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Decay Data Evaluation Project (DDEP): evaluation of the ^{237}U, ^{236}Np, ^{236m}Np and ^{241}Pu decay characteristics

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Abstract. The results of decay data evaluations are presented for ^{237}U, ^{236}Np, ^{236m}Np and ^{241}Pu. These evaluated data have been obtained within the Decay Data Evaluation Project and the IAEA CRP "Updated Decay Data Library for Actinides" using information published up to 2007.

1 Introduction

Comprehensive decay data evaluations of important applications-oriented actinides are being carried out within the Decay Data Evaluation Project (DDEP) [1] and the IAEA CRP "Updated decay data library for actinides" [2]. These studies constitute part of these concerted efforts.

The following decay characteristics of ^{237}U, ^{236}Np, ^{236}mNp and ^{241}Pu have been evaluated: half-life, decay energy, energies and probabilities of alpha, beta and electron-capture transitions, energies and transition probabilities of gamma transitions (P[γ+ce]), internal conversion coefficients, and energies and absolute emission probabilities of gamma rays, X-rays and electron emissions (Pe).

Evaluation results are given below for the most important decay data. More detailed recommended data and comments can be found on the DDEP web site which is located at: http://www.nucleide.org/DDEP_WG/DDEPdata.htm [3].

2 Evaluation procedure

Only the data for the main transitions of the different decay characteristics are given. Detailed comments on each characteristic can be found on the DDEP web site [3].

2.1 Half-lives

Evaluated ^{237}U and ^{241}Pu half-lives have been obtained by averaging the available experimental results, see ref. [3]. Differences in the recommended half-lives when compared with the equivalent data from recent ENSDF evaluations [4,5] arise from variations in the evaluation technique [1,3,6], especially the use of the limitation of relative statistical weights (LRSW method) in the DDEP statistical procedure.

The evaluated total half-life of ^{236}Np is based on the evaluated partial half-lives $T_{1/2}(\alpha)$, $T_{1/2}(\beta^-)$ and $T_{1/2}$(EC) measured in ref. [7]. A small difference in the evaluated total half-life as compared with the recent ENSDF evaluation of $1.53(5) \cdot 10^3$ years [8] is due to well-defined changes made to the recommended β^- and EC branches.

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2.2 Decay energies

Q-values have been adopted from the atomic mass tables of Audi et al. [9], except for Q(β^-) of ^{241}Pu. Our evaluation of this value differs slightly from the value of 20.78(13) keV [9] (see also ref. [3], and comments therein).

2.3 Energies and probabilities of α-particle emissions

α-particle emission energies have been deduced from Q(α) values and the level energies of the daughter nuclei, taking into account the recoil energies [3]. Values recommended by Rytz have been used for the energies of the most intense α groups [10].

The probabilities of the most intense α transitions have been obtained by averaging the available experimental results [3]. Probabilities for the remaining α transitions have been calculated from the gamma-transition intensity balances of the corresponding levels of the daughter nuclei.

Table 1. Evaluated energies and probabilities of β^- emissions in the decay of ^{237}U.

Endpoint energy keV	Average energy keV	Probability ×100
147.7 (6)	39.0 (2)	1.3 (7)
186.2 (6)	49.8 (2)	2.9 (7)
237.2 (6)	64.5 (2)	48.1 (25)
251.1 (6)	68.6 (2)	40.7 (32)
459.1 (6)	137.6 (2)	7 (4)

2.4 Energies and probabilities of β^- emissions

The energies of the β^- transitions (β^--spectrum endpoint energies) have been deduced from Q(β^-) and the level energies of the daughter nuclei [3]. β^--spectrum average energies have been calculated using the LOGFT computer program.

The emission probabilities of the β^- transitions have been derived from the gamma-transition intensity balances of the corresponding levels of the daughter nuclei.

2.5 Gamma-ray transition probabilities and internal conversion coefficients

Gamma-ray transition probabilities have been deduced from the absolute gamma-ray emission probabilities and the total internal conversion coefficients (ICC). The adopted ICC are theoretical values interpolated using the BRICC package. Multipolarities and mixing ratios for the gamma-ray transitions have been derived from the available experimental data. Measured ICC data have been directly adopted in some instances [3].

Table 2. Evaluated energies and probabilities of most intense γ rays and γ transitions (P(γ+ce) > 0.04) in the decay of ^{237}U.

Energy keV	Number of photons per 100 decays	P(γ+ce) ×100
13.81 (4)	0.099 (4)	48.7 (25)
26.3446 (2)	2.43 (6)	22 (5)
33.1963 (2)	0.130 (5)	23 (3)
43.420 (3)	0.024 (2)	4.3 (4)
59.5409 (1)	34.1 (8)	74 (3)
164.61 (2)	1.86 (3)	5.00 (11)
208.00 (1)	21.3 (3)	84.6 (19)

Table 3. Evaluated energies and emission probabilities of Np X-rays in the decay of ^{237}U.

Np X-rays	Energy keV	Number of photons per 100 decays
XL	11.89–22.20	51.3 (3)
XKα_2	97.069	14.7 (4)
XKα_1	101.059	23.4 (6)
XK$'\beta_1$	113.30–114.91	8.50 (27)
XK$'\beta_2$	117.46–118.43	2.92 (10)

2.6 Energies and probabilities of gamma-ray emissions

Evaluated energies and emission probabilities for the most intense gamma rays in the decay of ^{237}U and ^{241}Pu have been obtained by averaging the available experimental results [3]. Under certain circumstances, the energies of the prominent gamma rays have been adopted directly from the most accurate measurements, taking into account a correction of 5.8 ppm in the gamma-ray energy scale from ref. [11].

The energies of the gamma rays accompanying the β^- decay of ^{236}Np and ^{236m}Np have been adopted from measurements [12], while the energies of the gamma rays accompanying ^{236}Np and ^{236m}Np electron-capture decay have been adopted from the evaluated DDEP data for ^{240}Pu α decay [13].

Absolute emission probabilities of gamma rays in the decay of ^{236}Np have been deduced from the relative intensities measured in ref. [12] and using the adopted decay scheme and intensity balances at every nuclear level for each decay mode (see ref. [3]). The absolute emission probabilities of the gamma rays in the decay of ^{236m}Np have been deduced from the adopted decay scheme and the averaged experimental data of the relative gamma-ray emission probabilities.

Table 4. Evaluated energies and emission probabilities (Pe > 0.1) of Auger and conversion electrons in the decay of ^{237}U.

Electrons	Energy keV	Number of electrons per 100 decays
e_{AL}	5.04–13.52	48.8 (26)
ceL γ26.3	3.92–8.74	14.6 (50)
ceM γ13.8	8.07–10.15	36.0 (19)
ceL γ33.2	10.77–15.59	16.9 (24)
ceL γ59.5	37.11–47.93	28.6 (22)
ceK γ208.0	89.331 (10)	49.8 (13)
ceL γ208.0	185.57–190.39	10.1 (3)

Table 5. Evaluated energies, and emission and transition probabilities of the main γ transitions in the decay of ^{236}Np to levels of ^{236}Pu and ^{236}U.

Energy keV	Number of photons per 100 decays	P (γ+ce) ×100
44.63 (10) [^{236}Pu]	0.0161 (9)	12.0 (6)
45.242 (3) [^{236}U]	0.149 (3)	87.8 (6)
102.82 (2) [^{236}Pu]	0.81 (6)	12.0 (6)
104.234 (6) [^{236}U]	7.32 (13)	87.8 (6)
158.35 (2) [^{236}Pu]	3.8 (4)	11.8 (12)
160.307 (3) [^{236}U]	31.8 (15)	87.8 (43)

2.7 Probabilities of X-ray and Auger electron emissions

The absolute emission probabilities of the X-rays and Auger electrons have been calculated by means of the EMISSION computer code [14] and the evaluated decay data.

2.8 Transition probabilities of conversion electrons

The absolute emission probabilities of the conversion electrons (ce) have been deduced from the evaluated absolute gamma-ray emission probabilities and ICC values.

3 Evaluation results

Tables of evaluated data are given below for the main decay characteristics of ^{237}U, ^{236}Np, ^{236m}Np and ^{241}Pu. Uncertainties in the data are contained within parentheses, and refer to the corresponding last digits; thus, 8.50 (27) means 8.50 ± 0.27, and 9.2 (11) means 9.2 ± 1.1.

3.1 Evaluated ^{237}U decay data

The evaluated ^{237}U half-life is 6.749(16) days, and the adopted ^{237}U β^--decay energy (Q^--value) is 518.6(6) keV.

The results of the evaluation are given in tables 1–4 for the energies and probabilities of the different radiations accompanying the β^- decay of ^{237}U.

3.2 Evaluated ^{236}Np decay data

The evaluated total ^{236}Np half-life is $1.55(8) \cdot 10^3$years. Branching fractions for the ^{236}Np electron-capture, β^- and α decay modes have been evaluated to be 87.8(6)%, 12.0(6)% and 0.16(6)%, respectively. The probability of the β^- transition to the 6+ level in ^{236}Pu has been evaluated as 11.8(12)%.

The adopted ^{236}Np electron-capture (Q^+-value), β^- (Q^--value), and α-decay energies ($Q\alpha$) are 930(50), 480(50) and 5010(50) keV, respectively.

Evaluated data are given in tables 5 and 6 for the energies and probabilities of the most intense photon radiation accompanying the decay of ^{236}Np. Energies and emission probabilities for the other γ-rays as well as Auger and conversion electrons can be found in ref. [3].

Table 6. Evaluated energies and emission probabilities of U X-rays in the electron-capture decay of ^{236}Np.

U X-rays	Energy keV	Number of photons per 100 decays
XL	11.62–20.71	117.5 (30)
XKα_2	94.666	20.2 (3)
XKα_1	98.440	32.4 (5)
XK$'\beta_1$	110.42–111.96	11.68 (25)
XK$'\beta_2$	114.41–115.38	3.99 (11)

Table 7. Evaluated energies and probabilities of β^- emissions in the decay of ^{236m}Np.

Endpoint energy keV	Average energy keV	Probability ×100
492 (8)	143 (3)	11 (4)
537 (8)	158 (3)	36 (4)

Table 8. Evaluated energies, and emission and transition probabilities of the most intense γ transitions in the decay of ^{236m}Np to levels of ^{236}Pu and ^{236}U.

Energy keV	Number of photons per 100 decays	P (γ +ce) ×100
44.63 (10) [^{236}Pu]	0.015 (5)	11.2 (37)
45.242 (3) [^{236}U]	0.016 (5)	9.6 (30)
642.35 (9) [^{236}U]	1.08 (6)	1.24 (8)
687.60 (5) [^{236}U]	0.292 (21)	0.383 (28)

3.3 Evaluated ^{236m}Np decay data

The evaluated ^{236m}Np half-life is 22.5(4) hours. Branching fractions for the ^{236m}Np electron-capture and β^- decay modes have been evaluated as 53(1)% and 47(1)%, respectively.

The adopted ^{236m}Np β^- (Q^--value) and electron-capture decay energies (Q^+-value) are 537(8) and 993(13) keV, respectively.

Evaluated data are given in tables 7–9 for the energies and probabilities of the most intense radiation accompanying the decay of ^{236m}Np.

Table 9. Evaluated energies and emission probabilities of U X-rays in the electron-capture decay of ^{236m}Np.

U X-rays	Energy keV	Number of photons per 100 decays
XL	11.62–20.71	21.3 (8)
XKα_2	94.666	9.9 (10)
XKα_1	98.440	15.8 (15)
XK$'\beta_1$	110.42–111.96	5.7 (6)
XK$'\beta_2$	114.41–115.38	1.95 (15)

Table 10. Evaluated energies and probabilities of the most intense α-particle emissions ($P\alpha \geq 10^{-7}$) in the decay of ^{241}Pu.

Energy keV	P$\alpha \times 100$	Hindrance factor
4798.0 (5)	0.000029 (3)	18.6
4853.8 (5)	0.000295 (8)	4.5
4897.3 (5)	0.00203 (4)	1.3
4973.1 (5)	0.000032 (3)	276
4999.2 (5)	0.0000100 (12)	1300
5043.4 (5)	0.000025 (2)	1000

Table 11. Evaluated energies, emission and transition probabilities of the most intense γ transitions ($P(\gamma + ce) > 5 \cdot 10^{-6}$) in the decay of ^{241}Pu.

Energy keV	Number of photons per 100 decays	P(γ + ce) ×100
56.30 (12)	0.0000025 (2)	0.00051 (4)
103.680 (5)	0.000103 (2)	0.000536 (14)
148.567 (10)	0.0001863 (8)	0.001500 (27)

Table 12. Evaluated energies and emission probabilities of U X-rays in the decay of ^{241}Pu.

U X-rays	Energy keV	Number of photons per 100 decays
XL	11.62–20.71	0.001166 (40)
XKα_2	94.666	0.000300 (7)
XKα_1	98.440	0.000479 (10)
XK$'\beta_1$	110.42–111.96	0.000179 (5)
XK$'\beta_2$	114.41–115.38	0.000059 (2)

3.4 Evaluated ^{241}Pu decay data

The evaluated ^{241}Pu half-life is 14.33(4)years. Branching fractions for the ^{241}Pu β^- and α decay modes have been evaluated as 99.99756(2)% and 0.00244(2)%, respectively.

The adopted ^{241}Pu β^- (Q^--value) and α decay energies ($Q\alpha$-value) are 20.8(2) and 5140.0(5) keV, respectively.

Evaluated data are given in tables 10–12 for the energies and probabilities of the most intense radiation accompanying the α decay of ^{241}Pu.

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