$^{236}Np^{m}$ – COMMENTS ON EVALUATION OF DECAY DATA

by V.P.Chechev and N.K.Kuzmenko

This evaluation was completed in June 2006. The literature available by May 2006 was included.

1. DECAY SCHEME

From the systematics of isomer levels it was assumed in 1981Li30 (see also the analysis carried out in 1991Sc08) that the short-lived state of ^{236}Np (22,5 h) lies higher in energy than the long-lived state of ^{236}Np (1,55 10^{5} y). In line with this assumption we have considered the long-lived state of ^{236}Np as the ground state. Using Q values for electron capture decays of the isomer and ground states together with closed energy cycles we can estimate the energy level spacing between these states as 60(50) keV.
The decay scheme of the isomer $^{236}Np^{m}$ includes two decay modes: $ß^{-}$ decay to ^{236}Pu and electron capture decay (EC) to ^{236}U (see evaluations of 1991Sc08, 1996FiZX). The $ß^{-}$ -decay branching, $\Sigma P(ß^{-})$, has been adopted from 1969Le05. The EC -decay branching, ΣP(EC), has been obtained as the difference of $1-\Sigma P(ß^{-})$.

2. NUCLEAR DATA

Q^{-} ($^{236}Np^{m}$) is from 1969Le05 (the end-point energy of the β^{-} spectrum was measured). Q_{EC}($^{236}Np^{m}$) has been calculated from the closed energy cycle of decays ending in ^{232}Th. The values of Q^{-} ($^{236}Np^{m}$), Q_{α} (^{236}Pu), Q^{-} (^{232}Pa), Q_{EC}(^{232}Pa) and Q_{α}(^{236}U) from 2003Au03 were used in this calculation.
The half-life of $^{236}Np^{m}$ is from 1969Le05. This result agrees with other (less accurate) measurements (1949Ja01 – 22 h, 1984Gr33 – 22,5 h).

2.1. Electron Capture Transitions

The energies of the electron capture transitions have been deduced from the Q_{EC} value and the level energies (Table 1) obtained from the evaluated gamma-ray energies.

Table 1. ^{236}U levels populated in the $^{236}Np^{m}$ electron capture decay

Level number	Energy, keV	Spin and parity	Half-life	Probability of EC - transition (×100)
0	0,0	0^{+}	$2,342 \cdot 10^{7}$ yr	43,1(32)
1	45,242(3)	2^{+}	234 ps	8,3(30)
2	149,476(15)	4^{+}	124 ps	-
4	687,60(5)	1^{-}	3,8 ns	1,64(9)

The individual EC- transition probabilities $P(EC_{1,i})$ have been deduced from the intensity balance for each level and the total EC -decay probability $\Sigma P(e_{1,i})$.

2.2. Beta Transitions

The $ß^{-}$- transition energies have been deduced from the Q^{-} value and the level energies (Table 2) obtained from the evaluated gamma-ray energies.

Table 2. ^{236}Pu levels populated in the $^{236}Np^{m}$ $ß^{-}$ -decay

Level number	Energy, keV	Spin and parity	Half-life	Probability of $ß^{-}$- transition (× 100)
0	0,0	0^{+}	2,858 yr	36(4)
1	44,63(10)	2^{+}		11(4)

The ß$^{-}$- transition probabilities P($\beta_{1,0}$), P($\beta_{1,1}$) have been obtained from the ratio P($\beta_{1,0}$)/P($\beta_{1,1}$) =38(7)/12(5) measured in 1959Gi58 and the total ß$^{-}$ -decay probability ΣP($\beta_{1,i}$).

2.3. Gamma Transitions and Internal Conversion Coefficients (^{236}U)

The evaluated transition energies are virtually the same as the photon energies because nuclear recoil is negligible.

The gamma-ray transition probabilities have been obtained from the gamma-ray emission probabilities and the total internal conversion coefficients (ICC's). Multipolarities of gamma-ray transitions have been taken from 1991Sc08 and 1996FiZX. The gamma-ray transition probability P($\gamma_{1,0}$ +ce)(44,6-keV) has been deduced from the relation of P($\gamma_{1,0}$ +ce)(44,6-keV)= P($\beta_{0,1}$).

ICC's have been interpolated using the BRICC computer program, except for $\gamma_{4,1}$ (642,3-keV) and $\gamma_{4,0}$ (687,6-keV) because of nuclear penetration effects. The relative uncertainties of α_K, α_L, $\alpha_{M,}$ α_T for pure multipolarities have been taken as 2%.

α_K and α_L for $\gamma_{4,1}$(642,3-keV) and $\gamma_{4,0}$(687,6-keV) are experimental values from data in ^{240}Pu α-decay (1969Le05 and 1977Po05, see also the evaluation of 2004Be). α_M and α_T for these transitions have been evaluated using α_M/α_L and α_{NO}/α_M from 1971Dr11. More accurate ICC measurements for these transitions are required.

3. ATOMIC DATA

3.1. Fluorescence yields

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

3.2. X Radiations

The LX-ray energies are from 1996FiZX. The KX-ray energies and the relative KX-ray emission probabilities are from 1999Schönfeld.

The X-ray energies are based on the wavelengths given in the compilation of 1967Be65 (Bearden).

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

3.3. Auger Electrons

The ratios P(KLX)/P(KLL), P(KXY)/P(KLL) are taken from 1996Sc06.

4. ELECTRON EMISSIONS

The energies of the conversion electrons have been deduced from the gamma transition energies and the electron binding energies.

The emission probabilities of the conversion electrons have been deduced using evaluated P_γ and ICC values.

The absolute emission probabilities of K and L Auger electrons have been obtained with the EMISSION computer program.

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

5. PHOTON EMISSIONS

5.1. X-Ray Emissions

The absolute emission probabilities of KX- and LX-rays have been obtained with the EMISSION computer program.

For U LX-ray calculations the ratios P_{EC}(L2)/P_{EC}(L1) =0,115 and P_{EC}(L3)/P_{EC}(L1) =0 from the theoretical calculations of 1972Dzhelepov were used for all levels populated in the ^{236}Np^{m} electron capture decay.

5.2. Gamma Ray Emissions

5.2.1. Gamma Ray Energies (^{236}U)

The energies of gamma rays accompanying the ^{236}Np^{m} electron capture decay have been adopted from the evaluated DDEP data in ^{240}Pu α-decay (2004Be).

5.2.2. Gamma Ray Energies (^{236}Pu)

The energy of $\gamma_{1,0}$ (44,6 keV) accompanying the ß$^{-}$ - decay of ^{236}Np^{m} has been adopted from measurements in 1983Ah02.

5.2.3. Gamma-Ray Emission Probabilities (^{236}U)

The gamma-ray emission probability P(γ) for $\gamma_{1,0}$ (45,2 keV) has been obtained from the ratio $\Sigma P(e_i)$(45,2 keV) / $P(\gamma_{4,1})$(642,3 keV) = 9(3) measured in 1969Le05.

The evaluated gamma ray emission probability $P(\gamma_{4,1})$(642,3 keV) = 0,96(20)% has been deduced using the following values:

1) $\Sigma P(e_{1,i})$=53(1)%;
2) measured ratio P(XKa) / $P(\gamma_{3,1})$(642,3 keV)=27,6(10) from 1969Le05;
3) theoretical value of the ratio P(XKa)/P(XKß)=0,298(5);
4) relative (partial) intensities of gamma rays de-exciting level ''4'' [$\gamma_{4,2}$ (538,1 keV), $\gamma_{4,1}$ (642,3 keV), $\gamma_{4,0}$ (687,5 keV)], which have been deduced from the absolute gamma-ray emission probabilities evaluated in the ^{240}Pu α-decay (Table 5), and a_K for these gamma-rays;
5) the measured ratio ΣP_K (i) $P(EC_{1,i})$/ $\Sigma P(ß^-_{1,i})$=0,75(15) from 1956Gr11, which can be represented as $P_K^{(average)}$ = ΣP_K (i) $P(EC_{1,i})$/ Σ $P(EC_{1,i})$=0,67(13).

The most accurate evaluation of $P_K^{(average)}$ (and also the new evaluation of $P(\gamma_{4,1})$ (642,3 keV) and other values) may be obtained by using the theoretical P_K(i), the values of $P(EC_{1,i})$ deduced from $P(\gamma_{4,1})$(642,3 keV) = 0,96(20)%, and the fact that a contribution of the third term (with $P(EC_{1,4})$) to $P_K^{(average)}$ comprises ˜ 2,5%. This value has been taken as a fractional uncertainty for the $P_K^{(average)}$ = 0,75(2).Using the latter and the relations 1) - 4) we have deduced a more accurate evaluation of $P(\gamma_{4,1})$(642,3 keV) = 1,08(6)%, and correspondingly a more accurate evaluation for other decay data.

The gamma-ray emission probability $P(\gamma_{2,1})$ (104,2 keV) has been calculated from $P(\gamma_{2,1}$ +ce) (104,2 keV) = $P(\gamma_{4,2}$ +ce)(538,1 keV) assuming that the electron capture feeding of level "2" is negligible.

Table 5. Experimental and evaluated absolute emission probabilities of gamma rays de-exciting the ^{236}U level with energy of 687,6 keV in the decay of ^{240}Pu (per 10^8 a-decays) and the deduced relative intensities of these gamma rays

	Energy, keV	1969Le05	1971GuZY	1975OtZX	1975Dr05	1976GuZN	Evaluated	Evaluated relative intensities
$\gamma_{4,2}$	538,1	≈0,23 [a]		0,147(12)			0,147(12)	1,17(10)
$\gamma_{4,1}$	642,3	14,5 [a]	14,5(5) [b]	12,6(4)	13(1)	12,45(30)	12,6(3) [c]	100 (3)
$\gamma_{4,0}$	687,6	3,77(11)	3,70(15) [b]	3,30(13)		3,55(9)	3,56(15) [d]	28,3(13)

[a] Omitted from averaging as uncertainty is not quoted
[b] Omitted from averaging as the data of 1971GuZY have been revised in 1976GuZN
[c] Weighted mean of 3 experimental values; the uncertainty is the smallest quoted uncertainty
[d] Weighted mean of 3 experimental values; the uncertainty is external

5.2.3. Gamma-Ray Emission Probability (^{236}Pu)

The gamma-ray emission probability P(γ) for $\gamma_{1,0}$ (44,6 keV) has been obtained from $P(\beta_{1,1})$ and the adopted α_T for this gamma-ray transition.

6. REFERENCES

1949Ja01 R.A.James, A.E.Florin, H.H.Hopkins, Jr., and A.Ghiorso, NNES 14B (1949) 1604
(Half-life)
1956Gr11 P.R. Gray, Phys.Rev. 101(1956) 1306.
(Relative probability of K-electron capture in the decay of ^{236m}Np)
1959Gi58 J.E. Gindler , R.K. Sjoblom, J. Inorg. Nucl. Chem. 12 (1959) 8.
(Probabilities of beta transitions)
1967Be65 J.A. Bearden, Rev. Mod. Phys. 39 (1967) 78.
(X-ray energies)

1969Le05 C.M. Lederer, J.M. Jaklevic, S.G. Prussin, Nucl. Phys. A135 (1969) 36.
(Relative intensities of gamma rays)
1971GuZY R. Gunnink, R.J. Morrow, In: UCRL 51087 (1971).
(Emission probabilities of gamma-rays in the decay of ^{240}Pu)
1971Dr11 O. Dragoun, Z. Plajner, F. Schmutzler, NDT A9 (1971) 119.
(α_M / α_L and α_{NO} / α_M)
1972Dzhelepov B.S. Dzhelepov, L.N. Zyryanova, Yu.P. Suslov, Beta-processes, 1972, Nauka, Leningrad
(Fractional probabilities in L-electron capture)
1975OtZX H. Ottmar, P. Matussek, I. Piper In: Proc Int Symp Neutron Capture Gamma Ray Spectroscopy and Related Topics, 2nd, Petten, The Netherlands (1974), K. Abrahams, F Stecher-Rasmussen, P Van Assche, Eds, Reactor Centrum Nederland, p 658 (1975).
(Emission probabilities of gamma-rays in the decay of ^{240}Pu)
1975Dr05 T. Dragnev, K. Scharf, Intern. J. Appl. Radiat. Isotop. 26 (1975) 125.
(Gamma ray emission probabilities in the decay of ^{240}Pu)
1976GuZN R. Gunnink, J.E. Evans and A.L. Prindle, UCRL-52139 (1976).
(Emission probabilities of gamma-rays in the decay of ^{240}Pu)
1977Po05 W.L. Posthunus, K.E.G. Löbner, I. Piper e.a., Z. Phys. A281 (1977) 717
(ICC measurements)
1984Gr33 E.A.Gromova, S.S.Kovalenko, Yu.A.Nemilov, Yu.A.Selitsky, A.V.Stepanov, A.M.Fridkin, V.B.Funshtein, V.A.Yakovlev, G.V.Valsky and G.A.Petrov, At.Energ. 56 (1984) 212; Sov.At.Energy 56 (1984) 230
(Half-life)
1991Sc08 M.R.Schmorak, Nucl.Data Sheets 63 (1991) 139.
(Decay scheme, gamma ray multipolarities)
1996Sc06 E. Schönfeld and H. Janßen, Nucl. Instrum. Methods Phys. Res. A369, 527 (1996)
(Atomic data)
1996FiZX R.B. Firestone, Table of Isotopes, Eighth Edition, Volume II: A=151-272, V.S. Shirley (Editor), C.M. Baglin, S.Y.F. Chu, and J. Zipkin (Assistant Editors), 1996, 1998, 1999
(Decay scheme, LX ray energies, multipolarities)
1999Schonfeld E. Schonfeld and G. Rodloff - PTB-6.11-1999-1999-1, Braunschweig, February 1999
(KX-ray energies and relative emission probabilities)
2003Au03 G. Audi, A.H. Wapstra, and C. Thibault, Nucl. Phys. A729, 337 (2003)
(Q values)
2004Be M. M. Bé, V. Chiste, C. Dulieu, E. Browne, V. Chechev, N. Kuzmenko, R. Helmer, A. Nichols, E. Schönfeld, and R. Dersch. Table of Radionuclides, Vol.2. A = 151 to 242. ^{240}Pu. – Bureau International des Poids et Mesures, 2004. See also: Recommended Data by the Decay Data Evaluation Project working group. ^{240}Pu. http://www.nucleide.org/DDEP_WG/DDEPData.htm