^{134}Cs - Comments on evaluation of decay data
by M.-M. Bé

This evaluation was completed in February 2012.

1 Decay Scheme

^{134}Cs decays by β^- emission (99.9997 %) to excited levels of ^{134}Ba. A very weak electron capture (EC) branch to the 847-keV level of ^{134}Xe (0.0003 %) has been pointed out by Van Hise *et al.* (1975Va12).

The overall consistency of the decay scheme was checked by calculating the total energy carried away by the various emissions as determined below, it was found to be 2059 (1) keV per disintegration when the available energy is 2058.97 (33) keV.

2 Nuclear Data

Q values are from Audi (2011AuZZ).

The spins and parities are from A. A. Sonzogni (2004So32).

The ^{134}Cs half-life values are summarized in the tables below.
The results where converted from *a* ⇔ *d*, with 1 *a* = 365.242 198 78 *d*.

Published measured values not used in the evaluation because less precise or superseded (as a rule only one result per laboratory is considered in the statistical process):

Reference	$T_{1/2}$ (a)	Remarks
1938Alexeeva	≥ 1	
1951Glendenin	2.3 (3)	
1957Geiger	2.07 (2)	
1957Merrit	2.19 (2)	
1958Bayly	2.15 (+8, -4)	
1958Edwards	2.26 (5)	
1961Wyatt	2.07 (2)	
1963Dietz	2.046 (4)	Superseded by 1973Di01
1965Flynn	1.99 (2)	
1978Bulovic	2.04 (3)	
	$T_{1/2}$ (d)	
1982HoZJ	754.19 (15)	Superseded by 2002Un02
1992Un01	753.88 (11)	Superseded by 2002Un02

Measured values used in the evaluation:

Reference	$T_{1/2}$ (d)	Remarks
1972La14	751.7 (15)	2.058 (12) a ; 3 σ uncertainty
1973Di01	753.1 (44)	2.062(5) a ; 3 σ uncertainty divided by 3
1980RuZY	753.78 (30)	
1980Ho17	754.50 (7)	Unrealistic uncertainty
1997Ma75	754.52 (18)	
2002Un02	753.88 (15)	Uc questionable
χ^2 crit.	0.3	
χ^2 /(n-1)	0.4	
UWM	753.96	
WM	754.29	
Adopted	754.0 (5)	Or 2.0644 (14) *a*

In this set of data it is difficult to assess an uncertainty.
In Lagoutine *et al.*, they usually determined the uncertainty as: $\sigma = 3 \times u_{stat} + u_{sys}$
Where u_{stat} is the statistical component and u_{sys} the systematic component, their uncertainty cannot be simply divided by 3.
The uncertainty claimed by Houtermans (1980Ho17) is manifestly unrealistic.
The uncertainty given by Unterweger (2002Un02) was recently questioned (2012Un**).

Hence, the adopted value is the simple mean with an uncertainty which covers the most precise value.

2.1 β^- and Electron Capture transitions

The energies of β^- transitions were deduced from the Q values and the level scheme of ^{134}Ba.

The β^- transition probabilities were calculated from the gamma transition probability balance at each level of the decay-scheme. They are compared below with experimental results.

Comparison of adopted and measured values, as published in the two latest publications, of the β^- intensities, in %.

Ref	89-keV	415-keV	658-keV	891-keV	1454-keV
1968Hs01	27 (2)	3.0 (5)	70 (2)	0.045 (15)	0.008 (4)
1963Va06	28	1	71	0.045	0.005
Adopted	27.27 (3)	2.498 (8)	70.19 (8)	~0	0.06 (6)

A weak electron capture branch with 0.0003 % probability was observed by Van Hise *et al.* (1975Va12) from the measurement of a gamma ray with energy 847 keV, however this ray was not confirmed in later works, especially in the very precise measurements carried out by Miyahara (2002Mi06).

2.2 γ–ray Transitions

The γ-ray transitions probabilities were deduced from the γ-ray emission intensities and the internal conversion coefficients calculated with the BrIcc program v2.3-2011 (2008Ki07) for the "frozen approximation".
The multipolarities are from Chand *et al.* (1990Ch47) who measured the γ-γ directional correlations for seven cascades in ^{134}Ba.

Comparison between calculated and some measured K conversion coefficients, $\times 10^{-3}$:

Ref	242-keV	475-keV	563-keV	569-keV	604-keV	795-keV
1965Br02		9.4 (1)	5.6 (6)	8.2 (9)	4.85 (20)	2.5 (3)
1968Ab01			6	7.5		2.9
1968Na11		9.84 (208)	6.40 (73)	8.80 (99)	5.07 (50)	2.90 (33)
1990Ch47	71 (24)	9.34 (72)	6.05 (45)	7.93 (42)	5.03	2.71 (10)
1998Ga24						2.59 (5)
Adopted	72.2 (12)	9.6 (4)	6.03(9)	8.05 (12)	5.03 (7)	2.58 (4)

Ref	801-keV	1038-keV	1167-keV	1365-keV
1965Br02	2.6 (4)	1.62 (18)	1.05 (10)	0.72 (7)
1968Ab01	2.4			
1968Na11	2.78 (58)	1.68 (20)	1.05 (13)	0.79 (9)
1990Ch47	2.49 (12)	1.74 (9)	1.11 (6)	0.855 (32)
1990Ma29		1.515 (20)		0.842 (18)
1998Ga24	2.66 (8)			
Adopted	2.54 (4)	1.79 (6)	1.122 (16)	0.820 (12)

3 Atomic Data

Atomic values for ω_K, ϖ_L, and η_{KL}, are from Schönfeld and Janssen (1996Sc06).
The X-ray and Auger electron emission intensities were derived from the decay scheme data, they are compared with the measured values of Chand (1988Ch44).

	Chand **	Adopted
Kα	0.722 (15)	0.676 (6)
K'β1	0.1386 (39)	0.1289 (19)
K'β2	0.0312 (39)	0.0325 (8)

** Values converted with $I_{\gamma 604}$ = 97.63 (8) %

4 Radiation Emissions

4.1 γ-ray emissions

The measured values of the gamma-ray energies are listed below. No significant discrepancies were observed. The adopted gamma-ray transition energies are the weighted means calculated using the Lweight program (version 3), values published in 1967Le** have been omitted because often not consistent with the others.

Measured and adopted energies of gamma-ray emissions, in keV.

Ref	242	326	475	563	569	604
1965Br02			475.26 (10)	563.11 (12)	569.24 (12)	604.64 (12)
1967Ra10	242.694 (41)	326.51 (10)	475.355 (38)	563.325 (41)	569.371 (47)	604.744 (27)
1968Ab01			475.2 (5)	563.2 (5)	569.38 (56)	604.67 (50)
1968Na11			475.57 (42)^{O}	563.1 (5)	569.30 (51)	604.83 (54)^{O}
1975Va12	242.89 (5)	326.45 (10)	475.35 (5)	563.26 (5)	569.29 (3)	604.660 (20)
1976Gr11				563.227 (15)	569.315 (15)	604.699 (15)
1985GoZK			475.365 (2)	563.250 (3)	569.333 (3)	604.721 (2)
1987Wa28	242.738 (8)^{I}	326.589 (13)	475.364 (3)	563.240 (4)	569.328 (3)	604.720 (3)
χ^2 crit	**4.6**	**4.6**	**3**	**2.6**	**2.6**	**2.8**
χ^2 /n-1	**4.9**	**1.2**	**0.3**	**1.5**	**0.8**	**2.1**
WM	**242.755**	**326.585**	**475.3646**	**563.2462**	**569.3301**	**604.7201**
Adopted	**242.76 (5)**	**326.585 (14)**	**475.365 (2)**	**563.246 (3)**	**569.330 (2)**	**604.720 (3)**

Ref	795	801	1038	1167	1365
1965Br02	795.80 (16)	801.80 (16)	1038.46 (20)	1167.65 (25)	1364.97 (28)
1967Ra10	795.806 (50)	801.86 (28)	1038.61 (49)	1167.99 (39)	1365.08 (32)
1968Ab01	795.68 (49)^{O}	801.54 (50)^{O}	1038.17 (60)	1167.42 (50)	1364.93 (50)
1968Na11	796.02 (71)^{O}	802.00 (71)	1038.02 (92)	1168.4 (10)	1365.4 (12)^{O}
1975Va12	795.760 (20)	801.84 (3)	1038.50 (5)	1167.86 (6)	1365.13 (10)
1976Gr11	795.845 (22)	801.932 (22)	1038.571 (26)	1167.938 (26)	1365.152 (32)
1985GoZK	795.867 (4)^{I}	801.956 (4)		1167.968 (5)	1365.200 (5)
1987Wa28	795.859 (5)	801.948 (5)	1038.610 (7)	1167.968 (5)	1365.185 (7)
χ^2 crit	**3**	**2.8**	**2.8**	**2.6**	**2.8**
χ^2 /n-1	**5.8**	**2.8**	**1.3**	**1.1**	**1**
WM	**795.860**	**801.950**	**1038.605**	**1167.967**	**1365.1941**
Adopted	**795.86 (1)**	**801.950 (6)**	**1038.605 (8)**	**1167.967 (4)**	**1365.194 (4)**

^{I} Increased uncertainty ; ^{O} Outlier ; ^{U} unweighted mean

The measured relative γ ray intensities used for the statistical process are listed below. The different sets of data are consistent, then the adopted relative gamma-ray emission intensities are the weighted means, except as noted, calculated with the Lweight program (version 3).
The intensity of 847-keV gamma-ray in ^{134} Xe (0.0003 %) and an upper intensity limit for the 232 keV gamma-ray of ^{134}Ba (0.0012 %) are from Van Hise *et al.* (1975Va12).

The normalization factor has been deduced from the decay scheme using the formulas:

$$N = \frac{100}{\sum_i I_{\gamma_i}\left[1+\alpha_{T\,i}\right]} \qquad \text{and} \qquad dN^2 = \sum_i \left(\frac{\partial N}{\partial I_{\gamma_i}} dI_{\gamma_i}\right)^2 + \sum_i \left(\frac{\partial N}{\partial \alpha_{T_i}} d\alpha_{T_i}\right)^2 ,$$

where the sum is over all γ-ray transitions to the ^{134}Ba ground state, thus considering no direct β^- feeding to the ground state.
Te relative emission intensities involved in these formulas are: the 847-, 1168- and 604-keV gamma-ray transitions, and α_{847}, α_{1168} and α_{1168} their internal conversion coefficients.
The calculated normalization factor is 0.9763 (8).

Then, the absolute intensity of the 604-keV γ ray is 97.63 (8) %, it can be compared with the experimental result of 97.65 (13) % obtained by Miyahara *et al.* (2002Mi06).

Measured and adopted relative emission intensities of gamma-ray emissions. The values are in %.

Ref	242-keV (4,3)	326-keV (5,4)	475-keV (4,2)	563-keV (2,1)	569-keV (5,3)	604-keV (1,0)
1962Ha10				8.0 (12)	12.0 (15)^{o}	100
1965Br02			1.54 (15)	8.5 (8)	14.6 (14)^{o}	100 (5)
1967Le**			1.53 (31)	8.2 (7)	15.2 (7)	100
1967Ra10	0.020 (10)	0.020 (10)	1.54 (16)	9.1 (9)	16.1 (11)	100
1968Ab01			1.43 (20)^{o}	8.9 (10)	15.3 (16)	100
1968Na11			1.67 (11)^{o}	8.8 (5)	13.6 (7)^{o}	100 (3)
1970Ho06	0.0224 (20)		1.60 (8)^{o}	9.0 (5)	16.3 (10)	100 (6)
1975Va12	0.0215 (8)^{i}	0.015 (6)	1.50 (4)	8.59 (5)	15.82 (11)	100
1976De**			1.55 (3)	8.55 (12)	15.76 (23)	100
1980Yo05				8.57 (3)	15.78 (6)	100.0 (4)
1987Wa28	0.0322 (20)	0.0180 (15)	1.520 (10)	8.53 (6)	15.71 (10)	100.0 (7)
1988CH44	0.0294 (20)	0.0170 (17)	1.520 (20)	8.54 (7)	15.75 (3)	100.0 (7)
2002Mi06			1.503 (11)	8.530 (18)	15.728 (23)	100.00 (8)
χ^2 crit	**3.3**	**3.8**	**2.6**	**2.2**	**2.4**	
χ^2 /n-1	**7.2**	**0.14**	**0.4**	**0.4**	**0.3**	
UWM	**0.0251**	**0.0175**	**1.525**	**8.600**	**15.745**	
WM	**0.0247**	**0.0175**	**1.515**	**8.544**	**15.741**	
adopted	**0.0247 (32)**	**0.0175 (11)**	**1.515 (7)**	**8.544 (14)**	**15.741 (17)**	**100.00 (8)**

Ref	795-keV (3,1)	801-keV (5,2)	1038-keV (4,1)	1167-keV (2,0)	1365-keV (5,1)
1962Ha10					
1967Le**	87.3 (10)	8.9 (6)	1.12 (20)^{0}	2.25 (20)^{0}	3.37 (31)
1965Br02	90 (9)	9.0 (15)	1.06 (10)	1.99 (17)	3.5 (3)
1967Ra10	90 (7)	9.1 (8)^{0}	1.04 (8)	2.00 (22)	3.3 (3)
1968Ab01	90 (9)	9.4 (10)^{0}	1.1 (6)^{0}	1.94 (20)	3.4 (3)
1968Na11	89 (4)	8.1 (4)^{0}	1.06 (6)	2.06 (14)	3.55 (19)
1970Ho06	88 (4)	8.9 (4)	1.01 (6)	1.90 (10)	3.29 (17)
1975Va12	87.6 (4)	8.95 (4)	1.025 (10)	1.850 (27)	3.11 (4)
1976De**	87.4 (9)	8.85 (12)	1.023 (13)	1.84 (2)	3.09 (3)
1980Yo05	87.5 (3)	8.89 (3)	1.008 (5)	1.827 (8)	3.074 (13)
1987Wa28	87.5 (6)	8.97 (8)	1.016 (7)	1.841 (13)	3.109 (20)
1988CH44					
2002Mi06	87.54 (6)	8.898 (20)	1.021 (8)	1.834 (7)	3.094 (10)
χ^2 crit	**2.3**	**2.6**	**2.5**	**2.4**	**2.3**
χ^2 /n-1	**0.05**	**0.4**	**0.6**	**0.7**	**1.4**
UWM	**88.35**	**8.920**	**1.029**	**1.908**	**3.262**
WM	**87.539**	**8.905**	**1.0150**	**1.834**	**3.092**
adopted	**87.54 (6)**	**8.905 (15)**	**1.0150 (33)**	**1.834 (5)**	**3.092 (8)**

^{i} – Increased uncertainty to reduce its weight to 50 %.
^{0} - Outlier

Omitted data in the statistical process:
- Ewan (1964Ew04), superseded by Brown (1965Br02);
- van Wijngaarden (1963Va06) because they were not able to separate the 563-569 keV lines and 795-801 keV lines;
- Bashandy (1966Ba57) because they are significantly discrepant with other results;
- Stelson (1973St14) because there are no details in the publication, the values are only mentioned in the decay scheme;
- Verhaeghe (1954Ve09) and Yamanoto (1960Ya**) given without uncertainties;
- Meyer (1990Me15), same as Van Hise (1975Va12).

4.2 Electron emissions

The conversion electron emission intensities have been obtained from the γ-ray emission intensities and theoretical ICC values.

5. References

1954Ve09 J.Verhaeghe, J.Demuynck. Compt.Rend. Ac. sciences 239 (1954) 1374
1960Ya** Y.Yamanoto. Thesis, Osaka University (1960)
1962Ha10 A. K. Hankla, J. H. Hamilton, R. V. Stockendal, Bull. Am. Phys. Soc. 7(1962)566
[Gamma-ray emission intensities]
1963Va06 W. van Wijngaarden, R.D. Connor. Can. J. Physics 42 (1963) 504
[Gamma-ray energies]
1965Br02 R. A. Brown, G. T. Ewan, Bull. Am. Phys. Soc. 10(1965)82
[Gamma-ray energies, Gamma-ray emission intensities]
1966Ba57 E.Bashandy, A.Abd El-Haliem. Atomkernenergie 11 (1966) 316
1967Le** J.Legrand, J.P.Boulanger. C.R. Acad. Sc. Paris, B265 (1967) 782
[Gamma-ray energies, Gamma-ray emission intensities]

1967Ra10 D. E. Raeside, J. J. Reidy, M. L. Wiedenbeck, Nucl. Phys. A98(1967)54
[Gamma-ray energies, Gamma-ray emission intensities]
1968Ab01 A. Abdul-Malek, R. A. Naumann, Nucl. Phys. A106(1968)225
[Gamma-ray energies, Gamma-ray emission intensities]
1968Hs01 S.T. Hsue, *et al.* Nucl. Phys. A109 (1968) 423
[Gamma-ray energies]
1968Na11 T. S. Nagpal, Can. J. Phys. 46(1968)2579
[Gamma-ray energies, Gamma-ray emission intensities]
1970Ho06 S. Hofmann, H. K. Walter, A. Weitsch, Z. Physik 230(1970)37
[Gamma-ray emission intensities]
1972La14 F. Lagoutine, J. Legrand, C. Perrot, J. P. Brethon, J. Morel, Int. J. Appl. Radiat. Isotop. 23(1972) 219
[Half-life]
1973Di01 L. A. Dietz, C. F. Pachucki, J. Inorg. Nucl. Chem. 35(1973)1769
[Half-life]
1973St14 P. H. Stelson, S. Raman, J. A. McNabb, R. W. Lide, C. R. Bingham, Phys. Rev. C8(1973)368
[Gamma-ray emission intensities]
1975Va12 J. R. Van Hise, D. C. Camp, R. A. Meyer, Z. Physik A274(1975)383
[Gamma-ray energies, Gamma-ray emission intensities]
1976De** K. Debertin, U. Schötzig, K.F. Walz. PTB Jaresberich (1976) 160
[Gamma-ray emission intensities]
1976Gr11 R. C. Greenwood, C. W. Reich, R. G. Helmer, R. J. Gehrke, R. A. Anderl, Phys. Rev. C14(1976)1906
[Gamma-ray energies.]
1980Ho17 H. Houtermans, O. Milosevic, F. Reichel, Appl. Rad. Isotopes 31(1980)153
[Half-life]
1980RuZY A. R. Rutledge, J. S. Merritt, L. V. Smith, AECL-6788(1980)45
[Half-life]
1980Yo05 Y. Yoshizawa, Y. Iwata, T. Kaku, T. Katoh, J. -Z. Ruan, T. Kojima, Y. Kawada, Nucl. Instrum. Methods Phys. Res. 174(1980)109
[Gamma-ray emission intensities]
1982HoZJ D. D. Hoppes, J. M. R. Huchtinson, F. J. Schima, M. P. Unterweger, NBS – SP 626(1982)85
[Half-life]
1985GoZK V. Gorozhankin, *et al.* Report JINR P6 85.268 (1985)
[Gamma-ray energies]
1987Wa28 G. Wang, D. E. Alburger, E. K. Warburton, Nucl. Instrum. Methods Phys. Res. A260(1987)413
[Gamma-ray energies, Gamma-ray emission intensities]
1988Ch44 B. Chand, J. Goswamy, D. Mehta, S. Singh, M. L. Garg, N. Singh, P. N. Trehan, Nucl. Instrum. Methods Phys. Res. A273(1988)310
[Gamma-ray emission intensities]
1990Ch47 B. Chand, *et al.* Can. J. Phys. 68 (1990) 1479
[Multipolarities]
1990Ma29 N.M. Marchilashvili *et al.* Sov. J. Nucl. Phys. 51,1 (1990) 13
[Gamma-ray energies]
1992Un01 M. P. Unterweger, D. D. Hoppes, F. J. Schima, Nucl. Instrum. Meth. Phys. Res. A312(1992)349
[Half-life]
1996Sc06 E. Schönfeld *et al.* Nucl. Instrum. Meth. Phys. Res. A 369 (1996) 527
[Atomic Data]
1998Ga24 A.Gammal, *et al.* Phys. Rev. C58, 3 (1998)1829
[ICC]
1997Ma75 R. H. Martin, K. I. W. Burns, J. G. V. Taylor, Nucl. Instrum. Methods Phys. Res. A390(1997)267
[Half-life]

2002Mi06 H. Miyahara, N. Hayashi, K. Fujiki, N. Takeuchi, Y. Hino, Appl. Rad. Isotopes 56(2002)131
[Gamma-ray emission intensities]
2002Un02 M. P. Unterweger, Appl. Rad. Isotopes 56(2002)125
[Half-life]
2004So32 A. A. Sonzogni, Nucl. Data Sheets 103(2004)1
[Spins, parity,multipolarity]
2008Ki07 T. Kibédi, T. W. Burrows, M. B. Trzhaskovskaya, P. M. Davidson, C. W. Nestor Jr., Nucl. Instrum. Meth. Phys. Res. A589(2008)202
[Theoretical ICC]
2011AuZZ G. Audi, W.Meng. private communication
[Q]
2012Un** M. P. Unterweger, R. Fitzgerald. Appl. Rad. Isotopes 70,9 (2012) 1892
[Q]