^{99}Mo - Comments on evaluation of decay data

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1- DECAY SCHEME

Molybdenum 99 disintegrates to the technetium 99 excited levels by beta minus transitions. The 1205 keV (3/2-) and 1321 keV (1/2-) levels could be fed by non-unique 1st forbidden β^- decays. From lg ft systematic and with lg *ft* ≥ 8, the β^- branches to 1205 keV and 1321 keV levels, if they exist, would be expected ≤ 0,010% and ≤ 0,00014%, respectively. Forbiddeness of other possible β^--transitions is still greater. Therefore, all of these unobserved branches can be considered negligible.

Unlike the decay scheme of Peker based mainly on Goswamy (1992Go22), we have not found any justification for placing β^-- transition to the 534 keV level. The $P_{\gamma+ce}$ balance for this level has led to the evaluated probability of β^-- transition of the order of 0,0010(10) %. Also because of the significant lg *ft*, the attribution of 3/2+ to the 534 keV level seems to be unlikely.

Apart from that, in comparison with 1994Pe15 we have shown a β^--transition feeding the 1072 keV level. The spin and parity of this level are not defined exactly. Other J^π values are from Peker.

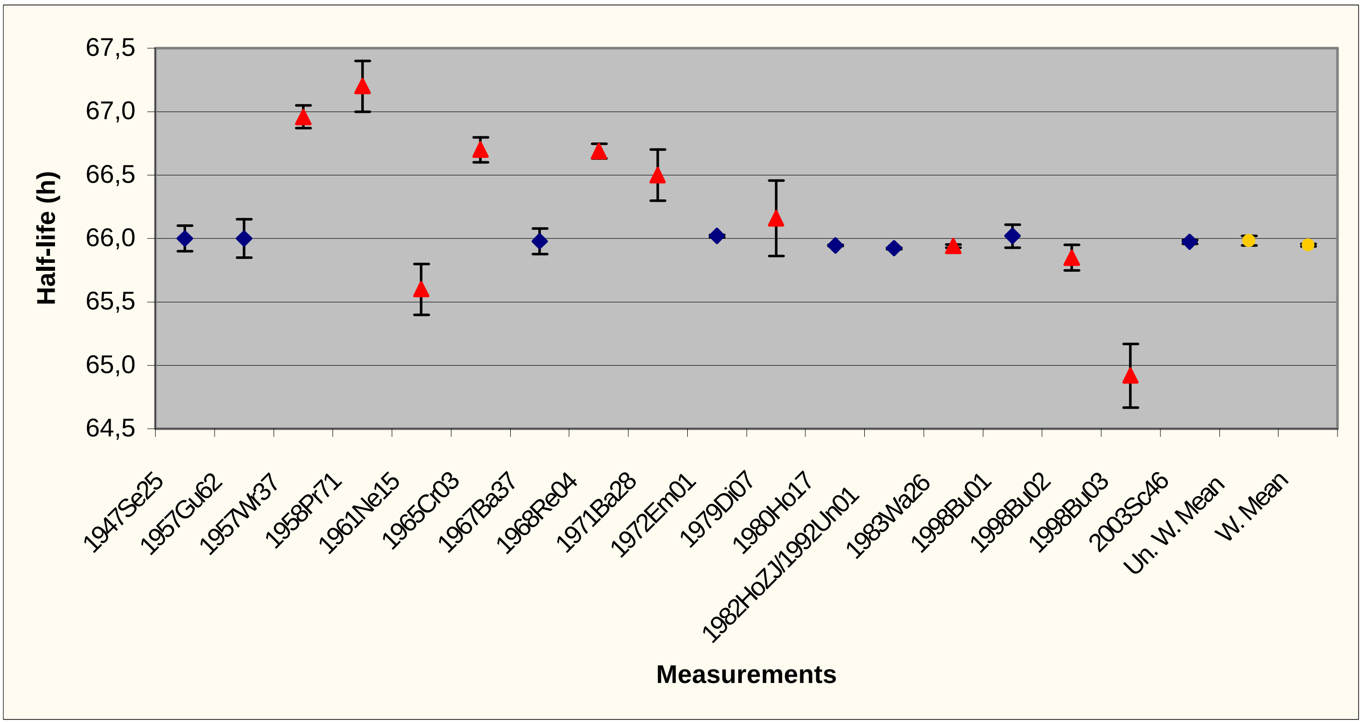
For this evaluation Mo-99 and Tc-99m are considered being in equilibrium. Therefore, the ratio of their activities is 1,1.

2- NUCLEAR DATA

Q^- is from Audi and Wapstra 1995 (95Au04).

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

66,0(1)	Seiler (1947Se25)	^{235}U(n,f) ic
66,00(15)	Gunn *et al.*(1957Gu62)	^{235}U(n,f),Mo(n,γ) pc
66,96(9)	Wright *et al.*(1957Wr37)	^{98}Mo(n,γ)
67,2(2)	Protopopov *et al.* (1958Pr71)	^{235}U(n,f) GM
65,6(2)	Newman (1961Ne15)	^{235}U(n,f) pc
66,7(1)	Crowther and Eldridge (1965 Cr03)	^{98}Mo(n,γ) well scin
65,98(10)	Baldwin (1967Ba37)	Mo(n,γ) from 2 meas. pc + scin
66,69(6)	Reynolds *et al.*(1968Re04)	^{235}U(n,f) ic
66,5(2)	Baba *et al.* (1971Ba28)	^{238}U(p,f)
66,02(1)	Emery *et al.* (1972Em01)	^{235}U(n,f)
66,16(30)	Dickens (1979Di07)	
65,945(3)	Houtermans *et al.* (1980Ho17)	ic
65,924(6)	Hoppes *et al.* (1982HoZJ)	ic
	Unterweger *et al.* (1992Un01)	
65,942(12)	Walz *et al.* (1983Wa26)	Superseded by 2003Sc49
66,02(9)	Butsev *et al.* (1998)	^{98}Mo(n,γ)
65,85(10)	Butsev *et al.* (1998)	235U(n,f)
64,92(25)	Butsev *et al.* (1998)	181Ta(12C,x) 99Mo
65,974(14)	Schrader *et al.* (2003Sc49)	ic



Looking at the graphical representation given above, it appears that 5 values are ≥ 66,5 h and 12 are in the range > 65,5 and < 66,5. The five high values are rejected of the statistical treatment (Chauvenet's criterion). The last value given by V.S. Butsev (1998) has also been rejected : $^{181}Ta(^{12}C,x)^{99}Mo$ is an exotic reaction, and the result is clearly outlier.

When processing the 17 values, the LWEIGHT program has detected 1957Wr37, 1958Pr71, 1961Ne15, 1965Cr03, 1968Re04, 1971Ba28, 1979Di07 and 2 values of 1998Bu (65,85(10) and 64,92(25)) to be outliers, based on Chauvenet's criterion. The Limited Relative Statistical Weight method increases the uncertainty for the 1980Ho17 value from 0,003 to 0,00481 and used the unweighted mean of 65,983(38) with the large uncertainty that does not correspond to the most accurate measured values (1980Ho17, 1982HoZJ or 1992Un01 and 2003Sc49).

With the set of the 5 most recent values (1972Em01, 1980Ho17, 1982HoZJ or 1992Un01, 1998Bu01 and 2003Sc49), the Limited Relative Statistical Weight method increases the uncertainty for the 1980Ho17 value from 0,003 to 0,00482 and used the weighted mean of 65,949 (14), where 0,014 is the external uncertainty, the reduced-χ^2 is 10,4.

The adopted value is 65,949(14) h or 2,7479(6) d.

- The measured half-life values of the 140,5 keV level of Tc-99 are in ns:

0,277	(14)	STEINER *et al.* (1969St04)
0,160	(20)	MCDONALD (1971Do02)
0,205	(4)	ALFTER *et al.*(1993Al23)
0,237	(14)	SHENOY *et al.* (1973Sh21)

The value of Steiner (1969) given here, is from the original article ; the NDS value (1994Pe15) from the same reference is very different : 0,192 ns.
The value of 0,160(20) ns from J.McDonald (1971) is very far from the others and is not taken into account.
The values from Alfter and Shenoy were determined by using the Moessbauer effect.
The uncertainty on the Alfter *et al.* (1993) value was increased 2,47 times by LRSW.
Reduced-χ^2 = 8,94

LWEIGHT has used the weighted average and the external uncertainty.
The adopted value from the LWEIGHT program is : **0,221(20) ns**

- The measured half-life value of the 181 keV level is **3,61(7) ns** (McDonald (1971))

- The values of the level energies are from NDS 73,1.

2.1 BETA-MINUS TRANSITIONS

The energies of β-transitions have been computed from the Q value and the adopted level energies. The probabilities of β⁻-transitions have been obtained from the $P_{\gamma+ce}$ balance for each level based on the P_{γ} normalization factor of 0,1212(15) (see section 4.2.3).

The sum of all the beta transition probabilities leaving the molybdenum must be equal to 100 %; this leads to a probability of 82,1(15)% for the beta transition feeding the 142 keV level, taking into account the gamma transitions feeding this level.

The measured energies and probabilities of some β-transitions are given below for comparison with calculated data:

	Measured[a]		Calculated	
	Energy, keV	Probability (%)	Energy, keV	Probability (%)
$\beta^-_{0,12}$	245	0,2	228,1(10)	0,011 (1)
$\beta^-_{0,9}$	450(10)	14	436,6(10)	16,45 (30)
$\beta^-_{0,4}$	840(5)	2	848,1(10)	1,18 (3)
$\beta^-_{0,2}$	1214(1)	80(2)	1214,5(10)	82,1 (15)

[a] Nagarajan (1971Na01) except $P(\beta^-_{0,2})$ for which unweighted mean of six experimental results quoted in Kholnov (1982KhZW) is given.

2.2 - GAMMA TRANSITIONS and INTERNAL CONVERSION COEFFICIENTS

The evaluated energies of the gamma transitions are the sums of the energies of gamma rays and the recoil energy.

2.2.1- INTERNAL CONVERSION COEFFICIENTS

The ICC have been evaluated using experimental information for the multipolarity admixture coefficients and the theoretical values from 1978Ro22 (Rösel *et al.*) and 1976Ba63 (Band *et al.*) (for $\gamma_{2,1}$).

The relative uncertainties of ICC were adopted to be 2%, for pure multipolarities. The ICC uncertainties for mixed multipolarities were evaluated by taking into account the uncertainties of the respective multipolarity admixture coefficients given in the referenced papers.

The internal conversion coefficients adopted in this evaluation are the theoretical values deduced from the Rösel et al. (1978Ro22) tables. They have been compared with experimental values.

<u>Transition 3-1 : 40,584 keV</u>

Internal Conversion Coefficients a_T
Some authors measured the mixing ratio δ :

δ	First author and NSR code	Transition	α_T (Rösel *et al.*)
-0,008 (8)	GARDULSKI (1974Ga01)	M1 + 0,0064%E2	3,80
0,03 (3)	SINGH (1982Si16)	M1 + 0,09%E2	3,87
-0,119 (8)	ALFTER (1993Al23)	M1 + 1,4%E2	4,18
	MCDONALD (1971Mc02)	M1 + 1,4(2)%E2	4,18(13) (adopted)

The E2 admixture of 1,4(2) % for $\gamma_{3,1}$(40,6 keV) has been adopted from 1971Mc02. The $\gamma\gamma(\theta)$ precise measurement of 1993Al23 confirmed this value (δ=–0,119(8)) and rejected the 0,0064 % value of 1974Ga01 which was adopted in Peker's evaluation (1994Pe15). This increases the total ICC for $\gamma_{3,1}$ from 3,76 to 4,18 and improves the intensity balance for the 140,5 keV and 181,1 keV levels.

Internal Conversion Coefficients a_K

a_K	Transition	First author and year
3,2 (2)	M1 transition	Ranakumar (1969)
3,7 (5)	M1 transition	Bashandy (1969Ba03)
3,27 (19)	Weighted average, external uncertainty	LWEIGHT (χ^2= 0,86)
Adopted: 3,50 (8)	M1+1,4(2)%E2	Rösel *et al.* (with the adopted admixture)

Internal Conversion Coefficients a_L

From the measurement of the K/L ratio of the conversion electron emission probabilities and, with α_K= 3,50(8), the α_L value is deduced :

K/L	a_L	First author and year
9,3 (20)	0,38(8)	RAVIER (1961)
8,3 (9)	0,42(5)	BASHANDY (1969Ba03)
	0,41(4)	LWEIGHT (χ^2= 0,18)
Adopted:	**0,560 (13)**	Rösel *et al.* for M1+1,4(2)%E2

Transition 1-0 : 140,511 keV

Internal Conversion Coefficients 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.* (1973)
0,1181(23)	LWEIGHT (reduced-χ^2= 0,44 weighted average and internal uncertainty)
Adopted: 0,119(3)	**Rösel *et al.* (1978) for M1+3,2(3)%E2**

Dickens and Love (1980) have 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

There are a significant number of measurements. However most authors gave different values with and without large uncertainties: these multipolarities make it possible to calculate the total internal conversion coefficients. We have assigned a 5% uncertainty to α_T:

/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 *et al.*(1993Al23)
	M1 + 4%(2) E2	0,121(6)	MCDONALD *et al.*(1971Mc02)
	M1+<3%E2		VOINOVA *et al.*(1971Vo06)
0,194(30)	M1+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.*(1969 Co18)
	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.* (1982Si15)
	M1+E2		AMTEY *et al.* (1966Am04)
	M1		BASHANDY (1969Ba54)
		0,120(2)	LWEIGHT (reduced-χ^2= 1,16), weighted average and external uncertainty= 0,0015
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 obtained is very close 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 ICCk 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 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 decay of Cs-137. With P_{ceK} = 6,84(19); P_γ = 6,00(35); α_K(661,6 keV) = 0,0896 (15) (Helmer in BÉ 1999 (1999BeZQ)), the value becomes 0,102(7).
- 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% assignment 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

From each measurement of the K/L ratios of the conversion electron emission probabilities, and with α_k = 0,104(3), a value for α_L is deduced :

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 (1968GeZW)
	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)

<u>Transition 2-0: 142,683 keV</u>

Internal Conversion Coefficients a_T

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

Internal Conversion Coefficients a_K

- The 2 following values were calculated from experimental data and given by the authors :
  23 (6)   Van Eijk *et al.* (1968)
  30 (3)   Bashandy (1969Ba54)

Van Eijk *et al.* (1968) calculated the K ICC value 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 and based on the ratio I_γ(142,7)/I_γ(140,5) = 0,00030(6) given by Van Eijk *et al.* (1968) and on α_K (140,5) = 0,104 (3).

K(142,7)/K(140,5)	α_K (142,7)	
0,072(4)	24 (6)	AMTEY *et al.* (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_γ(142,7)/I_γ(140,5) = 0,00021(3) given by Dickens and Love (1980Di16), with α_K(140,5) = 0,104(3), the same calculations give higher results for α_K(142,7) :

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

If we have taken 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 α_L

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

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

Transition 3-0 : 181,094 keV

Internal Conversion Coefficients α_T

0,140(5) DICKENS and LOVE (1980Di16)

GARDULSKI and WIENBECK (1974Ga01) measured a low multipole mixing ratio of 0,002(7) for a M3/E2 transition.

For a E2 transition, the theoretical value is : **0,149(3) (Rösel *et al.* (1978))**

Internal Conversion Coefficients α_K

0,13(3)		RAVIER *et al.* (1961)
0,127(11)*	E2 ≤ 12%M1	VAN EIJK *et al.* (1968)
0,133(20)	E2 transition	BASHANDY (1969Ba54)
0,12(1)		VOINOVA *et al.* (1972)
0,125(7)		LWEIGHT (reduced-χ^2 = 0,16, weighted average and the internal uncertainty)
0,125 (3)	E2 transition	**Rösel *et al.* (adopted)**

(*) value corrected for α_K(661keV Cs-137)= 0,0896(15) (Helmer in Bé 1999)

Internal Conversion Coefficients α_L

From the measurement of ratio K/L of conversion electron intensities, with α_K = 0,125(3), α_L can be deduced:

K/L	α_L	Transition	
4,9 (1)	0,025(6)		RAVIER *et al.* (1961)
6,8 (7)	0,0184(20)		BASHANDY (1969Ba03)
Adopted:	**0,0191 (4)**	E2	**Rösel *et al.* (1978)**

Transition 4-2 : 366,422 keV

Internal Conversion Coefficients α_T

0,0081 (2)		DICKENS and LOVE (1980)
0,00915 (18)	M1 transition	**Rösel *et al.* (1978) (adopted)**

Internal Conversion Coefficients a_K

0,0072 (10)		BASHANDY (1969Ba54)
0,00802(16)	M1 transition	**Rösel *et al.* (1978) (adopted)**

Transition 13-7 : 380,13 keV

Internal Conversion Coefficients a_K

0,009 (1)	M1+E2	BASHANDY (1969Ba54)
0,0091 (7)	M1+63(22)%E2	**Rösel *et al.* (1978) (adopted)**

- From the value of Bashandy (1969Ba54), it can be deduced a M1+63%E2 transition and multipole mixing ratio δ = 1,3(6).

Transition 14-7 : 410,27 keV

Internal Conversion Coefficients a_K

0,0060 (8)		BASHANDY (1969Ba54)
0,0065 (2)	M1+20(3)%E2	**Rösel *et al.* (1978) (adopted)**

Transition 9-4 : 411,492 keV

Internal Conversion Coefficients a_K

0,0030 (5)	E1 transition	BASHANDY (1969Ba54)
0,00226(5)	E1 transition	**Rösel *et al.* (1978) (adopted)**

Transition 12-6 : 457,60 keV

The E2 admixture of 72(55) % has been adopted from the evaluation of Kholnov (1982KhZW).

Internal Conversion Coefficients a_K

0,0054 (6)		BASHANDY (1969Ba54)
0,0054 (4)	M1+72(55)%E2	**Rösel *et al.* (1978) (adopted)**

Transition 6-2 : 528,790 keV

Internal Conversion Coefficients a_K

0,0050 (6)	E2 transition	BASHANDY (1969Ba54)
0,00375(8)	E2 transition	**Rösel**
0,00331(7)	M1 transition	**Rösel *et al.* (1978) (adopted)**

Transition 8-1: 621,771 keV

Internal Conversion Coefficients a_K

0,0020 (4)		BASHANDY (1969Ba54)
0,00227 (5)	M1 transition	**Rösel *et al.* (1978) (adopted)**

Transition 9-3 :739,503 keV

Internal Conversion Coefficient a_K

0,0016 (4)	M1 or E2	BASHANDY(1969Ba54)
0,00154 (40) *		VAN EIJK et a.l. (1968)
0,00151 (3)	E2+7,6%M1	**Rösel *et al.* (1978) (adopted)**

*value corrected for α_K(661keV Cs-137) = 0,0896(15) (Helmer in BÉ 1999)

The multipole mixing ratio : δ = 3,58(20) measured by Gardulski and Wiedenbeck (1974), leads to an E2 + 7,2% M1 transition.
Singh and Sahota (1982) indicated an E2 + 8,0(1)%M1 multipolarity.

Transition 9-2 : 777,924 keV

Internal Conversion Coefficient a_K

0,0005 (1)		BASHANDY (1969Ba54)
0,000518 (10)	E1 transition	**Rösel *et al.* (1978) (adopted)**

Transition 10-3 : 822,976 keV

Internal Conversion Coefficient a_K

0,0004 (1)		BASHANDY(1969Ba54)
0,0004 (1)	E1+1%M2 transition	SINGH (1982)
0,000461(9)	E1 transition	**Rösel *et al.* (1978) (adopted)**

For an E1+1%M2 transition, the theoretical value would be higher than the experimental values and we do not accept this type of transition.

Transition 13-3 : 960,759 keV

Internal Conversion Coefficient

Based on α_K = 0,0024(5) Bashandy deduced a M2 multipolarity. From the decay scheme Singh gave a M2 + E3 multipolarity. This is not consistent with the adopted spins and parities which lead to a M1+E2 transition. For a M1 transition, α_T = 0,00097 from the Rösel tables.

Transition 13-1 : 1001,348 keV

Internal Conversion Coefficient

Based on α_K = 0,0018(3) Bashandy deduced a M2+E3 multipolarity. This is not consistent with the adopted spins and parities which lead to a E2+M3 transition. For a E2 transition, α_T = 0,00083 from the Rösel tables.

2.2.2 GAMMA TRANSITION PROBABILITIES

The gamma transition probabilities have been calculated from the gamma emission probabilities and the internal conversion coefficients for the transitions occurring above the 142 keV level.

The total gamma and beta transition probabilities populating the 142 keV level is : 87,65(19)%.
Within the Tc-99m decay, the 2,17 keV gamma transition probability (from the level 2 to the level 1) is deduced to be : 99,0(4)%; the 142 keV gamma transition probability is evaluated to be : 1,0(1) % and the 140 keV gamma transition probability is 99,0(4)%.

So, the transition probabilities are deduced to be : 86,8(19)% and 0,88(6)% for the 2,17 keV and the 142 keV, respectively. Taking into account the level balance, the 140 keV transition probability is deduced to be 92,1(19) %.

3. Atomic Data

3.1. Fluorescence yields

- ω_k is from Bambynek (1984)
- ϖ_L , η_{KL} , η_{LM} are from Schönfeld and al.(1996)
- ϖ_M is from Hubbell and al. (1994)

3.2. X Radiations

The X-ray energies are based on the wave lengths in the compilation of 1967Be65 (Bearden). The relative K X-ray emission $K\beta/K\alpha$ and $K\alpha_2/K\alpha_1$ probabilities are taken from 1996Sc06.

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 total absolute emission probability of K X-rays (P_{XK}) has been computed using the adopted value of ω_K and the evaluated total absolute emission probability of K conversion electrons (P_{ceK}). The absolute emission probabilities of the K X-ray components have been computed from P_{XK} using the relative probabilities from 1996Sc06.

The measured values of the total absolute emission probability of K X-rays ($P_{XK}\times100$) are given below in comparison with the calculated (adopted) value:

Dickens and Love	Goswamy	Calculated (adopted)
11,3(5)	11,5(4)	11,2(2)

Above agreement of the measured and calculated values shows concord between the evaluated data for ^{99}Mo including the gamma-ray emission probabilities, gamma-multipolarity admixtures, ICC α_K and the fluorescence yield ω_K.

The total absolute emission probability of L X-rays has been computed using total absolute sums P_{ceL}, P_{ceK}, and atomic data of section 3 (ω_K, ϖ_L, η_{KL}).

M X-ray and Auger spectra have been investigated in Gerasimov. The influence of the chemical state on the K X-ray intensity has been studied in Yoshihara (1981Yo08).

4.2. GAMMA RAY EMISSIONS

4.2.1 GAMMA RAY ENERGIES

The γ-ray energies of $\gamma_{2,1}$(2,17 keV), $\gamma_{3,1}$(40,6 keV) and $\gamma_{1,0}$(140,5 keV) are taken from Gerasimov (1981Ge05), Gardulski (1972Ga37) and Helmer (2000He14), respectively. These values are based on the most accurate measurements with the electrostatic spectrometer ($E\gamma_{2,1}$, see also Lacasse (1971La12)) and curved-cristal spectrometer ($E\gamma_{3,1}$ and $E\gamma_{1,0}$, see also Helmer (1981He15)). The energies of $\gamma_{2,0}$(142,7 keV), $\gamma_{3,0}$(181,1 keV), $\gamma_{7,0}$(761,7 keV) and $\gamma_{11,0}$(1072,2 keV) have been computed from the Q value and the adopted energies of other gamma transitions using gamma cascades in the decay scheme. The energy of $\gamma_{15,4}$(689,6 keV) is taken from 1969Co18 (this γ-ray was seen also by Goswamy *et al.* (1992Go22) but was defined as some contamination in the source). All other gamma-ray energies have been adopted from the recent measurements with large volume Ge(Li) and high-purity Ge detectors by R.A. Meyer (1990Me15).

4.2.2 GAMMA RAY RELATIVE EMISSION PROBABILITIES

Several authors measured the relative emission probabilities to the emission probability of 739 keV line, and others to the emission probability of the 140,5 keV line.

In this evaluation the 739 keV line is taken as the reference line rather than the 140 keV line because the 739 line is not a part of the Tc-99m decay scheme, and the measurements carried out relative to this line, are more recent.

Measurements relative to the 140,5 keV line have been taken into account by converting the data so that they are relative to the 739 keV line.

The available experimental values for the γ-ray relative emission probabilities are given in Table 1. Where necessary, these data (including uncertainties) have been converted by the evaluators to values relative to the $\gamma_{9,3}$(739,5 keV) taken as 100. Some old references differ widely far from more recent studies and are not included in the statistical processing.

The adopted (evaluated) values are displayed in last column of Table 1. Reasons for adopting specific data are given in Table 2 which includes the following designations :

R indicates that the value was rejected due to Chauvenet criteria.

n is the number of values taken into account, WM is the weighted mean, *s* and *S* are the internal and external uncertainties of WM, respectively;

”c^2-table” is $(c^2)^{0,05}_{n-1}$,”*reduced* c^2-set” is $c^2/(n-1)$ for the given data set; s_{min} is the minimum experimental uncertainty for the given data set, *tS* is the external uncertainty multiplied by the Student’s factor *t* ,”MBAYS” is the uncertainty from a modified Bayesian analysis.

The doublet $\gamma_{14,7}$+$\gamma_{9,4}$(410-411 keV) has been calculated as two different lines because several authors were able to distinguish separated values.

For the doublet $\gamma_{7,3}$+$\gamma_{8,3}$(580-581 keV) several authors measured only one line, except Meyer (see Table 1).

For the doublet $\gamma_{12,4}$+ $\gamma_{8,1}$(620-622 keV) the emission intensity was computed for the two combined lines in order to take into account most of the measurements, and then these lines were separated by using the intensity ratio for components deduced from the measurements of Meyer of 0,09(3).

Table 1. Experimental and evaluated values for γ-ray relative emission probabilities

	keV	Van Eijk	Cook	Gehrke Heath	Morel	Dickens 1980	Yang 1980	Singh	Chen Da	Meyer 1990	Goswamy 1992	Evaluated
$\gamma_{3,1}$	**40,58**		6,9(8)	4,6(18) *R*	5,9(15)	8,68(27)		7,7(6)		8,6(5)	8,49(25)	8,43(20)
$\gamma_{1,0}$	**140,5**	649(25)	704(45)	730(49)	743(19)	747(12)	759(20)	686(49)	752(28)	755(26)	739(11)	739(11)
$\gamma_{2,0}$	**142,6**	0,195(40)				0,149(25)				0,189(11)		0,174(14)
$\gamma_{9,7}$	**158,8**		0,10(3)	0,095(30)	0,112(15)			0,11(4)		0,139(8)	0,156(6)	0,12(4)
$\gamma_{6,4}$	**162,4**			0,073(22)	0,067(15)			0,078(13)		0,097(5)	0,098(5)	0,094(5)
$\gamma_{3,0}$	**181**	48,7(23)	49,9(34)	49,6(42)	49,1(16)	50,1(7)		49,8(33)	48,7(13)	50,3(17)	49,4(8)	49,6(7)
$\gamma_{10,7}$	**242,3**		0,0070(25)					0,0118(44)		0,0117(17)	0,021(4)	0,0114(28)
$\gamma_{9,6}$	**249**	0,039(20)	0,05(2)					0,04(3)		0,024(3)	0,032(4)	0,0285(30)
$\gamma_{4,2}$	**366,4**	10,6(8)	10,7(6)	10,0(9)	9,8(3)	9,52(32)		9,8(8)		9, 92(25)	9,82(15)	9,85(15)
$\gamma_{13,7}$	**380,1**	0,071(20)	0,07(2)	0,058(15)	0,045(15)			0,07(2)		0, 075(3)	0,086(7)	0,075(4)
$\gamma_{5,2}$	**391,7**	0,016(4)									0,026(5)	0,021(5)
$\gamma_{14,7}$	**410,3**	0,010(5)						0,009(9)		0,016(4)		0,013(3)
$\gamma_{9,4}$	**411,5**	0,18(2)	0,13(2)	0,36(4) *R*	0,134(23)			0,14(2)		0,120(6)		0,133(10)
$\gamma_{12,6}$	**457,6**	0,039(20)	0,08(2)					0,04(2)		0,056(5)	0,067(5)	0,061(5)
$\gamma_{10,5}$	**469,6**		0,0060(15)*R*							0,022(4)	0,022(4)	0,022(4)
$\gamma_{6,2}$	**528,8**	0,39(5)	0,49(5)	0,36(4)	0,43(6)			0,44(4)		0,447(15)	0,47(2)	0,446(15)
$\gamma_{11,5}$	**537,8**		0,0100(25)					0,009(3)		0,013(5)	0,027(5)	0,012(4)
$\gamma_{7,3}$	**580,5**	0,026(7)						0,021(8)		0,036(4)	0,026(4)	0,0294(31)
$\gamma_{8,3}$	**581,3**									0,008(4)		0,008(4)
$\gamma_{12,4}$+ $\gamma_{8,1}$	**620 621,7**	0,21(3)	0,217(22)	0,19(6)	0,30(4)			0,26(2)		0, 232(11)	0,24(4)	0,236(11)

	keV	Van Eijk	Cook	Gehrke Heath	Morel	Dickens 1980	Yang 1980	Singh	Chen Da	Meyer 1990	Goswamy 1992	Evaluated
$\gamma_{15,4}$	**689,6**		0,0035(15)									0,0035(15)
$\gamma_{9,3}$	**739,5**	100	100	100	100	100	100	100	100	100	100	100
$\gamma_{7,0}$	**761,8**		0,019(5)							0,0092(8)	0,033(3)	0,019(11)
$\gamma_{9,2}$	**777,9**	35,1(24)	34,9(20)	35,8(30)	35,5(10)	35,8(9)		34,8(19)		35,3(12)	35,1(5)	35,3(5)
$\gamma_{10,3}$	**822,9**	1,04(8)	1,11(8)	1,09(10)	1,09(5)	1,09(5)		1,10(7)		1, 06(4)	1,10(2)	1,09(2)
$\gamma_{10,2}$	**861,2**		0,006(2)	0,015(6)				0,005(3)			0,006(3)	0,006(2)
$\gamma_{13,3}$	**960,722**	0,78(7)	0,78(6)	0,80(8)	0,76(4)	0,84(4)		0,79(6)		0, 76(4)	0,78(2)	0,78(2)
$\gamma_{12,2}$	**986,4**	0,013(5)	0,014(4)	0,016(4)						0,0108(9)	0,012(4)	0,0112(8)
$\gamma_{13,1}$	**1001**	0,045(13)	0,036(16)	0,027(4)	0,052(15)			0,045(12)		0,033(1)	0,045(4)	0,035(3)
$\gamma_{15,3}$	**1017**	0,006(3)									0,005(2)	0,0055(21)
$\gamma_{15,2}$	**1056,2**		0,008(2)					0,007(3)		0,0083(9)	0,0089(7)	0,0085(7)
$\gamma_{11,0}$	**1072,2**							0,010(4)				0,010(4)

Table 2. Results of data statistical processing on relative γ-ray emission probabilities

	n	WM	*s*	*S*	c^2		Final uncertainty
					table	set	and type
$\gamma_{3,1}$	6	8,43	0,16	0,20	14,07	1,82	0,20 *(S)*
$\gamma_{1,0}$	10	739	5,7	7,6	18,31	2	11 *(s_{min})*
$\gamma_{2,0}$	3	0,174	0,014	0,014		1	0,014 (S)*
$\gamma_{9,7}$	6	0,12 [d]	0,0047	0,0078	11,07	3	0,04 *(S)*
$\gamma_{6,4}$	5	0,094	0,0033	0,0042	9,49	1,6	0,005 *(s_{min})*
$\gamma_{3,0}$	10	49,6	0,42	0,20	16,92	0,13	0,7 *(s_{min})*
$\gamma_{10,7}$	4	0,0114	0,0014	0,0024	7,82	2,96	0,0028 *(tS)*
$\gamma_{9,6}$	5	0,0285	0027	0,0026	9,49	0,9	0,0030 *(s_{min})**
$\gamma_{4,2}$	9	9,85	0,11	0,08	15,51	0,58	0,15 *(s_{min})*
$\gamma_{13,7}$	7	0,075	0,0037	0,0042	12,59	1,3	0,004 *(S)**
$\gamma_{5,2}$	2	0,021	0,0035	0,005		2	0,005 (S)*
$\gamma_{14,7}$	3	0,013	0,003	0,002		0,56	0,003 *(s)*
$\gamma_{9,4}$	5	0,133	0,007	0,01		1,81	0,01 *(s)**
$\gamma_{12,6}$	5	0,061	0,0034	0,0040	9,49	1,4	0,005 *(s_{min})*
$\gamma_{10,5}$	3	0,022 [b]					0,004 [b]
$\gamma_{6,2}$	7	0,446	0,010	0,012	12,59	1,1	0,015 *(s_{min})*
$\gamma_{11,5}$	4	0,012	0,0017	0,0032	7,82	3,6	0,0038 *(tS)*
$\gamma_{7,3}$	4	0,0294	0,0025	0,0031		1,6	0,0031 *(s)*
$\gamma_{8,3}$	1	0,008					0,004
$\gamma_{12,4}+\gamma_{8,1}$	7	0,236	0,0083	0,0085	12,59	1	0,011 *(s_{min})**
$\gamma_{15,4}$		0,0035 [c]					0,0015 [c]
$\gamma_{9,3}$		100					
$\gamma_{7,0}$	3	0,019	0,0018	0,0077	5,99	18	0,011 (MBAYS)*
$\gamma_{9,2}$	9	35,3	0,34	0,17	15,51	0,2	0,5 *(s_{min})*
$\gamma_{10,3}$	8	1,09	0,015	0,0063	14,07	0,1	0,02 *(s_{min})**
$\gamma_{10,2}$	4	0,006	0,0014	0,0012	7,82	0,6	0,002 *(s_{min})*
$\gamma_{13,3}$	9	0,78	0,014	0,0083	15,51	0,08	0,02 *(s_{min})*
$\gamma_{12,2}$	5	0,0112	0,0015	0,0008	9,49	0,44	0,0008 *(s)*
$\gamma_{13,1}$	7	0,035	0,0017	0,0026	12,59	1,9	0,0028 *(tS)**
$\gamma_{15,3}$		0,0055 [d]					0,0021 [d]
$\gamma_{15,2}$	4	0,0085	0,00056	0,00025	7,82	0,22	0,0007 *(s_{min})**
$\gamma_{11,0}$		0,010 [e]					0,004 [e]

[a] Adopted from Goswamy (1992Go22)
[b] Adopted from Meyer (1990Me15) and 1992Go22 (the same values)
[c] Adopted from Cook (1969Co18)
[d] Unweighted average
[e] Adopted from Singh (1982Si16)
* LRSW increased an uncertainty for one of the values(1992Go22 or 1990Me15).

All values for relative γ-ray emission probabilities are given for the equilibrium mixture ^{99}Mo + $^{99}Tc^m$.

For $\gamma_{2,0}$(142,7 keV) the following measured intensity ratios of $\gamma_{2,0}/\gamma_{1,0}$(140,5 keV) have been used: $3,0(6)\cdot10^{-4}$ (Van Eijk), $2,0(2)\cdot10^{-4}$ (Ageev), $2,0(3)\cdot10^{-4}$ (Dickens, 1980Di16), $2,50(9)\cdot10^{-4}$ (Meyer, 1990Me15). The weighted average of these values is $2,29(16)\cdot10^{-4}$ with an external uncertainty; in terms of the $\gamma_{9,3}$(739,5 keV) a relative intensity of 0,169(12) is obtained.

For $\gamma_{11,0}$ (1072,2 keV) the relative γ-ray emission probability is taken from Singh (1982Si16).

4.2.3 GAMMA RAY ABSOLUTE EMISSION PROBABILITIES

Several absolute measurements of the emission intensity of the 739 keV line are available to give a consistent set of data.

Emission 9 - 3 : 739,500(17) keV

Absolute measurement : photon emission per 100 decays

11,9 (3)	Chen Da - 1985 (Ge(Li) gamma spectrometer) (measured)
12,3 (3)	Simonits (1981)
12,14 (22)	Dickens and Love(1980) (calculated)
12,00 (33)	Meyer (Fizika - 22 - p153 (1990))

Lweight has used the weighted average and the internal uncertainty. Reduced-χ^2=0,45
Adopted absolute g **emission probability: 12,12(15)%**

This absolute γ-ray emission probability can be compared with the value obtained by considering the balance of the decay scheme. The γ-ray absolute emission probabilities P_γ have been computed using relative (γ+ce)-probabilities (relatively to the 739,5 keV gamma ray) and the ^{99}Tc ground state intensity balance, which assumes no β-feeding to the g.s. and the 140,5 keV level as confirmed by the high degree of forbiddenness. The P_γ intensity of the 739 keV line has been deduced to be 12,18(17)% taking into account the correlation ΣP_β=1 and the factor of 1,100 for the gamma transitions in Tc-99m.

All the absolute gamma ray emission probabilities are given per 100 disintegrations of Mo-99 (in equilibrium with Tc-99m) taking into account the correction factor of 1,100 for $\gamma_{2,1}$(2,17 keV), $\gamma_{2,0}$(142,7 keV) and $\gamma_{1,0}$(140,5 keV) intensities.

It should be noted that Singh and Sahota (1982Si16) have reported nine controversial γ-rays at energies of 38,4; 163,4; 319,8; 321,0; 352,9; 599,6; 721,7; 940 and 1082,0 keV. These γ-rays have not been confirmed by Goswamy *et al.* (1992Go22) and are not placed in the decay scheme; neither are the 344,6 keV γ-ray observed by Cook *et al.* (1969Co18) and the 89,4; 455,84; 490,53 keV γ-rays observed by Meyer (1990Me15).

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. The emission probabilities have been calculated using the conversion coefficients given in 2.2. and the gamma emission probabilities.

Many measurements of conversion electron spectra for ^{99}Mo in equilibrium with ^{99}Tc^{m} have been made (1968Va14, 1969Ag04, 1969Ba03, 1969Ba54, 1969Ra01, 1971La12, 1971Vo06, 1973Le29, 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 gamma 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.

BETA-MINUS EMISSIONS

The β^- transition energies are derived from the level energies.
T. NAGARAJAN (1971Na01) analysed the β spectrum of Mo-99. This study revealed four β groups with end points :

	Energy keV	Transition probability
$\beta_{0,2}$	1214(1)	84
$\beta_{0,4}$	840(5)	2
$\beta_{0,9}$	450(10)	14
$\beta_{0,12}$	245	<0,2

No evidence was found for a β group with endpoint higher than 1214 keV.

These values are in a rough agreement with those established by considering the balance of the decay scheme (paragraph 2.1).

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