^{170}Tm - Comments on evaluation of decay data
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1. Decay Scheme

Since ^{170}Tm has spin and parity 1^- , it decays with detectable probability to the 0^+ ground states and 2^+ first excited levels in both ^{170}Yb and ^{170}Er. The only other levels below the decay energies are at 277 keV (4^+) and 573 keV (6^+) in ^{170}Yb and 260 keV in ^{170}Er. From the log *ft* systematics of 1998Si17, one expects the log *ft*'s of the 3rd forbidden decays to the 4^+ levels to be greater than 16, which corresponds to a β branch of less than 0,000 002% to the 4^+ level of ^{170}Yb and weaker branch to 4^+ in ^{170}Er. Since the branch to the 6^+ level will be a 5th forbidden decay, it will be even much weaker. Therefore, all of these unobserved β branches will be negligible.
For decay scheme see also Baglin (1996Ba01).

2. Nuclear Data

Q value is from Audi and Wapstra (1995Au04).
The ^{170}Tm half-life values are available, in days

125 (2)	1962Bo12	
134,2 (8)	1965Fl02	Omitted as outlier
128 (1)	1967Ke13	
128,6 (3)	1968Re04	
127,1 (3)	1969La34	(the original value of uncertainty is 3σ =0,9)
127,8 (6)	Average	

The outlier value of 1965Fl02 was omitted on the statistical considerations of its large deviation from the mean.
For statistical processing one third of the total 3σ-uncertainty, 0,9 days, stated in 1969La34, was used. Then, the weighted average is 127,8 d with an internal uncertainty of 0,21 d, a reduced-χ^2 of 4,85 and an external uncertainty of 0,45 d. In this case the different statistical procedures using the weighted average give the following values for a final uncertainty, in days: UINF - 0,45; PINF - 0,45; BAYS - 0,79; MBAYS - 0,56; LWM - 0,77; tS- 0,54. The LWEIGHT program using the LWM method has expanded the uncertainty to 0,77 d to include the accurate value of the 1968Re04. The EV1NEW program chooses the tS or MBAYS procedure for this case and gives 0,6 d. The latter value was adopted for the final uncertainty of the average.
It should be noted that without rejecting 1965Fl02 the Normalised Residuals technique leads almost to the same average of 127,9(6) days. It inflates the uncertainty of the 1965Fl02 value to 2,7 days and of each of the 1968Re04 and 1969La34 to 0,5 days.
A considerable discrepancy of few available experimental data on the ^{170}Tm half-life, all obtained before 1970, requires new ^{170}Tm half-life measurements.

2.1 b$^-$ - Transitions

The β^--decay probabilities have been computed from the $P_{\gamma+ce}$(Yb) of section 2.3 and balance correlations.

2.2. Electron Capture Transitions

The values of the electron capture probabilities to the ^{170}Er ground state and the level of 78,6 keV have been obtained from the balance correlations including the X K- and gamma emission probabilities. Indeed, we can write:

$$P_{XK}(Yb) = \omega_K(Yb)\, \alpha_K(84)\, P\gamma(84)$$
$$P_{XK}(Er) = \omega_K(Er)\ [\, P_K^{0,0}\, P(\varepsilon_{\,0,0}) + P_K^{0,1}\, P(\varepsilon_{\,0,1}) + \alpha_K(79)\, P\gamma(79)]$$

From here:

$$S \equiv \frac{P_{XK}(Er)}{P_{XK}(Yb)} = \frac{w_K(Er)}{w_K(Yb)} \cdot \frac{1}{a_K(84)\cdot Pg\,(84)}[P_K^{0,0}\cdot P(e_{0,0}) + P_K^{0,1}\cdot P(e_{0,1}) + a_K(79)\cdot Pg\,(79)]$$

Finally, for $P(\varepsilon_{0,0})$ and $P(\varepsilon_{0,1})$ the following expressions are obtained (see also 1988Kuzmenko):

$$P(e_{0,0}) = \frac{Pg\,(84)}{P_K^{0,0}}\{a_K(84)\cdot S\cdot \frac{w_K(Yb)}{w_K(Er)} - \frac{Pg\,(79)}{Pg\,(84)}[a_K(79) + P_K^{0,1}(1+a_T(79)]\}$$

$$P(e\,0{,}1) = Pg\,(79)\,.\,(1 + a_T(79))$$

In this calculation, the adopted values of ICC, P_K, ω_K, P_γ and the ratio of S = 0,035(1) measured in 1986Ve05 were used.

The fractional electron capture probabilities to the specific atomic shells (P_K, P_L, P_M ...) have been deduced from the tables of Schönfeld (1998Sc28).

2.3. Gamma Transitions and Internal Conversion Coefficients

The energies of gamma transitions are the energies of gamma rays with the recoil energy added. The probabilities of gamma transitions $P_{\gamma+ce}$ have been computed using the gamma-ray emission probabilities and the total internal conversion coefficients (ICC).

The theoretical values of ICC from Rosel et al. (1978Ro21) have been adopted for the gamma transitions which have the same multipolarity E2. The evaluated α_{NO} values have been computed from α_M(theoretical) using the ratio $\alpha_M/\ \alpha_{NO}$ = 3,77 (9) (1968Ni06).

The weighted mean of the eight measurement results for $\alpha_K(\gamma 84)$ [1,48 (5) (1966Di02), 1,41 (4) (1969Ne02), 1,37 (4) (1970Mo07), 1,41 (5) (1971Ca08), 1,46 (7) (1973Pl08), 1,39 (3) (1985Me18), 1,41 (3) (1986Ve01), and 1,43 (4) (1990Ke01)] is 1,41 with an internal uncertainty of 0,014 ; a reduced χ^2 of 0,6 and an external uncertainty of 0,011. Taking into account that a systematic error of the measurement method can contribute mainly to the measurement uncertainties, the smallest of the input uncertainties has been chosen as a final uncertainty of the weighted mean. The average value of $\alpha_K(\gamma 84)$ (experimental), equal 1,41 (3), agrees well with the theoretical value of 1,39(2). The relative uncertainty of the theoretical ICC has been adopted of 1,5%. This value of uncertainty provides overlapping $\alpha_K(\gamma 84)$ (theoretical) and $\alpha_K(\gamma 84)$ (experimental).

3. Atomic Data

The fluorescence yields are taken from 1996Sc06 (Schönfeld and Janβen). The X-ray energies are based on the wavelengths in the compilation of 1967Be65 (Bearden). The relative KX-ray emission $K\beta/K\alpha$, $K\alpha_2/K\alpha_1$, $K'\beta_2/K'\beta_1$ probabilities and the ratios P(KLX)/P(KLL), P(KLY)/P(KLL) are taken from 1996Sc06. The energies of Auger electrons are from 1977La19 (Larkins).

4. Photon Emissions

4.1. X-Ray Emissions

The absolute XK(Er), XK(Yb), XL(Yb) emission probabilities have been computed on the basis of the relative intensities $P_X/P_\gamma(84)$ measured in 1985Me18 and 1986Ve05. The absolute measurement results of 1989Egorov for XK(Yb) [$K\alpha_2$ = 1,00(2), $K\alpha_1$ = 1,69(4), $K'\beta_1$ = 0,54(2), $K'\beta_2$ = 0,14(1)] agree well with our evaluated values. The total absolute XK(Er) emission probability of 0,089(5) measured in 1990EgZY disagrees with the evaluated value of section "X Radiations".

The weighted mean of the two measurement results for the Yb $K\alpha_1$-ray, 0,675(17), was adopted as the evaluated value and the values on $K\alpha_2$, $K'\beta_1$, $K'\beta_2$ were computed from the relative probabilities from 1996Sc06. The analogous procedure was made for the Er with the $K\alpha_1$ value from the measurements of 1986Ve05 and the other values from the relative probabilities from 1996Sc06.

$P_{XK}/P_\gamma(84)$ for Er

Er	1985Me18	1986Ve05	adopted
$K\alpha_2$	} 0,0248 (6)	0,0133 (4)	0,0134 (4)
$K\alpha_1$	}	0,0238 (4)	0,0238 (4)
$K'\beta_1$	$6,3\,(2)\cdot10^{-3}$	$7,7\,(3)\cdot10^{-3}$	0,0077 (3)
$K'\beta_2$	$1,45\,(6)\cdot10^{-3}$	$2,2\,(1)\cdot10^{-3}$	0,0020 (1)

$P_{XK}/P_\gamma(84)$ for Yb

Yb	1985Me18	1986Ve05	average (EV1NEW)	adopted
$K\alpha_2$	0,377 (9)	0,381 (11)	0,379 (9)	0,383 (9)
$K\alpha_1$	0,680 (17)	0,668 (20)	0,675 (17)	0,675 (17)
$K'\beta_1$	0,2145 (32)	0,228 (7)	0,221 (12)	0,222 (7)
$K'\beta_2$	0,0533 (9)	0,0604 (19)	0,057(1)	0,058 (2)

$P_{XL}/P_\gamma(84)$ for Yb

Yb	adopted (1985Me18)
Ll	0,0238 (8)
$L\alpha+L\eta$	0,573 (18)
$L\beta$	0,603 (19)
$L\gamma$	0,0974 (31)
ΣXL	1,297 (27)

The total absolute Er LX emission probability has been computed using the adopted values of ω_K, ϖ_L, n_{KL}, the evaluated total KX absolute emission probability and the evaluated total absolute emission probabilities of L conversion electrons and electron capture.

It should be noticed that the absolute XK- emission probabilities of P_{XK}(Er)=0,113(6) and P_{XK}(Yb)=3,27 (12) per 100 disintegrations, calculated from the adopted values of ω_K, the evaluated total absolute emission probabilities of K conversion electrons (P_{ceK}) and the electron capture ($P_{\varepsilon K}$), agree well with the evaluated, 0,116 (3) and 3,31 (8), respectively.

For P_{XL}(Yb) such a calculation gives 2,93 (15) per 100 disintegrations - in comparison with the value of 3,22 (13), adopted from experimental data on $P_{XL}/P_\gamma(84)$.

The evaluated values of P_{XK}(Er) = 0,116 (3)%, P_{XK}(Yb) = 3,31 (8)% and P_{XL}(Yb) = 3,22 (13)% have been obtained directly from relative measurements of the intensity of peaks in the ^{170}Tm photon spectrum ($P_X/P_\gamma(84)$) with use of the $P_\gamma(84)$ value evaluated from independent experimental data. Unlike that the calculated value of P_{XK}(Er) = 0,113(6) has been founded on the adopted semiempirical and theoretical values ω_K, $P_K(\varepsilon_{0,1})$, and $\alpha_K(\gamma 79)$ as well as the evaluated $P_\gamma(79)$. In the calculation of P_{XK}(Yb) = 3,27 (12)% the same value of $P_\gamma(84)$ is used as in the evaluation of 3,31 (8)%. However, the adopted ω_K(Yb) and theoretical value of $\alpha_K(\gamma 84)$ have been used instead of the experimental relative intensity $P_{XK}/P_\gamma(84)$.
Above agreement of the evaluated and calculated values shows a concordance of the obtained decay characteristics for ^{170}Tm.

4.2. Gamma Emissions

The energy of 78,6 keV γ-ray has been obtained as the weighted mean of the following three measurements results: 78,59 (2) keV (1958Ch36), 78,7 (5) keV (1969Ha20) and 78,6 (4) keV (1970Mo07).

The 84,25 keV γ-ray energy has been adopted from 2000He14.

The absolute emission probability for the γ-ray of 84,25 keV (per 100 disintegrations) has been obtained with use of the weighted mean of the three measurement results: 2,54 (6) (1973Pl08), 2,56 (4) (1987GeZU, 1988GeZS) and 2,37 (4) (1990Ke01). This weighted average is 2,48 with an internal uncertainty of 0,03, a reduced-χ^2 of 6,3 and an external uncertainty of 0,06. In this case the different statistical procedures using the weighted average give the following values for a final uncertainty: UINF - 0,064; PINF - 0,064; BAYS - 0,091; MBAYS - 0,091; LWM - 0,109; tS - 0,084. The EVINEW program has chosen MBAYS for this case and hence the uncertainty of 0,09. This value was adopted as the uncertainty of the evaluated $P\gamma(84)$. It should be noted that the Rajeval technique leads to the same result of 2,48(9). The normalised Residuals technique gives only sligttly greater value of 2,51(4).

The absolute emission probability for the γ-ray of 78,6 keV has been obtained with use of the weighted mean of the results of measurements of the ratio of $P_\gamma(79)/P_\gamma(84)$: 0,00122 (24) (1970Mo07), 0,0015 (2)(1985Me18) and 0,00140 (8) (1986Ve01). The LRSW method has expanded the uncertainty of the 1986Ve01 from 0,00008 to 0,00015 in order to reduce its relative weight from 79% to 50%. Then, the weighted mean is 0,00139 with an internal uncertainty of 0,00011, a reduced-χ^2 value of 0,4 and an external uncertainty of 0,00007. The adopted value of $P_\gamma(79)/P_\gamma(84)$ is 0,00139 (11).

5. Electron Emissions

The energies of the conversion electrons have been calculated from the gamma-transition energies given in 2.3 and the electron binding energies. The energies of the Auger electrons are taken from 1977La19 (Larkins).

The emission probabilities of the conversion electrons have been calculated using the conversion coefficients given in 2.3. The values of the emission probabilities of K-Auger electrons have been calculated using the transition probabilities given in 2.1 and 2.2, the atomic data given in 3. and the conversion coefficients given in 2.3.

6. References

1958Ch36 E. L. Chupp *et al.*, Phys. Rev., 1958, V.112. P.518. [Energy of γ79]
1962Bo12 Bonner *et al.*, Phys. Rev., 1962, V. 127. P. 217. [Half-life]
1965Fl02 K. F. Flynn *et al.*, Nucl. Sci. Eng., 1965, V. 22. P. 416. [Half-life]
1966Di02 R. S. Dingus *et al.*, Nucl. Phys., 1966, V. 83. P.545. [$\alpha_K(\gamma 84)$]
1967Be65 J. A. Bearden, Rev. Mod. Phys., 1967, V.39. P.78. [X-ray energies]
1967Ke13 W. I. Kerrigan, J. Inorg. Nucl. Chem., 1967, V. 29. P. 2657. [Half-life]
1968Ni06 O. Nilsson *et al.*, Nucl. Phys., 1968, V. A120. P.561. [α_M/α_{NO}]

1968Re04 S. A. Reynolds *et al.*, Nucl. Sci. Eng., 1968, V.32. P.46. [Half-life]
1969Ha20 H. H. Hansen, S. Hellström, Z. Phys., 1969, Bd.223. S.139. [Energy of γ79]
1969La34 F. Lagoutine *et al.*, Int. J. Appl. Rad. Isot., 1969, V. 20. P. 868. [Half-life]
1969Ne02 G. C. Nelson, E. N. Hatch, Nucl. Phys., 1969, V. A127. P.560. [α_K(γ84)]
1970Mo07 S. Mohan, Phys. Rev., 1970, V. C1, N1. P. 254. [α_K(γ84), energy and relative probability of γ79]
1971Ca08 J. L. Campbell *et al.*, Nucl. Instrum. Meth., 1971, V.92. P.237. [α_K(γ84)]
1973Pl08 J. Plch, J. Zderadicka, L. Kokta, Czech. J. Phys., 1973, V. 23, N 4. P. 1181. [α_K(γ84), absolute γ84 emission probability]
1977La19 F. P. Larkins, Atomic Data and Nuclear Data Tables, 1977, V.20. P.313. [Auger electron energies]
1978Ro21 F. Rösel, H. M. Fries, K. Alder, H. C. Pauli, Atomic Data and Nuclear Data Tables,1978, V.21. P. 293. [Internal conversion coefficients]
1985Me18 D. Mehta *et al.*, Nucl. Instrum. Meth., 1985, V. A242, N1. P.149. [α_K(γ84), $P_X/P\gamma(84)$, Pγ(79)/Pγ(84)]
1986 Ve01 Rao N. Venkateswara *et al.*, J. Phys.(London), 1986, V. G12. P.45.[α_K(γ84),Pγ(79)/Pγ(84)]
1986Ve05 Rao N. Venkateswara *et al.*, Indian J. Phys., 1986, v.60A. P.162. [$P_X/P_\gamma(84)$]
1987GeZU A. M. Geidelman et al., Abstracts of 37th Conference on Nuclear Spectroscopy and Atomic Nuclear Structure, Yurmala, 14-17 April, 1987, LO Nauka, Leningrad, 1987.P. 133. [Absolute γ84 emission probability]
1988GeZS A. M. Geidelman, Yu. S. Egorov, N. K. Kuzmenko, V. G. Nedovesov, V. P. Chechev, G. E. Shukin, Proc. Intern. Conf. Nuclear Data for Science and Technology, Mito, Japan, 1988, p 909. [Absolute γ84 emission probability]
1988Kuzmenko N. K. Kuzmenko, V. G. Nedovesov, V. P. Chechev, Izmeritelnay Tekhnika, 1988, N 9, P. 47. [1988 decay data evaluation, absolute γ84 emission probability]
1989Egorov A. G. Egorov, Yu. S. Egorov, V. G. Nedovesov, G. E. Shchukin, K. P. Yakovlev, Program and Thesis, Proc. 39th Ann. Conf. Nucl. Spectrosc. Struct. At Nuclei, Leningrad, 1989, p 505. [Yb XK-ray emission probabilities]
1990EgZY A. G. Egorov, V. G. Nedovesov, G. E. Shchukin, K. P. Yakovlev, Program and Thesis, Proc. 40th Ann. Conf. Nucl. Spectrosc. Struct. At Nuclei, Leningrad, 1990, p 486. [Er X K-ray emission probability]
1990Ke01 T. Kempisty *et al.*, Nucl. Instrum. Meth. Phys. Res., 1990, V. A286, P. 535. [Absolute γ84 emission probability, α_K(γ84)]
1995Au04 G. Audi and A. H. Wapstra, Nucl. Phys. , 1995, V. A595, P. 409.[Q values]
1996Ba01 C. M. Baglin, Nuclear Data Sheets, 1996, V.77, N1. P.125.[Decay scheme]
1996Sc06 E. Schönfeld, H. Janβen, Nucl. Instr. Meth. Phys. Res., 1996, V.A369. P.527.[Atomic data]
1998Sc28 E. Schönfeld, Appl. Rad. Isotopes, 1998, V.49. P.1353. [Fractional electron capture probabilities]
1998Si17 B. Singh, J. L. Rodriguez, S. S. Wong, J. K. Tuli, Nucl. Data Sheets,1998, 84, 487. [lg *ft*]
2000He14 R. G. Helmer and C. van der Leun, Nucl. Instrum. Meth., 2000, V. A450, P. 35. [γ-ray energies]