^{243}Cm -Comments on evaluation of decay data by V.P. Chechev

This evaluation was done in October 2010 with a literature cut-off by the same date.

1. DECAY SCHEME

The structure of the adopted scheme of ^{243}Cm decay is based on the evaluations by E. Browne (2003Br12) and Y.A. Akovali (2004Ak21). The decay scheme includes two decay modes: α decay to ^{239}Pu (99.71 (3) %) and electron capture decay (EC) to ^{243}Am (0.29 (3) %).

EC branching was obtained from the EC decay half-life of 1.0 (1) × 10^4 y, as determined in 1958Ch38 from a ratio of ^{243}Am and ^{243}Cm α activities (correction for the half-lives of ^{243}Am and ^{243}Cm adopted by DDEP does not change this value), and from the total ^{243}Cm half-life of 29.1 (1) y (correction for the recommended below value of the ^{243}Cm half-life does not change the EC branching). The EC decay occurs 100 % to the ground state 5/2- of ^{243}Am (1958Ch38, 2004Ak21).

In the ^{243}Cm α decay to ^{239}Pu the intense population takes place only to levels in ^{239}Pu with the energy less than 400 keV (8 excited levels and ground state) and in this part the decay scheme is well defined. Nevertheless, a number of gamma-ray transitions with energy less than 200 keV were not observed in the ^{243}Cm α decay, such as 7.86-keV, 49.4-keV, 61.5-keV, 67.8-keV, 88.1-keV, 102.0-keV, 106.1-keV, 106.5-keV, and 166.4-keV. These transitions, included in the ^{243}Cm decay scheme, have been derived from measurements of ^{239}Np and ^{239}Am decays.

For levels with higher energy, the decay scheme has not been completed since many gamma-ray transitions have not been observed yet. In addition, many levels were placed in the ^{243}Cm α decay scheme based only on questionable weak α transitions. Therefore, further measurements are needed to determine the γ transitions and ^{243}Cm α decay scheme with greater precision.

2. NUCLEAR DATA

Q(α) and Q(EC) values are from Audi et al. (2003Au03).

The recommended ^{243}Cm half-life is based on the experimental results given in Table 1.

Table 1. Experimental values of ^{243}Cm half-life (in years)

Reference	Author(s)	Original value	Re-estimated value	Comments
1950Th52	Thompson et al.	Roughly 100		Not used
1953As40	Asaro	35		Not used
1958Ch38	Choppin and Thompson	29.0 (8)	28.5 (2) [a]	Relative activity to ^{244}Cm
1986Ti03	Timofeev et al.	29.20 (12)	29.20 (13) [a]	Relative activity to ^{244}Cm

[a] Re-estimated by the evaluator to the ^{244}Cm half-life of 18.11 (3) y

The weighted average of 29.0 for this two re-estimated discrepant experimental data set is dominated by the accurate value of 1986Ti03. The LWEIGHT computer program, which uses a *Limitation of Relative Statistical Weights* (LRSW method), has expanded the 1986Ti03 uncertainty from 0.13 to 0.20 and used a weighted mean (28.85) and an external uncertainty (0.35) for the average of the adjusted data set ($\chi^2/\nu = 6.13$).

The recommended value of the ^{243}Cm half-life is **28.9 (4) years**.

The value of 5.5 (9) × 10^{11} years was adopted for ^{243}Cm spontaneous fission (SF) half-life from the measurement of 1987Po19. SF branching of 5.3 (9) ×10^{-9} % has been obtained using the adopted values of SF half-life and total half-life of 28.9 (4) y.

2.1. Alpha Transitions

The energies of the alpha transitions have been obtained from the Q(α) value and ^{239}Pu level energies given in Table 2 from 2003Br12 where they were deduced from a least-squares fit to gamma ray energies.

Table 2. ^{239}Pu levels populated in ^{243}Cm α-decay

Level	Energy (keV)	Spin and parity	Half-life	Probability of α-transition (×100)
0	0	1/2+	24100 (11) y	1.3 (2)
1	7.861 (2)	3/2+	36 (3) ps	4.4 (2)
2	57.275 (2)	5/2+	101 (5) ps	1.05 (12)
3	75.705 (3)	7/2+	83 (8) ps	5.7 (2)
4	163.76 (3)	9/2+	73 (4) ps	0.1
5	192.8 (10)	11/2+		0.7
6	285.460 (2)	5/2+	1.12 (5) ns	73.4 (4)
7	330.124 (4)	7/2+		11.3 (2)
8	387.42 (2)	9/2+		1.6 (1)
9	391.584 (3)	7/2-	193 (4) ns	0.2
10	427 (3) ?			0.03
11	434 (3)	(9/2-)		0.14
12	451 (5) ?			0.06
13	462 (3)	(11/2+)		0.03
14	469.8 (4)	(1/2-)		≤ 0.01
15	481 (3) ?			0.01
16	487 (3)	(11/2-)		0.02
17	492.1 (3)	3/2-		0.009
18	499 (3)			0.007
19	505.6 (2)	(5/2-)		0.007
20	538 (3)			0.002
21	543 (3) ?			0.006
22	556.2 (5)	(7/2-)		0.002
23	746 (3)			0.003
24	756 (3)			0.003
25	763 (3)			0.001
26	813 (3)			0.0015
27	850 (15)			0.00039

The probabilities of the most intense α-transitions (I_α > 1 %) have been obtained by averaging experimental values from the spectrometric measurements (Table 3). Probabilities of the rest of alpha transitions have been adopted from the magnetic spectrometer measurements of 1966Ba07. The probability of the $\alpha_{0,9}$ transition (0.2 %) from 1966Ba07 disagrees with the value deduced from the gamma-ray transition intensity balance (> 0.4 %).

The α-decay hindrance factors have been calculated using the ALPHAD computer program from the ENSDF evaluation package with r_0 (^{239}Pu) = 1.4996 fm (see 2003Br12).

Table 3. Experimental (per 100 α decays) and recommended probabilities (per 100 decays) of the most intense α-transitions (I_α > 1 %) observed in ^{243}Cm α decay *

	α-part. energy	1957 As83	1963 Dz07	1966Ba07	1973 Ah04	2009 KoZV	Evaluated from α measurement results (per 100 α decays)	Deduced from P(γ+ce) balance	Recommended(per 100 (α+ EC) decays)
$\alpha_{0,0}$	6066	1.0 (2) [a]		1.5 (2) [a]			1.3 (2) [a]		1.3 (2)
$\alpha_{0,1}$	6058	5		4.7 (3) [a]	4.3 (2)	4.5 (3)	4.4 (2) [a]		4.4 (2)
$\alpha_{0,2}$	6010		0.95		1.05 (5)	1.1 (2)	1.05 (12) [b]		1.05 (12)
$\alpha_{0,3}$	5992	6.0 (2) [a]	5.4 (2)	5.63 (20) [a]	5.6 (2)	5.8 (2)	5.7 (2) [a]		5.7 (2)
$\alpha_{0,6}$	5785	73 (4) [a]	73 (4)	73.54 (40) [a]	74.2 (8)	72.9 (12)	73.6 (4) [a]	73.8 (26)	73.4 (4)
$\alpha_{0,7}$	5742	11.5 (6) [a]	12.3 (6)	10.65 (60) [a]	11.1 (2)	11.6 (4)	11.3 (2) [a]	11	11.3 (2)
$\alpha_{0,8}$	5686		1.7	1.6	1.52 (5)	1.8 (1)	1.6 (1) [a]		1.6 (1)

[a] Weighted average, uncertainty is the smallest experimental one.
[b] Weighted average, uncertainty is external.

2.2. Gamma Transitions and Internal Conversion Coefficients

The recommended energies of the gamma-ray transitions are virtually the same as those of the gamma-ray energies because the nuclear recoil is negligible for ^{239}Pu.

The probabilities of gamma-ray transitions $\gamma_{1,0}$ (7.86 keV), $\gamma_{3,2}$ (18.43 keV), $\gamma_{2,0}$ (57.27 keV), $\gamma_{3,1}$ (67.84 keV), $\gamma_{4,2}$ (106.47 keV), and $\gamma_{5,3}$ (117.1 keV) have been deduced from intensity balances at the ^{239}Pu levels "0" (0 keV), "3" (75.7 keV), "2" (57.3 keV), "1" (7.86 keV), "4" (163.8 keV), and "5" (192.8 keV), respectively.

The rest of gamma-ray transition probabilities (P_γ) have been deduced from their evaluated gamma-ray emission probabilities and total internal conversion coefficients (ICCs).

ICCs have been interpolated using the BrIcc computer program, version v2.2a, data set BrIccFO (2008Ki07). Multipolarities of the gamma-ray transitions and E2/M1 mixing ratios (δ) are based on the measurements of conversion electrons (ce) in ^{239}Am, ^{239}Np and ^{243}Cm decays and γ(θ) measurements by 1972Kr07, 1990Si12 from polarized ^{239}Np. The multipolarities have been taken from 2003Br12. The δ values have been adopted mainly from 2003Br12, except as noted below.

The δ values for $\gamma_{6,3}$ (209.75 keV), $\gamma_{6,2}$ (228.18 keV), and $\gamma_{6,1}$ (277.60 keV) have been taken from γ(θ) measurements of 1972Kr07, 1990Si12. Asymmetric uncertainties of 1972Kr07, 1990Si12 were symmetrized by transformation to equivalent symmetric normal distribution using a method described in 2003Au03 (p. 21): for $\gamma_{6,3}$ δ = -0.004 (+1 -24) → δ = -0.019(15) and for $\gamma_{6,2}$ δ = + 0.004 (+9 -1) → δ = +0.009 (6). The value of δ = 0.24 (4) has been adopted for $\gamma_{7,6}$ (44.66 keV) to provide more accurate intensity balances at the levels "6" (285.46 keV) and "7" (330.12 keV).

ICCs for the E1(+M2) anomalously converted 106.1-keV gamma-ray transition are from conversion electron measurements of 1959Ew90.

3. ATOMIC DATA

The fluorescence yields, X-ray energies and relative probabilities, and Auger electrons energies and relative probabilities are from the SAISINUC software.

4. ALPHA EMISSIONS

The recommended energies of alpha particles have been deduced from the energies of alpha transitions taking into account the recoil energies for ^{239}Pu.

In Table 4 the deduced (recommended) values of α-particle energies for the four intense α-transitions are compared with the experimental results from spectrometric measurements of 1957As83, 1963Dz07 and 1966Ba07. Other measurement results can be found in 1953As14, 1957As70, 1962Iv01, 1963Le17, 1970By01, 1971Bb10, 1976BaZZ, and 1977VaZW. Most of them have lesser accuracy in comparison with the recommended values.

Table 4. Experimental and recommended values of α -particle energies (keV) in the decay of ^{243}Cm

	Measured [a]			Evaluated in 1991Ry01	Recommended
	1957As83	1963Dz07	1966Ba07		
$\alpha_{0,0}$	6061 (3) [b]		6067 (2) [b]	6066.2 (17)	6067.2 (10)
$\alpha_{0,3}$	5987 (3) [b]	5992 (3)	5993 (2) [b]	5991.8 (15)	5992.7 (10)
$\alpha_{0,6}$	5780 (3) [b]	5785 (3)	5784.5 (10)	5785.2 (9)	5786.4 (10)
$\alpha_{0,7}$	5736 (3) [b]	5740 (3)	5741.6 (10)	5742.1 (9)	5742.5 (10)

[a] Original values have been adjusted for changes in calibration energies as suggested in 1991Ry01.

[b] Uncertainty deduced or guessed by A. Rytz.

5. ELECTRON EMISSIONS

The energies of the conversion electrons have been obtained from the gamma-ray transition energies and the atomic electron binding energies.

The emission probabilities of the conversion electrons were deduced using the evaluated P_γ and ICC values. The total absolute emission probabilities of K and L Auger electrons were calculated using the EMISSION computer program.

6. PHOTON EMISSIONS

6.1 X - Ray emissions

The absolute emission probabilities of Pu KX- and LX-rays were calculated using the EMISSION computer program (Table 5).

Table 5. Measured (1972Ah02) and calculated absolute Pu KX-ray emission probabilities (%).

	1972Ah02	Calculated
$K\alpha_2$ (Pu)	13.5 (5)	13.34 (28)
$K\alpha_1$ (Pu)	20.8 (8)	21.1 (5)
$K\beta'_1$ (Pu)	7.6 (3)	7.75 (21)
$K\beta'_2$ (Pu)	2.6 (1)	2.69 (8)

The good agreement between measured and calculated KX-ray emission probabilities supports the recommended γ-ray emission probabilities and assigned multipolarities.

6.2. Gamma emissions

6.2.1. Gamma ray energies

The gamma ray energies have been taken mainly from 2003Br12. They are based on measurements of γ-ray transitions observed in ^{239}Np and ^{239}Am decays by 1959Ew90, 1964Ba31, 1965Ma17, 1972Po04, 1979Bo30, and 1982Ah04. The energies of gamma rays $\gamma_{9,8}$ (4.16 keV), $\gamma_{1,0}$ (7.86 keV), $\gamma_{3,2}$ (18.43 keV), $\gamma_{2,1}$ (49.41 keV), $\gamma_{8,7}$ (57.30 keV), $\gamma_{5,3}$ (117.1 keV), and $\gamma_{22,2}$ (498.9 keV) have been deduced directly from the adopted ^{239}Pu level energies.

Earlier measurement results can be found in 1953As14, 1955Sc08, and 1956Ne17.

The gamma rays reported in 1963Le17 only, have not been placed in the decay scheme.

6.2.2. Gamma ray emission probabilities

The absolute gamma ray emission probabilities (Pγ) were adopted from the experimental values given by 1972Ah02 multiplied by 0.9971 (3), except when noted below.

Pγ of gamma rays $\gamma_{1,0}$ (7.86 keV), $\gamma_{3,2}$ (18.43 keV), $\gamma_{2,0}$ (57.27 keV), $\gamma_{3,1}$ (67.84 keV), $\gamma_{4,2}$ (106.47 keV), and $\gamma_{5,3}$ (117.1 keV) have been obtained from P(γ+ce) values deduced from intensity balances (see section 2.2).

Pγ of gamma ray $\gamma_{7,6}$ (44.66 keV) has been deduced using the ratio Iγ(44.66 keV) / Iγ(254.4 keV) = 0.13 (1) / 0.1091 (22) in ^{239}Np β^- decay (2005Tr08, 2008BeZV) and P$\gamma_{7,3}$ (254.4 keV) = 0.11 (1) % measured in 1972Ah02.

Pγ of gamma ray $\gamma_{8,7}$ (57.30 keV) has been deduced from the total intensity of doublet P$\gamma_{2,0}$ (57.27 keV) + P$\gamma_{8,7}$ (57.30 keV) = 0.14 (1) % measured in 1972Ah02 and P$\gamma_{2,0}$ (57.27 keV) = 0.06 % from transition probability balance at the 57 keV level.

Pγ of gamma ray $\gamma_{9,7}$ (61.46 keV) has been deduced using the ratio Iγ(61.46 keV) / Iγ(334.31 keV) = 1.29 (2) / 2.05 (2) in ^{239}Np β^- decay (2005Tr08, 2008BeZV) and P$\gamma_{9,2}$ (334.31 keV) = 0.024 (2) % measured in 1972Ah02.

Pγ of gamma ray $\gamma_{4,3}$ (88.06 keV) has been deduced using from the ratio Iγ(88.06 keV) / Iγ(106.47 keV) = 0.006 (2) / 0.049 (2) in ^{239}Np β^- decay (2005Tr08, 2008BeZV) and P$\gamma_{4,2}$ (106.47 keV) = 0.015 %.

Pγ of gamma ray $\gamma_{8,6}$ (101.96 keV) has been deduced using data from ^{239}Am ε decay (1972Po04).

Pγ of gamma ray $\gamma_{9,6}$ (106.12 keV) has been deduced using data from ^{239}Np β^- decay of the relative intensity Iγ(106.12 keV) / Iγ(334.31 keV) = 25.32 (17) / 2.055 (13) as measured in 2005Tr08 and P$\gamma_{9,2}$ (334.31 keV) = 0.024 (2) % measured in 1972Ah02.

Pγ of gamma ray $\gamma_{7,4}$ (166.39 keV) has been deduced using the ratio Iγ(166.39 keV) / Iγ(254.4 keV) = 0.016 (7) / 0.1091 (22) in^{239}Np β^- decay (2005Tr08, 2008BeZV) and P$\gamma_{7,3}$ (254.4 keV) = 0.11 (1) % measured in 1972Ah02.

7. CONSISTENCY OF RECOMMENDED DATA

The most accurate Q(α) value, Q_α (M), is taken from the atomic mass adjustment table of Audi et al. (2003Au03). Comparison of Q_α (eff) (deduced as the sum of average energies per disintegration ($\sum E_i \times P_i$) for all emissions accompanying ^{243}Cm α- decay) with the tabulated decay energy Q_α (M) × 0.9971 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, γ- ray, X-ray, etc. Consistency (percentage deviation) is determined by $\{[Q_\alpha\ (M) \times 0.9971 - Q(eff))] / Q_\alpha\ (M) \times 0.9971\ \} \times 100$. "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 current ^{243}Cm decay data evaluation we have Q_α (M) × 0.9971 = 6150.9 (10) keV and Q(eff) = 6171 (35) keV, i.e. consistency is better than 1.0 %.

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