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

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This evaluation was completed in March 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 $^{148m}$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 emission intensities is the fact that the metastable state is in equilibrium with the ground state (with its significantly shorter half-life of (5.370 (15) 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

$^{148m}$Pm decays 94.4 (5) % via $\beta^-$-transitions to four excited levels of $^{148}$Sm, and via an isomeric transition of 5.6 (5) %.

After a certain time (~ 50 d), the ratio of the activities A($^{148m}$Pm)/A($^{148}$Pm) becomes constant.

The $^{148m}$Pm decay scheme is complete and consistent. Its overall consistency is verified by the comparison between $Q_{calc}$ = 2612 (21) keV deduced from the evaluated average energies of all emissions, and $Q_{eff}$ (2608 (6) keV) from the 2012 atomic mass evaluation of M. Wang et al. (2012Wa38). The level energies, spins, parities along with the multipolarities and mixing ratios of the γ-rays presented in this evaluation are taken from the evaluation of 2000Bh03. Further details are provided in section 2.3.

## 2 Nuclear Data

### 2.1. Half-life

The experimental half-life values of $^{148m}$Pm are given in Table 1, resulting in a recommended value of **41.29 (13) d**.

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

| Reference | $T_{1/2}$ values (d) | Uncertainty |
|---|---|---|
| 1951Fo** | 43[c] | |
| 1952Ki25 | 42 | 1 |
| 1952Lo01 | 48[c] | |
| 1955Fo18 | 43[c] | |
| 1959Bh95 | 45.8[d] | 2.9 |
| 1959Ei31 | 50[b] | 1 |
| 1961El02 | 41.8 | 0.2 |
| 1961Ha23 | 46[c] | |
| 1962Sc04 | 45.5[d] | 0.5 |

| Reference | $T_{1/2}$ values (d) | Uncertainty |
|---|---|---|
| 1962Re03 | 40.6 | 0.4 |
| 1963Ba31[a] | 41[c] | |
| 1971Mo04 | 40.9 | 0.2 |
| 1971BaZW | 41.4 | 0.8 |
| 1971Wa05 | 41.3 | 0.1 |
| **Recommended*** | **41.29** | **0.13** |
| LWEIGHT reduced $\chi^2$ = 2.76 (critical $\chi^2$ = 3.02) | | |

[a] 1963Ba31 quotes the same value as 1963Ew01 and 1963Ba06 by the same authors (hence not listed)
[b] Rejected by the LWEIGHT program due to the Chauvenet principle
[c] Not used – all five cases where no uncertainty given
[d] Two values from 1959Bh95 and 1962Sc04 have been rejected by the evaluator, as they are not consistent with other measured values and since their reported values for $^{148}Pm$ were also rejected due to the Chauvenet principle, it is judged that their half-life values are not reliable
* Recommended value is the weighted mean of 1952Ki25, 1961El02, 1962Re03, 1971Mo04, 1971BaZW and 1971Wa05, where the value of 1971Wa05 amounts to 63 % of the total weight

The IT decay daughter $^{148}Pm$ has an evaluated half-life of **5.370 (15) d** and the $\beta^-$-decay daughter $^{148}Sm$ is effectively stable, with a half-life of **7 (3) × $10^{15}$ a**.

## 2.2. Branching fraction

$^{148m}Pm$ decays via $\beta^-$ (**94.4 (5) %**) to four excited levels of $^{148}Sm$ and via IT (**5.6 (5) %**). Table 2 shows the measured and recommended IT branching fraction.

Table 2: Experimental branching fractions for $^{148m}Pm$ IT decay

| Reference | %IT | Comments | Method |
|---|---|---|---|
| 1952Ki25 | 7.4 | $I_{\beta(2700)}$ following IT decay[1] | $(^{148}Nd)_2O_3$(p,n), $E_p$=8.9 MeV; Al, Be, Pb absorbers, 180° low resolution beta-ray spectrometer |
| 1955Fo18 | 5–10 | $I_{\beta(2700)}$ following IT decay[1] | U(p,f), $E_p$=340 MeV; Al absorber and GM tube |
| 1959Bh95 | ~20 | | $(^{148}Nd)_2O_3$(p,n), $E_{p(max)}$= 12 MeV; measured $I_\gamma$ with NaI(Tl), $I_\beta$ with anthracene scintillator, $\gamma\gamma$-, $\gamma\beta$-coin |
| 1960Sc12[a] | ~5 | No information on how this was deduced. | $^{147}Pm(n_{th},\gamma)$ in Materials Testing Reactor |
| 1961El02 | 5–10 | Qualitative estimate only of $I_{\beta(2300)}$ following IT decay | $(^{148}Nd)_2O_3$(p,n), $E_p$ not given and $^{147}Pm(n_{th},\gamma)$ in Oak Ridge Research Reactor; measured $I_\gamma$ with NaI(Tl), $I_\beta$ with prop. counter and absorbers, $\gamma\gamma$-coin |
| 1961Br41[a] | 5.8 (15)<br>5.5 (18) | $I_{\gamma(1460)}$ of 1.5 (4) % following IT decay[2]<br>$I_{\gamma(75)}$ – decay of intermediate 75 keV level[3] | No details of production method; measured $I_{ce}$ with magnetic spectrograph |

| Reference | %IT | Comments | Method |
|---|---|---|---|
| 1962Sc04 | 8 | By comparing the $I_{\gamma(1460)}$ to the $I_{\gamma(630)}$ at equilibrium | $(^{148}Nd)_2O_3$(p,n), $E_p$ not given; measured $I_\gamma$ with NaI(Tl), $I_{ce}$ with magnetic spectrograph and intermediate-image spectrometer, $I_\beta$ with Pilot B crystal, $\gamma\gamma$-, $\gamma\beta$-coin |
| 1962Re03 | ~7<br>6.5 (17)<br>5.1 (18) | From $I_{\beta(2600)}$ following IT decay[1]<br>From $I_{\gamma(1460)}$ of 1.6 (3) % following IT decay[4]<br>From $I_{\gamma(75)}$ – decay of intermediate 75 keV level[5] | $^{147}Pm(n_{th},\gamma)$ in Materials Testing Reactor; measured $I_\gamma$ with NaI(Tl), $I_{ce}$ with magnetic spectrograph, $I_\beta$ with prop. counter and anthracene scintillator |
| 1963Ba31 | 6.6 (10)<br>6.1 (10)<br>7.6 (16)<br>10 (4)<br>6.9 (7)<br>6.6 (6) | From $I_{\gamma(76)}$ – decay of intermediate 76 keV level[6]<br>From $I_{\gamma(62)}$ – decay of isomeric 137 keV level[7]<br>From $I_{\beta(2600)}$ following IT decay[1]<br>From $I_{\gamma(1460)}$ of 1.6 (3) % following IT decay[4]<br>Mean value of the 4 values quoted by the authors<br>Mean value of the 4 values calculated by evaluator | $^{148}Nd(d,2n),E_d$=12 MeV; Measured $I_\gamma$ with NaI(Tl), $I_{ce}$ and $I_\beta$ with "Copenhagen" six-gap spectrometer |
| 1970GrYP | ~7-7.5 | From $I_\beta$'s deduced from $I_\gamma$ and conversion electron measurements | Measured $I_\gamma$ with Ge(Li) and $I_{ce}$ with $\beta$-spectrometer |
| 1971Mo04 | 4.6 (5) | From mean of three relative intensity ratios at long decay time, i.e. once equilibrium reached: $I_{\gamma(550)}/I_{\gamma(1465)}$, $(I_{\gamma(611)}+I_{\gamma(630)})/I_{\gamma(1465)}$ and $(I_{\gamma(1014)}+I_{\gamma(915)}+I_{\gamma(726)}+I_{\gamma(433)}+I_{\gamma(414)})/I_{\gamma(1465)}$ | $^{147}Pm(n_{th},\gamma)$ in NRU reactor; measured $I_\gamma$ with GeLi detector |

| | | |
|---|---|---|
| **Recommended** | **5.6 (5)** | Using method described in 1971Mo04, with evaluated relative intensities measured at equilibrium (described below) |

[a] Superseded by 1962Re03

[1] Measured absolute intensity of the high energy beta group (~2600–2700 keV) emitted by $^{148}Pm$ ground state, as fed from the IT decay at long times, thus indicates the IT branching fraction.

[2] Measured the relative intensity of the 1460 keV $\gamma$ ray as 1.5 (4) % of the long-lived decays, then based on relative intensity calculated branching as 5.8 (15) %. Used ~ 26 % as absolute intensity per decay for the 1460 keV $\gamma$ ray.

[3] Calculated absolute transition probability of 5.5 (18) % for the 75 keV $\gamma$ ray from measured intensity of 1.2 (4) % and calculated ICCs for M1 transition, with $\alpha_T$=3.64 (see Table VII of 1961Br41).

[4] Measured the relative intensity of the 1460 keV $\gamma$ ray as 1.6 (3) % (see Table II of 1962Re03, i.e. 0.017 (3) × 0.94 × 100) of the long-lived decays, then based on relative intensity calculated branching as 6.5 (17) %. Used ~ 24 % (see Table I of 1962Re03) as absolute intensity per decay for the 1460 keV $\gamma$ ray.

[5] Calculated absolute transition probability of 5.1 (18) % for the 75 keV $\gamma$ ray from measured intensity of 1.0 (4) % (see Table II of 1962Re03, i.e. 0.011 (4) × 0.94 × 100) and calculated ICCs for M1 transition, with $\alpha_T$=3.64 (see Table III of 1962Re03).

[6] Calculated absolute transition probability of 6.6 (10) % for the 76 keV $\gamma$ ray from measured intensity of 1.6 (4) % (see Table 10 of 1963Ba31) assuming M1 transition.

[7] Calculated absolute transition probability of 6.1 (10) % for the 62 keV $\gamma$ ray from measured K conversion electron intensity of < 0.6 % (see Table 10 of 1963Ba31) assuming E4 transition.

The recommended IT branching fraction has been determined using the method described in 1971Mo04, which involves calculating the ratios of three different sets of relative γ-ray emission intensities at equilibrium. Each ratio yields a value for the branching fraction, and then the weighted mean of these three values is used to calculate the final recommended value, but due to the strong correlation in this method, the lowest experimental uncertainty is assigned to the value, rather than the calculated uncertainty of the weighted mean.

From 1971Mo04 the ratio of the decay rate of $^{148}$Pm to $^{148m}$Pm at equilibrium is:

$$\boldsymbol{R_i = \frac{\lambda_i}{\lambda_m}\left(1 - \frac{\lambda_m}{\lambda_g}\right)^{-1}} \quad (1)$$

where $\lambda_i$ is the IT partial decay constant, $\lambda_g$ and $\lambda_m$ are the ground and metastable state decay constants, then $\lambda_i/\lambda_m$ is the IT transition probability. Using the recommended half-lives of 5.370 (15) d and 41.29 (13) d then:

$$\boldsymbol{R_i = 1.149\ (5)\ \frac{\lambda_i}{\lambda_m}} \quad (2)$$

Since all of the $^{148m}$Pm β decays are to the 1594.31 keV level or above, and these feed γ transitions passing through either of the levels at 1161.53 keV or 1180.24 keV, then with reference to the decay scheme presented here, one finds:

$$\boldsymbol{1 - \frac{\lambda_i}{\lambda_m} = I_{550} = (I_{611} + I_{630}) = (I_{414} + I_{433} + I_{726} + I_{915} + I_{1014})} \quad (3)$$

where in each case $I_x$ denotes the transition probability for the transition of energy *x*.

Due to the existence of the IT branch, all measured transition intensities include a minor contribution from the $^{148}$Pm formed, which can be taken into account by including a correction term based on the absolute intensity evaluated for transition *x* following decay of the ground state.

For example, for the 550 keV transition is the sum of two components from $^{148m}$Pm IT decay AND $^{148}$Pm β decay, which contribute to the measured intensity, giving a combined intensity:

$$\boldsymbol{I_{550}^C = 1 - \frac{\lambda_i}{\lambda_m} + 0.227R_i = 1 - 0.739\frac{\lambda_i}{\lambda_m}} \quad (4)$$

since the absolute transition probability (γ-ray and conversion electrons) of the 550 keV γ-ray from $^{148}$Pm is 0.227 (6) (from companion evaluation of $^{148}$Pm) and by using Eqn. 2.

Equivalent equalities can be found for the $(I_{611} + I_{630})$ cascade:

$$\boldsymbol{I_{611}^C + I_{630} = 1 - \frac{\lambda_i}{\lambda_m} + 0.01043R_i = 1 - 0.988\frac{\lambda_i}{\lambda_m}} \quad (5)$$

and the $(I_{414} + I_{433} + I_{726} + I_{915} + I_{1014})$ cascade;

$$\boldsymbol{I_{414} + I_{433} + I_{726} + I_{915}^C + I_{1014} = 1 - \frac{\lambda_i}{\lambda_m} + 0{,}12R_i = 1 - 0{,}862\frac{\lambda_i}{\lambda_m}} \quad (6)$$

where the 611 keV and 915 keV γ-rays include the two components.

Finally, the 1465 keV γ-ray's metastable component can be shown to be:

$$\boldsymbol{I_{1465} = 0.222R_i = 0.255\frac{\lambda_i}{\lambda_m}} \quad (7)$$

By dividing each of Eqns. 4 – 6 by Eqn. 7, and using the relative intensities given in Table 4 we can determine three values for $\lambda_i/\lambda_m$ of 0.056 (4), 0.056 (5) and 0.056 (5) respectively, giving a weighted mean of **0.056 (5)** and using the highest individual uncertainty.

This recommended IT branching fraction of **5.6 (5) %** is consistent with experimental values determined from direct measurements of the 75 keV *γ* ray of 1961Br41: 5.5 (18) %, 1962Re03: 5.1 (18) % and 1963Ba31: 6.6 (10) %.

## 2.3. Gamma Transitions

*Energies*

The measured γ-ray transition energies in $^{148}Sm$ following the $^{148m}Pm$ $\beta^-$ decay and from the isomeric transition are given in Table 3. These have been measured by a number of authors.

The evaluated $^{148}Sm$ transition energies are deduced from the adopted level energy differences from 2000Bh03 and are consistent with the measured values given in 1977Ka14.

For the isomeric transition, the level energy is assumed to be the same as the sum of the energy of the two γ-rays inferred from the conversion electron measurements of 1970GrYP, i.e. 137.1 keV, not 137.9 keV as in 2000Bh03, where an inconsistency exists between the “adopted energy levels”, the actual energy level quoted for the isomer and the two γ-rays cascading from it. This decision is also supported by the $^{149}Sm(d,^{3}He)$ reaction measurements reported in 1988No02 and 1989Le01 for example.

Seven unplaced γ-rays consist of five seen by 1970FoZZ (hence also 1984LaZZ), as well as one each observed by 1959Ei31 and 1967Cl05.

Table 3: Measured and recommended energies (keV) of γ-rays in $^{148}Sm$ from the decay of $^{148m}Pm$

| | 1959Ei31 | | 1962Re03 | | 1967Cl05 | | 1970FoZZ | | 1970Gr09 | | 1970GrYP | | 1971Mo04* | | 1977Ka14 | | 1984LaZZ§ | | Recommended | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{148}Pm$ | | | | | | | | | | | | | | | | | | | | |
| γ2,1 | | | 60.1 | 0.5 | | | | | | | 61.3 | 0.05 | | | | | | | 61.30 | 0.05 |
| γ1,0 | | | 74.6 | 0.5 | 75.6 | 0.2 | 75.33 | 0.4 | 75.9 | 0.6 | 75.8 | 0.1 | | | | | 75.3 | 0.4 | 75.8 | 0.1 |
| $^{148}Sm$ | | | | | | | | | | | | | | | | | | | | |
| γ9,8 | | | 98 | 0.5 | 98.5 | 0.2 | 98.17 | 0.25 | 99.2 | 0.6 | 98.5 | 0.1 | 98.5 | 0.1 | 98.48 | 0.03 | 98.15 | 0.25 | 98.48 | 0.03 |
| γ8,7 | | | 188 | 1 | 189.5 | 0.3 | 189.61 | 0.06 | 190.2 | 0.6 | 189.7 | 0.2 | 189.5 | 0.1 | 189.63 | 0.03 | 189.61 | 0.06 | 189.63 | 0.03 |
| γ9,7 | 290 | 5 | 286 | 2 | 288 | 0.2 | 288.09 | 0.06 | 288.4 | 0.6 | 288.1 | 0.2 | 288 | 0.1 | 288.11 | 0.03 | 288.09 | 0.06 | 288.11 | 0.03 |
| Unplaced | | | | | | | 295.06 | 0.1 | | | | | | | | | | | | |
| γ9,6 | | | | | | | 298.88 | 0.25 | | | | | | | 299.1 | 0.2 | | | 299.1 | 0.2 |
| γ7,4 | | | 309 | 2 | 311.7 | 0.3 | 311.62 | 0.06 | 312 | 0.6 | 311.5 | 0.4 | 311.7 | 0.1 | 311.63 | 0.03 | 311.62 | 0.06 | 311.63 | 0.03 |
| γ8,5 | | | | | | | 362.48 | 0.1 | | | | | | | 362.09 | 0.03 | 362.5 | 0.1 | 362.09 | 0.03 |
| γ4,3 | 420 | 5 | 412 | 2 | 414.1 | 0.3 | 414.02 | 0.06 | 414.1 | 0.3 | 413.8 | 0.4 | 414.1 | 0.1 | 414.07 | 0.03 | 414.02 | 0.06 | 414.07 | 0.03 |
| γ4,2 | | | 431 | 2 | 432.7 | 0.3 | 432.71 | 0.06 | 432.9 | 0.1 | 432.5 | 0.4 | 432.7 | 0.1 | 432.78 | 0.03 | 432.71 | 0.06 | 432.78 | 0.03 |
| γ9,5 | | | | | 443.1 | 0.4 | 460.5 | 0.1 | | | | | | | 460.57 | 0.03 | 460.5 | 0.1 | 460.57 | 0.03 |
| γ8,4 | | | 498 | 2 | 501.1 | 0.4 | 501.25 | 0.06 | 501.4 | 0.1 | 501.1 | 0.5 | 501.1 | 0.1 | 501.26 | 0.03 | 501.25 | 0.06 | 501.26 | 0.03 |
| Unplaced | | | | | | | 533.59 | 0.15 | | | | | | | | | 533.6 | 0.15 | | |
| γ1,0 | | | 560 | 5 | 548 | 5 | 550.22 | 0.06 | 550.2 | 0.3 | 550.4 | 0.5 | 550.1 | 0.1 | 550.27 | 0.03 | 550.22 | 0.06 | 550.27 | 0.03 |
| γ5,3 | | | | | | | 553.26 | 0.19 | | | | | | | 553.24 | 0.03 | 553.3 | 0.2 | 553.24 | 0.03 |
| γ5,2 | | | | | | | 571.88 | 0.15 | | | | | | | 571.95 | 0.03 | 571.9 | 0.15 | 571.95 | 0.03 |
| Unplaced | | | | | 592.4 | 0.4 | | | | | | | | | | | | | | |
| γ9,4 | | | 596 | 5 | 599.5 | 0.3 | 599.69 | 0.06 | 599.7 | 0.1 | 599.6 | 0.6 | 599.5 | 0.1 | 599.74 | 0.03 | 599.69 | 0.06 | 599.74 | 0.03 |
| γ2,1 | | | | | 611.1 | 0.3 | 611.23 | 0.06 | 611.4 | 0.1 | 611.2 | 0.6 | 611.1 | 0.1 | 611.26 | 0.03 | 611.23 | 0.06 | 611.26 | 0.03 |
| γ3,1 | 630 | 5 | 627 | 5 | 629.9 | 0.2 | 629.95 | 0.06 | 629.8 | 0.3 | 629.7 | 0.6 | 629.9 | 0.1 | 629.97 | 0.03 | 629.95 | 0.06 | 629.97 | 0.03 |
| γ6,3 | | | | | | | | | | | | | | | 714.7 | 0.2 | | | 714.7 | 0.2 |
| γ7,3 | 740 | 5 | 723 | 5 | 725.6 | 0.2 | 725.67 | 0.08 | 725.6 | 0.1 | 725.6 | 0.7 | 725.6 | 0.1 | 725.70 | 0.03 | 725.67 | 0.08 | 725.70 | 0.03 |
| Unplaced | | | | | | | 874.17 | 0.23 | | | | | | | | | 874.2 | 0.25 | | |
| Unplaced | | | | | 896.2 | 0.3 | 896.36 | 0.3 | | | | | | | | | 896.4 | 0.3 | | |
| From g.s. | | | | | | | 914.97 | 0.12 | | | 914 | | | | | | 915 | 0.1 | | |
| γ8,3 | 910 | 10 | 913 | 5 | 914.9 | 0.2 | 915.31 | 0.06 | 915.1 | 0.3 | 915.6 | 0.8 | 914.9 | 0.1 | 915.33 | 0.03 | 915.31 | 0.06 | 915.33 | 0.03 |
| γ9,3 | 1005 | 10 | 1011 | 10 | 1013.7 | 0.3 | 1013.8 | 0.08 | 1013.6 | 0.3 | 1013.6 | 0.9 | 1013.7 | 0.1 | 1013.81 | 0.03 | 1013.8 | 0.08 | 1013.81 | 0.03 |
| Unplaced | | | | | | | 1121.26 | 0.33 | | | | | | | | | 1121.3 | 0.3 | | |
| γ6,1 | | | | | | | 1345.02 | 0.3 | | | | | | | 1344.6 | 0.2 | 1345 | 0.3 | 1344.6 | 0.2 |
| From g.s. | 1470 | 15 | 1460 | 10 | 1465.1 | 0.2 | 1465.19 | 0.1 | 1465.2 | 0.6 | 1464.5 | 1.5 | 1465.1 | 0.1 | | | 1465.2 | 0.1 | 1465.12 | 0.03 |
| Unplaced | 1610 | 15 | | | | | | | | | | | | | | | | | | |

* Uncertainty of 0.1 keV on energy assumed on 1971Mo04 data
§ The values in 1984LaZZ are from 1970FoZZ, with the uncertainties rationalised

*Emission Intensities*

A number of relative (see Table 4) measurements have been published for the γ-ray intensities. No absolute measurements have been made. Details of the detectors used and the measurement timescale are given in Table 5.

Table 4: Measured relative intensities of γ-rays in $^{148}Sm$ from the decay of $^{148m}Pm$, the 629,97 keV γ ray being the reference line

| | Energy | 1959Bh95* | | 1961El02 | 1962Sc04 | 1962Re03 | | 1963Ba31 | | 1969Gr32 | 1970FoZZ | | 1970Gr09 | | 1970GrYP | | 1971Mo04 | | 1977Ka14 | | Recommended | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{148}Pm$ | | | | | | | | | | | | | | | | | | | | | | |
| $\gamma_{2,1}$ | 61.30 | | | | | | | | | | | | | | | | | | | | | |
| $\gamma_{1,0}$ | 75.8 | ~4 | | 2.4 | | 1.1 | 0.4 | 1.7 | 0.5 | | 7.3 | 0.8 | 1.1 | 0.2 | | | | | | | | |
| $^{148}Sm$ | | | | | | | | | | | | | | | | | | | | | | |
| $\gamma_{9,8}$ | 98.48 | ~4 | | | 9.1 | 3.2 | 0.4 | 3.4 | 0.8 | | 3.3 | 1.7 | 3.5 | 0.5 | 6.4 | 0.7 | 4.29 | 0.12 | 2.78 | 0.05 | 3.33 | 0.29 |
| $\gamma_{8,7}$ | 189.63 | 11 | | 7.2 | 3.8 | ~1.0 | | 1.5 | | | 1.2 | 0.1 | 1.1 | 0.2 | 1.6 | 0.1 | 1.39 | 0.05 | 1.24 | 0.03 | 1.31 | 0.07 |
| $\gamma_{9,7}$ | 288.11 | | | | | 11 | 2 | | | 17 | 13.0 | 0.2 | 14 | 2 | 15 | 1 | 13.9 | 0.3 | 14.1 | 0.1 | 13.7 | 0.4 |
| $\gamma_{,}$ | 295.06 | 20 | 5 | 16.9 | 14.0 | | | 16 | 3 | | 0.08 | 0.01 | | | | | | | | | | |
| $\gamma_{9,6}$ | 299.1 | | | | | | | | | | 0.20 | 0.02 | | | | | | | 0.1 | 0.02 | 0.15 | 0.05 |
| $\gamma_{7,4}$ | 311.63 | | | | | 5 | 2 | | | 5 | 4.07 | 0.09 | 4.5 | 0.7 | 3.7 | 0.3 | 4.46 | 0.12 | 4.4 | 0.05 | 4.29 | 0.11 |
| $\gamma_{8,5}$ | 362.09 | | | | | | | | | | 0.19 | 0.02 | | | | | | | 0.2 | 0.02 | 0.195 | 0.014 |
| $\gamma_{4,3}$ | 414.07 | 20 | 4 | }25.3 | 13.9 | 19 | 4 | 24 | 4 | 25 | 20.2 | 0.5 | 22 | 3 | 22.5 | 1.5 | 20.8 | 0.5 | 21.0 | 0.2 | 20.9 | 0.2 |
| $\gamma_{4,2}$ | 432.78 | | | | 13.9 | 8 | 3 | | | | 5.7 | 0.1 | 5.8 | 0.9 | 6.2 | 0.7 | 6.35 | 0.20 | 6.0 | 0.1 | 5.9 | 0.1 |
| $\gamma_{9,5}$ | 460.57 | | | | | | | | | | 0.45 | 0.01 | | | | | | | 0.47 | 0.02 | 0.45 | 0.01 |
| $\gamma_{8,4}$ | 501.26 | | | | | 8 | 3 | | | | 7.5 | 0.02 | 8.1 | 1.2 | 7.9 | 0.8 | 7.74 | 0.19 | 7.6 | 0.1 | 7.51 | 0.02 |
| $\gamma_{,}$ | 533.6 | | | | | | | }105 | 15 | | 0.32 | 0.02 | | | | | | | | | | |
| $\gamma_{1,0}$ | 550.27 | 100 | 20 | 120.5 | 100.0 | 99 | 5 | | | 120 | 106.2 | 3.2 | 109.5 | 16.4 | 112.6 | 4.6 | 106.1 | 1.9 | 106.6 | 0.8 | 106.5 | 0.7 |
| $\gamma_{5,3}$ | 553.24 | | | | | | | | | | 0.34 | 0.04 | | | | | | | 0.45 | 0.04 | 0.4 | 0.05 |
| $\gamma_{5,2}$ | 571.95 | | | | | | | | | | 0.24 | 0.01 | | | | | | | 0.24 | 0.01 | 0.24 | 0.007 |
| $\gamma_{9,4}$ | 599.74 | | | | | | | | | 12 | 14.1 | 0.3 | 14 | 2 | 15.1 | 0.5 | 13.9 | 0.3 | 14.09 | 0.13 | 14.07 | 0.11 |
| $\gamma_{2,1}$ | 611.26 | | | | | | | | | 6 | 6.6 | 0.1 | 7 | 1 | 7.0 | 0.3 | 6.29 | 0.22 | 6.16 | 0.1 | 6.4 | 0.2 |
| $\gamma_{3,1}$ | 629.97 | 100 | 20 | 100 | 100.0 | 100 | | 100 | | 100 | 100.0 | 3.2 | 100 | 15 | 100 | | 100 | 1.4 | 100 | 0 | 100 | |
| $\gamma_{6,3}$ | 714.7 | | | | | | | | | | | | | | | | | | 0.051 | 0.006 | 0.051 | 0.006 |
| $\gamma_{7,3}$ | 725.70 | 30 | 6 | 45.8 | 37.0 | 33 | 3 | 38 | 7 | 35 | 36.3 | 0.8 | 34.9 | 5.2 | 36.3 | 1.2 | 36.8 | 0.7 | 36.89 | 0.29 | 36.79 | 0.25 |
| $\gamma_{8,3}$ | 915.33 | 23 | 5 | 25.3 | 20.8 | 20 | 2 | 22 | 4 | 23 | 20.4 | 0.8 | 22.1 | 3.3 | 22.0 | 1.7 | 22.1 | 0.6 | 19.29 | 0.2 | 20.4 | 0.5 |
| $\gamma_{9,3}$ | 1013.81 | 25 | | 25.3 | 23.1 | 21 | 2 | 21 | 4 | 21 | 21.4 | 0.5 | 23.2 | 3.5 | 19.5 | 1.8 | 22.9 | 0.6 | 22.79 | 0.19 | 22.6 | 0.23 |
| $\gamma_{6,1}$ | 1344.6 | | | | | | | | | | 0.06 | 0.01 | | | | | | | 0.066 | 0.005 | 0.0648 | 0.0045 |
| $\gamma_{,}$ | 1465.12 | | | 2.4 | 4.9 | 1.7 | 0.3 | 2.5 | 1 | | 1.5 | 0.1 | 1.7 | 0.3 | 2.1 | 0.2 | 1.43 | 0.16 | | | 1.59 | 0.1 |

* States intensities are "correct to 20%" above 400 keV, with larger uncertainties below 400 keV

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 |
| 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 |
| 1969Gr32 | GeLi | 2-3 hours after irradiation |
| 1970FoZZ | GeLi | Immediately after irradiation, then two and twelve weeks later |
| 1970Gr09 | GeLi | Made 24 measurements, but no timescale given |
| 1970GrYP | GeLi | No timing details given |
| 1971Mo04 | GeLi | 3 to 75 days |
| 1977Ka14 | GeLi | Four sources produced periodically over 10 month measuring period |

The absolute intensities have been determined from placing the γ-rays into the decay scheme, and assuming the 550 keV γ-ray has a $P_{(\gamma+ce)}$ of 94.4 (5) %, i.e. it is emitted in every single $\beta^-$ decay, so all higher levels decay through this level to the ground state, with no direct beta-feeding to the ground state. Assuming the transition is E2, then $\alpha_T$ = 0.009 98 (14), gives $P_{(\gamma)}$ = 93.5 (14) % for a relative intensity of 106.5 (7). Thus for the 629.95 keV γ-ray, with a relative intensity of 100, then $P_{(\gamma)}$ = 87.8 (14) %, where the normalisation factor of 0.878 (14) is obtained from 93.5 × 100/106.5.

*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 1961Br41, 1961Ha23 (measured conversion electrons and deduced multipolarities) , 1962Re03, 1962Sc04, 1963Ba31 (measured conversion electrons and γ-ray directional correlations), 1968Wy02, 1977Ka14 (γ-ray directional correlations), and 1963Ku09, 1970GrYP (measured conversion electrons).

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

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

| | Energy | 1963Ba31 | | 1970GrYP | | BrIcc | |
|---|---|---|---|---|---|---|---|
| $^{148}Pm$ | | | | | | | |
| $\gamma_{1,0}$ | 75.8 | 2.9 | 0.4 | 2.5 | 0.8 | 2.9 | 0.4 |
| $^{148}Sm$ | | | | | | | |
| $\gamma_{9,8}$ | 98.15 | 1.9 | 0.8 | 1.0 | 0.2 | 1.488 | 0.021 |
| $\gamma_{8,7}$ | 189.61 | 0.17 | | 0.11 | 0.04 | 0.176 9 | 0.025 |
| $\gamma_{9,7}$ | 288.09 | 0.062 | 0.020 | 0.048 | 0.009 | 0.076 3 | 0.001 1 |
| $\gamma_{7,4}$ | 311.62 | 0.012 | 0.004 | 0.011 | 0.002 | 0.011 41 | 0.000 16 |
| $\gamma_{4,3}$ | 414.02 | 0.006 5 | 0.002 0 | | | 0.005 72 | 0.000 09 |
| $\gamma_{4,2}$ | 432.71 | 0.017 | 0.005 | 0.017 | 0.003 | 0.015 44 | 0.000 22 |
| $\gamma_{8,4}$ | 501.25 | 0.003 3 | 0.000 9 | 0.003 2 | 0.000 8 | 0.003 69 | 0.000 07 |
| $\gamma_{1,0}$ | 550.22 | | | 0.007 9 | 0.000 6 | 0.008 25 | 0.000 12 |
| $\gamma_{9,4}$ | 599.69 | | | 0.002 0 | 0.000 7 | 0.002 49 | 0.000 04 |
| $\gamma_{2,1}$ | 611.23 | 0.002 4 | 0.000 8 | 0.002 5 | 0.000 8 | 0.002 37 | 0.000 04 |
| $\gamma_{3,1}$ | 629.95 | 0.006 0 | 0.001 2 | | | 0.005 91 | 0.000 09 |
| $\gamma_{7,3}$ | 725.67 | 0.003 8 | 0.000 7 | 0.004 6 | 0.000 4 | 0.004 24 | 0.000 06 |
| $\gamma_{8,3}$ | 915.31 | 0.002 5 | 0.000 5 | 0.002 5 | 0.000 4 | 0.002 54 | 0.000 04 |
| $\gamma_{9,3}$ | 1013.8 | 0.002 0 | 0.000 4 | 0.002 4 | 0.000 4 | 0.002 06 | 0.000 04 |

## 2.4. 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 emission intensities is presented in Table 7. Note that all experimental measurements were made relative and only appear absolute after consideration of the decay scheme.

Table 7: Measured intensities and recommended absolute intensities of $\beta^-$-emissions from the decay of $^{148m}Pm$

| | 1962Sc04 | | 1962Re03 | | 1963Ba31† | | Recommended | |
|---|---|---|---|---|---|---|---|---|
| | E (keV) | $I_\beta$ (%) | E (keV) | $I_\beta$ (%) | E (keV) | $I_\beta$ (%) | E (keV) | $I_\beta$ (%) |
| $\beta_{0,9}$ | 390 (30) | 45 | | | 400 (30) | 48 (10) | 414 (6) | 54.0 (9) |
| $\beta_{0,8}$ | 490 (30) | 13 | 510 | 37 | 500 (30) | 28 (10) | 513 (6) | 18.1 (9) |
| | 560 (25) | 16 | 610 | 19 | | | | |
| $\beta_{0,7}$ | 680 (20) | 18 | 680 | 8 | 690 (30) | 16 (5) | 702 (6) | 21.8 (7) |
| | | | 800 | 24 | | | | |
| $\beta_{0,4}$ | | | | | | | 1014 (6) | 0.93 (45) |

† Same data as published in 1963Ew01 and 1963Ba06 by the same authors

## 2.5. 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

| Sm | | Pm | |
|---|---|---|---|
| $\omega_K$ | 0.926 (4) | $\omega_K$ | 0.922 (4) |
| $\omega_L$ | 0.158 (6) | $\omega_L$ | 0.148 (6) |
| $\eta_{KL}$ | 0.857 (4) | $\eta_{KL}$ | 0.861 (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 probabilities have been calculated using the computer program EMISSION (v3.10, 28-Jan-2003) described in 2000Sc47.

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