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

This evaluation was done originally in 2004 (2004BeZQ, 2005ChZU) and then updated in June 2009 with a literature cut-off by the same date.

1 Decay Scheme

The decay scheme can be basically considered completed though weak alpha transitions to some highly excited ^{238}U levels (with energy more than 307 keV, see 2002Ch52) are possible but have not been observed yet. They are expected from data on level spins and Q(α) value and cannot appreciably influence intensity balances at the four lower levels well established.

2 Nuclear Data

Q(α) value is from 2003Au03.

The recommended half-life of ^{242}Pu is based on the experimental results given in Table 1. Re-estimated values were used for averaging where necessary.

Table 1. Experimental values of ^{242}Pu half-life (in 10^5 years).

Reference	Author(s)	Original value	Re-estimated value	Measurement method
1956Bu64	Butler et al.	3.73 (5)	3.65 (5) [a]	^{242}Pu/^{238}Pu, mass- and α-spectrometry
1956Bu92	Butler et al.	3.79 (5)		Specific activity, ionization chamber
1956Me37	Metch et al.	3.88 (10)	3.85 (10) [a]	^{242}Pu/^{240}Pu, mass- and α-spectrometry
1969Be06	Bemis et al.	3.869 (16)	3.82 (3) [b]	^{242}Pu/^{239}Pu, mass- and α-spectrometry
1970Du02	Durham and Molson	3.66 (7)	3.67 (7) [a]	^{242}Pu/^{238}Pu, mass- and α-spectrometry
1976Bu23	Bulaynitsa et al.	3.702 (7) [c]		Specific activity, 4πα-X coincidences
1976Os05	Osborne and Flotov	3.763 (9)		Calorimetry
1978MeZL	Meadows	3.736 (25)	3.708 (29) [a]	^{242}Pu/^{239}Pu, mass- and α-spectrometry
1979Ag03	Aggarwal et al.	3.742 (24)		^{242}Pu/^{239}Pu, mass- and α-spectrometry
1979Ag03	Aggarwal et al.	3.766 (25)		^{242}Pu/^{238}Pu, mass- and α-spectrometry

[a] Re-estimated in 1979Ag03 using the values of 87.74 yr for ^{238}Pu half-life and 24110 yr for ^{239}Pu half-life.
[b] Re-estimated in 1976Bu23 as a result of analysis of systematic uncertainties in 1969Be06 and using better values of auxiliary half-lives (see also 1979Ag03).
[c] Quoted uncertainty, corresponding to 95 % confidence level, has been reduced by a factor 2.

The weighted average of the ten values is 3.7304 with the internal uncertainty 0.0051 and external uncertainty 0.0116 and $\chi^2/\nu = 3.16$. The uncertainty of 1976Bulaynitsa was increased to 0.00724 to adjust weights according to the Limitation of Relative Statistical Weight method.

The LWEIGHT computer program has used the weighted average and expanded the uncertainty to 0.0284 so range includes the most precise value of 3.702 (1976Bu23).

The recommended value of ^{242}Pu half-life is 3.73 (3)·10^5 years.

The recommended spontaneous fission half-life of ^{242}Pu is based on the experimental results given in Table 2.

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

Reference	Author(s)	Original value	Re-estimated value [a]	Measurement method
1956Studier	Studier and Hirsch	6.7 (7)		Quoted by Mech et al.(1956); no details available
1956Me37	Mech et al.	7.06 (19)	6.79 (19)	α/SF; low geometry α-counting and Ar-CH_3 counter for SF
1956Bu92	Butler et al.	6.64 (10)	6.65 (10)	α/SF; ionization chamber
1961Dr04	Druin et al.	6.6 (7)		Gas scintillator; relative to α half-life of ^{238}Pu
1963Ma50	Malkin et al.	7.45 (17)		Gas scintillator; specific activity
1978MeZL	Meadows	6.80 (5)	6.74 (5)	α/SF; relative to half-life of ^{239}Pu
1980Kh05	Khan et al.	7.43		Mica fission track detector
1988SeZY	Selickij et al.	6.86 (26)		Fission fragment detection in 2π geometry

[a] Re-estimated in 2000Ho27.

Omitting the value of 1980Kh05 reported without uncertainty, the weighted average of the seven remaining values is 6.79 with the internal uncertainty 0.032 and external uncertainty 0.090 and $\chi^2/\nu = 2.94$.

The adopted value of the ^{242}Pu spontaneous fission is 6.79 (10)·10^{10} years where the uncertainty is the smallest quoted experimental uncertainty.

2.1 α Transitions

The energies of the alpha transitions have been obtained from the Q value and the level energies given in Table 3 from 2002Ch52.

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

Level number	Energy, keV	Spin and parity	Half-life	Probability of α-transition (x100)
0	0,0	0^+	4.468 (5)·10^9 yr	76.53 (17)
1	44.915 (13)	2^+	206 (3) ps	23.44 (17)
2	148.39 (3)	4^+		0.030 4 (13)
3	307.19 (8)	6^+		0.000 84 (6)

The probabilities of the transitions of $\alpha_{0,0}$, $\alpha_{0,1}$and $\alpha_{0,2}$ have been obtained by averaging the direct alpha-emission measurement results (the most accurate of them are from 1986Va33) and the values deduced from the gamma-ray transition probability (P(γ+ce)) balances at the corresponding ^{238}U levels. The deduced values are based on the measurements of absolute gamma-ray emission probabilities (P(γ)) from 1986Va33 (see Table 6) and adopted total internal conversion coefficients (ICCs).

Such averaging is possible as in 1986Va33 the independent measurements were carried out for alpha-emission intensities (with Si(Au) detector) and gamma-ray intensities (with two Ge detectors). The correlation between these measurements can be only due to the same sources used but it is negligible taking into account a large difference between the methods and detectors. Determination of the ^{242}Pu disintegration rates for six sources required for the absolute gamma intensity measurements was made in 1986Va33 using absolute alpha particle counting under well-defined low solid angles, i.e. out of connection with the alpha - emission intensity measurements with Si(Au) detector.

The probability of the $\alpha_{0,3}$-transition has been deduced from the P(γ+ce) balance at the ^{238}U level of 307.19 keV (Table 4).

Table 4. Experimental, deduced and recommended values of α-transition probabilities ($\times$100) in ^{242}Pu decay.

	α-particle energy (keV)	1953Asaro	1956Hu96	1976Baranov	1986Va33	Deduced from P(γ) measured in 1986Va33	Recommended
$\alpha_{0,0}$	4902	80 (6) [a]	74 (4) [a]	79.7 (20) [b]	76.45 (17)	77.3 (6)	76.53 (17) [c]
$\alpha_{0,1}$	4858	20 (6) [a]	26 (4) [a]	20.2 (20) [b]	23.52 (17)	22.7 (6)	23.44 (17)[c]
$\alpha_{0,2}$	4756	-	-	-	0.0290 (14)	0.031 7 (13)	0.030 4 (13)
$\alpha_{0,3}$	4600	-	-	-	-	0.000 84 (6)	0.000 84 (6)

[a] No uncertainties were quoted by the authors. The uncertainties adopted here were estimated by R. Vaninbroukx from the spectra shown in the papers (1986LoZT).
[b] The uncertainties of 2.7 for 79.7 and 1.1 for 20.2 quoted by the authors were re-estimated by R. Vaninbroukx (1986LoZT).
[c] Weighted average of the five values including direct measurement results and deduced value, uncertainty is the smallest quoted one.
[d] Weighted average of the two values including direct $\alpha_{0,2}$-transition measurement result and deduced value, uncertainty is the smallest quoted one.

2.2 γ Transitions

The recommended energies of gamma-ray transitions are virtually the same as the gamma-ray energies because nuclear recoil is negligible for ^{234}U.

The gamma-ray transition probabilities have been deduced from the gamma-ray emission probabilities and total internal conversion coefficients (ICCs). The ICCs have been interpolated using the BrIcc package with the so called "*Frozen Orbital*" approximation (2008Ki07). The uncertainties in the ICCs for pure multipolarities have been taken as 2 %. The multipolarities have been taken from 2002Ch52.

3 Atomic Data

3.1. Fluorescence yields

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

3.2 X-rays and Auger electrons

The energies of U LX-rays taken from the SAISINUC software supporting programs agree with the measurements of 1994Le37 where the fine structure of LX radiation was measured in decay of ^{240}Pu.

The U KX-ray energies have been taken from 1999Schönfeld where the calculated values based on X-ray wavelengths from 1967Be65.

The relative KX-ray emission probabilities have been taken from 1999Schönfeld.

The energies of Auger electrons are from the SAISINUC software supporting programs. The ratios P(KLX)/P(KLL), P(KXY)/P(KLL) are taken from 1996Sc06.

4 Alpha Emissions

The α-emission energies have been obtained from Q value and ^{238}U level energies taking into account the ^{238}U recoil energies. In Table 5 the recommended values of α-emission energies are compared with the experimental results from alpha-spectrometric measurements and also with the evaluated data by A. Rytz (1991Ry01).

Table 5. Experimental and recommended α-emission energies in decay of ^{242}Pu (keV).

	Measured [a]				1991Ry01	Recommended
	1953Asaro	1956Hu96	1956Ko67	1968Ba25		
$\alpha_{0,0}$	4904.6 (20)	4903.7 (30)	4907.2 (30)	4900.4 (12)	4902.3 (14)	4902.3 (10)
$\alpha_{0,1}$	4860.6 (20)	4859.7 (30)	4863.2 (30)	4856.1 (12)	4858.1 (15)	4858.2 (10)
$\alpha_{0,2}$	-	-	-	-	-	4756.2 (10)
$\alpha_{0,3}$	-	-	-	-	-	4600.1 (10)

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

5 Electron Emissions

The energies of conversion electrons have been obtained from the gamma-ray transition energies and the atomic-electron binding energies. The emission probabilities of the 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 probability of U MX–rays (αβ) in decay of ^{242}Pu has been deduced from the relative intensity P(XMαβ)/P(XLηβ) = 0.41 (4) measured in 1990Po14.

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).

6.2 Gamma-ray Emissions

The energies of gamma-rays have been adopted from 1972Sc01.

The absolute emission probabilities of the gamma-rays $\gamma_{1,0}$ (44.915 keV) and $\gamma_{2,1}$ (103.50 keV) have been deduced from the recommended P(α) values (Table 4) and the adopted total ICCs on the basis of intensity balances at the corresponding ^{238}U levels. The absolute emission probability of the gamma-ray $\gamma_{3,2}$ (158.80 keV) has been adopted from the direct measurement of 1986Va33 (Table 6).

Table 6. Experimental and recommended absolute emission probabilities of gamma-rays (×100) in ^{242}Pu decay.

	Energy (keV)	1972Sc01	1986Va33	Recommended
$\gamma_{1,0}$	44.915	-	0.0372 (7)	0.0384 (8)
$\gamma_{2,1}$	103.50	0.0081 (9) [a]	0.00263 (9)	0.00253 (12)
$\gamma_{3,2}$	158.80	0.005 (2) [a]	0.000298 (20)	0.000298 (20)

[a] Not used in the evaluation as considered in 1986LoZT.

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}Pu 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)} ×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}Pu decay data evaluation we have Q(M) = 4984.5 (10) keV and Q(eff) = 4984 (13) keV. Thereafter, the percentage deviation is (0.01 ± 0.26) %, i.e. consistency is superior.

8 References

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