$^{99}Tc^{m}$ - Comments on evaluation of decay data
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This evaluation was completed in December 2000. The half-life has been updated in January 2004.

1. DECAY SCHEME

Tc-99m mainly decays to the ground level of Tc-99.
Very weak beta minus transitions to the ground and two excited levels of Ru-99 have been observed.
The J^{π} values and the level energies are from Peker(1994Pe15).

2. NUCLEAR DATA

Q_{IT} ($^{99}Tc^{m}$) from the 142,7 keV level energy
Q^{-}($^{99}Tc^{m}$) from Audi and Wapstra (1995)

2.1 HALF-LIFE

- The measured half-life values are, in hours:

1	6,13(5)	CROWTHER and ELDRIDG	(1965)	1965Cr03	rejected
2	6,006(7)	GOODIER and WILLIAMS	(1966)	1966Go22	
3	6,014 (4)	VUORINEN	(1969)	1969Vu03	
4	6,031 (12)	LEGRAND et al.	(1970)	1970Le07	
5	6,007 (2)	SANTRY and BOWES	(1989)	1989Sa**	
6	6,03 (13)	DECOMBAZ et al.	(1972)	1972De76	
7	6,02 (1)	EMERY et al.	(1972)	1972Em01	
8	6,049 (35)	EMERY et al.	(1972)	1972Em01	rejected
9	6,02 (3)	MEYER	(1974)	1974Me**	
10	6,008 (4)	RUTLEDGE et al.	(1980)	1980RuZY	TcO_4Na
11	6,006 (2)	HOUTERMANS et al.	(1980)	1980Ho17	No precision
12	6,0072 (10)	AYRES and HIRSHFELD	(1982)	1982Ay**	Normal saline solution
13	6,0170(19)	AYRES and HIRSHFELD	(1982)	1982Ay**	Acid solution
	6,0062 (7)	WALZ et al.	(1983)	1983Wa26	Superseded by 2003Sc49
14	6,020(2)	KOLTSOV et al.	(1998)	1998Ko**	TcO_4Na
15	6,0058(12)	SCHRADER	(2004)	2004Sc49	TcO_4Na
16	6,0071(21)	Da SILVA et al.	(2004)	2004Si04	TcO_4Na

The chemical medium probably has an influence on the half-life. Changes in the half-life values have been observed with the modification of external environment or chemical composition (influence on internal conversion of electrons of 2,17 keV transition in external shells : Mazaki (1980Ma03), Koltsov, and others).

Comparisons of the decay constant of Tc-99m in different chemical environments were made. In the following table λ_0 is the decay constant for Tc-99m in the form of pertechnetate (TcO_4).

Author	Type of source	Source pair	Relative variation of decay constant, %
Koltsov	Sulfide	$[\lambda_0 - \lambda\,(Tc_2S_7)] / \lambda_0$	0,14 (8)
Koltsov	Silver	$[\lambda_0 - \lambda\,(Ag)] / \lambda_0$	0,35 (7)
Koltsov	Gold	$[\lambda_0 - \lambda\,(Au)] / \lambda_0$	0,25 (7)
Mazaki	Sulfide	$[\lambda_0 - \lambda\,(Tc_2S_7)] / \lambda_0$	0,32 (7)
Mazaki	Sulfide - metal	$[\lambda\,(Tc_2S_7) - \lambda\,(Metal)] / \lambda\,(Metal)$	0,056 (3)
Ayres		Acid solution – Normal saline	0,16

If we consider the set of 16 measured values given in the table above, where :
- Emery *et al.*(1972) and Ayres and Hirshfeld (1982) measured the half-life of Tc-99m by 2 different methods or 2 media: both values were taken into account. (NB : the experiment and results described by Ayres and Hirshfeld are the same as those described by Hoppes *et al.* in NBS-SP-626 (1982) 85 and by Unterweger *et al.* in NIM A312 (1992) 349) ;
- the value of Crowther and Eldridge (1965) and the second value of Emery et al. (1972) are rejected due to the Chauvenet criterion.

With the set of 14 remaining values, LWEIGHT recommended the unweighted average (Reduced-χ^2 = 5,3) and expanded the uncertainty to include the most precise value of 6,0072 (Ayres *et al.* 1983). This leads to 6,014 (7) h.

With the 7 most recent values (from 10 to 16) (>1980), the LWEIGHT program derived the weighted mean and expanded the uncertainty: the recommended value is 6,0089 (19) h. (Reduced-χ^2 = 10,2).

Nevertheless, the most commonly used chemical composition is sodium pertechnetate (TcO_4Na) in a physiological saline solution, this solution is chemically stable. This is the result of the way of production of $^{99}Tc^{m}$ for medical purposes. The metallic matrix have been made for very specific studies and do not correspond to a general use.

Then, taking into consideration the most recent values obtained from a (TcO_4Na) solution, i.e. values 10 – 12 – 14 – 15 – 16 ; the value 14 (Koltsov) is outlier, omitting it the weighted mean is 6,006 7 (7) with the internal uncertainty, the reduced χ^2 is 0,32.

Conclusions :

- Due to the fact that the pertechnetate solution is a stable solution and the most commonly used, *the adopted half-life is : 6,006 7 (10) h,* uncertainty of the most precise measurement value.

- Uncertainty should be enlarged to 0,009, to take into account a possible chemical effect of 0,15% for other solutions, then the half life would be : 6,007 (9) h.

DECAY Tc-99m to Tc-99

- Measured half-life of the 140,5 keV level in ns:

0,277	(14)	STEINER *et al.*	(1969St04)
0,160	(20)	MCDONALD *et al.*	(1971Mc02)
0,205	(4)	ALFTER *et al.*	(1993Al23)
0,237	(14)	SHENOY *et al.*	(1973Sh21)

The value of Steiner *et al.*(1969) is from the original article; the NDS value from the same reference has been adjusted to 0,192 ns.
The value of 0,160(20) ns from McDonald *et al.* (1971) deviates far from the others and is not taken into account.
The Steiner *et al.*(1969) and Shenoy *et al.*(1973) values were determined using the Mössbauer effect.
The uncertainty in the Alfter *et al.* (1993) value was increased 2,47 times by LWEIGHT.
Reduced-χ^2 = 8,94
LWEIGHT has used the weighted average and the external uncertainty.

The adopted value is : **0,221(20) ns**

- **Level energy of technetium 99**

The values of the level energies are from NDS 73,1
Level 2 142,6833 (11)
Level 1 140,5108 (10)

2.2 GAMMA TRANSITIONS and INTERNAL CONVERSION COEFFICIENTS

The energies of the gamma transitions are derived from the energies of the gamma rays, taking recoil into account. The probabilities of gamma transitions $P_{\gamma+ce}$ have been computed using the evaluated absolute gamma-ray emission probabilities and the total internal conversion coefficients (ICC).

INTERNAL CONVERSION COEFFICIENTS

The ICC have been evaluated using the experimental information of the multipolarity admixture coefficients and the theoretical values from Rösel *et al.* and Band *et al.* (for $\gamma_{2,1}$ 2,17 keV).
For pure multipolarities the uncertainties on the ICC values are adopted to be 2%. For mixed multipolarities the uncertainties of ICC were evaluated taking into account the uncertainties of respective multipolarity admixture coefficients.
The ICC adopted values are compared with the measured values, and are, generally, in good agreement.

<u>Transition 2-1: 2,17 keV</u>

No experimental value has been found. Band theoretical values (1976Ba63):
$\alpha_{T} =$ 1,35 (4) 10^{10} and $\alpha_{M} =$ 1,19 (3) 10^{10}

<u>Transition 1-0: 140,511 keV</u>

Total Internal Conversion Coefficient a_T

Experimental measurements :

0,118 (8)	AMTEY *et al.* (1966)
0,113 (6)	DICKENS and LOVE (1980)
0,122 (5)	VUORINEN (1969)
0,118 (3)	LEGRAND *et al.* (1973Le29)
0,1181(23)	LWEIGHT (reduced χ^2= 0,44; weighted average and internal uncertainty)
Adopted: 0,119(3)	**Rosel *et al.* for M1+3,3(3)%E2**

Dickens and Love (1980) determined α_T from the α_k value given by Gardulski and Wiedenbeck (1974) and the K/L/MN values reported by Hager and Selzer and by Medsker (NDS 12-4 - 1974)

α_T was evaluated by Vuorinen (1969) from measurements of conversion electrons in coincidence with fluorescence X-rays.

Multipolarity

Large number of measurements have been made. However, most of the authors gave different values without, or with a large uncertainty. These multipolarities permit the calculation of the total internal conversion coefficients, to which we have assigned a 5% uncertainty:

/d/	**Transition**	a_T **(Rösel)**	
0,31 (2)	M1 + 8,25% E2	0,132(7)	SINGH and SAHOTA (1982Si16)
0,178 (12)	M1 + 3,1% E2	0,119(6)	ALFTER (1993Al23)
	M1 + 4%(2) E2	0,121(6)	MCDONALD *et al.*(1971Mc02)
	M1+<3%E2		VOINOVA *et al.*(1972Vo06)
0,194(30)	M1+3,8%E2		VUORINEN (1969Vu03)
	M1+<8%E2		VAN EIJK *et al.*(1968Va14) calculated from ICCk
	M1+9%(5)E2	0,134(7)	VAN EIJK *et al.*(1968) calculated from K/L ratio
	M1+2,8%E2	0,118(6)	COOK *et al.*(1969Co18)
	M1+7(3)%E2	0,129(7)	MEYER (1974)
	M1+1,4%E2	0,114(6)	DICKENS and LOVE (1980Di16)
	M1+6,5(40)E2	0,128(7)	AGEEV *et al.*(1969Ag04)
0,118(6)	M1+1,4(2)%E2	0,114(6)	GARDULSKI and WIEDENBECK (1974Ga01)
	M1+2,8(3)%E2	0,118(6)	GEIGER (1968GeZW)
	M1+9%E2		SIMONITS *et al.* (1981Si15)
	M1+E2		AMTEY *et al.* (1966Am04)
	M1		BASHANDY (1969Ba54)
		0,120(2)	LWEIGHT (reduced-χ^2= 1,16), weighted average and external uncertainty= 0,002
0,186 (8)	**M1+ 3,2(3)%E2**	**0,119(3)**	**Adopted (Rösel *et al.*)**

From each determination of the multipolarity of the transition, the Rösel theoretical internal coefficient was calculated. From the set of the 10 deduced ICC values the LWEIGHT program recommends a weighted mean of 0,120(2). The value is very closed to that obtained by considering the 4 experimental values for α_T (see table above).

Internal Conversion Coefficients a_K

Experimental values:

0,096(6)	VOINOVA *et al.* (1971Vo06)
0,093 (6)	VOINOVA *et al.* (1971Vo06)
0,102 (7)	VAN EIJK *et al.* (1968Va14)
0,094 (8)	VUORINEN (1969Vu03)
0,102 (5)	DICKENS and LOVE (1980Di16)
0,096 (3)	LWEIGHT (χ^2=0,35; weighted average and internal uncertainty)
0,104 (3)	**Rösel *et al.* (1978) (adopted)**

- α_K was measured by Voinova *et al.* (1971) with a spectrometer which provided simultaneous measurement of conversion electrons and γ-ray spectra.

- Van Eijk *et al.*(1968) calculated α_K from measurements of the 140,5 keV gamma-ray emission probability (P_γ) relative to the gamma-ray emission probability of the 661,6 keV gamma transition in the decay of Cs-137, and from measurements of the conversion electron emission probability P_{ce} of the 140,5 keV K-conversion line relative to the conversion electron emission probability of the 661,6 keV K-conversion line in the decay of Cs-137: P_{ceK} =6,84(19); P_γ =6,00(35); α_K(661,6 keV) = 0,0896 (15) (Helmer in 1999BeZQ).
- Vuorinen (1969) evaluated the internal conversion coefficient α_K by measuring the electron conversion emissions following the conversion of the 140 keV gamma-ray in coincidence with fluorescence X-rays.
- α_K given by Dickens and Love (1980) was computed from the tables of Hager and Seltzer for a M1 transition and a 1,4% E2 admixture. An 5% uncertainty assigned to α_K reflects the added uncertainty to the usual 3% due to the rapid change of α_k with admixture. This value is not taken into account in our calculations.

Internal Conversion Coefficients a_L

α_L can be deduced from measurements of the K/L ratio of the conversion electron emission probabilities, and with α_k = 0,104(3) :

K/L	α_L	
8,1 (5)	0,0125(8)	BASHANDY(1969Ba03)
7,70 (30)	0,0132(7)	VAN EIJK *et al.* (1968Va14)
8,3 (3)	0,0122(6)	RAVIER *et al.* (1961Ra04)
7,63 (32)	0,0133(7)	BRAHMAVAR (1968)
7,8 (3)	0,0130(6)	GEIGER (1968 GeZW)
	0,0128(3)	LWEIGHT has used the weighted average and the internal uncertainty. Reduced-χ^2 =0,52
Adopted	**0,0129(4)**	Rösel *et al.* (1978)

Transition 2-0: 142,683 keV

Internal Conversion Coefficients a_T

For a M4 transition the theoretical value from Rösel is : **40,9(8).**

Internal Conversion Coefficients a_K

- The two following values were calculated from experimental data, and listed by the authors:
  - 23 (6) VAN EIJK *et al.* (1968)
  - 30 (3) BASHANDY (1969Ba54)

Van Eijk *et al.* (1968) calculated the K ICC from the ratios of K(142,7)/K(140,5) = 0,072(32) and I_γ(142,7)/I_γ(140,5) = 0,00030(6), after correction for α_K (661,6 keV, Cs-137) = 0,0896(15)
Bashandy (1969) calculated the K ICC from internal conversion spectra and photon emission probabilities I_γ(142)/I_γ(140) = 0,00030(6)

- The following α_K coefficients are calculated from the K(142,7)/K(140,5) ratio given by the authors, based on the ratio I_γ(142,7)/I_γ(140,5) = 0,00030(6) [Van Eijk (1968)] and α_K (140,5) = 0,104(3).

K(142,7)/K(140,5)	α_K(142,7)	
0,072(4)	24 (6)	AMTEY (1966Am04)
0,0746(12)	25 (6)	GEIGER (1968GeZW)
0,075 (8)	26 (6)	AGEEV *et al.* (1969Ag04)

If we take into account the ratio $I_\gamma(142,7)/I_\gamma(140,5)$ = 0,00021(3) given by Dickens and Love (1980Di16), with $\alpha_K(140,5)$ = 0,104(3) the same calculations give higher results for $\alpha_K(142,7)$:

K(142,7)/K(140,5)	$\alpha_K(142,7)$	
0,072(4)	34 (6)	AMTEY (1966)
0,0746 (12)	36 (5)	GEIGER (1968)
0,075 (8)	36 (7)	AGEEV *et al.* (1969)

If we take into account all the six possible data, the weighted average, with the external uncertainty, calculated by LWEIGHT is 29,5(18) (reduced-χ^2 = 0,87)

The **adopted** theoretical K conversion coefficient, for a M4 transition, is **: 29,3(6)** (Rösel *et al.* (1978)).

Internal Conversion Coefficients a_L

From the measurement of the ratio of the conversion electron intensities, with α_K = 29,3(6), it can be deduced that α_L (BASHANDY and IBRAHIEM) is closed to the adopted theoretical value:

K/L	α_L		
2,9 (5)	10,1 (18)	M4 transition	BASHANDY and IBRAHIEM (1969Ba03)
Adopted:	**9,35 (20)**	M4 transition	RÖSEL *et al.* (1978)

3. ATOMIC DATA

3.1. FLUORESCENCE YIELDS

The fluorescence yields are taken from Schönfeld and Janβen (96Sc06).

3.2. X RADIATIONS

The X-ray energies are based on the wavelengths given by Bearden and were converted into energy with 1Å =1,00001481(92) 10^{-10}m
The emission intensities are calculated with the EMISSION program from PTB. No experimental data have been found.

3.3. AUGER ELECTRONS

The energies of Auger electrons are from 1977La** (Larkins).
The ratios P(KLX)/P(KLL) and P(KLY)/P(KLL) are taken from 1996Sc06.

4. PHOTON EMISSIONS

4.1. X-RAY EMISSIONS

The absolute emission probabilities of K X-rays (P_{XK}) have been computed using the adopted value of ω_K , the evaluated internal conversion coefficients and the emission probabilities.

4.2. GAMMA RAY EMISSIONS

4.2.1 GAMMA RAY ENERGIES

The γ-ray energies of $\gamma_{2,1}$(2,17 keV) and $\gamma_{1,0}$(140,5 keV) are taken from Gerasimov *et al.* (1981Ge05) and Helmer (2000He14), respectively. These values are based on the most accurate measurements with an electrostatic spectrometer ($E\gamma_{2,1}$, see also 1971La12 – Lacasse and Hamilton) and curved-crystal spectrometer ($E\gamma_{1,0}$, see also 1981He15 – Helmer *et al.*). The energy of $\gamma_{2,0}$ (142,7 keV) has been computed as the sum of the adopted energies of $\gamma_{2,1}$(2,17 keV) and $\gamma_{1,0}$(140,5 keV) .

4.2.2 GAMMA RAY EMISSION INTENSITIES

140,511 keV (1,0)

Absolute values (per 100 decays)

88,20 (26)	Chen Da (1985)
87,30(21)	Simonits *et al.* (1981Si15)
88,75 (14)	Rutledge *et al.* (1980Ru20)
87,2 (5)	Dickens and Love (1980Di16) (calculated)
88,0 (24)	Legrand *et al.* (1973Le29)

LWEIGHT has been used to derive the weighted average and expand the uncertainty so that the range includes the most precise value of 88,75(14). This leads to the average of 88,4(4) % (reduced-χ^2 = 2,24). Omitting the calculated value of Dickens and Love (1980) and the value of Simonits (1981) from statistical considerations, we have a weighted average of 88,5 % with an external uncertainty of 0,2. LWEIGHT has increased the uncertainty of Rutledge *et al.* (1980) to 0,258. Reduced-χ^2 = 1,14.
The **adopted** value is **: 88,5(2)%**

142,675 keV (2,0)

Relative measurements of the $\gamma_{1,0}$(140,5 keV) line are not precise: from 0,00020(3) of Dickens *et al.*(1980) to 0,00030(6) of Van Eijk *et al.* (1969).
The ratio of $I_{\gamma+ce}$(142,7)/$I_{\gamma+ce}$(140,5) from the ^{99}Mo+^{99}Tc^{m} evaluation for the “slow” component of the 140,5 keV transition is 0,0097(7), corresponding to I_{γ}(142,7)/ I_{γ}(140,5) = 0,00026(2) and P_{γ}(142,7) = **0,023(2)%** (**adopted value**).

5. ELECTRON EMISSIONS

The energies of the conversion electrons have been calculated from the gamma-transition energies given in 2.2 and the electron binding energies. Emission probabilities have been calculated using the conversion coefficients given in 2.2. and the adopted gamma emission probabilities.

Measurements of conversion electron spectra for ^{99}Tc^{m} (in equilibrium with ^{99}Mo) have been made in many studies (Van Eijk-1968Va14, Ageev-1969Ag04, Bashandy-1969Ba03, Bashandy-1969Ba54, Ravier-1961Ra01, Lacasse-1971La12, Voinova-1971Vo06, Legrand-1973Le29, Gerasimov-1981Ge05). However, the computed values of the conversion electron energies and emission probabilities are more accurate.

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 2.2.

Experimental Auger spectra can be found in 1981Ge05 (Gerasimov *et al.*).

Tc-99m to Ru-99 b- DECAY

From Alburger *et al.* (1980Al02) the total transition probability of the β-transition is: 0,0037(6)%

2- NUCLEAR DATA

Level energy of Ru-99

The values of the level energies are from Peker (NDS 73,1)

Level 2 322,38 (6)
Level 1 89,68 (5)

2.1- b-TRANSITIONS

Only Alburger *et al.* (1980) have totally studied the beta decay of Tc-99m.
The lg ft values were calculated by Singh *et al.* (1998) and derived from measurements by Alburger *et al.* (1980):

Transition	Energy	lg ft Singh *et al.*	lg ft Alburger *et al.*	Nature
0-0	434,8 (26)	9,4	9,39(11)	unique first-forbidden
0-1	346,7(20)	8,7	8,66(8)	first-forbidden
0-2	113,8 (20)	8,50	7,79(3)	first-forbidden

The adopted values of lg ft and average beta energies have been calculated using the LOGFT program and the level energies from ENSDF.

2.2 GAMMA TRANSITIONS and INTERNAL CONVERSION COEFFICIENTS

Multipolarity
Transition 322 keV M1+(E2)
Transition 233 keV (M1+E2)
Transition 89 keV 29%M1+E2 ($\delta = -1,56(2)$ measured by Kistner (1976Ki02))

Internal Conversion Coefficients
No experimental data have been found in the known literature.
The Rösel tables were used to deduce theoretical coefficients :

keV	a_T	a_K	a_L	a_M
322,4	0,01747	0,01519		
232,8	0,0478	0,0412		
89,6	1,492	1,171	0,270	0,0512

3. ATOMIC DATA

The fluorescence yields taken from 96Sc06 (Schönfeld and Janβen) are:
$\omega_K = 0,796(4)$, $\varpi_L = 0,0453(11)$, $n_{KL} = 1,000(4)$

4. PHOTON EMISSIONS

4.1 X-RAY EMISSIONS

The emission intensities are very low and have not been calculated.

4.2 GAMMA EMISSIONS

Energy, keV	Relative emission probability	Absolute emission intensity	Author(s)
322	$0,97 \times 10^{-6}$ (15)		Jones and Griffin (1970Jo24)
	$1,10 \times 10^{-6}$ (10)		Decombaz *et al.* (1972De76)
	$1,13 \times 10^{-6}$ (9)		Alburger *et al.*.(1980Al02)
	$1,09 \times 10^{-6}$ (6)	$0,96 \times 10^{-4}$(6)	LWEIGHT reduced-χ^2 = 0,42 weighted mean and internal uncertainty
232	$0,95 \times 10^{-7}$ (17)	$0,84 \times 10^{-5}$ (15)	Alburger *et al.*. (1980)
89		$1,04 \times 10^{-3}$ (20)	deduced from the level balance

For the 322 keV and the 232 keV gamma-rays, the measured emission probabilities are relative to the 140,5 keV emission probability. The absolute emission probabilities are deduced from the adopted absolute emission probability of the 140,5 keV gamma-ray: 88,5(2) %.

For the 89 keV line, no experimental value is available.
The 89 keV level is mainly fed by the beta transition from Tc-99m. With a beta transition probability of 2,6(5)*10^{-3} and a_T = 1,49(5), the absolute emission probability is : 1,04(20)*10^{-3}.

5. ELECTRON EMISSIONS

For the 434,8 and 346,7 keV β^- transitions, the energies and transition probabilities were measured by Alburger (1980).
For the third β^- transition of 113,8 keV, no direct experimental data was found.
The energy is estimated by Alburger *et al.* (1980), and the absolute transition probability is derived from 3 experimental and relative values :

$P_\gamma(322)/P_\gamma(140,5) = 1,10(6) \times 10^{-6}$	Decombaz *et al.*(1972)
$P_\gamma(322)/P_\gamma(140,5) = 0,97(15) \times 10^{-6}$	Jones and Griffin (1970Jo24)
$P_\gamma(322)/P_\gamma(140,5) = 1,113(9) \times 10^{-6}$	Alburger *et al.*(1980)

The weighted mean of γ emission probability relative to the 140 keV-line calculated by Alburger *et al.* (1980) is: $1,10(6) \times 10^{-6}$.

The gamma transitions probabilities are calculated from the gamma emission probabilities and the internal conversion coefficients :

$P_\gamma(322) = P_\gamma(322) \times (1 + \alpha_T(322))$
$P_\gamma(322) = 1,10 \times 10^{-6} \times P_\gamma(140,5)$
$P_\gamma(322) = 1,10 \times 10^{-6} \times 88,5 \times 1,0175 = 0,99 \times 10^{-4}$

As the level 0 is feeding by 93% of the transitions starting from the 322 keV-level, the probability of the 322-keV β transition can be deduced : $0,99 \times 10^{-6}/0,93$= **1,06(6) ´ 10^{-4}.**

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