^{148}Pm - Comments on evaluation of decay data

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This evaluation was completed in February 2013 with the same literature cut-off date.

Limitation of Relative Statistical Weights Method (LWM) was applied to average the decay data when appropriate (unless otherwise stated) by use of the LWEIGHT program and/or the Excel implementation of same. All uncertainties are given as the combined uncertainty to one standard deviation.

The ^{148}Pm samples used in the various measurements were produced via the ^{148}Nd(p,n), (d,2n), ^{147}Pm(n,γ) or U(p,f) reactions.

Impurities are other promethium isotopes (^{149,150}Pm) produced from further capture reactions on the original target, or from an incomplete purification of the production source, leading to the presence of other neodymium isotopes (^{149,150}Nd). However, radiochemical separation or ion-exchange chromatography was performed before measurements in almost all of the published reports in order to reduce the level of impurities.

The most important complication in measuring the emissions intensities is the fact that the ground state is in equilibrium with the metastable state (with its significantly longer half-life of (41.29 (13) d), and both are produced in almost equal quantities via the ^{147}Pm(n,γ) reaction. All emission intensity measurements must be made at “short” and “long” times following the source production, so that the measured intensities can be associated with the decay of the relevant isomer. In general, multiple measurements over a period of weeks and months have been performed.

1 Decay Scheme

^{148}Pm decays 100 % via β^--transitions to nine excited levels and the ground state of ^{148}Sm.

The ^{148}Pm decay scheme is complete and consistent. Its overall consistency is verified by the comparison between Q_{calc} = 2478 (24) keV deduced from the evaluated average energies of all emissions, and Q_{β^-} (2471 (6) keV) from the 2012 atomic mass evaluation of M. Wang et al. (2012Wa38). There are two gamma rays observed by 1977Ka14, but only as upper limits, not placed in this decay scheme. The level energies, spins, and parities, along with the multipolarities and mixing ratios of the γ-rays presented in this evaluation, are taken from 1977Ka14, as also used in 2000Bh03. Further details are provided in section 2.2.

It should be noted that both sets of the *absolute* and *relative* intensity measurements for the 550.27 keV γ-ray are discrepant.

2 Nuclear Data

2.1. Half-life

The experimental half-life values of ^{148}Pm are given in Table 1, resulting in a recommended value of **5.370 (15) d**.

Table 1: Experimental values of ^{148}Pm half-life (in days)

Reference	$T_{1/2}$ values (d)	Uncertainty
1943Ku**	5.3^c	
1947Pa**	5.3^c	
1951Fo**	5.3^c	
1952Lo01	5.3^c	
1955Fo18	5.3^c	
1959Bh95	4.2^d	0.2
1959Ei31	5.5^d	0.1
1961El02	5.4	0.1
1962Re03	5.39	0.06

Reference	$T_{1/2}$ values (d)	Uncertainty
1962Sc04	5.0[d]	0.5
1963Ba31[a]	5[c]	
1971Ca23[b]	5.3675	0.0153
1971Mo04	5.37	0.04
Recommended[e]	**5.370**	**0.015**
LWEIGHT reduced χ^2 = 0.076 (critical χ^2 = 3.786)		

[a] 1963Ba31 quotes the same value as 1963Ew01 and 1963Ba06 by the same authors (hence not listed)
[b] Unweighted mean of four published values, two in each of 1970Ca09 and 1971Ca23, and using simple arithmetic mean of the four uncertainties
[c] Not used – all six cases where no uncertainty given
[d] Rejected – three values rejected by the LWEIGHT program due to the Chauvenet principle
[e] Recommended value is the weighted mean of 1961El02, 1962Re03, 1971Ca23 and 1971Mo04, where the value of 1971Ca23 amounts to 81 % of the total weight, due to its far lower uncertainty, which is also adopted as the uncertainty on the recommended value

The decay daughter ^{148}Sm is effectively stable, with a half-life of **7 (3) × 10^{15} a**.

2.2. Gamma Transitions

Energies

The measured γ-ray transition energies in ^{148}Sm following the ^{148}Pm decay are given in Table 2. These have been measured by a small number of authors, with only one complete set (1977Ka14). Since all published values are compatible, the values of 1977Ka14, with their significantly lower uncertainties, have been adopted.

Table 2: Measured energies (keV) of γ-rays in ^{148}Sm from the decay of ^{148}Pm

1959Ei31		1962Re03		1967Cl05		1970GrYP		1970FoZZ		1971Mo04*		1977Ka14		1984LaZZ§	
												303.59	0.03		
												362.8	0.2		
												393.80	0.03		
560	5	550	5	550.1	0.2	550.4	0.5	550.22	0.06	550.1	0.1	550.27	0.03	550.22	0.06
												592.83	0.03		
						611.2	0.6			611.1	0.1	611.26	0.03		
												819.27	0.03		
								874.17	0.23			874.18	0.03	874.2	0.25
								896.36	0.3			896.42	0.03	896.4	0.3
												903.94	0.03		
910	10	910	5	914.9	0.2			914.97	0.12	914.1	0.1	914.85	0.03	915.0	0.1
												1113.88	0.03		
												1152.5	0.2		
												1371.3	0.2		
												1454.21	0.03		
1470	15	1460	10	1465.1	0.2	1464.5	1.5	1465.19	0.1	1465.1	0.1	1465.12	0.03	1465.2	0.1
												1507.68	0.03		
												1664.15	0.03		
												1734.12	0.03		
												1763.7	0.2		
												2284.39	0.03		
												2314.0	0.2		

* Uncertainty of 0.1 keV on energy assumed
§ The values in 1984LaZZ are from 1970FoZZ, with the uncertainties rationalised

Emission Intensities

A number of relative (see Table 3) and absolute (see Table 4) measurements have been published for the γ-ray intensities. The relative measurements of 1977Ka14 are the only complete set, with twentytwo γ-rays identified, although two of these were only measured as intensity upper limits and have not been included in the decay scheme.

Table 3: Measured relative intensities of γ-rays in ^{148}Sm from the decay of ^{148}Pm

	Energy	1959Bh95*		1962Sc04	1971Mo04§		1977Ka14		1984LaZZ†	
$\gamma_{1,0}$	303.59						0.17	0.02		
$\gamma_{4,0}$	362.8						<0.01			
$\gamma_{5,0}$	393.80						0.07	0.01		
$\gamma_{6,0}$	550.27	75	15	82	105	3	99.1	0.7	127	9
$\gamma_{9,0}$	592.83						1.59	0.03		
$\gamma_{2,1}$	611.26				5.0	0.3	4.60	0.05		
$\gamma_{3,1}$	819.27						0.06	0.01		
$\gamma_{4,1}$	874.18						1.06	0.03	1.59	0.09
$\gamma_{5,1}$	896.42						4.42	0.04	10.0	0.2
$\gamma_{6,1}$	903.94						0.19	0.01		
$\gamma_{7,1}$	914.85	60	12	65	56.4	1.5	51.6	0.4	68.2	6.8
$\gamma_{8,1}$	1113.88						0.10	0.01		
$\gamma_{9,1}$	1152.5						0.013	0.006		
$\gamma_{10,1}$	1371.3						0.062	0.006		
$\gamma_{5,2}$	1454.21						0.23	0.01		
$\gamma_{8,2}$	1465.12	100	20	100	100	3	100		100	3
$\gamma_{10,2}$	1507.68						0.025	0.004		
$\gamma_{8,5}$	1664.15						0.051	0.005		
$\gamma_{9,5}$	1734.12						0.174	0.003		
$\gamma_{8,6}$	1763.7						0.028	0.003		
$\gamma_{1,0}$	2284.39						0.20	0.01		
$\gamma_{4,0}$	2314.0						<0.001			

* Original values of 60 (12), 40 (8) and 100 (20) were revised as quoted by 1961El02 due to presence of ^{144}Pm

§ 1971Mo04 quotes absolute intensities also, but these are based on assuming 50 % β-feeding to ^{148}Sm ground state

† Although 1984LaZZ is a private communication, it is a detailed report of 55 pages which was never formally published. I also believe the report relates to work carried out in the early 1970s (see 1970FoZZ, 1974DuZO and 1974LoZL) and I note the report's first author was a summer visitor at Vanderbilt University (probably in 1974). The report was only registered in NSR in 1984.

After careful consideration of the earlier "absolute" measurements, e.g. 1961El02, 1962Re03, 1963Ba31 and 1970FoZZ, it was decided to use the only true absolute intensity, measured by 1971Ca23, for the 1465.12 keV γ ray of **0.222 (5)** to normalise the relative measurements. Once this was achieved, it was clear that the earlier measurements using NaI detectors (and those unpublished in 1970FoZZ/1984LaZZ which used a GeLi detector) were incompatible with the measurements of 1971Mo04 and 1977Ka14. The evaluator has thus chosen to use the weighted means of the three γ ray intensity measurements common to both sets to calculate the recommended absolute intensities (see Table 4). In each case the two values are consistent and the external uncertainty has been quoted on the recommended value.

Table 4: Measured/recommended absolute intensities (per decay) of γ-rays in ^{148}Sm from the decay of ^{148}Pm

	Energy	1961El02*		1962Re03		1963Ba31		1970FoZZ		1971Ca23		1971Mo04		1977Ka14§		Recommended† (per decay)	
$\gamma_{1,0}$	303.59													0.377×10^{-3}	0.045×10^{-3}	0.377×10^{-3}	0.045×10^{-3}
$\gamma_{4,0}$‡	362.8													$< 2.2\times10^{-5}$			
$\gamma_{5,0}$	393.80													1.55×10^{-4}	0.22×10^{-4}	1.55×10^{-4}	0.22×10^{-4}
$\gamma_{6,0}$	550.27	0.25	0.02	0.31	0.02	0.27	0.05	0.28	0.02			0.233	0.007	0.220	0.005	0.225	0.006
$\gamma_{9,0}$	592.83													0.0035	0.0001	0.0035	0.0001
$\gamma_{2,1}$	611.26											0.0112	0.0007	0.0102	0.0003	0.0104	0.0004
$\gamma_{3,1}$	819.27													1.33×10^{-4}	0.22×10^{-4}	1.33×10^{-4}	0.22×10^{-4}
$\gamma_{4,1}$	874.18							0.0035	0.0002					0.0024	0.0001	0.0024	0.0001
$\gamma_{5,1}$	896.42							0.0220	0.0005					0.0098	0.0002	0.0098	0.0002
$\gamma_{6,1}$	903.94													4.2×10^{-4}	0.2×10^{-4}	4.2×10^{-4}	0.2×10^{-4}
$\gamma_{7,1}$	914.85	0.13	0.02	0.17	0.02	0.15	0.03	0.150	0.015			0.125	0.003	0.115	0.003	0.120	0.005
$\gamma_{8,1}$	1113.88													2.22×10^{-4}	0.23×10^{-4}	2.22×10^{-4}	0.23×10^{-4}
$\gamma_{9,1}$	1152.5													2.9×10^{-5}	1.3×10^{-5}	2.9×10^{-5}	1.3×10^{-5}
$\gamma_{10,1}$	1371.3													1.38×10^{-4}	0.14×10^{-4}	1.38×10^{-4}	0.14×10^{-4}
$\gamma_{5,2}$	1454.21													5.11×10^{-4}	0.25×10^{-4}	5.11×10^{-4}	0.25×10^{-4}
$\gamma_{8,2}$	1465.12	0.20	0.02	0.24	0.02	0.23	0.05	0.220	0.007	0.222	0.005	0.222	0.005	0.222	0.005	0.222	0.005
$\gamma_{10,2}$	1507.68													5.6×10^{-5}	0.9×10^{-5}	5.6×10^{-5}	0.9×10^{-5}
$\gamma_{8,5}$	1664.15													1.13×10^{-4}	0.11×10^{-4}	1.13×10^{-4}	0.11×10^{-4}
$\gamma_{9,5}$	1734.12													3.86×10^{-4}	0.11×10^{-4}	3.86×10^{-4}	0.11×10^{-4}
$\gamma_{8,6}$	1763.7													6.2×10^{-5}	0.7×10^{-5}	6.2×10^{-5}	0.7×10^{-5}
$\gamma_{1,0}$	2284.39													4.44×10^{-4}	0.24×10^{-4}	4.44×10^{-4}	0.24×10^{-4}
$\gamma_{4,0}$‡	2314.0													$< 2\times10^{-6}$			

* Uncertainty of 0.02 on intensity assumed – as no uncertainty given

§ 1977Ka14 values are calculated from relative measurements normalised to recommended absolute emission of 1465.12 keV γ-ray

† Recommended values are the same as the normalised 1977Ka14 values, except for the 550.27 and 914.85 keV γ-ray values which are weighted means of the five available absolute values, including that of 1977Ka14 after initial normalisation through the 1465 keV γ-ray

‡ Two γ-rays at 362.8 and 2314.0 keV not placed in scheme (measured as upper limit only)

Measurement conditions

The γ-ray intensities were measured with the detectors and under the timing conditions shown in Table 5.

Table 5: Conditions of the γ-ray intensity measurements

Reference	Detector	Timescale
1959Bh95	NaI	2 days to 3 months
1959Ei31	NaI	No timing details given
1961El02	NaI	Up to 250 days
1962Sc04	NaI	At 24 hrs and "equilibrium"
1962Re03	NaI	"Immediately after irradiation" to "several months"
1963Ba31	NaI	2 days to 140 days
1967Cl05	GeLi	No details given, but measured combined energy spectrum
1970FoZZ	GeLi	Immediately after irradiation, then two and twelve weeks later
1970GrYP	GeLi	No timing details given
1971Ca23	NaI	During first 34 – 50 hrs, and a further 40 days, following irradiation
1971Mo04	GeLi	3 to 75 days
1977Ka14	GeLi	Four sources produced periodically over 10 month measuring period
1984LaZZ	Same measurements as reported in 1970FoZZ	

Multipolarities and Internal Conversion Coefficients

The γ-ray multipolarities and the mixing ratios have been taken from the adopted gamma data within the evaluation of 2000Bh03 based on mainly on 1977Ka14 (γ-ray directional correlations), but also considering 1962Re03, 1968Wy02 (γ-ray directional correlations), 1962Sc04, 1963Ba31 (measured conversion electrons and γ-ray directional correlations), and 1970GrYP (measured conversion electrons).

All internal conversion coefficients have been calculated using the BrIcc code (2008Ki07), as implemented in the SAISINUC evaluation tool (2008DuZX). In Table 6 these values are compared with available measured data, where general agreement is seen.

Table 6: Comparison of BrIcc and measured K-shell internal conversion coefficients (α_K)

	Energy	1962Sc04*		1963Ba31		1970GrYP				BrIcc	
$\gamma_{6,0}$	550.27	0.0081	-			0.0079	0.0006			0.008 25	0.000 12
$\gamma_{2,1}$	611.26					0.0025	0.0008			0.002 39	0.000 05
$\gamma_{4,1}$	874.18	0.0050	0.0014							0.002 80	0.000 04
$\gamma_{7,1}$	914.85			0.000 68	0.000 19					0.001 050	0.000 015
$\gamma_{8,2}$	1465.12			0.000 47	0.000 14					0.000 449	0.000 007
$\gamma_{10,2}$	1507.68	0.0006	0.0002							0.000 428	0.000 006

* Obtained from ^{148}Eu EC decay for γ-rays in common

2.3. Beta Transitions

Energies and Emission Probabilities

Beta-particle energies were determined from the difference between the adopted Q-value and the final level energies of daughter ^{148}Sm. Beta-particle emission probabilities were determined by balancing the proposed decay scheme through consideration of the βγ-population and γ-depopulation of these same levels. Only the 2nd level has no beta-feeding based on published data. A comparison with measured energies and absolute emission intensities is presented in Table 7. The adopted values are consistent, within the uncertainty limits, with the two sets of results having uncertainties.

Table 7: Measured/recommended absolute intensities (%) of β^--emissions from the decay of ^{148}Pm

	1961El02		1962Sc04		1962Re03		1963Ba31†		Recommended	
	E (keV)	I_β(%)	E (keV)	I_β(%)	E (keV)	I_β(%)	E (keV)	I_β(%)	E (keV)	I_β(%)
$\beta_{0,0}$	2520	55	2460 (20)	22	2600 (200)	45 (9)	2480 (30)	50 (5)	2471 (6)	55.5 (7)
$\beta_{0,1}$	1970	12	1900 (50)	6	2000 (200)	14*	1930 (30)	10 (2)	1921 (6)	9.3 (6)
$\beta_{0,3}$									1047 (6)	0.236 (9)
$\beta_{0,4}$									1017 (6)	0.093 (3)
$\beta_{0,5}$	1060	33	1020 (15)	72	1100 (200)	41 (9)	1020 (30)	40 (5)	1006 (6)	33.3 (6)
$\beta_{0,6}$									807 (6)	0.018 (3)
$\beta_{0,7}$									549 (6)	0.0138 (14)
$\beta_{0,8}$									413 (6)	1.360 (22)
$\beta_{0,9}$									187 (6)	0.0965 (34)
$\beta_{0,10}$									157 (6)	0.0091 (15)

* 2000 keV intensity deduced by 1962Re03 from decay scheme, not directly measured
† Same data as published in 1963Ew01 and 1963Ba06 by the same authors

2.4. Conversion electrons

The energies of the internal conversion electrons have been deduced using γ-ray energies and electron binding energies from 1977La19 and 1996FiZX. Absolute conversion electron emission intensities have been calculated by using γ-ray internal conversion coefficients and absolute emission intensities.

3 Atomic Data

The recommended fluorescence yields shown in Table 8 were obtained from 1996Sc06.

Table 8: Recommended atomic data

ω_K	0.926 (4)
ω_L	0.158 (6)
η_{KL}	0.857 (4)

The energies of the K-Auger electrons were obtained from 1998ScZM, whereas the energies and the yield of Sm X-rays were obtained from 1999ScZX (data stored in SAISINUC). The X-ray and Auger electron emission intensities have been calculated from the decay scheme parameters using the computer program EMISSION (v3.10, 28-Jan-2003) described in 2000Sc47.

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