^{127}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 1970Ap02 and 1965Au01 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 gamma-ray emission probabilities were expressed in terms of the emission probability of the 417.99-keV gamma ray (100 %), and weighted mean data were derived as appropriate.

Nuclear Data

^{127}Te undergoes beta decay to various nuclear levels of ^{127}I through five β^- and nine subsequent γ emissions.

Half-life (^{127}Te)

The recommended half-life has been determined from the measurements of Seaborg *et al*. (1940Se01), Knight *et al*. (1956Kn20), Majumdar and Chatterjee (1963Ma20), Qaim and Ejaz (1968Qa02), and Bormann *et al*. (1970Bo22). A value of 9.35 hours was derived in terms of LWM, with the uncertainty increased from ± 0.06 to the lowest measured value of ± 0.10 hour.

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

Reference	Half-life (hours)
1940Se01	9.3 ± 0.5
1956Kn20	9.35 ± 0.10
1963Ma20	9.36 ± 0.20
1968Qa02	9.23 ± 0.13
1970Bo22	9.48 ± 0.13
Recommended value	9.35 ± 0.10*

* uncertainty increased from ± 0.06 to the lowest measured value of ± 0.10 hour.

Q values

Q^- of 702 (4) keV was adopted from the evaluated tabulations of 2011AuZZ, which compares with an earlier value of 702 (3) keV from 2003Au03.

Gamma Rays

Energies

Gamma transition energies were deduced from the structural details of the proposed decay scheme. The ^{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. Many of the lower-energy nuclear levels recommended by 2011Ha31 are primarily based on accurate gamma-ray energy measurements of the equivalent EC decay of ^{127}Xe by 1977Ge10 (observed gamma-ray emissions at 57.61 (2), 145.252 (10), 172.132 (10), 202.860 (10) and 374.991 (12) keV).

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

Nuclear level number	Nuclear level energy (keV)	Spin and parity	^{127}Te radionuclidic decay
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 β^- decay of ^{127}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)
$\gamma_{2,1}$ (I)	145 (2)	145 (5)	145.2 (1)	145.252 (14)
$\gamma_{3,2}$ (I)	–	–	172.1 (5)	172.132 (12)
$\gamma_{2,0}$ (I)	203 (3)	203 (1)	202.9 (1)	202.860 (8)
$\gamma_{4,2}$ (I)	215 (4)	214 (1)	215.1 (1)	215.13 (6)
$\gamma_{4,1}$ (I)	360 (4)	360.0 (5)	360.3 (1)	360.38 (6)
$\gamma_{3,0}$ (I)	–	–	375.0 (4)	374.991 (9)
$\gamma_{4,0}$ (I)	418 (2)	417.0 (5)	417.9 (1)	417.99 (6)
$\gamma_{5,0}$ (I)	–	–	618.6 (3)	618.31 (13)

* 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.

Emission Probabilities

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.

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. However, the assignment of this gamma transition in the decay scheme of ^{127}Te permits an accurate relative emission probability to be calculated from the gamma population-depopulation balance of the 57.608-keV nuclear level, assuming no direct beta population of this particular $7/2^+$ level ($3/2^+ \rightarrow 7/2^+$ would constitute a second forbidden non-unique transition):

$$TP_\gamma(57.608\text{ keV}) = TP_\gamma(145.252\text{ keV}) + TP_\gamma(360.38\text{ keV}) = 0.59\,(9)\,F + 13.9\,(2)\,F$$

$$= 14.49\,(22)\,F,$$

where *TP* is the transition probability of the relevant gamma ray, and
F is the normalisation factor for the relative γ-ray emission probabilities.

Thus, the relative γ-ray emission probability P_γ^{rel}(57.608 keV) can be expressed as follows:

$$P_\gamma^{rel}(57.608\text{ keV}) = \frac{TP_\gamma^{rel}(57.608\ keV)}{(1\ +\ \alpha_{tot})} = \frac{14.49\ (22)}{(1\ +\ 3.72\ (6))} = 3.07\ (6)$$

Relative gamma-ray emission probabilities for ^{127}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)	3.07 (6)‡
$\gamma_{2,1}$ (I)	145.252 (14)	0.51 (6)	0.33 (3)	0.40 (6)
$\gamma_{3,2}$ (I)	172.132 (12)	–	0.03 (2)	0.03 (2)
$\gamma_{2,0}$ (I)	202.860 (8)	5.4 (2)	5.86 (21)	5.6 (2)
$\gamma_{4,2}$ (I)	215.13 (6)	3.9 (2)	3.91 (17)	3.9 (2)
$\gamma_{4,1}$ (I)	360.38 (6)	14.8 (1)	13.6 (1)	13.6 (2)
$\gamma_{3,0}$ (I)	374.991 (9)	–	0.03 (2)	0.03 (2)
$\gamma_{4,0}$ (I)	417.99 (6)	100	100	100
$\gamma_{5,0}$ (I)	618.31 (13)	–	0.013 (2)	0.013 (2)

* weighted mean of appropriate measurements of 1965Au01 and 1970Ap02, from which NRM values were adopted.
† gamma transition common to the β^- decay of both ^{127}Te and ^{127m}Te.
‡ derived from γ population-depopulation balance of the 57.608-keV nuclear level, assuming no direct population by β^- decay on the basis of spin-parity considerations ($3/2^+ \rightarrow 7/2^+$).

Two specific numerical procedures were used to analyse 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
145.252 (14)	LWM NRM	0.42 (9) 0.40 (6)	4.50 2.63	6.63 3.84
202.860 (8)	LWM NRM	5.6 (2) 5.6 (2)	2.52 2.52	6.63 3.84
215.13 (6)	LWM NRM	3.9 (2) 3.9 (2)	0.00 0.00	6.63 3.84
360.38 (6)	LWM NRM	14.2 (6) 13.6 (2)	72 3.85	6.63 3.84

Multipolarities and Internal Conversion Coefficients

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. Many of the gamma-ray transitions possess (M1 + E2) multipolarity, and assessments have been made of a significant number of these mixing ratios by Krane (1977Kr13, 1980Kr22). Various proposed mixing ratios have been assessed by the evaluator, and specific selections have been made as follows:

- 57.608-keV gamma ray, 99.3 % M1 + 0.7 % E2;
- 172.132-keV gamma ray, 99.3 % M1 + 0.7 % E2;
- 202.860-keV gamma ray, 79 % M1 + 21 % E2;
- 215.13-keV gamma ray, 96.0 % M1 + 4.0 % E2;
- 360.38-keV gamma ray, 96.4 % M1 + 3.6 % E2; and
- 417.99-keV gamma ray, 99.4 % M1 + 0.6 % E2.

Additionally, the 618.31-keV (M1 + E2) gamma transition was arbitrarily assigned a mixing ratio of 1.0 ± 0.5 (50 % M1 + 50 % E2) in this reasonably comprehensive exercise. Both the 145.252- and 374.991-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: 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)
172.132 (12)	−	−	− 0.084 (7) (M1 + 0.7(1)%E2)	− 0.085 (6) (M1 + 0.7(1)%E2)	− 0.085 ± 0.006* (M1 + 0.7(1)%E2)
202.860 (8)	−	+ 0.52 (5) (M1 + 21(3)%E2)	+ 0.52 (5) (M1 + 21(3)%E2)	−	+ 0.52 ± 0.05† (M1 + 21(3)%E2)
215.13 (6)	− 0.20 (2) or > 200	−	− 0.203 (15)	−	− 0.203 ± 0.015† (M1 + 4.0(5)%E2
360.38 (6)	0.18 (8) or 2.29 (7)	−	+ 0.194 (15)	−	+ 0.194 ± 0.015† (M1 + 3.6(5)%E2)
417.99 (6)	−	−	− 0.08 (3)	−	− 0.08 ± 0.03† (M1 + 0.6(3)%E2)
618.31 (13)	−	−	−	−	1.0 ± 0.5 (50%M1 + 50%%E2)

* adopted directly from 1980Kr22.
† adopted directly from 1977Kr13.

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

E_γ (keV)	Multipolarity	α_K	α_L	α_{M+}	α_{tot}	
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^-
145.252 (14)	E2	0.357 (5)	0.0907 (13)	0.0233	0.471 (7)	β^-
172.132 (12)	99.3%M1 + 0.7%E2 δ = − 0.085 (6)	0.1419 (20)	0.0185 (3)	0.0046	0.1650 (24)	β^-
202.860 (8)	79%M1 + 21%E2 δ = + 0.52 (5)	0.0965 (17)	0.0142 (5)	0.0036	0.1143 (22)	β^-
215.13 (7)	96.0%M1 + 4.0%E2 δ = − 0.203 (15)	0.0782 (11)	0.01031 (16)	0.00249	0.0910 (13)	β^-
360.38 (7)	96.4%M1 + 3.6%E2 δ = + 0.194 (15)	0.0201 (3)	0.00256 (4)	0.00054	0.0232 (4)	β^-
374.991 (9)	E2	0.01671 (24)	0.00257 (4)	0.00062	0.0199 (3)	β^-
417.99 (6)	99.4%M1 + 0.6%E2 δ = − 0.08 (3)	0.01381 (20)	0.001741 (25)	0.000429	0.01598 (23)	β^-
618.31 (13)	50%M1 + 50%E2 δ = 1.0 (5)	0.0047 (4)	0.00061 (3)	0.00019	0.0055 (4)	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 has been 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 adopted from Hashizume (2011Ha31) and a Q_{β^-} value of 702 (4) keV from the evaluated tabulations of 2011AuZZ were used to deduce the energies and uncertainties of the beta-particle transitions.

Absolute beta-particle emission probabilities were derived from γ population-depopulation of the various nuclear levels of ^{127}I, based on the relative emission probabilities of the γ rays, their normalisation factor of 0.009 97 (11), and the theoretical internal conversion coefficients. The $\beta^-_{0,0}$ emission directly to the ground state of ^{127}I can be derived by two routes:

(i) relative β^- emission probabilities determined from γ population-depopulation of the nuclear levels of ^{127}I

$$P_{\beta^-_{0,0}} \;=\; 100 \;-\; \sum^{all\ other\ \beta^-} P^{rel}_{\beta^-}\ x\ F$$

$$P_{\beta^-_{0,0}} \;=\; 100 \;-\; [122.33\ (43)\ \ x\ \ 0.00997\ (11)] \;=\; 100 \;-\; 1.220\ (14)$$
$$=\; (98.780 \pm 0.014)\ \%$$

(ii) relative γ-ray emission probabilities populating the ground state of ^{127}I directly

$$P_{\beta^-_{0,0}} \;=\; 100 \;-\; \sum^{\gamma\ to\ ground\ state} P^{rel}_{\gamma}\,(1 \;+\; \alpha_{tot})\ x\ F$$

$$P_{\beta^-_{0,0}} \;=\; 100 \;-\; [0.013\ (2) + 101.598\ (23) + 0.03\ (2) + 6.2\ (2) + 14.5\ (3)]\ x\ 0.00997\ (11)$$
$$=\; 100 \;-\; [122.341\ (361)\ \ x\ \ 0.00997\ (11)] \;=\; 100 \;-\; 1.220\ (14)$$
$$=\; (98.780 \pm 0.014)\ \%$$

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

Transition	E_β (keV)	P_β	Transition type	log*ft*
$\beta^-_{0,5}$	84 ± 4	0.00013 ± 0.00002	allowed	8.38 ± 0.10
$\beta^-_{0,4}$	284 ± 4	1.19 ± 0.02	allowed	6.086 ± 0.022
$\beta^-_{0,3}$	327 ± 4	0.0006 ± 0.0003	allowed	9.58 ± 0.22
$\beta^-_{0,2}$	499 ± 4	0.025 ± 0.003	allowed	8.57 ± 0.06
$\beta^-_{0,0}$	702 ± 4	98.780 ± 0.014	allowed	5.490 ± 0.010
		∑ 99.996 (25)		

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 latter ratio of 18.9 (58/3.07). There is a lack of γ-ray spectroscopy measurements of ^{127}Te (and ^{127m}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.

Atomic Data

The X-ray and Auger electron data have been calculated from the 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 ^{127}Te.

			Energy (keV)	Photons per 100 disint.
XL		(I)	3.485 – 5.060	0.011 9 (6)
	XL_l	(I)	3.485	0.000 226 (8)
	XL_{α}	(I)	3.927 – 3.938	0.005 97 (18)
	XL_{η}	(I)	3.779	0.000 088 (3)
	XL_{β}	(I)	4.221 – 4.508	0.004 76 (11)
	XL_{γ}	(I)	4.801 – 5.060	0.000 678 (17)
XK_{α}	$XK_{\alpha2}$	(I)	28.3175 (4)	0.030 9 (7)
	$XK_{\alpha1}$	(I)	28.6123 (3)	0.057 4 (12)
$XK'_{\beta1}$	$XK_{\beta3}$	(I)	32.2397 (3)	)
	$XK_{\beta1}$	(I)	32.2951 (4)	) 0.016 5 (4)
	$XK''_{\beta5}$	(I)	32.544	)
$XK'_{\beta2}$	$XK_{\beta2}$	(I)	33.042 (2)	)
	$XK_{\beta4}$	(I)	33.120	) 0.003 74 (12)
	$XKO_{2,3}$	(I)	33.166	)

Electron energies were obtained from the 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

A Q_{β}- value of 702(4) keV has been adopted from the atomic mass evaluation of Audi and Wang *et al*. (2011AuZZ). This value has been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{127}Te beta-decay process (i.e. β^{-}, electron, γ, etc.):

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 702\ (4)\ \text{keV}$$

Percentage deviation from the Q-value of Audi and Wang is (0.0 ± 0.9) %, which supports the derivation of a highly consistent decay scheme.

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