

## Comments on evaluation of decay data by M.M. Bé

Complete references can be found in the "Table de Radionucléides" volume, only additional references are given here.

This evaluation was completed in November 1997 with minor editing in March 1998.

### 1) Decay scheme

The  $J^\pi$  values are from **NDS 70,2** (1993).

The level energies are deduced from the  $\gamma$ -ray energies.

### 2) Nuclear Data

- The Q value is from **Audi and Wapstra** 1995
- The measured half-life values are, in years :

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

1. The value from **M. Yanokura et al.** has been omitted because it is dependent on :

- the EC/ $\alpha$  branching ratio of At-211,
- the probability for the 6868 keV  $\alpha$ -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 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  $3\sigma$ , it has been divided by 3 to give 38 (1).

3. The uncertainty on the **Alburger's** value is given for  $2\sigma$ , 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 et al.** value has been increased 3,6 times to (17) in order to reduce the relative weight of the value to 50%. Then  $\sigma_{\text{int}} = 0,13$ ;  $\sigma_{\text{ext}} = 0,75$  and, reduced- $\chi^2 = 36,2$ . The final value is the weighted average and the uncertainty is expanded to include the most precise value.

Since this set of values is very discrepant, the use of several other analysis techniques gives values from 33,3 (14) [Chauvenet technique] to 31,6 (2) [Rajeval technique], are this values better than the LRSW one. It seems useful to wait for new measurements.

## 2.1) Electron-Capture Transitions

- The EC transition energies are deduced from  $Q(\text{EC}) = 2388,2$  (21) and from the individual level energies.
- The transition probabilities are deduced from the total gamma-ray transition probability balances at each level.
- The electron-capture subshell ratios were calculated by using the LOGFT program for the first forbidden unique and second forbidden transitions and by the EC-Capture program for the allowed transition.

### LOGFT calculated values

level	$P_K$	$P_L$	$P_{M+}$	(L+M+...)/K
570	0,7965	0,1501	0,04920	0,25
1633	0,7326	0,19849 (21)	0,06895 (9)	0,365

### EC-capture calculated values

2340		0,647 (7)	0,353 (7)	
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Experimental values from **Mandal et al.** for the transitions to the 570 and 1633 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:  $\omega_K$ ,  $K\alpha/(K\alpha + K\beta)$ ,  $\alpha_K$ ,  $\alpha_T$  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. This large increase due to new data has encouraged us to choose 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 level:

A. De Beer,  $P_L = 66,3$  (1,4), this measurement does not depend on any other data.

M. Tan,  $P_L = 66,3$  (1,4), this measurement depends on  $\alpha_K$  and  $\alpha_T$  for the 570 keV  $\gamma$ -transition. In this case  $\alpha_K = 0,0159$  and  $\alpha_T = 0,0218$ .

These values are in agreement with the results of the LOGFT program.

## 2.2) $b^+$ transitions

A weak  $\beta^+$  transition to the 570 level was reported by **Rupnik** (1972).

## 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**, [67Ri00, 67Se15], 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.

The  $\alpha$  set of measured values is (All the values are multiplied by  $10^2$ ) :

$\alpha_K$  - 570 keV

67Kl02	1.56	0.07
67Va25	1.59	0.06
67Se15	1.60	0.10
68An04	1.56	0.05
68He00	1.55	0.05
69An00	1.60	0.05
69Ba53	1.50	0.03
74Mu16	2.30	0.03

No value has a relative weight greater than 50%.  
74Mu16] is rejected due to the Chauvenet criterion  
Internal uncertainty = 0,018 ; external uncertainty = 0,23.  
Reduced- $\chi^2 = 1,54$

LRSW has used the weighted average and the external uncertainty.  
The adopted value is = 1,55 (2)

$\alpha_K$  - 897 keV

70Ah00	1.90	0.30
74Ah03	1.81	0.25
75Ja04	1.60	0.30
88Fu05	1.90	0.23

No value has a relative weight greater than 50%.  
Internal uncertainty = 0,13 ; external uncertainty = 0,06 ;  
Reduced- $\chi^2 = 0,24$

LRSW has used the weighted average.  
The adopted value is = 1,81 (13)

$\alpha_K$  - 1064 keV

67Se15	8.50	0.50
67Kl02	9.00	0.90
68An04	8.40	0.80
68He00	9.60	0.30
69An00	9.40	0.90
69Ba53	9.50	1.40
74Av03	9.43	0.47
74Mu16	9.50	1.10
88Fu05	9.86	0.35

No value has a relative weight greater than 50%.  
Internal uncertainty = 0,17 ; external uncertainty = 0,16 ;  
Reduced- $\chi^2 = 0,9$   
LRSW has used the weighted average.

The adopted value is = 9,42 (17)

$\alpha_K$  - 1770 keV

71Al03	0.340	0.030
74Al03	0.300	0.050
88Fu05	0.362	0.019

No value has a relative weight greater than 50%.  
Internal uncertainty = 0,15 ; external uncertainty = 0,13 ;  
Reduced- $\chi^2 = 0,75$

LRSW has used the weighted average.  
The adopted value is = 0,351 (15)

Bi-207, ICC  $\alpha_L$

$\alpha_L$  - 570 keV

67Se15	0.49	0.03
68An04	0.452	0.047
68He00	0.444	0.021
69Ba53	0.50	0.10

Reduced- $\chi^2 = 0,59$   
Internal uncertainty = 0,0064 ; external uncertainty = 0,0049.

The adopted value is = 0,448 (6)

88Fu05 0.4460.007

$\alpha_L$  - 1064 keV

67Se15	2.33	0.15
68He00	2.56	0.10
69Ba53	2.97	0.46
74Av03	2.25	0.16
88Fu05	2.51	0.10

Reduced- $\chi^2 = 1,23$   
 Internal uncertainty = 0,059 ; external uncertainty = 0,065  
 LRSW has used the weighted average and the external uncertainty.  
 The adopted value is = 2,47 (7)

$\alpha_L$  - 1770 keV

74Av03	0.041	0.009	
88Fu05	0.0569	0.0048	<---

Reduced- $\chi^2 = 2,43$   
 This uncertainty is increased by 1,87 to reduce its relative weight  
 LRSW has used the weighted average and the external uncertainty.  
 The adopted value is = 0,049 (8)

Bi-207, ICC  $\alpha_{M+}$

The  $\alpha_{NOP}$  have been added to the  $\alpha_M$  values in the [74Av03] and [88Fu05] references

$\alpha_M$  - 570 keV

67Se15	0.10	0.07
68An04	0.172	0.047
69Ba53	0.168	0.035
88Fu05	0.146	0.003

The uncertainty of [88Fu05] is increased by 8,68  
 Reduced- $\chi^2 = 1,49$   
 Internal uncertainty = 0,018 ; external uncertainty = 0,023.  
 LRSW has used the weighted average and the external uncertainty.  
 The adopted value is = 0,15 (2)

$\alpha_M$  - 1064 keV

67Se15	0.44	0.09
69Ba53	1.05	0.17
74Av03	0.72	0.07
88Fu05	0.81	0.03

The uncertainty of [88Fu05] is increased by 1,75  
 Reduced- $\chi^2 = 5,42$   
 Internal uncertainty = 0,037 ; external uncertainty = 0,086.  
 LRSW has used the weighted average and the external uncertainty.  
 The adopted value is = 0,73 (9)

$\alpha_M$  - 1770 keV

74Av03	0.010	0.002
88Fu05	0.0157	0.001

The uncertainty of [88Fu05] is increased by 1,18  
 Reduced- $\chi^2 = 4,06$   
 Internal uncertainty = 0,0014 ; external uncertainty = 0,0028.  
 LRSW has used the weighted average and the external uncertainty.  
 The adopted value is = 0,0128 (28)

LRSW averages of experimental results : (  $\alpha \times 10^{+2}$  )

Transition	$\alpha_K$	$\alpha_L$	$\alpha_{MNOP}$	$\alpha_T = \alpha_K + \alpha_L + \alpha_{M+}$
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328				
570	1,55 (2)	0,448 (6)	0,15 (2)	2,15 (3)
897	1,82 (13)			
1064	9,42 (17)	2,47 (6)	0,73 (9)	12,6 (2)
1442	0,27 (4)	0,042 (8)	0,012 (3)	0,32 (4)
1770	0,351 (15)	0,049 (8)	0,013 (3)	0,413 (17)

For the 1770 keV transition the theoretical internal-pair formation coefficient is  $\alpha_{\pi} = 0,025 (5) 10^{-2}$

#### Theoretical values from Rösel ( $\alpha \times 10^{+2}$ )

The uncertainty is assumed to be 3%.

Transition	$\alpha_K$	$\alpha_L$	$\alpha_M$	$\alpha_{NOP}$	$\alpha_T$
570 (E2)	1,6	0,446	0,11	0,0332	2,19
897 (M1)	2,01	0,339			2,5
1064 (M4)	9,77	2,48	0,617		
1442 (E2)	0,275	0,0475	0,0141 (MNOP)		
1770 (M1)	0,368	0,056			

#### • Gamma transition probabilities

The transition probabilities were calculated from the LRSW adopted values of the ICC (except for the 897  $\gamma$ -transition where the ICC are from **Rösel et al.**) and of the absolute emission probabilities.

E $\gamma$	$\alpha_T$ LRSW	Absolute Transition Intensity
328		0,00076 (8)
570	0,0215 (3)	99,86 (4)
897	0,025 (1)	0,134 (6)
1064	0,126 (2)	83,97 (56)
1442	0,0032 (4)	0,131 (2)
1770	0,0041 (2)	6,90 (23)

#### • The mixing ratios are from NDS 70,2 (1993)

### 4.1) X-ray emissions

#### • $\omega_K$ is from **Bambynek**, $\bar{\omega}_L$ $\eta_{KL}$ $\eta_{LM}$ from **Schönfeld et al.**, $\bar{\omega}_M$ from **Hubbell et al.**

A value of  $\omega_K = 0,972 (8)$  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 $1 \text{ \AA} = 1,00001481 (92) 10^{-10} \text{ m}$ .

• The emission intensities are calculated with the EMISSION program from PTB, taking the uncertainties into account they are in reasonable agreement with the adopted values evaluated from experimental measurements (TECDOC-619).

	EMISSION	TECDOC
K $\alpha_2$	21,69 (24)	22,6 (12)
K $\alpha_1$	36,5 (4)	38,2 (20)
K $\beta_1'$	12,46 (23)	13,0 (10)
K $\beta_2'$	3,76 (10)	3,9 (3)
XL	33,2 (14)	32,5 (13)

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  $\gamma$ -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 probabilities were done relatively to that of the 570 keV gamma-ray. All the results are given relatively to the 570  $\gamma$ -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.

##### Gamma - 897 keV

69Ra13	0.150	0.015	The uncertainty of [89Sc00] is increased by 1,46
75JA04	0.14	0.02	Reduced- $\chi^2 = 1,11$
80Yo05	0.122	0.013	Internal uncertainty = 0,0053 ; external uncertainty = 0,0056.
89Sc00	0.1274	0.0052	LRSW has used the weighted average and the external uncertainty.
91Li10	0.153	0.015	The adopted value is = 0,134 (6)

##### Gamma - 1064 keV

67Do09	78.4	2.40	No value has a relative weight greater than 50%.
69Ra13	78.7	4.00	Internal uncertainty = 0,16 ; external uncertainty = 0,22.
72Ro03	75.6	0.50	Reduced- $\chi^2 = 2,02$
68He00	74.0	2.00	The final uncertainty is increased to include the most precise value.
75JA04	75.5	2.30	LRSW has used the weighted average.
73Wi10	77.7	0.45	The adopted value is = 76,29 (50)
80Yo05	75.79	0.25	
89De00	76.5	0.50	
89Sc00	76.584	0.367	
90He00	76.4	0.50	
91Li10	77.7	1.4	

##### Gamma - 1442 keV

69Ra13	0.150	0.015	Internal uncertainty = 0,0022 ; external uncertainty = 0,0018.
75JA04	0.15	0.02	Reduced- $\chi^2 = 0,65$
80Yo05	0.132	0.005	LRSW has used the weighted average and the internal uncertainty.
79Si17	0.144	0.024	The adopted value is = 0,134 (2)
89Sc00	0.1337	0.0026	
91Li10	0.147	0.012	

##### Gamma - 1770 keV

67Do09	7.07	0.35	
69Ra13	7.5	0.4	-- This value is rejected due to the Chauvenet criterium

75JA04	6.95	0.20	Reduced- $\chi^2 = 0,14$
80Yo05	7.026	0.029	Internal uncertainty = 0,026 ; external uncertainty = 0,01.
89Sc00	7.023	0.068	The adopted value is = 7,028 (26)
91Li10	7.11	0.13	

#### Gamma - 328 keV

A weak gamma emission was reported by **Schima**, considering the intensities of the gamma following Coulomb excitation or  $\beta$ - decay, a ratio of  $I_{\gamma}(328)/I_{\gamma}(897) = 0,0055$  (5) is applied.

#### Gamma - 1460 keV

A transition with  $E_{\gamma} = 1460$  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.

#### Relative Intensities:

$E_{\gamma}$	LRSW analysis
570	100
897	0,134 (6)
1064	76,29 (50)
1442	0,134 (2)
1770	7,028 (26)

#### Absolute emission probabilities:

Considering the decay scheme, the absolute emission probability of the 570 gamma ray is calculated by:

$$\Sigma I(\gamma + ce)(570 + 897) = 100$$

The  $\alpha$  coefficients are from the LRSW analysis.

$E_{\gamma}$	Absolute $\gamma$ -ray intensity
328	0,00076 (8)
570	97,76 (3)
897	0,131 (7)
1064	74,58 (49)
1442	0,131 (2)
1770	6,87 (3)

### 5) Electron emissions

- The numbers of Auger electrons emitted have been calculated by using the EMISSION program.
- The numbers of conversion electrons have been deduced from the conversion coefficients and the gamma emission probabilities.

### 6) Main production modes

From CEA/LMRI

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