Comments on evaluation of decay data by M.M. Bé and V. Chisté

This evaluation was completed in November 1997 and reviewed in December 2009.

1) Decay scheme

The J^{π} values are from **NDS 70,2** (1993).
The level energies are deduced from the γ-ray energies.

2) **Nuclear Data**

- The Q value is from **Audi *et al.* 2003**
- The measured half-life values are, in years:

28 (3)	**J. Sosniak et al.**, Can. J. Phys 37,1 (1959) 1
30,2 (5)	**G. Harbottle**, J. Inorg. Nucl. Chem. 12 (1959) 6
38 (3)	**E.H. Appelman**, Phys. Rev. 121,1 (1961) --- uncertainty divided
38 (4)	**T. Rupnik**, Phys. Rev. C6,4 (1972) 1433
33,4 (8)	**M. Yanokura et al.**, Nuclear Physics A299 (1978) 92 --- omitted from analysis
	Hoppes et al (1982)
34,9 (4)	**D.E. Alburger et al.**, Phys. Rev. C 41,5 (1990) 2320 --- uncertainty divided
32,7 (8)	**W.J. Lin et al.**, J. Radioanal. Nucl. Chem. Letters 153,1 (1991) 51
31,55 (5)	**M.P. Unterwegger et al.**, NIM A312 (1992) 349 --- replaces [82HoZJ], Hoppes et al.
31,549 (41)	**M.P. Unterwegger,** Applied Rad. Isot. 56 (2002) 125 – replaces the previous one

1. The value from **M. Yanokura et al.** has been omitted because it is dependent on:
   - the EC/α branching ratio of At-211,
   - the probability for the 6868 keV α-transition from Po-211 to the 569,7 keV level in Pb-207,
   - the half-life of At-211,
   - the decay probability of Bi-207 feeding the 569,7 keV level in Pb-207.

All these data were updated since 1978, it should be necessary to re-calculate the value taking into account all these parameters. So, this value is not included in the data set.

2. The uncertainty on the **Appelman**'s value is given for 3σ, it has been divided by 3 to give 38 (1).

3. The uncertainty on the **Alburger**'s value is given for 2σ, it has been divided by 2 to give 34,9 (2).

Conclusion: **The adopted value of *32,9 (14) a*** is from the LRSW analysis of the seven accepted values. The uncertainty on the Unterwegger (2002) value has been increased to (0,177) in order to reduce its relative weight to 50 %. Then σ_{int} = 0,13; σ_{ext} = 0,75 and, reduced-χ^2 = 36,2. The final value is the weighted average and the uncertainty is expanded to include the most precise value.
New measurements would be desirable.

2.1) Electron-Capture Transitions

- The EC transition energies are deduced from Q(EC) = 2397,2 (21) keV and from the individual level energies.
- The transition probabilities are deduced from the total gamma-ray transition probability balance at each level.
- The electron-capture sub shell ratios were calculated by using the LOGFT program.

LOGFT calculated values

level	P_K	P_L	P_{M+}	(L+M+...)/K
570	0,797(8)	0,150 (3)	0,049 (1)	0,25
1633	0,733(7)	0,199 (4)	0,069 (1)	0,365
2340		0,651 (6)	0,349 (6)	

Experimental values from **Mandal et al.** for the transitions to the 570-keV and 1633-keV levels:

level	P_K	(L+M+...)/K
570	0,59 (6)	0,68 (16)
1633	0,73 (6)	0,37 (12)

The P_K value for the transition to the 570 keV level is the weighted average of two values (0,62 (8) and 0,59 (6)) obtained by two different coincidence method measurements. These values are dependant on: ω_K, $K\alpha/(K\alpha + K\beta)$, α_K, α_T and on the EC branching ratios. By using, for these parameters, the values evaluated in this work the re-calculated value for the first P_K is = 0,73 instead of 0,62, in agreement, within the uncertainty limits, with the theoretical values from the LOGFT program.

Experimental values from **A De Beer et al.** and **M. Tan et al.** for the transition to the 2340-keV level:

A. De Beer, P_L = 0,663 (14), this measurement does not depend on any other data.
M. Tan, P_L = 0,57 (3), this measurement depends on α_K and α_T for the 570 keV γ-transition. In this case α_K = 0,0159 and α_T = 0,0218.

2.2) β^+ transitions

A weak β^+ transition to the 570-keV level was reported by **Rupnik** (1972) to be (1,2 (2)) 10^{-2} %.

2.3) Gamma transitions

- Internal Conversion coefficients

The adopted values are from the LRSW analysis of all the values published after 1963. An earlier value from **R.A. Ricci** (1957) was not used due to its large uncertainty. The values from **E. Baldinger et al.** (1967) have been replaced by those of **E. Baldinger et al.** (1969). Two set of values were published by **Sen and Rizvi**, [1967Ri00, 1967Se15], one in a B.A.P.S. abstract (June), the other one in N.I.M. (July); only the last one was used because it gave a detailed description.

Internal Conversion coefficients measured values (**All values are multiplied by 10^2**) :

- 570 keV gamma transition

	α_K - 570 keV	u_c	
1967KL02	1,56	0,07	
1967VA25	1,59	0,06	1969Ba53 and 1974Mu16 are rejected due to the Chauvenet criterion
1967SE15	1,60	0,10	Internal uncertainty = 0,009; external uncertainty = 0,24
1968AN04	1,56	0,05	Reduced-χ^2 = 0,15
1969HE19	1,55	0,05	No value has a relative weight greater than 50 %.
1969AnZU	1,60	0,05	LRSW has used the weighted average and the external uncertainty.
1969BA53	1,50	0,15	The evaluated value is = 1,574 (24)
1974MU16	2,30	0,03	

	α_L - 570 keV	u_c	
1967SE15	0,49	0,03	Reduced-χ^2 = 1,1
1968AN04	0,452	0,047	Internal uncertainty = 0,0060 External uncertainty = 0,0064
1969HE19	0,444	0,021	1988Fu05 amounts for 74 %
1969BA53	0,50	0,10	LRSW has used the weighted average and the external uncertainty
1974AV03	0,483	0,018	The evaluated value is = 0,452 (6)
1988FU05	0,446	0,007	

	α_M - 570 keV	u_c	
1967SE15	0,10	0,05	Reduced-χ^2 = 3
1974AV03	0,138	0,010	Internal uncertainty = 0,003; external uncertainty = 0,005
1988FU05	0,112	0,003	weighted average and external uncertainty = 0,114 (5)

	α_{NOP} - 570 keV	u_c	
1974AV03	0,0288	0,0032	
1988FU05	0,0341	0,0017	

	α_{M+} - 570 keV	u_c	
1968AN04	0,172	0,047	Reduced-χ^2 = 1,5
1969BA53	0,168	0,035	Internal uncertainty = 0,003; external uncertainty = 0,004
1974AV03	0,167	0,010	evaluated: weighted average = 0,1485 (39)
1988FU05	0,1461	0,0034	

- 897 keV gamma transition

	α_K - 897 keV	u_c	
1970AhZX	1,90	0,30	No value has a relative weight greater than 50 %.
1974AV03	1,81	0,25	Internal uncertainty = 0,13; external uncertainty = 0,07 reduced-χ^2 = 0,24
1975JA04	1,60	0,30	LRSW has used the weighted average.
1988FU05	1,90	0,23	The evaluated value is = 1,82 (13)

- 1064 keV gamma transition

	α_K - 1064 keV	u_c	
1967SE15	8,5	0,5	1967Se15, 1967Kl02 and 1988Fu05 are rejected due to Chauvenet criterion
1967KL02	9,0	0,9	
1969ANZU	9,4	0,9	Reduced-χ^2 = 0,03
1969HE19	9,6	0,3	Internal uncertainty = 0,23; external uncertainty = 0,04
1969AN00	9,4	0,9	
1969BA53	9,5	1,3	Adopted: weighted average = 9,53 (23)
1974AV03	9,43	0,47	
1974MU16	9,5	1,1	
1988FU05	9,86	0,35	

	α_L - 1064 keV	u_c	
1967SE15	2,33	0,15	Reduced-χ^2 = 1,3
1969BA53	2,97	0,46	Internal uncertainty = 0,06; external uncertainty = 0,07
1974AV03	2,23	0,16	Adopted: weighted average = 2,47 (7)
1988FU05	2,51	0,10	

	α_M - 1064 keV	u_c	
1967SE15	0,44	0,09	Reduced-χ^2 = 2,2 ; Critical-χ^2 = 4,6
1974AV03	0,55	0,05	Internal uncertainty = 0,022; external uncertainty = 0,033
1988FU05	0,615	0,026	Adopted: weighted average = 0,591 (33)
	α_{M+} - 1064 keV	u_c	
1969BA53	1,05	0,17	

	α_{NOP} - 1064 keV		
1974AV03	0,17	0,03	Internal uncertainty = 0,012; external uncertainty = 0,010
1988FU05	0,198	0,013	Adopted: weighted average = 0,194 (12)

- 1442 keV gamma transition

	α_K - 1442 keV	u_c	
1974AV03	0,27	0,04	
	α_L - 1442 keV		
1974AV03	0,042	0,008	

- 1770 keV gamma transition

	α_K - 1770 keV	u_c	
1971Al03	0,34	0,03	Reduced-χ^2 = 0,65
1974AV03	0,30	0,05	Internal uncertainty = 0,018; external uncertainty = 0,014
1988FU05	0,362	0,019	Uncertainty increased to 0,025 to reduce weight to 50 %
			evaluated: weighted average = 0,346 (18)

	α_L - 1770 keV	u_c	
1974AV03	0,041	0,009	Mean = 0,0049 (8), WM = 0,053
1988FU05	0,0569	0,0048	Internal uncertainty = 0,04; external uncertainty = 0,07
			evaluated: simple mean = 0,049 (8)

	α_{M+} - 1770 keV		Mean = 0,0126 (31), WM = 0,0136
1974AV03	0,0095	0,0024	Internal uncertainty = 0,0029; external uncertainty = 0,0017
1988FU05	0,0157	0,0017	evaluated: simple mean = 0,0126 (31)

Comparison of experimental results and theoretical values : ($\alpha \times$ **10^2**)

Theoretical ICC values were derived from the Band *et al.* tables with the program BrIcc for the "frozen orbital" approximation (Kibédi *et al.*).
Multipolarities and mixing ratios were deduced from comparison between measured and theoretical ICC values and by comparison with δ values obtained by angular correlation measurements.

	α_K	α_L	α_M	α_{M+}	α_T	δ	**Multipolarity**
570 keV							
Exper.	1,574 (24)	0,452 (6)	0,114 (5)	0,1485 (39)	2,174 (9)		
BrIccFO	1,583 (23)	0,439 (7)	0,1081 (16)		2,16 (3)		E2
Adopted	1,583 (23)	0,439 (7)	0,1081 (16)		2,16 (3)		E2
897 keV	α_K						
Exper.	1,82 (13)						
BrIccFO	1,82 (8)					0,3 (3)	M1+8,3%E2
Adopted	1,82 (8)	0,304 (12)	0,071 (13)		2,22 (9)		
1064 keV	α_K	α_L	α_M	α_{NOP}	α_T		
Exper.	9,53 (23)	2,47 (7)	0,591 (3)	0,194 (12)	12,78 (24)		
BrIccFO	9,43 (14)	2,38 (4)	0,589 (9)	0,1833 (25)	12,57 (18)	0,01 (1)	M4+0,01%E5
Adopted	9,53 (23)	2,47 (7)	0,591 (33)	0,194 (12)	12,78 (24)		
1442 keV	α_K	α_L					
Exper.	0,27 (4)	0,042 (8)					
BrIccFO	0,271 (4)	0,0468 (7)					E2
Adopted	0,271 (4)	0,0468 (7)					
1770 keV	α_K	α_L	α_M	α_{M+}	α_T		
Exper.	0,346 (18)	0,049 (8)		0,0126 (31)	0,408 (20)		
BrIccFO	0,342 (5)	0,0555 (8)			0,442 (7)	0,05 (5)	M1+0,0025%E2
Adopted	0,342 (5)	0,0556 (8)			0,442 (7)	0,05 (5)	
Measured internal-pair formation coefficient, α_π = 0,025 (5) 10^{-2} (**Allan 1971**)							

• Gamma transition probabilities

The transition probabilities were calculated from the adopted values of the ICC and the absolute emission intensities.

4.1) X-ray emissions

• ω_K is from **Bambynek**, ϖ_L η_{KL} η_{LM} from **Schönfeld et al.**, ϖ_M from **Hubbell et al**.
A value of ω_K = 0,972 (8) was measured by **Hansen et al.** (1972) and is in good agreement.
• X-ray energy: the wavelengths are from **Bearden** and converted into energy with
1 Å = 1,000 014 81 (92) 10^{-10} m.
• The emission intensities are calculated with the EMISSION program from PTB.
The ratios used are in good agreement with the measured values from **Dasmahapatra et al.**

	EMISSION	Measured
$K\alpha_2/K\alpha_1$ =	0,5950 (25)	0,5984 (42)
$K\beta/K\alpha$ =	0,279 (4)	0,283 (9)
$K\beta_2'/K\beta_1'$ =	0,302 (5)	0,302 (30)

• Some others measurements were made by **Campbell et al.**:
$K\beta_1/K\alpha_1$ = 0,2215 (30)
$K\beta_2/K\alpha_1$ = 0,083 (1)

4.2) Gamma emissions

The γ-ray energies are from **Helmer *et al.*** for those of 569, 1063 and 1770 keV. Those at 897 and 1442 keV are from **Jardine** and 368 keV is from level energies.
All the experimental emission intensities were done relatively to that of the 570 keV gamma-ray, except **Lin et al.** where the absolute intensity is assumed to be 97,75.
The adopted values are from the LRSW analysis of all the known values, except Aubin et al. because no uncertainties were given.

897 keV	I_{rel}	u_c	
1969Ra13	0,150	0,015	
1975Ja04	0,14	0,02	Reduced-χ^2 = 1,23; critical-χ^2 = 3,3
1980Yo05	0,122	0,013	Internal uncertainty = 0,0043; external uncertainty = 0,0048
1989Sc**	0,1274	0,0052	LRSW has used the weighted average and the external uncertainty.
1991Li10	0,153	0,015	The adopted value is = 0,1313 (48)

1064 keV	I_{rel}	u_c	
1967Do09	78,4	2,40	
1969Ra13	78,7	4,00	
1972Ro03	75,6	0,50	
1968He00	74,0	2,00	
1975JA04	75,5	2,3	
1973Wi10	77,7	0,45	
1980Yo05	75,79	0,25	
1989De**	76,5	0,50	Reduced-χ^2 = 2; critical-χ^2 = 2,3
1989Sc**	76,584	0,367	Internal uncertainty = 0,15; external uncertainty = 0,22
1990He16	76,4	0,50	LRSW has used the weighted average.
1991Li10	77,7	1,4	The adopted value is = 76,29 (22)

1442 keV	I_{rel}	u_c	
1969Ra13	0,150	0,015	Internal uncertainty = 0,0025; external uncertainty = 0,0018
1975JA04	0,15	0,02	Reduced-χ^2 = 0,65; critical-χ^2 = 3
1980Yo05	0,132	0,005	LRSW has used the weighted average and the internal uncertainty.
1979Si17	0,144	0,024	The adopted value is = 0,1345 (23)
1989Sc**	0,1337	0,0027	
1991Li10	0,147	0,012	

1770 keV	I_{rel}	u_c	
1967Do09	7,07	0,35	
1969Ra13	7,5	0,4	<--- This value is rejected due to the Chauvenet criterion
1975JA04	6,95	0,20	Reduced-χ^2 = 0,14; critical -χ^2 = 3,3
1980Yo05	7,026	0,029	Internal uncertainty = 0,026; external uncertainty = 0,01
1989Sc**	7,023	0,068	The adopted value is = 7,028 (26)
1991Li10	7,11	0,13	

Gamma - 328 keV
A weak gamma emission was reported by **Schima**, with a relative intensity of 0,0045 (36).

Gamma - 1460 keV
A transition with Eγ = 1460 keV was reported by **Singh et al.**, nevertheless in spite of its relatively great intensity (= 1,65 (6)), it has never been confirmed by other authors.

<u>Absolute emission intensities:</u>

Considering the decay scheme, the absolute emission intensity of the 570 keV gamma ray is calculated by:
$\Sigma P(\gamma + ce)(570 + 897) = 100$
The α_T coefficients are those determined above.

Eγ	**Absolute γ-ray intensity**
328	0,0044 (35)
570	97,76 (3)
897	0,1284 (47)
1064	74,58 (22)
1442	0,1315 (22)
1770	6,871 (26)

5) Electron emissions

- The intensities of Auger electrons emitted were deduced from the decay scheme data by using the EMISSION program.
- The intensities of conversion electrons were calculated from the conversion coefficients and the gamma emission intensities.

6) Main production modes

From CEA/LMRI

7) References

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