^{147}Pm - Comments on evaluation of decay data by V. Chisté and M. M. Bé

This evaluation was completed in May 2011, including all publications by this date.

1 Decay Scheme

^{147}Pm disintegrates 100 % by beta minus emissions to the^{147}Sm ground state mainly.

A good agreement was found between the effective Q value (224.5 (4) keV) calculated from the decay scheme data and the adopted and recommended value from the mass adjustment of Audi (2003Au03).

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).

Experimental ^{147}Pm half-life values (in years) are given in Table 1:

Table 1: Experimental values of ^{147}Pm half-life.

Reference	Experimental value (a)	Comments
E. A. Melaika (1955Me52)	2.52 (8)	Outlier.
R. P. Schuman (1956Sc87)	2.66 (2)	Outlier.
W. F. Merritt (1957Me47)	2.64 (2)	
J. P. Cali (1959Ca**)	2.7 (1)	Outlier.
E. I. Wyatt (1961Wy01)	2.50 (3)	Superseded by 1968Re04.
F. P. Roberts (1963Ro20)	2.67 (6)	Superseded by 1965Wh04.
S. C. Anspach (1965An07)	2.618 (7)	
J. F. Eichelberger (1965Ei04)	2.6226 (20)	Superseded by 1967Jo07.
K. F. Flynn (1965Fl02)	2.60 (2)	
E. J. Wheelwright (1965Wh04)	2.620 (5)	
K. C. Jordan (1967Jo07)	2.6234 (4)	
S. A. Reynolds (1968Re04)	2.62 (1)	
Recommended value	**2.6234 (4)**	**χ^2 = 0.64**

A weighted average has been calculated using LWEIGHT computer program (version 3). The Melaika (1955Me52), Schuman (1956Sc87) and Cali (1959Ca**) values have been shown to be outlier, based on the Chauvenet's criterion and thus were omitted in the final calculation. The largest contribution to the weighted average comes from the value of K. C. Jordan (1967Jo07), with a statistical weight of 98 %.

The adopted value is the weighted average of 2.6234 a with an internal uncertainty of 0.0004 a. The reduced-χ^2 value is 0.64.

For ^{147}Sm, the experimental half-life values (in years) are given in Table 2:

Table 2: Experimental values of ^{147}Sm half-life.

Reference	Experimental value (10^{11} a)	Comments
W. F. Libby (1934Li03)	0.92 (6)	Corrected for (Sm nat./Sm-147) = 0.1498 by R. D. MacFarlane (1961Ma05).
R. Hosemann (1936Ho**)	1.5 (1)	Corrected for (Sm nat./Sm-147) = 0.1498 by R. D. MacFarlane (1961Ma05).
P. Cuer (1946Cu**)	1.3 (1)	
E. Picciotto (1949Pi**)	1.00 (5)	Corrected for (Sm nat./Sm-147) = 0.1498 by R. D. MacFarlane (1961Ma05).
G. Beard (1954Be69)	1.25 (6)	Superseded by 1958Be78.
G. E. Leslie (1956Le55)	1.15 (6)	
G. Beard (1958Be78)	1.06 (4)	Corrected for wrong Sm content by P. M. Wright (1961Wr02). Original value: 1.28 (4). Superseded by 1987Al28.
M. Karras (1960Ka**)	1.14 (5)	Superseded by 1960Ka23.
M. Karras (1960Ka23)	1.17 (5)	
R. D. MacFarlane (1961Ma05)	1.15 (5)	Superseded by 1970Gu14.
P. M. Wright (1961Wr02)	1.05 (2)	
D. Donhoffer (1964Do01)	1.04 (3)	
K. Valli (1965Va16)	1.08 (2)	
M. C. Gupta (1970Gu14)	1.06 (2)	
B. Al-Bataina (1987Al28)	1.05 (4)	
J. B. Martins (1992Ma56)	1.06 (4)	Corrected for wrong Sm content by F. Begemann (2001Be81). Original value: 1.23 (4).
N. Kinoshita (2003Ki26)	1.17 (2)	Questioned by 20099Ko15.
K. Kossert (2009Ko15)	1.070 (9)	
Recommended value	**1.079 (12)**	**χ^2 = 3.9**

The first 3 values (1934Li03, 1936Ho** and 1946Cu**) have been shown outliers, based on the Chauvenet's criterion and thus were omitted in the final calculation. With the eleven remaining values (1949Pi**, 1956Le55, 1960Ka23, 1961Wr02, 1964Do01, 1965Va16, 1970Gu14, 1987Al28, 1992Ma56, 2003Ki26 and 2009Ko15), a weighted average has been calculated using LWEIGHT computer program (version 3). The largest contribution to the weighted average comes from the value of K. Kossert (2009Ko15), with a statistical weight of 46 %.

The adopted value is the weighted average of $1.079 \cdot 10^{11}$ a with an external uncertainty of $0.012 \cdot 10^{11}$ a. The reduced-χ^2 value is 3.9.

2.1 β- Transitions

The maximum energies of the β^- transitions in the decay of ^{147}Pm → ^{147}Sm have been obtained from the Q^- value (2003Au03) and the level energies from N. Nica (2009Ni02) (Table 3).

Table 3: ^{147}Sm levels populated in the decay of ^{147}Pm and adopted β^- transition probabilities.

Level Number	Level energy, (keV)[a]	Spin and parity	Half-life*	Adopted P_{β^-} (%)
0	0	$7/2^-$	$1.060\ (11)\cdot10^{-11}$	99.994 56 (13)
1	121.223 (12)	$5/2^-$	0.798 (17) ns	0.005 44 (13)
2	197.298 (11)	$3/2^-$	1.25 (3) ns	0.000 000 40 (7)

* Given by N. Nica (2009Ni02),
[a] from least-squares fit to E_γ's.

The adopted β^- transition probabilities and the associated uncertainties (Table 3) were deduced from the γ transition probability balance at each level of the decay scheme.

The values of log ft and average β^- energies have been calculated with the program LOGFT for the unique 1st and 1st forbidden β^- transitions.

2.2 γ Transitions

The γ-ray transition probabilities were calculated using the γ-ray emission intensities and the relevant internal conversion coefficients (see **4.2 γ Emissions**).

For all γ transitions, the internal conversion coefficients (ICC) and the associated uncertainties were interpolated from theoretical values of I. M. Band et al. (2002Ba85) using the BrIcc computer program (2008Ki07) for the "frozen orbital" approximation.

For multipolarity and mixing ratio of the γ-ray transitions, the evaluators used:

1) The multipolarities of the 76- and 197-keV γ-ray transitions are from N. Nica (2009Ni02):

76-keV γ-ray: M1 + E2, δ = 0.655 (34);
197-keV γ-ray: E2.

2) For the 121-keV γ-ray transition, the adopted mixing ratio (δ) is the weighted mean of the δ values found in the literature and shown in the Table 4.

Table 4: Experimental and recommended mixing ratio and ICC.

E_γ (keV)	δ experimental (mixing ratio)	Comments
121.220 (7)	0.25 (21) (1958An36) -0.06 (2) (1962Al19)[a] -0.33 (4) (1962Sc09) 0.34 (3) (1966Av02) -0.35 (4) (1966Go26)[£] -0.38 (3) (1970Va38) -0.40 (+26,-15) (1971Be53) -0.278 (20) (1989Ad10)	Calculated* from K/L = 6.2 (6). Calculated by 1977Kr13 (γγ(θ)). Calculated* from L_1:L_2:L_3 = 1.0 (2): 0.24 (4): 0.16 (2). Calculated* from K: L_{1+2}:L_3 = 450 (40): 73 (7): 10 (1). Calculated by 1977Kr13 (γγ(θ)). Superseded by 1970Va38. Calculated by 1977Kr13 (γγ(θ)). Calculated by 1977Kr13 (γγ(θ)).
Recommended value	- 0.317 (19), χ^2 = 1.7	α_K(BRICC – 121-keV γ-ray) = 0.815 (12).

[a] Outlier value, based on the Chauvenet's criterion and thus was omitted in the final calculation.
[£] Superseded by 1970Va38.
* Using BriccMixing program, version 2.2a (same package of BrIcc computer program).

3 Atomic Data

Atomic values, ω_K, ϖ_L, n_{KL} and the X-ray relative probabilities are from Schönfeld and Janβen (1996Sc06).

4 Photon Emissions

4.1 X-ray Emissions

The X-ray absolute intensities were deduced from the decay data using the EMISSION computer code.

4.2 Gamma emissions

The energies of the γ-rays given in Table 5 were derived from the ^{147}Sm adopted levels (Table 2).

The experimental absolute values of the 121-keV γ-ray emission intensities in the decay of ^{147}Pm are given in the table 5.

Table 5: Absolute experimental γ-ray emission intensities for the 121-keV transition.

Reference	Absolute γ-ray intensity (10^{-3} %)	Comments
H. Langevin-Joliot (1956La17)	3.0 (5)	
N. Starfelt (1957St05)	3.4 (5)	
R. S. Mowatt (1970Mo02)	2.73 (18)	
D. McConnon (1971Mc09)	2.93 (14)	
H. H. Hansen (1973HaHY)	3.0 (3)	
U. Schötzig (1990Sc08)	2.65 (6)	
Recommended value	**2.72 (6)**	**χ^2 = 1.33**

The adopted value is the weighted average of $2.72 \cdot 10^{-3}$ % with an external uncertainty of $0.06 \cdot 10^{-3}$ %. The reduced-χ^2 value is 1.33.

For the 197-keV γ-ray emission, the adopted value of the γ-ray relative intensity ($1.2\ (2) \cdot 10^{-4}$) comes from the unique measurement found in the literature given by P. H. Barrett (1969Ba33).

Our recommended γ-ray emission probabilities are given in Table 6.

Table 6: Recommended relative and absolute γ-ray intensities (%).

Eγ (keV)	Relative γ-ray intensity (%)	Absolute γ-ray intensity (%)
(76.073 (10))[a]	$4.1\ (7) \cdot 10^{-6}$	$1.1\ (2) \cdot 10^{-8}$
121.220 (17)	100	$2.72\ (6) \cdot 10^{-3}$
197.299 (12)	$1.2\ (2) \cdot 10^{-4}$	$3.3\ (5) \cdot 10^{-7}$

[a] not observed in this decay scheme.

The 76-keV γ-ray transition has been observed in the ^{147}Eu electron capture decay, but not in the ^{147}Pm β^- decay. From the ^{147}Eu electron capture decay (1989Ad10):
I_γ(76 keV)/I_γ(197 keV) = 0.0344 (11) and
I_γ(197 keV) = $1.2\ (2) \cdot 10^{-4}$. Then I_γ(76 keV) = $4.1\ (7) \cdot 10^{-6}$.
This very weak transition was included in the decay scheme.

5 References

1934Li03 W. F. Libby, Phys. Rev. 46(1934)196 [^{147}Sm half-life].
1936Ho** R. Hosemann, Z. Physik 99(1936)405 [^{147}Sm half-life].
1946Cu** P. Cuer, C. M. G. Lattes, Nature 158(1946)197 [^{147}Sm half-life].
1949Pi** E. Picciotto, Compt. Rend. (Paris) 229(1949)117 [^{147}Sm half-life].
1954Be69 G. B. Beard, M. L. Wiedenbeck, Phys. Rev. 95(1954)1245 [^{147}Sm half-life].
1955Me52 E. A. Melaika, M. J. Parker, J. A. Petruska, R. H. Tomlinson, Can. J. Chem. 33(1955)830 [Half-life].
1956La17 H. Langevin-Joliot, M. Lederer, J. Phys. Radium 17(1956)497 [P_γ].
1956Le55 G. E. Leslie, Nucl. Sci. Abstr. 10(1956)1099 [^{147}Sm half-life].
1956Sc87 R. P. Schuman, M. E. Jones, A. C. Mewherter, J. Inorg. Nucl. Chem. 3(1956)160 [Half-life].
1957Me47 W. F. Merritt, P. J. Campion, R. C. Hawkings, Can. J. Phys. 35(1957)16 [Half-life].
1957St05 N. Starfelt, J. Cederlund, Phys. Rev. 105(1957)241 [P_γ].
1958An36 N. M. Anton'eva, A. A. Bashilov, B. S. Dzhelepov, B. K. Preobrashenskii, Bull. Acad. Sci. USSR, Phys. Ser. 22(1959)899 [121-keV mixing ratio].
1958Be78 G. B. Beard, W. H. Kelly, Nucl. Phys. 8(1958)207 [^{147}Sm half-life].
1959Ca** J. P. Cali, L. F. Lowe, Nucleonics 17(1959)86 [Half-life].
1960Ka** M. Karras, N. Nurmia, Nature 185(1960)601 [^{147}Sm half-life].
1960Ka23 M. Karras, Ann. Acad. Sci. Fenn. A VI(1960)65 [^{147}Sm half-life].
1961Ma05 R. D. MacFarlane, T. P. Kohman, Phys. Rev. 121(1961)1758 [^{147}Sm half-life].
1961Wy01 E. I. Wyatt, S. A. Reynolds, T. H. Handley, W. S. Lyon, H. A. Parker, Nucl. Sci. Eng. 11(1961)74 [Half-life].
1961Wr02 P. M. Wright, E. P. Steinberg, L. E. Glendenin, Phys. Rev. 123(1961)205 [^{147}Sm half-life].
1962Al19 Y. A. Aleksandrov, B. Bemer, Bull. Acad. Sci. USSR, Phys. Ser. 26(1963)1171 [121-keV mixing ratio].
1962Sc09 C. F. Schwerdtfeger, H. J. Prask, J. W. Mihelich, Nucl. Phys. 35(1962)168 [121-keV mixing ratio].
1963Ro20 F. P. Roberts, E. J. Wheelwright, W. Y. Matsumoto, HW-77296 (1963)[Half-life].
1964Do01 D. Donhoffer, Nucl. Phys. 50(1964)489 [^{147}Sm half-life].
1965An07 S. C. Anspach, L. M. Cavallo, S. B. Garfinkel, J. M. R. Hutchinson, C. N. Smith, NP – 15663 (1965) [Half-life].
1965Ei04 J. F. Eichelberger, Report MLM – 1221(1965)5 [Half-life].
1965Fl02 K. F. Flynn, L. E. Glendenin, E. P. Steinberg, Nucl. Sci. Eng. 22(1965)416 [Half-life].
1965Va16 K. Valli, Ann. Acad. Sci. Fenn. A VI(1965)177 [^{147}Sm half-life].
1965Wh04 E. J. Wheelwright, D. M. Fleming, F. P. Roberts, J. Phys. Chem. 69(1965)1220 [Half-life].
1966Av02 M. P. Avotina, E. P. Grigorev, A. Z. Zolotavin, V. O. Sergeev, V. E. Tre-Nersesyants, J. Vrzal, N. A. Lebedev, J. Liptak, Y. Urbanets, Bull. Acad. Sci. USSR, Phys. Ser. 30(1967)1350 [121-keV mixing ratio].
1966Go26 T. Goworek, J. Wawryszczuk, Acta Phys. Pol. 29(1966)655 [121-keV mixing ratio].
1967Jo07 K. C. Jordan, MLM – 1399(1967)16 [Half-life].
1968Re04 S. A. Reynolds, J. F. Emery, E. I. Wyatt, Nucl. Sci. Eng. 32(1968)46 [Half-life].
1969Ba33 P. H. Barrett, D. A. Shirley, Phys. Rev. 184(1969)1185 [197-keV I_γ].
1970Gu14 M. C. Gupta, R. D. MacFarlane, J. Inorg. Nucl. Chem. 32(1970)3425 [^{147}Sm half-life].
1970Mo02 R. S. Mowatt, J. S. Merritt, Can. J. Phys. 48(1970)453 [P_γ].
1970Va38 Y. Vavryshchuk, T. Goworek, K. Klishchevska, Bull. Acad. Sci. USSR, Phys. Ser. 34(1971)1922 [121-keV mixing ratio].
1971Be53 R. A. Belt, E. G. Funk, J. W. Mihelich, Nucl. Phys. A175(1971)129 [121-keV mixing ratio].
1971Mc09 D. McConnon, Int. J. Appl. Radiat. Isotop. 22(1971)253[P_γ].
1973HaXY H. H. Hansen, Proc. Int. Conf. Inner Shell Ionization Phenomena and Future Applications, Atlanta 3(1972)2157 [P_γ].
1977Kr13 K. S. Krane, At. Data and Nucl. Data Tables 19(1977)363 [mixing ratio].
1987Al28 B. Al-Bataina, J. Jänecke, Radiochimica Acta 42(1987)159 [^{147}Sm half-life].
1989Ad10 I. Adam, Zh. T. Zhelev, D. Zakoutski, B. Kracik, I. Penev, Bull. Acad. Sci. USSR, Phys. Ser. 53(1989)6 [^{147}Eu ε decay to ^{147}Sm].
1990Sc08 U. Schötzig, Nucl. Instrum. Meth. Phys. Res. A286(1990)523 [P_γ].

1992Ma56 J. B. Martins, M. L. Terranova, M. M. Correa, Nuovo Cim. 105(1992)1621 [^{147}Sm half-life].
1996Sc06 E. Schönfeld, H. Janβen, Nucl. Instrum. Meth. Phys. Res. A369(1996)527 [Atomic data].
2001Be81 F. Begemann, K. R. Ludwig, G. W. Lugmair, K. Min, L. E. Nyquist, P. J. Patchett, P. R. Renne, C. –Y. Shih, I. M. Villa, R. J. Walker, Geochim. Cosmochim. Acta 65(2001)111 [Correction for^{147}Sm half-life].
2002Ba85 I. M. Band, M. B. Trzhaskovskaya, C. W. Nestor, Jr., P. O. Tikkanen, S. Raman, Atomic Data Nucl. Data Tables 81(2002)1 [Theoretical ICC].
2003Au03 G. Audi, A. H. Wapstra, C. Thibault, Nucl. Phys. A729(2003)337 [Q].
2003Ki26 N. Kinoshita, A. Yokoyama, T. Nakanishi, J. Nucl. Radiochem. Sci. 4(2003)5 [^{147}Sm half-life].
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].
2009Ko15 K. Kossert, G. Jörg, O. Nähle, C. Lierse, V. Gostomski, Appl. Rad. Isotop. 67(2009)1702 [^{147}Sm half-life].
2009Ni02 N. Nica, Nucl. Data Sheets 110(2009)749 [E_γ, E_{level}, spin, parity].