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

1. DECAY SCHEME

From the systematics of the isomer levels it has been 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 ($1.55 \times 10^5$ y). In line with this assumption we consider the long-lived state of $^{236}$Np as the ground state. Using Q values for electron capture decay of the isomer and ground state and a close energy cycle we can estimate the energy level spacing between these states as $60(50)$ keV.

The decay scheme of the long-lived $^{236}$Np includes three decay modes: $\beta^-$ decay to $^{236}$Pu, electron capture decay (EC) to $^{236}$U and $\alpha$ decay to $^{232}$Pa (see evaluations in 1991Sc08, 1996FiZX). A favored $\alpha$-particle branch to the (6-) level at $\approx 400$ keV is expected in $^{232}$Pa from $\alpha$ systematics (1972El21, 1980Sc26, 1991Sc08). However, this decay was not observed experimentally.

The $\beta^-$-decay branching, $\Sigma P(\beta^-)$, and alpha-decay branching, $\Sigma P(\alpha)$, have been deduced from the partial half-lives $T_{1/2}(\beta^-)$ and $T_{1/2}(\alpha)$, respectively. The EC -decay branching, $\Sigma P(EC)$, has been obtained as the difference of $1 - \Sigma P(\beta^-) - \Sigma P(\alpha)$.

2. NUCLEAR DATA

$Q^-$, $Q_{EC}$, $Q(\alpha)$ values are from 2003Au03.

The total half-life of $^{236}$Np is based on the evaluated partial half-lives $T_{1/2}(\alpha)$, $T_{1/2}(\beta^-)$, $T_{1/2}(EC)$ measured in 1981Li30.

The evaluated $T_{1/2}(\alpha) = 9.5(35) \times 10^7$ years has been obtained as an average of the two measurements of 1981Li30 (specific activity, $^{232}$U gamma-ray of 894 keV was measured): $9.4(35) \times 10^7$ and $9.6(35) \times 10^7$ years. A standard deviation of the individual measurement has been adopted for the uncertainty of the evaluated alpha-decay half-life using a rule that the uncertainty assigned to the recommended value should be greater than or equal to the smallest uncertainty in any experimental value. $T_{1/2}(\beta^-) = 1.29(3) \times 10^8$ years has been adopted here from the $^{236}$Pu growth measurement of 1981Li30. The result of this measurement is independent of the decay scheme, and it is equal to the weighted average of $1.34(15)$, $1.29(3)$, $1.32(9)$, $1.69(30)$, $1.29(3)$, $1.31(8)$ (in $10^6$ years) given in 1981Li30. The uncertainties of these measurements do not include any estimation of uncertainties from the decay scheme parameters. It agrees well with an earlier measurement in 1972En06 ($1.29 \pm 0.07 - 0.05 \times 10^5$ yr).

The evaluated $T_{1/2}(EC) = 1.77(10) \times 10^5$ years has been obtained as an average of the two $^{236}$U/$^{235}$U mass ratio measurements in 1981Li30: $1.75(10) \times 10^5$ and $1.79(10) \times 10^5$ years. These $^{236}$U growth measurement results are independent of the decay scheme. A standard deviation of the individual measurement has been adopted for the uncertainty of the evaluated partial EC-decay half-life using a rule that the uncertainty assigned to the recommended value should be greater than or equal to the smallest uncertainty in any experimental value. $T_{1/2}(\beta^-) = 1.29(3) \times 10^8$ years has been adopted here from the $^{236}$Pu growth measurement of 1981Li30. The result of this measurement is independent of the decay scheme, and it is equal to the weighted average of $1.34(15)$, $1.29(3)$, $1.32(9)$, $1.69(30)$, $1.29(3)$, $1.31(8)$ (in $10^6$ years) given in 1981Li30. The uncertainties of these measurements do not include any estimation of uncertainties from the decay scheme parameters.

Thus, the recommended value of the total $^{236}$Np half-life obtained from the relation $T_{1/2} = [(T_{1/2}(\alpha))^{-1} + (T_{1/2}(\beta^-))^{-1} + (T_{1/2}(EC))^{-1}]^{-1}$ is equal to $1.55(8) \times 10^5$ years.

2.1.1. Electron Capture Transitions

The energies of the electron capture transitions have been obtained from the $Q_{EC}$ value and the level energies (Table 1) based on the evaluated gamma-ray energies.
Table 1. $^{236}\text{U}$ levels populated in the $^{236}\text{Np}$ electron capture decay

<table>
<thead>
<tr>
<th>Level number</th>
<th>Energy, keV</th>
<th>Spin and parity</th>
<th>Half-life</th>
<th>Probability of $\varepsilon$ - transition (x100)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0,0</td>
<td>$0^+$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>45,242(3)</td>
<td>$2^+$</td>
<td>234 ps</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>149,476(15)</td>
<td>$4^+$</td>
<td>124 ps</td>
<td>0,0(44)</td>
</tr>
<tr>
<td>3</td>
<td>309,783(8)</td>
<td>$6^+$</td>
<td>58 ps</td>
<td>87,8(43)</td>
</tr>
<tr>
<td>4</td>
<td>687,60(5)</td>
<td>1</td>
<td>3,8 ns</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>744,15(8)</td>
<td>3</td>
<td>&lt;0,1 ns</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>848,3(8)</td>
<td>5</td>
<td></td>
<td>~0,09</td>
</tr>
</tbody>
</table>

The probabilities of the electron capture transitions $P(\text{EC}_{0,2})$ and $P(\text{EC}_{0,3})$ have been obtained from $P(\text{EC}_{0,2}) + P(\text{EC}_{0,3}) = 100\% - \sum P(\beta^-) - \sum P(\alpha) = 87,8(6)\%$ and $P(\text{EC}_{0,3}) = P(\gamma_{3,2} + \text{ce})(150\text{-keV})$. The upper limit of $P(\text{EC}_{0,2}) < 4,4\%$ has been obtained from $P(\text{EC}_{0,2}) = 0,0(44)\%$. The estimate of $P(\text{EC}_{0,6}) \sim 0,1\%$ is from 1996FiZX.

2.1.2. Beta Transitions

The energies of the $\beta^-$ transitions have been calculated from the $Q^-$ value and the level energies (Table 2) based on the evaluated gamma-ray energies.

Table 2. $^{236}\text{Pu}$ levels populated in $^{236}\text{Np}$ $\beta^-$ -decay

<table>
<thead>
<tr>
<th>Level number</th>
<th>Energy, keV</th>
<th>Spin and parity</th>
<th>Half-life</th>
<th>Probability of $\beta^-$ transition (x100)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0,0</td>
<td>$0^+$</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>1</td>
<td>44,63(10)</td>
<td>$2^+$</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>147,45(10)</td>
<td>$4^+$</td>
<td>2,858 yr</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>305,80(11)</td>
<td>$6^+$</td>
<td></td>
<td>11,8(12)</td>
</tr>
</tbody>
</table>

The $\beta^-$ transition probability $P(\beta_{0,3}) = P(\gamma_{3,2} + \text{ce})(158\text{ -keV})$, and $P(\beta_{0,2}) = 12,0(6)\% - P(\beta_{0,3}) = 0,2(14)\%$. From this result follows an upper limit of $P(\beta_{0,2}) < 1,6\%$.

2.2. Gamma Transitions and Internal Conversion Coefficients

The evaluated energies of gamma-ray transitions 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 probability and the total internal conversion coefficients (ICC’s). Multipolarities of gamma-ray transitions have been taken from 1991Sc08 and 1996FiZX. Internal conversion coefficients (ICC) have been interpolated using the BRICC computer program, except for $\gamma_{4,1}$ (642,3 -keV) and $\gamma_{4,0}$ (687,6 -keV). The fractional uncertainties in $\alpha_K, \alpha_L, \alpha_M, \alpha_T$ for pure multipolarities have been taken as 2%.

$\alpha_K$ and $\alpha_L$ for $\gamma_{4,1}$ (642,3 -keV) and $\gamma_{4,0}$ (687,6 -keV) are experimental values from $^{240}\text{Pu} \alpha$-decay (1969Le05 and 1977Po05, see also the evaluation of 2004Be). $\alpha_M$ and $\alpha_T$ for these transitions have been evaluated using $\alpha_M/\alpha_L$ and $\alpha_{5\alpha}/\alpha_M$ 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 obtained from the gamma transition energies and the atomic electron binding energies.
The emission probabilities of the conversion electrons have been obtained using evaluated P(\(\gamma\)) and ICC values.
The absolute emission probabilities of K and L Auger electrons have been obtained using the EMISSION computer program.
\(\beta^-\) 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 deduced from experimental data and theoretical internal conversion coefficients using the EMISSION computer program.
For LX-ray calculations the theoretical ratios \(P_{EC}(L2)/P_{EC}(L1) = 0.115\) and \(P_{EC}(L3)/P_{EC}(L1) = 0\) have been obtained for the level ‘‘3’’ (309 keV) of \(^{236}\text{U}\) (1972Dzhelepov). The calculated relative intensities of KX- rays accompanying the electron capture of \(^{236}\text{Np}\) are in a good agreement with the experimental results (Table 3).

<table>
<thead>
<tr>
<th>X_K</th>
<th>1983Ah03 (experimental)</th>
<th>Adopted (deduced)</th>
</tr>
</thead>
<tbody>
<tr>
<td>K(\alpha_2)</td>
<td>0.61(2)</td>
<td>0.66(7)</td>
</tr>
<tr>
<td>K(\alpha_1)</td>
<td>0.99(3)</td>
<td>1.0(1)</td>
</tr>
<tr>
<td>K(\beta_1')</td>
<td>0.38(2)</td>
<td>0.38(4)</td>
</tr>
<tr>
<td>K(\beta_2')</td>
<td>0.131(7)</td>
<td>0.13(1)</td>
</tr>
</tbody>
</table>

5.2. Gamma Ray Emissions
5.2.1. Gamma Ray Energies (\(^{236}\text{U}\))
The energies of gamma rays accompanying the \(^{236}\text{Np}\) electron capture decay have been adopted from the evaluated DDEP data on the \(^{240}\text{Pu}\) \(\alpha\)-decay (2004Be).

5.2.2. Gamma Ray Energies (\(^{236}\text{Pu}\))
The energies of gamma rays \(\gamma_{1,0}\) (44.6 keV), \(\gamma_{2,1}\) (102.8 keV), \(\gamma_{3,2}\) (158.3 keV) accompanying \(\beta^-\) decay of \(^{236}\text{Np}\) have been adopted from measurements given in 1983Ah02.
5.2.3. Gamma-Ray Emission Probabilities ($^{236}$U)

The evaluated gamma ray emission probabilities $P(\gamma)$ have been deduced using the relative gamma ray intensities from 1983Ah02 (Table 4), the quantity $\sum P(\beta^-) = 12.05(60)\% = P(\gamma_{2,1} + ce)$ (102.8 keV) and the intensity balance at each level. We have assumed that the populations to the two lower levels (“0” and “1”) in $\beta^-$ decay are negligible and have taken into account the intensity balance of the gamma-ray transitions to these levels, that is $P(\gamma_{1,0} + ce)$ (44.6 keV) = $P(\gamma_{2,1} + ce)$ (102.8 keV).

Table 4. Gamma rays in the decay of the long-lived $^{236}$Np measured in 1983Ah02

<table>
<thead>
<tr>
<th></th>
<th>Energy, keV</th>
<th>Relative intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma_{1,0}$ ($^{236}$U)</td>
<td>45.23(3)</td>
<td>0.4(1)</td>
</tr>
<tr>
<td>$\gamma_{2,1}$ ($^{236}$Pu)</td>
<td>102.82(2)</td>
<td>2.9(2)</td>
</tr>
<tr>
<td>$\gamma_{2,1}$ ($^{236}$U)</td>
<td>104.23(2)</td>
<td>23(1)</td>
</tr>
<tr>
<td>$\gamma_{3,2}$ ($^{236}$Pu)</td>
<td>158.35(2)</td>
<td>13.5(7)</td>
</tr>
<tr>
<td>$\gamma_{3,2}$ ($^{236}$U)</td>
<td>160.33(2)</td>
<td>100</td>
</tr>
</tbody>
</table>

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

The evaluated gamma ray emission probabilities $P(\gamma)$ have been deduced using the relative gamma ray intensities from 1983Ah02 (Table 4), the relation of $\sum P(EC_{0,1}) = 87.8(6)\% = P(\gamma_{2,1} + ce)$ (104.23 keV) and the intensity balance at each level. We have assumed that the populations to the two lower levels (“0” and “1”) in the electron capture decay are negligible and have taken into account the intensity balance relation for the gamma-ray transitions to these levels, that is $P(\gamma_{1,0} + ce)(45.2 keV) = P(\gamma_{2,1} + ce)(104.2 keV)$.

The evaluated gamma ray emission probabilities for $\gamma$-rays de-exciting level $4^+$($\gamma_{4,2}$ (538.1 keV), $\gamma_{4,1}$ (642.3 keV), and $\gamma_{4,0}$ (687.5 keV)) have been deduced from the relation $P(\gamma_{5,4} + ce)(56.6 keV) = P(\gamma_{4,2} + ce)(538.1 keV) + P(\gamma_{4,1} + ce)(642.3 keV) + P(\gamma_{4,0} + ce)(687.5 keV)$ using the relative intensities for these $\gamma$-rays evaluated from the $^{240}$Pu $\alpha$-decay (Table 5) and assuming $P(EC_{0,4}) = 0$.

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$^8$ $\alpha$-decays) and the deduced relative intensities of these gamma rays

<table>
<thead>
<tr>
<th></th>
<th>Energy, keV</th>
<th>1969Le05</th>
<th>1971GuZY</th>
<th>1975OtZX</th>
<th>1975Dr05</th>
<th>1976GuZN</th>
<th>Evaluated</th>
<th>Evaluated relative intensities</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma_{4,2}$</td>
<td>538.1</td>
<td>$\approx 0.23^a$</td>
<td>14.5$^a$</td>
<td>14.5(5)$^b$</td>
<td>0.147(12)</td>
<td>13(1)</td>
<td>0.147(12)</td>
<td>1.17(10)</td>
</tr>
<tr>
<td>$\gamma_{4,1}$</td>
<td>642.4</td>
<td>3.77(11)</td>
<td>3.70(15)$^b$</td>
<td>3.30(13)</td>
<td>3.56(15)$^d$</td>
<td>28.3(13)</td>
<td>100 (3)</td>
<td></td>
</tr>
<tr>
<td>$\gamma_{4,0}$</td>
<td>687.6</td>
<td>1.4(5)$^b$</td>
<td>14.5(5)$^b$</td>
<td>12.6(4)</td>
<td>12.45(30)</td>
<td>3.35(10)</td>
<td>3.56(15)$^d$</td>
<td>28.3(13)</td>
</tr>
</tbody>
</table>

$^a$ 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
6. REFERENCES

(X-ray energies)

(Relative intensities of gamma rays)

(Emission probabilities of gamma-rays in the decay of $^{240}$Pu)

($\alpha_M / \alpha_L$ and $\alpha_{SN} / \alpha_M$)

(Fractional probabilities in L-electron capture)

(Half-life)

(Emission probabilities of gamma-rays in the decay of $^{240}$Pu)

(Gamma ray emission probabilities in the decay of $^{240}$Pu)

(Emission probabilities of gamma-rays in the decay of $^{240}$Pu)

1977Po05 W.L. Posthunus, K.E.G. Lübner, I. Piper e.a., Z. Phys. A281 (1977) 717  
(ICC measurements)

(Systematics of nuclear level properties)

(Half-life, partial half-lives)

(Gamma-ray relative intensities and energies, KX-ray energies)

(Decay scheme, gamma-ray multipolarities)

(Atomic data)

(Decay scheme, LX ray energies, multipolarities)

(K X-ray energies and relative emission probabilities)

(Q values)