^{245}Cm -Comments on evaluation of decay data by V.P. Chechev

Evaluated in November 2010 with a literature cut-off by the same date.

1. DECAY SCHEME

^{245}Cm decays 100 % to levels of ^{241}Pu by emission of α particles and, with a very small branch of 5.9 (9) × 10^{-7} % by spontaneous fission. The adopted ^{241}Pu levels populated in the ^{245}Cm α decay are based generally on the evaluation by Martin (2005Ma88). Questionable ^{241}Pu levels with energies of 260.5 and ≈ 376 keV as reported from α spectrometric measurements of 1975Ba65 were not included into the current evaluation. The 260.5-keV nuclear level was judged in 1975Ba65 as belonging possibly to ^{243}Am α decay, while the 376-keV nuclear level was not identified by 1975Ba65 and may belong to ^{239}Pu α decay along with the ≈ 384-keV energy level. However, the latter has been identified as $13/2^+$ belonging to the ^{241}Pu 7/2 [624] rotational band populated in the ^{245}Cm α decay (1975Ba65), and therefore has been included in the proposed decay scheme.

The decay scheme overall consistency is supported by the agreement between Q(calc) = 5640 (30) keV, deduced from the evaluated average energies and intensities of all emissions, and Q(α) = 5622.3 (5) keV, deduced from measured α-particle energies. Percentage deviation of Q(calc) from the adopted Q(α) and the Q(α) value of Audi *et al*. (2003Au03) is –(0.3 ± 0.5) %.

2. NUCLEAR DATA

Q(α) value has been deduced from the five alpha transition energies obtained from the α particle energies measured in 1975Ba65 and adjusted for changes in calibration energies by Rytz (1991Ry01). This approach (Table 1) similar to the evaluation by Martin (2005Ma88) is due to absence of an adjusted Q(α) value for ^{245}Cm in 2003Au03. Audi *et al.* (2003) chose Q(α) = 5623 (1) keV reported in 1975Ba65.

Table 1. ^{245}Cm Q(α) values deduced from α-transition energies

Energy of ^{241}Pu level (keV)	Energy of α particles (keV) (experimental)	Energy of α-transition (keV)	Deduced Q(α) value (keV)
41.9722 (9)	$\alpha_{0,1}$ 5488.5 (5)	5579.7 (5)	5621.7 (5)
95.7795 (12)	$\alpha_{0,2}$ 5436.1 (5)	5526.4 (5)	5622.2 (5)
175.0523 (14)	$\alpha_{0,5}$ 5361.8 (12)	5450.9 (12)	5625.9 (12)
231.935 (9)	$\alpha_{0,6}$ 5303.6 (12)	5391.7 (12)	5623.6 (12)
301.172 (16)	$\alpha_{0,7}$ 5234.4 (12)	5321.4 (12)	5622.5 (12)

The weighted average of the deduced Q(α) data set is 5622.3 keV, the internal uncertainty is 0.31, the external uncertainty is 0.55, χ^2/ν = 3.05, χ^2/ν (critical) = 3.30. The smallest value of experimental uncertainties is ± 0.5 keV. The recommended **Q(α)** value is **5622.3 (5) keV**.

The ^{245}Cm half-life is based on the experimental results given in Table 2.

Table 2. Experimental values of ^{245}Cm half-life (in 10^3 years)

Reference	Author(s)	Original value	Re-estimated value	Comments
1954Hu50	Hulet *et al.*	≈ 20		Not used
1954Fr19	Friedman *et al.*	11.5 (50)	11.3 (50) [a]	Relative specific activity to ^{244}Cm - not used.
1955Br02	Browne *et al.*	14.3 (29)		α counting - not used.
1957Hu76	Huizenga *et al.*	7.5 (19)		H. Diamond, Priv. Com. no details - outlier.
1961Ca01	Carnall *et al.*	9.32 (28)	9.60 (29) [a]	Relative specific activity to ^{244}Cm - outlier.
1969Me01	Metta *et al.*	8.265 (180)	8.270 (180) [a]	Relative specific activity to ^{244}Cm
1971Ma32	MacMurdo *et al.*	8.532 (53)	8.537 (71) [a,b]	Relative specific activity to ^{244}Cm
1982Po14	Polyukhov *et al.*	8.445 (100)	8.450 (100) [a]	Relative specific activity to ^{244}Cm
2009KoZV	Kondev *et al.*	8.245 (70)		Daughter in-growth from ^{249}Cf sample

[a] Re-estimated by the evaluator on the basis of the recommended ^{244}Cm half-life of 18.11 (3) years.
[b] Uncertainty has been revised in 1989Ho24.

In the six values adopted in the data analysis, the LWEIGHT computer program identified two outliers (1957Hu76 and 1961Ca01), and indicated that the four remaining experimental values are discrepant: there are two separate groups of measured values at 8.5×10^3 and 8.25×10^3 years. A similar situation for measurements of ^{239}Pu half-life by the specific activity method (24 400 and 24 100 years) was resolved to the benefit of the lower value on the basis of the detected presence of impurities leading to overestimations of half-life. This method involves the determination of the number of atoms and disintegration rate of the radionuclide with good accuracy, and thereby requires absolute efficiencies (2009KoZV). Daughter growth in a sample in which the parent is shorter lived does not require such efficiencies, and has been successfully adopted recently to determine the ^{240}Pu half-life (2008KoZP). Therefore, for statistical processing the evaluator has chosen two consistent experimental results obtained with different methods: 1969Me01 (re-estimated) and 2009KoZV, and omitted the other two measurements. The weighted average for this limited set of only two measurements is 8.25×10^3 years with an internal uncertainty of 0.065 and external uncertainty of 0.0084 (χ^2/ν = 0.02).

The recommended value for the ^{245}**Cm half-life** is **8.25 (7) × 10^3 years**.

A value of 1.4 (2) × 10^{12} years was adopted for ^{245}Cm spontaneous fission (SF) half-life from the measurement of 1985Dr10. SF branching of 5.9 (9) × 10^{-7} % has been derived from the adopted SF half-life and total half-life of 8.25 (7) × 10^{3} years.

2.1. Alpha Transitions

The energies of alpha transitions $\alpha_{0,1}$, $\alpha_{0,2}$, $\alpha_{0,5}$, $\alpha_{0,6}$ and $\alpha_{0,7}$ have been obtained from the experimental α particle energies taking into account the recoil energies for ^{241}Pu (Table 1). The energies of the remaining alpha transitions have been obtained from Q(α) value and ^{241}Pu level energies given in Table 3 from the Adopted Levels, Gammas of 2005Ma88 where they were deduced from a least-squares fit to gamma-ray energies.

Table 3. ^{241}Pu levels populated in ^{245}Cm α-decay

Level	Energy (keV)	Spin and parity	Half-life	Probability of α- transition (%)
0	0.0	5/2+	14.33 (4) a	0.58
1	41.9722 (9)	7/2+		0.83
2	95.7795 (12)	9/2+		0.04
3	161.314 (4)	11/2+		0.39 (22)
4	161.6852 (9)	1/2+	0.88 (5) μs	0.0210 (9)
5	175.0523 (14)	7/2+		93.2 (5)
6	231.935 (9)	9/2+		5.0 (1)
7	301.172 (16)	11/2+		0.32
8	385 (3)	(13/2+)		≤0.005

The experimental values for the α-transition probabilities of ^{245}Cm from spectrometric measurements are presented in Table 4. Uncertainties were not reported in the cited references, but these for the most intense α-transitions $\alpha_{0,5}$ (5362 keV) and $\alpha_{0,6}$ (5304 keV) observed in 1975Ba65 were estimated in 1976BaZZ. The data of 1966Ba07 for ^{245}Cm are not given in Table 4 as those were superseded in 1975Ba65 by the same group. The probabilities of the α-transitions $\alpha_{0,3}$ and $\alpha_{0,4}$ (observed as a doublet with an energy of ~5370 keV) have been deduced from intensity balances at the ^{241}Pu levels "3" (161.3 keV) and "4" (161.7 keV), respectively. Probabilities of the remaining alpha transitions have been adopted from the magnetic spectrometer measurements of 1975Ba65.

Table 4. Experimental and recommended probabilities (per 100 decays) of alpha transitions observed in ^{245}Cm α decay

	α-particle energy	1960As11	1963Dz07	1966Fr03	1975Ba65	Deduced from P(γ+ce) balance	Recommended
$\alpha_{0,0}$	5529			1.1	0.58		0.58
$\alpha_{0,1}$	5488			0.9	0.83		0.83
$\alpha_{0,2}$	5436			0.2	0.04		0.04
$\alpha_{0,3}$	5372					0.39 (22)	0.39 (22)
$\alpha_{0,4}$	5371					0.0210 (9)	0.0210 (9)
$\alpha_{0,5}$	5362	93	90	91	93.2 (5)	95.3 (21)	93.2 (5)
$\alpha_{0,6}$	5303	7	7	6.2	5.0 (1)		5.0 (1)
$\alpha_{0,7}$	5234		2	0.5	0.32		0.32
$\alpha_{0,8}$	5152				≤ 0.005		≤ 0.005

The α decay hindrance factors have been calculated using the ALPHAD computer program from the ENSDF evaluation package with $r_0(^{241}Pu)$ = 1.4969 (12) fm (2005Ma88).

2.2. Gamma Transitions and Internal Conversion Coefficients

The recommended energies of the gamma-ray transitions are the same as those of the gamma-ray energies with correction to the minor nuclear recoil for ^{241}Pu.

The gamma-ray transition probabilities ($P_{\gamma+ce}$) have been deduced from their evaluated gamma-ray emission probabilities (P_γ) and total internal conversion coefficients (ICCs), apart from $P_{\gamma+ce}$ values for the gamma-ray transitions $\gamma_{6,5}$ (56.9 keV) and $\gamma_{7,6}$ (69.2 keV). The latter values have been deduced directly from intensity balances at the ^{241}Pu levels "6" (231.9 keV) and "7" (301.2 keV), respectively.

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 the ^{240}Pu (n,γ)-reaction and have been taken from 2005Ma88, except as noted below.

The δ values for $\gamma_{6,5}$ (56.9 keV) and $\gamma_{7,6}$ (69.2 keV) have been obtained from the total ICC deduced using the expression $1+ \alpha_T = P_{\gamma+ce} / P_\gamma$.

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 for the five transitions ($\alpha_{0,1}$, $\alpha_{0,2}$, $\alpha_{0,5}$, $\alpha_{0,6}$, $\alpha_{0,7}$) used for obtaining Q(α) have been adopted from the most precise measurements of 1975Ba65. The remaining α particle energies have been deduced from the Q(α) value, taking into account the recoil energies for ^{241}Pu.

The recommended α-particle energies are compared in Table 5 with the experimental results from spectrometric measurements (1960As11, 1963Dz07, 1966Fr03 and 1975Ba65).

Table 5. Experimental and recommended α-particle energies (keV) in the decay of ^{245}Cm [a]

	1960As11	1963Dz07	1966Fr03	1975Ba65	Recommended
$\alpha_{0,0}$			5530 (3)	5529.0 (5)	5530.4 (5)
$\alpha_{0,1}$			5497 (5)	5488.5 (5)	5488.5 (5)
$\alpha_{0,2}$			5447 (5)	5436.1 (5)	5436.1 (5)
$\alpha_{0,3}$				5370	5371.7 (5)
$\alpha_{0,4}$				5370	5371.4 (5)
$\alpha_{0,5}$	5360	5361	5359 (2)	5361.8 (12)	5361.8 (12)
$\alpha_{0,6}$	5305	5305	5306 (2)	5303.6 (12)	5303.6 (12)
$\alpha_{0,7}$		5245	5239 (3)	5234.4 (12)	5234.4 (12)
$\alpha_{0,8}$				≈ 5151	5152 (3)

[a] Authors' experimental values have been adjusted for changes in calibration energies, as suggested in 1991Ry01.

5. ELECTRON EMISSIONS

The energies of the conversion electrons have been obtained from the gamma-ray transition energies and the atomic electron binding energies from 1977La19.

The emission probabilities of the conversion electrons have been deduced using the evaluated P_γ and ICC values. Measurements of the ^{241}Pu conversion electrons following thermal neutron capture in ^{240}Pu were carried out by 1998Wh01.

The total absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program (1996Sc06, 2000Sc47).

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 6). In 1980Di13 the emission probabilities of Pu KX-rays were measured relatively to P_γ ($\gamma_{5,0}$ 175.0 keV). The experimental absolute P(KX) values are given in Table 6 using the evaluated P_γ ($\gamma_{5,0}$ 175.0 keV) = 9.83 (22) %.

Table 6. Experimental (1980Di13) and calculated absolute Pu KX-ray emission probabilities (%)

	1980Di13	Calculated
$K\alpha_2$ (Pu)	20.0 (7)	19.0 (5)
$K\alpha_1$ (Pu)	30.9 (11)	30.1 (7)
$K\beta'_1$ (Pu)	11.1 (5)	11.1 (3)
$K\beta'_2$ (Pu)	3.7 (2)	3.84 (12)

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 (E_γ) have been taken from 2005Ma88 (^{241}Pu, Adopted Levels, Gammas). They are based mainly on measurements of γ rays from ^{245}Cm α decay by 1980Di13, 1992Daniels, 1994Sh31, 1998Wh01 and γ rays from thermal neutron capture in ^{240}Pu by 1998Wh01 (Table 7). The gamma-ray energies for $\gamma_{7,6}$ (69.2 keV), $\gamma_{5,2}$ (79.3 keV), $\gamma_{2,0}$ (95.8 keV), $\gamma_{6,2}$ (136.1 keV), $\gamma_{7,2}$ (205.4 keV), and $\gamma_{6,0}$ (231.9 keV) have been deduced directly from the adopted ^{241}Pu level energies. Other, less accurate measurements of E_γ can be found in 1955Pe32, 1966Ba07, 1991Po17.

6.2.2. Gamma-ray emission probabilities

The relative gamma-ray emission probabilities (I_γ) are weighted averages of the experimental values from 1980Di13 and 1992Daniels, except as noted otherwise in Table 7. The LWEIGHT computer program was used for statistical processing, with the uncertainty assigned to the average value always greater than or equal to the smallest uncertainty of the values used to calculate the average.

The normalization factor (N) was obtained from the intensity balance to the ground state of ^{241}Pu:

$$\Sigma(1+\alpha_T)I_\gamma\,(\gamma_{1,0}, \gamma_{2,0}, \gamma_{4,0}, \gamma_{5,0}, \gamma_{6,0}) + P(\alpha_{0,0}) = 1$$

assuming $P(\alpha_{0,0})$ = 0.006 (1) (1975Ba65, 2005Ma88),

N = P_γ (175.0 keV) = 0.0983 (22).

This adopted value agrees with the directly measured P_γ (175.0 keV) of 0.095 (7) (1980Di13) and 0.101 (1) (1992Daniels).

The absolute gamma-ray emission probabilities (P_γ) have been deduced from the evaluated relative gamma-ray emission probabilities (Table 7) using the derived normalization factor of 0.0983 (22).

Table 7. Experimental (E_γ^{exp}) and recommended gamma-ray energies and experimental and evaluated relative emission probabilities (I_γ^{exp}) in the decay of ^{245}Cm

	E_γ^{exp} from ^{245}Cm decay	**Recommended E_γ (keV)**	I_γ^{exp} (1980Di13)	I_γ^{exp} (1992Daniels)	I_γ^{exp} (1998Wh01)	**Evaluated I_γ**
$\gamma_{1,0}$	41.93 (3) [a]	**41.972 (1)**	3.68 (18)	4.10 (39)		**3.75 (18)** [a]
$\gamma_{2,1}$	53.72 (4) [a]	**53.807 (1)**	0.70 (4)	0.77 (4)		**0.74 (4)** [a]
$\gamma_{6,5}$	56.89 (3) [b]	**56.89 (3)**	0.38 (2)	0.325 (32)		**0.365 (20)** [a]
$\gamma_{3,2}$	65.44 (8) [a]	**65.535 (3)**	0.12 (4)	0.20 (2)		**0.18 (2)** [a]
$\gamma_{7,6}$	69.17 (6) [c]	**69.237 (18)**	0.07 (3)	-		**0.07 (3)**
$\gamma_{5,2}$	79.27 (4) [a]	**79.2728 (18)**	1.58 (9)	1.22 (7)		**1.22 (7)** [d]
$\gamma_{2,0}$	95.786 (3) [b, d]	**95.7795 (12)**				**0.111 (23)** [e]
$\gamma_{7,5}$	126.09 (4) [b]	**126.09 (4)**			0.07 (2)	**0.07 (2)** [b]
$\gamma_{5,1}$	133.05 (8) [a]	**133.081 (2)**	29.2 (15)	28.6 (4)		**28.6 (4)** [a]
$\gamma_{6,2}$	136.127 (20) [b]	**136.156 (9)**	1.18 (7)	1.15 (3)		**1.15 (3)** [a]
$\gamma_{7,3}$	139.87 (4) [b]	**139.858 (16)**	0.06 (2)	0.06 (3)	0.09 (1)	**0.08 (9)** [f]
$\gamma_{4,0}$	161.72 (8) [a]	**161.685 (1)**	0.09 (4)	0.067 (2)		**0.072 (2)** [a]
$\gamma_{5,0}$	175.01 (9) [a]	**175.0523 (14)**	100	100	100	**100**
$\gamma_{6,1}$	189.965 (10) [b]	**189.965 (10)**	2.03 (13)	2.07 (4)		**2.07 (4)** [a]
$\gamma_{7,2}$	205.404 (20) [a]	**205.393 (16)**	-	0.115 (19)	0.08 (1)	**0.09 (1)** [g]
$\gamma_{6,0}$	231.96 (3) [b]	**231.935 (9)**	0.16 (4)	0.117 (18)	0.11 (2)	**0.119 (18)** [h]
$\gamma_{-1,1}$	388.16 (5) [b]	**388.16 (5)**			0.19 (1)	**0.19 (1)** [b]

[a] Weighted averages of experimental values from 1980Di13 and 1992Daniels (see also1994Sh31, 2005Ma88).
[b] Experimental value from 1998Wh01.
[c] Reported only in 1980Di13, but also adopted in the level scheme of 1994Sh31.
[d] From 1992Daniels; higher value leads to a large intensity imbalance at the 96-keV and 175-keV levels
[e] Obscured by the Pu Kα_2 X-ray; I_γ is from I_γ/I_γ(53.8 keV) = 0.15 (3) in Adopted Gammas (2005Ma88).
[f] Weighted averages of experimental values from 1980Di13, 1992Daniels and 1998Wh01.
[g] Weighted averages of experimental values from 1992Daniels and 1998Wh01.
[h] Weighted averages of experimental values from 1980Di13, 1992Daniels and 1998Wh01.

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