^{239}U – COMMENTS ON EVALUATION OF DECAY DATA

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1. DECAY SCHEME

Decay scheme is based on 2003Br12. Most (99 %) of ^{239}U beta decay feeds the well-studied ^{239}Np levels below 118 keV. However more than 30 excited states of ^{239}Np have been associated with weak ^{239}U beta transitions and in this part the decay scheme cannot be considered as completed.

Several unplaced gamma rays were observed in 2006Wo03. These gamma rays carry ≤ 2 % of the total intensity of all the gamma rays placed in the decay scheme.

Wong and Griffin (2006Wo03), based on the energies of many of these gamma rays, suggested different versions of their placement including alternative with respect to 2003Br12. These suggestions require an additional careful analysis. Therefore the evaluators have been accepted only small change in the decay scheme from 2003Br12 associated with moving the 1197-keV level off and adding the new 849,45-keV level.

The 1197-keV level stated in 2003Br12 has been deleted from the level scheme since the 535-, 1122- and 1197- keV gamma transitions previously reported were not observed in 2006Wo03 and attributed to possible impurities. The new (declared in 2006Wo03) 849,45-keV level de-exciting via 502-, 608-, 728-, 775- and 849- keV gamma rays has been placed to the decay scheme.

It should be noted that a number of ^{239}Np levels reported only from nuclear reactions may be populated (according to the data of 2006Wo03) in ^{239}U β^--decay.

Several gamma rays previously reported were not observed with high reliability in 2006Wo03. They were ascribed to fission product impurities in their study.

2. NUCLEAR DATA

Q^- value is from 2003Au03.

The recommended half-life of ^{239}U is based on the experimental results given in Table 1.

Table 1. Experimental values of ^{239}U half-life (in minutes)

Reference	Author(s)	Original value	Re-estimated	Measurement method
1943Mi10	Mitchell et al.	23,54 (5)		β-counting
1947Fe05	Feather and Krishnan	23,5 (7)		β- and gamma-ray counting
1969Hu21	Hunt et al.	23,40 (5)		β-counting
1989Ab05	Abzouzi et al.	23,44 (2) [a]	23,44 (11)	Gamma-ray counting
2008Griffin	Griffin	23,37 [b]	23,37 (10)	Liquid scintillation counting

[a] Uncertainty may include only statistical errors. The evaluators have taken into account the contribution of possible systematic errors (uncertainty of the Type B) associated with the gamma-ray counting method (see Comments on evaluation of ^{233}Th half-life).
[b] Author did not report the uncertainty. Possible statistical and systematic errors associated with the used LSC method were discussed in 2008De10 under the measurements of ^{233}Th half-life (22 min). The evaluators have estimated an overall relative uncertainty of ~ 0,4 % (see Comments on evaluation of ^{233}Th half-life).

The unweighted mean of the 6 values from Table 1 is 23,45 (3), the weighted mean is 23,46, the internal uncertainty is 0,032, the external uncertainty is 0,035. The LWEIGHT computer program recommended the weighted mean and its internal uncertainty. The smallest experimental uncertainty is 0,05. Therefore, the recommended value of ^{239}U half-life is 23,46 (5) minutes.

2.1. Beta Transitions

The energies of β^- transitions have been obtained from the Q^- value and the ^{239}Np level energies given in Table 2 from 2003Br12.

Table 2. ^{239}Np levels populated in ^{239}U β^--decay

Level	Energy (keV)	Spin and Parity	Half-life	
0	0,0	5/2+	2,356 (3) d	14,4 (22)
1	31,1310 (12)	7/2+		9,4 (15)
2	71,210 (2)	9/2+		
3	74,664 (1)	5/2-	1,39 (3) ns	72,8 (19)
4	117,727 (20)	7/2-	= 40 ps	2,2 (4)
5	122,5 (10)	(11/2+)		
6	173,10 (4)	9/2-		
7	241,36 (5)	(11/2-)		
8	260,799 (17)	(3/2-)		
9	438,83 (5)	(11/2+)		
10	448,178 (16)	(3/2-)		
11	452,736 (2)	(5/2+,7/2-)		
12	474,36 (6)			0,0033 (4)
13	517,998 (20)	(7/2-)		0,063 (2)
14	530,29 (6)			0,0029 (4)
15	563,89 (4)			0,0247 (7)
16	579,40 (4)	(9/2-)		
17	662,282 (17)	(5/2-)		0,261 (6)
18	695,229 (23)	(7/2-)		0,0118 (11)
19	781,93 (4)			
20	784,94 (5)			
21	819,26 (3)	(7/2)		0,228 (3)
22	844,10 (3)	(5/2,7/2)		0,215 (3)
23	849,44 (9)			0,0264 (4)
24	863,46 (6)	(3/2,5/2,7/2)		0,0005 (2)
25	959,18 (3)			0,0284 (7)
26	964,234 (20)	(7/2-)		0,211 (3)
27	966,55 (5)	(7/2,9/2-)		0,0008 (2)
28	992,158 (22)	(7/2-)		0,0262 (9)
29	1013,64 (8)			0,0074 (4)
30	1040,37 (4)	(5/2-,7/2)		0,0077 (4)
31	1049,24 (4)	(9/2-)		0,0059 (4)
32	1096,99 (3)			0,0060 (5)

The emission probabilities of β^--transitions have been deduced from the P(γ+ce) balance at each level of ^{239}Np. β^--transitions with P(β) < 0,5 % are tentative because of unplaced γ-ray transitions (see 2006Wo03).

2.2. Gamma-ray Transitions and Internal Conversion Coefficients

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

The gamma-ray transition probabilities have been obtained from the gamma-ray emission probabilities and the total internal conversion coefficients (ICC). Multipolarities of gamma-ray transitions have been taken from 2003Br12. The ICC have been interpolated using the BrIcc package with the so called "*Frozen Orbital*" approximation (2008Ki07). The relative uncertainties of the ICC for pure multipolarities have been taken as 2 %.

P($\gamma_{2,0}$ + ce)(71,2-keV) and P($\gamma_{7,2}$ + ce)(170,2-keV) have been obtained from the level P(γ+ce) balance assuming that there is no beta-feeding to the 2- and 7- levels, respectively.

The M1/E2 mixing ratios for $\gamma_{1,0}$ - 31,1 keV (0,028), $\gamma_{4,3}$ - 43,1 keV (0,126) and $\gamma_{6,4}$ -55,2 keV (0,26) have been taken from ^{243}Am α decay (2003Br12).

The remaining gamma transition multipolarities and M1/E2 mixing ratios have been adopted from ^{239}U β^{-}-decay (see 2003Br12) based on measurements of 1957Ho07, 1964Bl11, 1969En02.

3. ATOMIC DATA

The atomic data (fluorescence yields, X-ray energies and relative probabilities, and Auger electrons energies and relative probabilities) have been deduced by using the SAISINUC software (2002Be).

4. ELECTRON EMISSIONS

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

The absolute emission probabilities of the conversion electrons have been obtained using the recommended P_γ and ICC values.

The absolute emission probability of K Auger electrons has been deduced from the recommended ΣKX = 0,305 (10) %. The absolute emission probability of L Auger electrons has been obtained using the recommended P_γ and ICC values with the EMISSION computer program.

β^{-} average energies have been calculated using the LOGFT computer program.

5. PHOTON EMISSIONS

5.1. X-Ray Emissions

The recommended absolute emission probabilities of KX- rays have been obtained using the total number of K vacancies of 0,314 (10) % deduced in 2008Griffin from their KX-ray measurements.

The recommended absolute emission probabilities of LX-rays have been obtained using the recommended P_γ , ICC values and the total number of K vacancies with the EMISSION computer program. The calculated total absolute intensity of LX-rays of 16,1 (5) % can be compared with the value of 17 (4) % measured in 2008Griffin (here the author's value of 18,1 % has been corrected to the evaluated P$\gamma_{2,0}$ (74,7 keV) = 51,6 (13) % used instead of 53,9 (5) % measured in 2008Griffin). The uncertainty of the measured LX-ray intensity was not given in 2008Griffin. It has been accepted by the evaluators using the relative uncertainty of the detection efficiency for energies at and below 20 keV ~ 20 % estimated in 2008De10.

5.2. Gamma-Ray Emissions

The gamma ray energies < 120 keV have been obtained from the adopted level energies.

The gamma ray energies > 120 keV have been adopted from 2006Wo03. They agree mainly with the values from 2003Br12 based on experimental data of 1964Bl11, 1969Cl12, 1971Ar47, 1975Pa04, 1979Bo30, 1982Ah04 and data from nuclear reactions. The exceptions comprise the gamma-ray transitions feeding the ^{239}Np ground state and the gamma rays with energies from 2006Wo03 different from 2003Br12. In such cases the recommended gamma ray energies have been obtained from the adopted level energies.

Several unplaced gamma rays observed in decay of ^{239}U, a-decay of ^{243}Am, and the particle transfer reactions were discussed in 2006Wo03 in detail. The transfer reactions and a-spectroscopy give direct information on level energies, but with uncertainties ~ 3 keV. Gamma ray spectroscopy, unsupported by coincidence correlations, gives relatively precise energies, but often placements are ambiguous. Therefore, all such gamma rays have been qualified by the evaluators as unplaced in the decay scheme.

The absolute emission probabilities for most intense gamma rays have been evaluated from experimental data (Table 4). The results of 1984Holloway are superseded by the same group in 1996Sa23 and have not been included in the procedure of averaging.

Table 4. Experimental and evaluated absolute emission probabilities (%) for most intense gamma-rays in decay of ^{239}U.

Eγ (keV)	1964 Bl11	1965 Yurova	1968 Ma06	1969 Cl12	1984 Holloway	1996 Sa23	2008 Griffin	**Evaluated**
31,1					0,065 (7)	0,064 (7)	0,075 (4)	**0,072 (4)**
43,5	4,1 (2)			4,45 (60)	4,18 (13)	4,07 (11)	4,93 (15)	**4,35 (28)**
74,7		47 (4)	62 (9)	50 (5)	48,2 (10)	49,2 (12)	53,9 (5)	**51,6 (13)**
86,7				0,060 (6)	0,052 (6)	0,053 (6)	0,054 (5)	**0,055 (5)**
117,7				0,145 (15	0,13 (4)	0,14 (3)	0,099 (9)	**0,113 (9)**

$P\gamma_{2,0}$ (71,2 keV) and $P\gamma_{7,2}$(170,2 keV) have been obtained from the P(γ+ce) and α_T .The value of $P\gamma_{4,3}$ (43,1 keV) has been deduced using the ratio $P\gamma_{4,3}$ / $P\gamma_{4,0}$ = 0,115 (12) from 1969En02.

The remaining absolute gamma ray emission probabilities for gamma rays with energy more than 120 keV have been deduced from relative gamma ray emission probabilities P_γ^{rel} (2006Wo03). Thereto the evaluators have used the coefficient k = P_γ^{rel} (74,7 keV) / 0,539 (5) given in 2008Griffin. It was corrected to the evaluated P_γ (74,7 keV) = 0,516 (13) taking also into account the detection efficiency uncertainty (0,7 %): k = 218,1 (48). The obtained P_γ agree with the values from 2003Br12 based on experimental data of 1964Bl11, 1965Yurova, 1968Ma06, 1969Cl12, 1971Ar47 and 1984Holloway.

6. 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 ^{233}Th β- 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 ^{239}U decay data evaluation we have Q(M) = 1261,5 (16) keV and Q(eff) = 1263 (36) keV, i.e. consistency is better than 2 %.

7. REFERENCES

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