^{206}Tl - Comments on Decay Data Evaluation

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This evaluation was completed in September 2006 with a literature cut off by the same date. The Saisinuc software (2002BeXX) and associated supporting programs were used in assembling the data following the established protocol within the DDEP collaboration.

1. Decay Scheme

The nuclide ^{206}Tl ($J^{\pi}=0^{-}$) disintegrates 100 % by β^{-} emissions. The strongest β^{-}-decay branch of 99.885 (14) % populates the $J^{\pi}=0^{+}$ ground state of the daughter nuclide ^{206}Pb. The level schemes of ^{206}Tl and ^{206}Pb are based on the ENSDF evaluation of Browne (1999Br39).

2. Nuclear Data

$Q(\beta^{-})$ value is taken from the evaluation of Audi *et al.* (2003Au03).

The experimental half-life data for the ^{206}Tl ground state are presented in Table 1. These data were evaluated using different techniques (see for example 1992Ra08, 1994Ka08 and 2004MaXX and references therein) and the results are presented in Table 2. The value of 1961Nu01 was excluded from the data analysis, since no uncertainty was quoted in the original publication. The LRSW value of $T_{1/2}$=4.202 (11) min is recommended here with $\chi^2_{\nu} = 1.54$ ($\chi^2_{\nu} = \chi^2$/N-1) which is smaller than the critical value of $\chi^2_{\nu\ crit} = 2.64$ (99 % confidence level). The lifetimes of the excited states of the daughter nuclide ^{206}Pb are taken from the ENSDF evaluation of Browne (1999Br39).

Table 1. Experimental data for the half-life of ^{206}Tl

Author	$T_{1/2}$, min	Used in the evaluation
1941Fa04	4.23 (3)	Yes
1953Sa11	4.19 (2)	Yes
1959Po64	4.29 (5)	Yes
1961Nu01	4.2	No
1970Fl12	4.27 (5)	Yes
1971Pe03	4.183 (17)	Yes
1972CoYX	4.14 (5)	Yes
1972Gr01	4.2 (2)	Yes
1972Wi18	4.27 (5)	Yes

Table 2. Evaluated values for the half-life of ^{206}Tl

Method/Author [a)]	**Evaluated $T_{1/2}$, min**	**c^2/N-1**
UWM	4.222 (19)	2.02
WM	4.202 (11)	1.54
LRSW	4.202 (11)	1.54
NRM	4.202 (11)	1.54
RM	4.202 (11)	1.41
1999Br39	4.200 (17)	

[a)] UWM – Unweighted Mean; WM – Weighted Mean; LRSW – Limitation of Relative Statistical Weight; NRM – Normalized Residual; RM – Rajeval.

2.1. b^- Transitions

The experimental data for the maximum $\beta_{0,0}$ energy, $E_{\beta 0,0\ max}$, are presented in Table 3. The LRSW value of 1527 (3) keV ($\chi^2_\nu = 1.48$ is smaller than $\chi^2_{\nu\ crit} = 4.61$ (99 % confidence level)) is comparable with $Q(\beta^-) = 1532.4$ (6) keV (2003Au03). The $E_{\beta\ max}$ values for the $\beta_{0,1}$ and $\beta_{0,2}$ transitions were determined from $Q(\beta^-)$ (2003Au03) and the 2^+ and 0^+ level energies that were deduced from the corresponding transition energies (see section 2.2 and Table 4 for details). The $\beta_{0,1}$ and $\beta_{0,2}$ transition probabilities, P_β, were deduced from the decay scheme and the corresponding absolute γ–ray transition probabilities, $P_{\gamma+ce}$, as detailed in section 2.2 and Table 5. The P_β value for the $\beta_{0,1}$ transition is an upper limit, since the possible feeding from the 1166.4 keV level ($J^\pi=0^+$) via the yet unobserved 363.3 keV γ–ray transition ($\gamma_{2,1}$) was not taken into account. It should be noted that only a limit for $P_{\gamma 2,1}$ is reported in the literature (see section 2.2 for details). The $\beta_{0,0}$ transition probability was determined as: $P_{b\,0,0} = 100 - P_{b\,0,1} - P_{b\,0,2}$.

The lg *ft* values were calculated using the LOGFT program from the ENSDF evaluation package. The lg *f* values are based on the work of Gove and Martin (1971Go40). For the first forbidden $\beta_{0,0}$ transition (0^- ->0^+) the shape factor was measured by several authors, as shown in Table 3. The fit to the experimental data using the expression $S(W) = 1 + aW + b/W$, where W is the electron energy, yields the shape factor coefficients, *a* and *b*, which are also presented in Table 3. The value of $a = -0.020$ (2) (with $b = 0.000$) (1972Wi18) is recommended in the present evaluation. It should be noted that using this parameterization of the shape factor, a lg *f* value of 2.85 for the $\beta_{0,0}$ transition (0^- ->0^+) can be obtained. It is in a good agreement with lg *f* = 2.78, deduced using the LOGFT program (1971Go40).

Table 3. Measured $E_{\beta 0,0\ max}$ values and shape factor parameters *a* and *b* (S(W)=1+*a*W+*b*/W) for the first forbidden $0^- \rightarrow 0^+$ decay of ^{206}Tl

Author	*a*	*b*	$E_{b0,0\ max}$, keV	Used in the evaluation
1951Al14			1510 (10)	No
1961Ho17	-0.154	-0.484	1571 (10)	No
1970Fl12	-0.017 (5)	0.030 (9)	1523 (4)	Yes
1971Pe03	0.00 (1)	0.00	1534 (5)	Yes
1972Wi18	-0.020 (2)	0.000	1527 (4)	Yes
Adopted	**-0.020 (2)**	**0.000**	**1532.4 (6)**	

Table 4. Level energies, $E_{\beta\ max}$, P_β and log *ft* values in decay of ^{206}Tl

	Level energy, keV	$E_{b-\ max}$, keV	P_b ´ 100	Nature	log *ft*
$\beta_{0,0}$	0.0	1532.4 (6)	99.885 (14)	First forbidden	5.1775 (13)
$\beta_{0,1}$	803.06 (3)	729.3 (6)	0.0051 (3)	First forbidden Unique	8.60^{1U} (3)
$\beta_{0,2}$	1166.4 (5)	366.0 (8)	0.110 (14)	First forbidden	5.99 (6)

2.2 Gamma Transitions and Electron Internal Conversion Coefficients

The γ–ray transition energies, multipolarities, absolute transition probabilities and electron internal conversion coefficients are presented in Table 5.

The γ–ray transition multipolarities are taken from the ENSDF evaluation of Browne (1999Br39). The recommended γ1,0 transition energy of 803.06 (3) keV is determined as the weighted mean of 803.10 (5) keV (1972Ma63) and 803.04 (3) keV (1996Ra16), the two most precise values reported in the literature. The γ2,0 transition between the excited 0^+ level and the 0^+ ground state is a pure E0, and hence, there is no γ–ray component associated with the decay of the former level. The transition energy is taken from the work of Draper *et al.* (1977Dr08) where the K-shell conversion electron energy was measured with a Si(Li) detector. The γ2,1 transition was not observed and its energy is inferred from the energy difference between the excited 0^+ and 2^+ levels. The electron internal conversion coefficients were calculated using a program supplied by the Saisinuc software (2002BeXX) which uses interpolated values of Band *et al.* (2002Ba85) with the hole being taken into account. The $P_{\gamma+ce}$ values for the γ1,0 and γ2,1 transitions were determined from the absolute γ–ray emission probabilities, P_γ, shown in Table 6, and the total electron internal conversion coefficients as: $P_{g+ce} = P_g \times (1 + a_T)$.

Experimental and evaluated P_γ values are shown in Table 6. The LRSW value of $P_{\gamma 1,0}$= 0.0050 (3) % (χ^2_ν = 2.40 is smaller than $\chi^2_{\nu\ cryt}$ = 4.61 (99 % confidence level)) is recommended for the γ1,0 transition. As stated above, the $\gamma_{2,1}$ transition was not observed experimentally and only a limit for its absolute

emission probability was given in 1972CoYX and 1972Gr01. The value of $P_{\gamma 2,1} < 0.00026$ % (1972CoYX) is adopted in the present evaluation. The γ2,0 transition is a pure E0 ($0^+ \rightarrow 0^+$) and hence $P_{\gamma 2,0}$ is zero. The recommended $P_{\gamma+ce}(\gamma_{2,0})$ value here is deduced from the measured absolute KX-ray yield, $P_{XK}(\gamma_{2,0})$, the corresponding fluorescence yield, ω_K, and the K/T conversion electrons ratio. The value of $P_{XK}(\gamma_{2,0}) = 0.09\ (1)$ %, deduced as a weighted mean of 0.08 (2) % (1972CoYX) and 0.10 (2) % (1972Gr01) (see Table 6), is adopted in the present work. It should be noted that an electron shake-off component of 0.02 % has been taken into account in these values. The K-shell to total conversion electrons ratio of K/T = 0.85 (6) was deduced from K/L = 5.7 (4), a weighted mean of the measured K/L = 5.61 (38) and 6 (1) in 1990Tr01 and 1977Dr08, respectively. This value is in very good agreement with that of K/T = 0.855, calculated using the electronic factors of Ω_K(E0) and Ω_L(E0) that are given by the BRICC program (2005KiZW). Using a K-fluorescence yield value of $\omega_K = 0.963\ (4)$ (1996Sc06) one then obtains:

$$P_{g+ce}(g\ 2{,}0) = P_{ce}(g\ 2{,}0) = \left(P_{KX}(g\ 2{,}0)/w_K\right)/(K/T) = 0.110\ (14)\ \%$$

Table 5. Energies, multipolarities, absolute transition probabilities and electron internal conversion coefficients for γ–ray transitions following β^-–decay of ^{206}Tl

	Energy, keV	$P_{\gamma+ce} \times 100$	Multi-polarity	α_K	α_L	α_M	α_N	α_T
$\gamma_{1,0}$	803.06 (3)	0.0051 (3)	E2	0.00801 (24)	0.00174 (5)	$4.19\ (13)10^{-4}$	$1.06\ (3)10^{-4}$	0.0103 (3)
$\gamma_{2,1}$	363.3 (5)	0.00015 (15)	(E2)	0.0414 (12)	0.0187 (6)	0.00476 (14)	0.00120 (4)	0.066 (2)
$\gamma_{2,0}$	1166.4 (5)	0.110 (14)	E0					

Table 6 Experimental and evaluated γ–ray emission probabilities.

Authors	**$P_{g1,0}$, %**	**$P_{XK}(g_{2,0})$ %[a)]**	**$P_{g2,1}$, %**	**Comment [b)]**
1968Zo02	0.0055 (5)			Not used
1970Zo02	0.0055 (4)			Expt.
1972CoYX	0.0041 (6)	0.08 (2)	<0.00026	Expt.
1972Gr01	0.004 (1)	0.10 (2)	<0.001	Expt.
Adopted	**0.0050 (3)**	**0.09 (1)**	**<0.00026**	**Evaluated**

[a)] Absolute KX-ray yield

[b)] Expt. – experimental value used in the present evaluation. The 1968Zo02 value is superseded by 1970Zo02

3. Atomic Data

The Atomic data (Fluorescence yields, X-Ray energies and Relative probabilities, and Auger electrons energies and Relative probabilities) were provided by the Saisinuc software (2002BeXX). Details regarding the origin of these data can be found in 1996Sc06, 1998ScZM, 1999ScZX, 2000ScXX and 2003DeXX.

4. Photon Emissions

4.1 X-Ray Emissions

The X-ray yield in β^- decay of ^{206}Tl is produced entirely in the decay of the 1166.4 keV (E0, $0^+ \rightarrow 0^+$) transition. Contributions from the much weaker 803.06 and 363.3 keV transitions can be neglected, since their X-ray yields are several orders of magnitude smaller than that of the 1166.4 keV transition.

For the 1166.4 keV E0 ($0^+ \rightarrow 0^+$) transition, the number of vacancies in the K-shell per 100 disintegrations was determined as:

$$N_K = P_{ceK} = P_{XK} / w_K = 0.090\,(10) / 0.963\,(4) = 0.093\,(11).$$

The corresponding number of vacancies in the L shell per 100 disintegrations was then determined as:

$$N_L = P_{ceL} + n_{KL} \times N_K = 0.0163\,(22) + 0.811\,(5) \times 0.093\,(11) = 0.092\,(11)\ \%$$

where $P_{ceL} = P_{ceK} / (K/L) = 0.0163\,(22)\ \%$ with K/L= 5.7 (4), a weighted mean of 5.61 (38) (1990Tr01) and 6 (1) (1977Dr08). The number of X-rays per 100 disintegrations was then calculated as:

$$P_{XK} = w_K \times N_K \text{ and } P_{XL} = \bar{w}_L \times N_L$$

4.2 Gamma Emissions

The number of γ rays per 100 disintegrations was evaluated from the available experimental data, as described in section 2.2 (see also Table 6).

5. Electron Emissions

The energies of the conversion electrons were calculated from the γ–ray transition energies presented in Table 5 and the corresponding electron shell binding energies (1977La19). For the γ1,0 transition, the number of conversion electrons of type x = T,L,M,N and O, where T stands for total, L for L-shell electrons, etc., per 100 disintegrations was calculated from the absolute photon intensity ($P_{\gamma 1,0}$ per 100 disintegrations) recommended in the present evaluation (see Table 6), and the corresponding electron internal conversion coefficients (see Table 5), $\alpha_{x1,0}$: $ec_{1,0x} = P_{g1,0} \times a_{x1,0}$. For the γ2,0 transition, the number of K and L conversion electrons per 100 disintegrations was determined from the measured P_{XK} yield, w_K value and the K/L sub-shell ratio, as detailed in section 4.1.

The number of K and L Auger electrons per 100 disintegrations, $P(e_{AK(L)})$ was calculated from the number of vacancies in the K and L shells and the corresponding $P_{XK(L)}$ yield: $P(e_{AK}) = N_K - P_{XK}$ and $P(e_{AL}) = N_L - P_{XL}$.

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