^{127m}Te - Comments on evaluation of decay data

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Evaluation Procedure

Limitation of Relative Statistical Weight Method (LWM) and other analytical procedures were applied to average the measured decay data when appropriate.

Decay Scheme

A simple decay scheme was constructed primarily from the gamma-ray studies of 1965Au01 and 1970Ap02 in which Ge(Li) gamma-ray detectors were used. An earlier study involved the use of low-resolution NaI(Tl) detectors (1956Kn20), and these data have not been considered in this particular evaluation. The relative emission probabilities of gamma rays emitted from mixtures of ^{127}Te and ^{127m}Te in secular equilibrium were quantified by 1965Au01 and 1970Ap02 in terms of the emission probability of the 417.99-keV gamma ray (100 %) in the β^- decay of ^{127}Te, and weighted mean data were derived as appropriate.

Nuclear Data

^{127m}Te undergoes IT decay directly to the ground state of ^{127}Te, with a small β^- branch to a number of nuclear levels of ^{127}I defined in terms of four β^- and five subsequent γ emissions.

Half-life (^{127m}Te)

The recommended half-life has been determined from the measurements of Seaborg *et al.* (1940Se01), Knight *et al.* (1956Kn20), Andersson *et al.* (1965An05), and Eastman and Krane (2008Ea01). A value of (106.1 ± 0.7) days was preferred as recommended by the Rajeval technique, rather than adopt the value determined by the LWM.

Half-life measurements (^{127m}Te).

Reference	Half-life (days)
1940Se01	92 ± 2
1951Co34	~ 115*
1956Kn20	105 ± 2
1965An05	109 ± 2
2008Ea01	106.1 ± 0.7
Recommended value	106.1 ± 0.7†

* no uncertainty quoted, and therefore not included in the averaging procedures.
† Rajeval analysis adopted, in alignment with the measurement of Eastman and Krane.

Various procedures were considered in the analysis of the disparate data set: limitation of relative statistical weight method (LWM), normalised residual method (NRM), Rajeval technique, bootstrap method, and Mandel-Paule approach:

Analytical method	Half-life (days)	χ^2/(N-1)	χ^2/(N-1)$_{critical}$
LWM	104 ± 4	19.56	3.78
NRM	106.2 ± 0.6	2.47	2.60
Rajeval	106.1 ± 0.7	0.82	–
Bootstrap	104 ± 5	22.23	–
Mandel-Paule	103 ± 8	25.58	–

Q values

The nuclear-level energy of ^{127m}Te was adopted as Q_{IT} (88.23 (7) keV from 2011Ha31). A Q^- value of 790 (4) keV was obtained by summing the evaluated Q^- for the ground-state β^- decay taken from the tabulations of 2011AuZZ (702 (4) keV) with the nuclear-level energy for the metastable state of 88.23 (7) keV.

Gamma Rays

Energies

Gamma-ray transition energies were deduced from the structural details of the proposed decay scheme. The ^{127}Te and ^{127}I nuclear-level energies of 2011Ha31 were adopted, and used to determine the energies of the gamma-ray transitions between the depopulating-populating levels.

Adopted energies, spins and parities for the nuclear levels of ^{127}Te and ^{127}I.

Nuclear level number	Nuclear level energy (keV)	Spin and parity	^{127}Te radionuclidic decay
^{127}Te nuclear level:			
0	0.0	3/2 +	^{127m}Te
1	61.161 ± 0.019	1/2 +	–
2	88.23 ± 0.07	11/2 –	^{127m}Te
^{127}I nuclear level:			
0	0.0	5/2 +	^{127}Te and ^{127m}Te
1	57.608 ± 0.011	7/2 +	^{127}Te and ^{127m}Te
2	202.860 ± 0.008	3/2 +	^{127}Te
3	374.992 ± 0.009	1/2 +	^{127}Te
4	417.99 ± 0.06	5/2 +	^{127}Te
5	618.31 ± 0.13	3/2 +	^{127}Te
6	628.69 ± 0.16	7/2 +	^{127m}Te
7	650.92 ± 0.08	9/2 (+)	^{127m}Te
8	716.50 ± 0.06	(11/2 +)	^{127m}Te

Gamma-ray energies identified with the IT and β^- decay modes of ^{127m}Te.

Transition	E_γ (keV)			
	1956Kn20	1965Au01	1970Ap02	Recommended*
$\gamma_{1,0}$ (I)	58.5 (1)	57.6 (5)	57.63 (8)	57.608 (11)
$\gamma_{2,0}$ (Te)	–	87 (1)	88.26 (8)	88.23 (7)
$\gamma_{7,1}$ (I)	–	591 (1)	593.3 (1)	593.31 (8)
$\gamma_{6,0}$ (I)	–	–	628.6 (3)	628.69 (16)
$\gamma_{7,0}$ (I)	–	–	651.0 (2)	650.92 (8)
$\gamma_{8,1}$ (I)	–	657 (1)	658.9 (1)	658.89 (6)

* nuclear level energies of 2011Ha31 were used to determine the recommended energies of the gamma-ray transitions – gamma recoil of negligible impact on these data.

<u>Emission Probabilities</u>

Although judged to be a rather limited data set, a reasonably consistent decay scheme was derived from the relative gamma-ray emission probabilities measured by Auble and Kelly (1965Au01) and Apt *et al*. (1970Ap02) for a mixture of ^{127}Te and ^{127m}Te in secular equilibrium. These relative emission probabilities were normalised to the 100 % value assigned to the 417.99-keV gamma ray, which is identified exclusively with the β^- decay of ^{127}Te.

Relative gamma-ray emission probabilities for ^{127m}Te, as adopted from measurements of a mixture of ^{127}Te and ^{127m}Te in secular equilibrium.

Transition	E_γ (keV)	P_γ^{rel}		
		1965Au01	1970Ap02	Recommended*
$\gamma_{1,0}$ (I)†	57.608 (11)	61 (1)	56 (5)	58 (1)‡
$\gamma_{2,0}$ (Te)	88.23 (7)	25 (1)	12 (1)	8.56 (16)#
[$\gamma_{4,0}$ (I)]	417.99 (6)	[100]	[100]	^{127}Te decay only [100]
$\gamma_{7,1}$ (I)	593.31 (8)	0.22 (4)	0.24 (2)	0.24 (2)
$\gamma_{6,0}$ (I)	628.69 (16)	–	0.009 (2)	0.009 (2)
$\gamma_{7,0}$ (I)	650.92 (8)	–	0.03 (1)	0.03 (1)
$\gamma_{8,1}$ (I)	658.89 (6)	1.43 (6)	1.30 (10)	1.40 (6)

* weighted mean of appropriate measurements of 1965Au01 and 1970Ap02 (identical LWM and NRM values).
† gamma transition common to the β^- decay of both ^{127}Te and ^{127m}Te.
‡ determined from a weighted mean value of 61 (1) and subtraction of 3.07 (6) contribution from ^{127}Te β^- decay.
# calculated from IT branching fraction of 0.9727 (7), a normalisation factor of 0.00997 (11) for the relative γ-ray emission probabilities, and theoretical internal conversion coefficients of M4 88.23-keV γ transition.

Two specific numerical procedures were used to analysis the limited and somewhat disparate data set of P_γ^{rel} measurements of mixtures of ^{127}Te and ^{127m}Te in secular equilibrium: limitation of relative statistical weight method (LWM), and normalised residual method (NRM).

E_γ (keV)	Analytical method	P_γ^{rel}	$\chi^2/(N-1)$	$\chi^2/(N-1)_{critical}$
57.608 (11)	LWM NRM	61 (1) 61 (1)	0.96 0.96	6.63 3.84
593.31 (8)	LWM NRM	0.24 (2) 0.24 (2)	0.20 0.20	6.63 3.84
658.89 (6)	LWM NRM	1.40 (6) 1.40 (6)	1.24 1.24	6.63 3.84

The 57.608-keV gamma-ray emission is common to both ^{127}Te and ^{127m}Te and has only been quantified by 1965Au01 and 1970Ap02 in terms of ^{127}Te-^{127m}Te mixture in secular equilibrium, with a relative emission probability of 61 (1). Nevertheless, an accurate relative emission probability of 3.07 (6) can be determined from the gamma population-depopulation balance of the 57.608-keV nuclear level in the β^- decay of ^{127}Te, based on the assumption of no direct beta transition to this particular $7/2^+$ level ($3/2^+ \rightarrow 7/2^+$ would represent a second forbidden non-unique transition). Hence, an equivalent relative emission probability of 58 (1) can be calculated for the 57.608-keV gamma ray in the β^- decay of ^{127m}Te.

<u>Multipolarities and Internal Conversion Coefficients</u>

The nuclear level scheme specified by Hashizume (2011Ha31) has been used to define the multipolarities of the gamma transitions on the basis of known spins and parities. Detailed internal-conversion coefficient studies have been carried out by Kalinauskas *et al*. (1972Ka31, 1972Ka61) and Soni *et al*. (1977So06) on the 88.23-keV gamma ray that arises from the IT decay mode. These measurements of various ICC ratios and quantification of α_K are given below, and have been compared with equivalent theoretical internal conversion coefficients obtained from the frozen orbital approximation for M4 gamma transition (M4 BrIccFO).

Comparison of measured internal-conversion coefficient data with BrIcc frozen orbital calculations for the 88.23-keV M4 gamma transition.

	Ratios				α_K
	K : L : M : N+O	$L_I : L_{II} : L_{III}$	$M_I : M_{II+III} : M_{IV+V}$	(N+O) : L	
1972Ka31	0.99 (5) : 1 : 0.248 (24) : 0.050 (4)	0.599 (19) : 0.144 (8) : 1	1 : 2.29 (14) : 0.093 (23)	−	−
M4 BrIccFO	0.960 (21) : 1 : 0.238 (5) : 0.050 (1)	0.596 (14) : 0.137 (3) : 1	1 : 1.98 (4) : 0.0694 (15)		
1972Ka61	−	−	−	0.050 (4)	−
M4 BrIccFO				0.050 (1)	
1977So06	−	−	−	−	484 (23)
M4 BrIccFO					486 (7)

Mixing ratios for the 57.608- and 593.31-keV gamma transitions with (M1 + E2) multipolarity have been determined by 1965Au01 and 1967Ge10, and the data assessed by Krane (1977Kr13, 1980Kr22). Specific mixing ratios have been selected to give the following multipolarities: (99.3 % M1 + 0.7 % E2) for the 57.608-keV gamma ray, and (95 % M1 + 5 % E2) for the 593.31-keV gamma ray. An additional (M1 + E2) gamma transition of 628.69 keV was arbitrarily assigned a mixing ratio of 1.0 ± 0.5 (50 % M1 + 50 % E2). The 650.92- and 658.89-keV gamma rays were defined as E2 transitions. These data were used to determine recommended internal conversion coefficients from the frozen orbital approximation of Kibédi *et al.* (2008Ki07), based on the theoretical tabulations of Band *et al.* (2002Ba25, 2002Ra45).

Gamma-ray emissions from β^- decay: multipolarities and mixing ratios of (M1 + E2) transitions.

E_γ (keV)	δ				
	1965Au01	**1967Ge10**	**1977Kr13**	**1980Kr22**	**Recommended**
57.608 (11)	−	− 0.084 (6) (M1 + 0.7(1)%E2)	− 0.084 (6) (M1 + 0.7(1)%E2)	− 0.083 (5) (M1 + 0.7(1)%E2)	− 0.083 ± 0.005* (M1 + 0.7(1)%E2)
593.31 (8)	− 0.24 (13) or − 5.68 (9)	−	− 0.23 (3) (M1 + 5(1)%E2)	− 0.23 (3) (M1 + 5(1)%E2)	− 0.23 ± 0.03* (M1 + 5(1)%E2)
628.69 (16)	−	−	−	−	1.0 ± 0.5 (50%M1 + 50%E2)
650.92 (8)	−	−	−	−	E2
658.89 (6)	−	−	−	−	E2

* Adopted directly from 1980Kr22.

Gamma-ray emissions: recommended energies, multipolarities, and theoretical internal conversion coefficients (frozen orbital approximation).

Transition	E_γ (keV)	Multipolarity	α_K	α_L	α_{M+}	α_{tot}	
$\gamma_{1,0}$ (I)	57.608 (11)	99.3%M1 + 0.7%E2 δ = − 0.083 (5)	3.16 (5)	0.449 (8)	0.111	3.72 (6)	β^-
$\gamma_{2,0}$ (Te)	88.23 (7)	M4	486 (7)	506 (8)	146 (3)	1138 (17)	IT
$\gamma_{7,1}$ (I)	593.31 (8)	95%M1 + 5%E2 δ = − 0.23 (3)	0.005 78 (9)	0.000 722 (11)	0.000 178	0.006 68 (10)	β^-
$\gamma_{6,0}$ (I)	628.69 (16)	50%M1 + 50%E2 δ = 1.0 (5)	0.004 5 (4)	0.000 58 (3)	0.000 12	0.005 2 (4)	β^-
$\gamma_{7,0}$ (I)	650.92 (8)	E2	0.003 62 (5)	0.000 488 (7)	0.000 122	0.004 23 (6)	β^-
$\gamma_{8,1}$ (I)	658.89 (6)	E2	0.003 51 (5)	0.000 472 (7)	0.000 118	0.004 10 (6)	β^-

A normalisation factor of 0.009 97 (11) was calculated from the internal conversion coefficients and relative emission probabilities of the gamma-ray transitions populating the ground states of ^{127}Te and ^{127}I. An important feature of these calculations is the measurement of the ratio of the 417.99-keV γ-ray emission probability of ^{127}Te to the total β^- emission probability of ^{127}Te and ^{127m}Te in secular equilibrium by Apt *et al*. (1970Ap02), which was adopted in the evaluation:

$$\frac{P_\gamma(417.99\ keV)}{\sum(^{127}Te+\ ^{127m}Te)\beta^-} = \frac{100\ F}{[(122.33\ (43)+X)+\ 273.80\ (586)]\ F} = 0.0097\ (1),$$

where F is the normalisation factor for the relative γ-ray emission probabilities, and X is the relative emission probability of the β^- decay of ^{127}Te directly to the ground state of ^{127}I.

100 = 0.0097 (1) [396.13 (588) + X]

$$X = \frac{100}{0.0097\ (1)} - 396.13\ (588) = 10309\ (106) - 396.13\ (588) = 9913\ (106)$$

Therefore, within the β^- decay of ^{127}Te:

$$\sum(^{127}Te)\beta^- = 9913\ (106)\ F + 122.33\ (43)\ F = 100\ \%$$

F = 100 / 10035 (106) = 0.009 97 ± 0.000 11

Beta-particle Emissions

Energies and emission probabilities

Beta-particle energies were determined from the structural detail of the proposed decay scheme. Nuclear-level energies were adopted from Hashizume (2011Ha31), along with Q_{IT} and Q_{β^-} values of 88.23 (7) and 702 (4) keV, respectively, from 2011Ha31 and the evaluated tabulations of 2011AuZZ, and used to deduce the energies and uncertainties of the beta-particle transitions.

Emission probabilities were derived from γ population-depopulation of the various nuclear levels of ^{127}I, based on the relative γ-ray emission probabilities, their normalisation factor of 0.009 97 (11), and the theoretical internal conversion coefficients. Direct beta decay to the ground state of ^{127}I would constitute a third forbidden non-unique transition ($11/2^- \rightarrow 5/2^+$), and has been assumed to be zero.

Beta-particle emission probabilities per 100 disintegrations of ^{127}**Te**^{m}**.**

Transition	E_β (keV)	P_β	Transition type	log*ft*
$\beta^-_{2,8}$	74 ± 4	0.014 1 ± 0.000 6	1st forbidden non-unique	8.61 ± 0.08
$\beta^-_{2,7}$	139 ± 4	0.002 7 ± 0.000 2	1st forbidden non-unique	10.18 ± 0.05
$\beta^-_{2,6}$	161 ± 4	0.000 09 ± 0.000 02	1st forbidden unique	11.30 ± 0.11
$\beta^-_{2,1}$	732 ± 4	2.71 ± 0.07	1st forbidden unique	9.873 ± 0.017
		∑ 2.73 (7)		

The proposed decay scheme is heavily dependent on the γ-ray studies of Apt *et al*. (1970Ap02), particularly their measurement of 0.0097 (1) for the $P_\gamma(417.99\ keV)/\sum\beta^-$ ratio, and an estimate of 18.8 for the (^{127}Te + ^{127m}Te in secular equilibrium / ^{127}Te) ratio as applied to the 57.608-keV gamma-ray emission probability – current evaluation generates a latter value of 18.9 (58/3.07). There is a lack of γ-ray spectroscopy measurements of ^{127m}Te (and ^{127}Te) decay with HPGe detectors that would assist greatly in quantifying the absolute γ-ray emission probabilities with much greater confidence, and hence derive a more satisfactory decay scheme.

Branching Fractions and P_γ^{rel}**(88.23-keV IT decay)**

^{127m}**Te(**β^-**)**^{127}**I**: summation of the β^- emissions deemed to populate specific nuclear levels of ^{127}I, based on the population-depopulation of the observed γ-ray emissions, their relative emission probabilities and associated normalisation factor of 0.009 97 (11), and the theoretical internal conversion coefficients. Direct beta decay to the ground state of ^{127}I has been assumed to be zero (spin and parity changes of $11/2^- \rightarrow 5/2^+$ would constitute a third forbidden non-unique transition).

$$\sum(^{127m}Te)\beta^- = 273.80\ (586)\ F$$

where F is the normalisation factor for the relative emission probabilities of the γ rays.

Thus, BF(^{127m}Te(β^-)^{127}I) = 273.80 (586) x 0.009 97 (11) = 2.73 (7) % [0.0273 (7)]

^{127m}Te(IT)^{127}Te: derived directly from ^{127m}Te(β^-)^{127}I branching fraction.

BF(^{127m}Te(IT)^{127}Te) = 100 − 2.73 (7) = 97.27 (7) % [0.9727 (7)]

P_{γ}^{rel}(88.23-keV IT decay):

IT branch = 97.27 (7) = $TP_{\gamma}^{abs}(88.23\ keV)$

where $TP_{\gamma}^{abs}(88.23\ keV)$ is the absolute transition probability of the 88.23-keV gamma emission.

$$P_{\gamma}^{rel}(88.23\ keV) = \frac{TP_{\gamma}^{abs}(88.23\ keV)}{(1+\alpha_{tot}) * F} = \frac{97.27\ (7)}{1139\ (17) * 0.00997\ (11)} = 8.56\ (16)$$

Atomic Data

The X-ray and Auger electron data have been calculated using evaluated X-ray data (1999ScZX, 2003De44), gamma-ray data, and atomic data from 1977La19, 1996Sc06 and 1998ScZM. Both the X-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.01, 28 January 2003). This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

K and L X-ray emission probabilities per 100 disintegrations of ^{127m}Te.

			Energy (keV)	Photons per 100 disint.
XL		(Te)	3.335 – 4.829	7.0 (3)
	L_l	(Te)	3.335	0.146 (5)
	L_α	(Te)	3.759 – 3.770	3.86 (11)
	L_η	(Te)	3.605	0.036 9 (13)
	L_β	(Te)	4.030 – 4.302	2.45 (5)
	L_γ	(Te)	4.572 – 4.829	0.333 (8)
XK_α	$XK\alpha_2$	(Te)	27.2020 (2)	10.3 (3)
	$XK\alpha_1$	(Te)	27.4726 (2)	19.3 (5)
$XK'_{\beta1}$	$XK\beta_3$	(Te)	30.9446 (3)	)
	$XK\beta_1$	(Te)	30.9960 (4)	) 5.51 (15)
	$XK\beta_5$	(Te)	31.236	)
$XK'_{\beta2}$	$XK\beta_2$	(Te)	31.7008 (5)	)
	$XK\beta_4$	(Te)	31.774	) 1.20 (5)
	XKO_{23}	(Te)	31.182	)
XL		(I)	3.485 – 5.060	0.177 (9)
	XL_l	(I)	3.485	0.003 36 (11)
	XL_α	(I)	3.927 – 3.938	0.089 (3)
	XL_η	(I)	3.779	0.001 30 (5)
	XL_β	(I)	4.221 – 4.508	0.070 7 (17)
	XL_γ	(I)	4.801 – 5.060	0.010 1 (3)
XK_α	$XK_{\alpha2}$	(I)	28.3175 (4)	0.459 (12)
	$XK_{\alpha1}$	(I)	28.6123 (3)	0.852 (21)
$XK'_{\beta1}$	$XK_{\beta3}$	(I)	32.2397 (3)	)

	$XK_{\beta 1}$	(I)	32.2951 (4)	)	0.245 (7)
	$XK''_{\beta 5}$	(I)	32.544	)	
$XK'_{\beta 2}$	$XK_{\beta 2}$	(I)	33.042 (2)	)	
	$XK_{\beta 4}$	(I)	33.120	)	0.055 5 (19)
	$XKO_{2,3}$	(I)	33.166	)	

Electron energies were obtained from electron binding energies tabulated by Larkins (1977La19) and the evaluated gamma-ray energies. Absolute electron emission probabilities were calculated from the evaluated absolute gamma-ray emission probabilities and associated internal conversion coefficients.

Data Consistency

Q-values of 88.23 (7) and 790 (4) keV have been adopted for the IT and β^- decay, respectively, based on the atomic mass evaluation of Audi and Wang (2011AuZZ) and the nuclear-level energy of ^{127m}Te (2011Ha31). An effective Q-value derived from these data has been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{127}Sb beta-decay process (i.e. β^-, electron, γ, etc.):

$$\text{effective Q-value} = \sum (Q_i \times BF_i) = 107.4\ (6)\ \text{keV}$$

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 106.1\ (9)\ \text{keV}$$

The percentage deviation from the effective Q-value is (1.2 ± 1.0) %, which indicates the derivation of a reasonably consistent decay scheme.

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