.

The energies of the 210-($\gamma_{4,3}$), 617-($\gamma_{7,2}$), and 883-($\gamma_{12,2}$) keV gamma rays, which were not observed in the ^{242}Cm α-decay, have been deduced from the adopted level energies. The energies of the remaining gamma rays have been taken from the measurements of 1981Le15 (^{242}Cm α-decay).

6.2.2. Gamma-ray emission probabilities

The absolute emission probabilities for gamma-rays of 44-($\gamma_{1,0}$), 102- ($\gamma_{2,1}$), 157-($\gamma_{3,2}$), and 210-($\gamma_{4,3}$) keV have been deduced from decay-scheme intensity balances using the probabilities of α-transitions evaluated directly from experimental data.

The absolute emission probabilities of > 300 keV gamma-rays (except for 883- and 1229-keV γ-rays) have been obtained from relative gamma-ray emission probabilities P(γ)/P(γ 561keV) measured in 1981Le15. The normalization factor P(γ 561keV) = $1.5 \cdot 10^{-4}$ per 100 disintegrations, which was used here, was estimated in 1981Le15 using a previous αγ coincidence measurement of the sum of the absolute emission probabilities of the 515-, 561-, 605-, and 617-keV gamma-rays (1963Le17).

P(γ 883keV) and P(γ 1229keV) are from 2002Ch52, using the experimental data on ^{238}Np β^--decay and ^{238}Am ε-decay, respectively.

7. 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 ^{242}Cm α- decay) with the tabulated decay energy Q(M) allows to check a consistency of the recommended decay-scheme parameters obtained in this evaluation.

Here E_i and P_i are the evaluated energies and emission probabilities of the i-th alpha particle, beta particle, gamma ray, X-ray, etc. Consistency (percentage deviation) is determined by $\{[Q(M) - Q(eff))]/Q(M)\} \times 100$. “Percentage deviations above 5 % would be regarded as high and imply a poorly defined decay scheme; a value of less than 5 % indicates the construction of a reasonably consistent decay scheme” (quoted from the article by A.L. Nichols in Appl. Rad. Isotopes 55 (2001) 23-70).

For the above ^{242}Cm decay data evaluation we have Q(M) = 6215.56 (8) keV and Q(eff) = 6217 (6) keV, i.e. consistency is better than 0.12 %.

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