^{238}U - Comments on evaluation of decay data by V. Chisté and M.M. Bé

This evaluation was completed in January 2006, and the literature available at this date has been included here.

1 Decay Scheme

^{238}U disintegrates by alpha emission to two excited levels and to the ground state of ^{234}Th. Spin and half-lives of excited states are from the mass-chain evaluation of Y.A. Akovali (1983El11 and 1994Ak05 for A = 234) and F.E. Chukreev (2002Ch52 for A = 238).

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).

Experimental ^{238}U half-life values (in years x 10^9) are given in Table 1:

Table 1: Experimental values of ^{238}U half-life.

Reference	Original value (10^9 a)	Revised Value by Schön (2004Sc03)	Comments
Kovarik (1932Ko02)	4.52		**Not used**. Natural U.
Schiedt (1935Schiedt)	4.42 (3)	4.46 (3) **(a)** 4.41 (5) **(b)**	**Not used**. Natural U. Corrected for ^{235}U. **(a)** ^{234}U and ^{238}U assumed to be in equilibrium. **(b)** ^{234}U and ^{238}U assumed to be not in equilibrium.
Curtis (1941Curtis)	4.514 (9)		**Not used**. Natural U. Lacking details.
Kienberger (1949Ki26)	4.490 (10)	4.495 (18)	**Not used**. Enriched U.
Kovarik (1955Ko13)	4.507 (9)	4.51 (2) **(a)** 4.46 (5) **(b)**	**Not used**. Natural U. **(a)** ^{234}U and ^{238}U assumed to be in equilibrium. **(b)** ^{234}U and ^{238}U assumed to be not in equilibrium.
Lechman (1957Le21)	4.56 (3)		**Not used**. Enriched U.
Steyn (1959St45)	4.460 (10)	4.457 (4) **(a)** 4.41 (4) **(b)**	**Not used**. Natural U. **(a)** ^{234}U and ^{238}U assumed to be in equilibrium. **(b)** ^{234}U and ^{238}U assumed to be not in equilibrium.
Jaffey (1971Ja07)	4.4683 (24)	4.468 (5)	Highly enriched U.
Recommended value		**4.468 (5)**	

The evaluators have chosen to follow the recommendations given by R. Schön (2004Sc03), who studied in detail various problems with the measurements of the half-life of ^{238}U. So, the recommended value is the half-life obtained by Jaffey (1971Ja07), but its original uncertainty was multiplied by 2 (as suggested by Schön (2004Sc03)) in order to take into account the systematic uncertainties which were not considered by 1971Ja07.

Experimental ^{234}Th half-life values (in days) are given in Table 2:

Table 2: Experimental values of ^{234}Th half-life.

Reference	Value (d)	Uncertainty (d)
M. Curie (1931Cu01)	24.5	
B.W. Sargent (1939Sa11)	24.1	0.2
G.B. Knight (1948Kn23)	24.101	0.025
Recommended value is (from 1994Ak05)	24.10	0.03

The recommended value is *24.10 d* with an uncertainty of *0.03 d*, from Y. A. Akovali (1994Ak05).

The evaluated spontaneous fission partial half-life of ^{238}U is based on the experimental results given in Table 3.

Table 3: Experimental values of spontaneous fission decay rate of ^{238}U (λ^{238}, in 10^{-17} year^{-1}).

Reference	Value	Uncertainty	Comments by Holden (2000Ho27)
W.J. Withehouse (1950Whitehouse)	8.38	0.52	Ionization chamber.
E. Sègres (1952Se67)	8.60	0.29	Ionization chamber.
R.L. Fleischer (1964Fl07)	6.85	0.20	**Not used.** Mica-uranium sandwich.
A. Spadavecchia (1967Sp12)	8.42	0.10	Rotating bubble chamber.
J.H. Roberts (1968Ro15)	7.03	0.11	**Not used.** Mica-uranium sandwich.
H.R. von Gunten (1969Vo24)	8.66	0.22	Fission products of ^{238}U.
D. Galliker (1970Ga27)	8.46	0.06	Rotating bubble chamber.
D. Storzer (1970Storzer)	8.49	0.76	Fission tracks in dated uranium glass.
J.D. Kleeman (1971Kl14)	6.8	0.6	**Not used.** Lexam-uranium sandwich.
W.M. Thury (1971Th17)	8.66	0.43	Third order coincidence.
M.P.T. Leme (1971Le11)	7.30	0.16	**Not used.** Mica-uranium sandwich.
H.A. Khan (1973Kh10)	6.82	0.55	**Not used.** Mica-uranium sandwich.
K.N. Ivanov (1974Iv04)	7.12	0.32	**Not used.** Mica-uranium sandwich.
V. Emma (1975Em03)	7.2	0.2	**Not used.** Mica-uranium sandwich.
G.A. Wagner (1975Wa37)	8.7	0.6	Fission tracks in dated uranium glass.
K. Thiel (1976Th12)	8.57	0.42	Fission tracks in dated uranium glass.
M. Kase (1978Ka40)	8.22	0.20	Ionization chamber.
A.G. Popeko (1980Po09)	7.9	0.4	Multiple neutron coincidence.
E.R.V. Spaggiari (1980Sp10)	9.26	0.17	**Not used.** Mica-uranium sandwich.
Z.N.R. Baptista (1981Ba70)	6.6	0.2	**Not used.** Mica-uranium sandwich.
J.C. Hadler (1981Hadler)	8.6	0.4	**Not used.** Mica-uranium sandwich.
H.G. de Carvalho (1982De22)	11.8	0.7	**Not used.** Fission tracks in ordinary glass.
S.N. Belenky (1983Be66)	8.35	0.40	Multiple neutron coincidence.
B. Vartanian (1984Va34)	8.23	0.43	**Not used.** Fissions tracks (plastic, uranium foils).
M.P. Ivanov (1985Iv01)	8.29	0.27	Double ionization chamber.
S.S. Liu(1991Liu)	7.03	0.21	**Not used.** Solid-state track detectors.
Recommended value of λ^{238} (in 10^{-17} years^{-1})	**8.451**	**0.060**	reduced $\chi^2 = 0.30$
Recommended half-life value (in 10^{15} years)	**8.202**	**0.060**	

The evaluators, following the recommendations of N.E. Holden (2000Ho27), have not used in their calculations the measurements with fission tracks in mica-uranium, lexan-uranium sandwiches or ordinary glass, because they significantly disagree with the rest (for more details see 2000Ho27). Thus the experimental values with associated uncertainties used in the weighted average calculation are those from 1950Whitehouse, 1952Se67, 1967Sp12, 1969Vo24, 1970Ga27, 1970Storzer, 1971Th17, 1975Wa37, 1976Th12, 1978Ka40, 1980Po09, 1983Be66 and 1985Iv01. A weighted average has been calculated using LWEIGHT computer program (version 3). Based on the Chauvenet's criterion, Popeko's value (1980Po09) has been shown to be an outlier.

The recommended value of λ^{238} is the weighted average (calculated with LWEIGHT computer program) of *8.451* 10^{-17} a^{-1} with an internal uncertainty of *0.046* 10^{-17} a^{-1}. However, evaluators have adopted an uncertainty of *0.060* 10^{-17} a^{-1}, minimum input value.

Using this value of λ^{238} and the formula:

$$t_{1/2} = \frac{\ln(2)}{\lambda^{238}},$$

the evaluators have deduced a partial spontaneous fission half-life of *8.202 (60)* 10^{15} *a* for ^{238}U and a spontaneous fission branching of 5.45 (4) 10^{-5} %.

2.1 α Transitions and Emissions.

The energies of the α-particle transitions given in Section 2.1 have been calculated from Q_α (2003Au03) and level energies.

The energies of $\alpha_{0,0}$, $\alpha_{0,1}$ and $\alpha_{0,2}$ emissions given in Section 4 are from A. Rytz (1991Ri01).

Measured α-emission intensities are given in Table 4.

Table 4: Measured α-emission intensities, in %.

Energy (keV)	1959Ko58	2000Ga05	Recommended Value
4198 ($\alpha_{0,0}$)	77 (4)	77.54 (50)	77.54 (50)
4151 ($\alpha_{0,1}$)	23 (4)	22.33 (50)	22.33 (50)
4038 ($\alpha_{0,2}$)	0.23 (7)	0.13 (3)	0.13 (3)

The results of these two intensity measurements (1959Ko58 and 2000Ga05) are consistent with each other. Evaluators have adopted the most recent and precise results of Garcia-Toraño (2000Ga05).

2 γ Transitions

The γ-ray probabilities of the 49- and 113-keV transitions have been deduced from decay-scheme balance by using the recommended experimental alpha emission intensity values (2000Ga05). (see **2.1 α Transitions and Emissions**).

Multipolarities of γ-ray transitions in the decay of ^{234}Th are from 1994Ak05:
49-keV γ-ray : E2
113-keV γ-ray: [E2]

The internal conversion coefficients (ICC's) have been calculated using the Icc99v3a computer program (GETICC dialog), which uses the new tables of Band et al (2002Ba85) (results of calculation for "hole" and "no hole" are the same). The evaluators have used a fractional uncertainty of 3 % for all conversion coefficients.

3 Atomic Data

Values of atomic values quantities ω_K, ϖ_L and n_{KL}, are from Schönfeld and Janβen (1996Sc06).

3.1 X rays and Auger electrons

The relative probabilities of X-ray and Auger electrons have been calculated from γ-ray data using the EMISSION computer program.

4 α Emissions

See **2.1 α Transitions and Emissions.**

5 Electron emissions

The Auger electrons emission probabilities have been calculated from γ-ray data using the EMISSION computer program.

6 Photon Emissions

6.1 K x-rays

X-ray emission probabilities have been calculated from γ-ray data using the EMISSION computer program.

6.2 γ-ray emissions

The energies of the γ-ray emissions given in Section 6 are from Y.A. Akovali (1994Ak05).

The absolute γ-ray emission intensities have been deduced from the absolute γ-ray transition probabilities and the internal conversion coefficients (ICC's). (see **2.2 γ Transitions.**).

Table 5 shows the recommended absolute γ-ray (photon) emission intensities of the 49- and 113-keV emissions as well as the experimental results obtained from direct measurements of emission intensities.

The agreement is not good, maybe due to experimental difficulties (many peaks of different contaminant isotopes in this energy region) when measuring these weak γ-ray intensities.

Table 5: Experimental absolute γ emission intensity in %.

γ Energy (keV)	1984Ro21	1990Ko40	1996Ru11	Recommended value
49.55	0.064 (8)	0.059 (2)		0.0697 (26)
113.5	0.0102 (15)		0.07 (1)	0.0174 (47)

A fair agreement has been found between the results given by J-C. Roy (1984Ro21) and the evaluators' recommended value for the 49-keV γ-ray.

For the 113-keV γ-ray, there is no good agreement either between results of direct experimental measurements or between those latter and the recommended value. In this energy region the experimental difficulties are associated with presence of many small peaks from different isotopes in the γ-ray spectrum.

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