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PROMETHIUM ISOTOPIC POWER DATA SHEETS

H. T. FULLAM
H. H. VAN TUYL

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H. T. Fullam and H. H. Van Tuyl

INTRODUCTION

The Division of Isotopes Development of the Atomic Energy Commission has assigned to Pacific Northwest Laboratory (Battelle-Northwest) the responsibility of developing technology for the preparation and use of promethium as a radioisotopic fuel in space, marine, and terrestrial power applications. Technology has been developed (and demonstrated on a several hundred gram scale) to permit large scale preparation of highly purified promethium. The half-life and specific heat generation rate were measured, and shielding requirements for promethium have been studied. The existence of ^{146}Pm in production and power fuels was discovered and its consequences investigated. Sources up to 60 W were prepared and are being investigated for long term stability. Several magacuries of promethium have been set aside from Purex process solutions for use in the development program.

Best estimates of the nuclear, chemical, and physical properties of promethium are summarized in the following pages. In many cases the chemical and physical properties have not yet been measured for promethium, but estimates have been made from measured values for neighboring rare earths.

DATA SHEET

Promethium 147 Half-Life 2.62 yr

A. Fuel Form (as produced): Metal

1. Composition

Constituent	Content, wt% Minimum	Maximum	Reference
Promethium	95	99	
Samarium	0.5	5	
Neodymium	0.5	2	
Yttrium	0	2	
Lead	0	2	
Aluminum	0	1	

Constituent	Content, ppm by Activity Minimum	Maximum	Reference
^{146}Pm	0.2	0.3	(1)
^{148m}Pm	0	0.03	
^{154}Eu	0.00001	0.01	

(Purity can be as high as 99.99% at time of separation, but ^{147}Pm decays to stable ^{147}Sm at the rate of 2.2%/mo.)

2. Specific Power (95 wt% Pm)

a. 0.3164 ± 0.0005 W/g (2)

b. 882.4 ± 1.7 Ci/g (2)

3. Radiation (Composition by Activity: 0.25 ppm ^{146}Pm, 0.025 ppm ^{148}Pm, 0.001 ppm, ^{154}Eu)

	Energy, MeV	Particles/W-sec	Source	Reference
a. Alpha		None		
b. Beta	0.225	1.03×10^{14}	^{147}Pm	(3)
	0.104	3.1×10^{9}	^{147}Pm	
	0.78	9.0×10^{6}	^{146}Pm	(4)
	2.48	1.0×10^{5}	^{148}Pm	(5)
	1.93	2.6×10^{4}	^{148}Pm	

	Energy, MeV	Particles/W-sec	Source	Reference
Beta	1.02	7.7×10^4	^{148}Pm	
	0.71	4.9×10^5	^{148m}Pm	
	0.52	6.2×10^5	^{148m}Pm	
	0.42	1.3×10^6	^{148m}Pm	
	1.855	1.0×10^4	^{154}Eu	(6)
	0.87	2.5×10^4	^{154}Eu	
	0.58	3.9×10^4	^{154}Eu	
	0.26	2.9×10^4	^{154}Eu	

	Energy, MeV	Photons/W-sec	Source	Reference
c. Gamma	0.121	3.1×10^9	^{147}Pm	(3)
	0.75	1.7×10^7	^{146}Pm	(4)
	0.45	1.7×10^7	^{146}Pm	
	1.465	5.2×10^4	^{148}Pm	(5)
	1.015	5.2×10^5	^{148m}Pm	
	0.916	4.6×10^5	^{148m}Pm	
	0.914	3.4×10^4	^{148}Pm	
	0.727	8.5×10^5	^{148m}Pm	
	0.630	2.2×10^6	^{148m}Pm	
	0.611	1.5×10^5	^{148m}Pm	
	0.601	2.1×10^5	^{148m}Pm	
	0.551	2.4×10^6	^{148m}Pm, ^{148}Pm	
	0.502	1.8×10^5	^{148m}Pm	
	0.433	1.5×10^5	^{148m}Pm	
	0.414	3.9×10^5	^{148m}Pm	
	0.062-0.313	7.2×10^5	^{148m}Pm	
	1.61	2.1×10^3	^{154}Eu	(6)
	1.276	3.9×10^4	^{154}Eu	
	1.006	2.0×10^4	^{154}Eu	
	0.997	1.1×10^4	^{154}Eu	
	0.874	1.5×10^4	^{154}Eu	
	0.758	2.1×10^3	^{154}Eu	
	0.724	2.1×10^4	^{154}Eu	

		Energy,Mev	Photons/W-sec	Source	Reference
	Gamma	0.693	3.1×10^3	^{154}Eu	
		0.593	6.2×10^3	^{154}Eu	
		0.248	6.2×10^3	^{154}Eu	
		0.123	3.3×10^4	^{154}Eu	
d.	Brems-Strahlung	0.22	2.6×10^4	^{147}Pm, ^{146}Pm, ^{148}Pm	(7)
		0.20	8.0×10^6	^{147}Pm	
		0.18	9.4×10^7	^{147}Pm	
		0.16	4.8×10^8	^{147}Pm	
		0.14	1.7×10^9	^{147}Pm	
		0.12	4.8×10^9	^{147}Pm	
		0.10	1.2×10^{10}	^{147}Pm	
		0.08	3.0×10^{10}	^{147}Pm	
		0.06	7.4×10^{10}	^{147}Pm	
		0.04	2.0×10^{11}	^{147}Pm	
		0.02	7.2×10^{11}	^{147}Pm	
e.	Neutrons		None		

4. Half Lives

Nuclide	Half Life	
^{147}Pm	2.620 + 0.005 yr	(2)
^{146}Pm	4.40 ± 0.2 yr	(8)
^{148m}Pm	41 days	
^{154}Eu	16 yr	

Since little information is available on promethium and its compounds, most of the data given in Sections 5, 6, 7 and 8 of the following tables were obtained by interpolation from existing data for neodymium, samarium and other rare earths. The data listed in brackets were obtained by interpolation.

5. Compatibility with Materials of Containment (9)

(Promethium metal)

6. Physical Properties (Promethium metal)	Value	Reference
a. Density g/cm^3	7.3	(10)
b. Coefficient of linear thermal expansion		
25 °C	[$6.7 \pm 0.4 \times 10^{-6}$]	(11-13)
Average -173 to 800 °C	[8.6×10^{-6}]	(11-13)
c. Heat capacity (cal/mole-°C) 0-1035 °C	[$C_p = 6.5 + 0.0025T$]	(13)
d. Melting Point (°C)	865 1080	(14) (15)
e. Boiling Point (°C)	[3200]	(13)
f. Phase Transition Temperature (°C)	[890]	(10)
g. Heat of Phase Transition (kcal/mole)	[0.73]	(10,11)
h. Heat of Vaporization (kcal/mole)	[60]	(10)
i. Heat of Fusion (kcal/mole)	[1.88] [1.95]	(10,11,13) (16)
j. Vapor Pressure (mmHg)	[$\log P = 6.50 - \frac{13,000}{T}$]	(17)
k. Thermal Conductivity		
(cal/sec-cm-°C) 300 °K	[0.031]	(17)
(W/cm °C) 300 °K	[0.179]	(16)
l. Thermal Diffusivity	-	
m. Viscosity	-	
n. Surface Tension (dynes/cm) 2300 °C	[40 - 70]	(18)
o. Total Hemispherical Emissivity	-	
p. Spectral Emissivity	-	
q. Crystallography BCC	a = 7.60 A°	(14)
r. Solubilities	-	
s. Diffusion Rates	-	

7. Mechanical Properties (Promethium metal)

	Value: Cast	Value: Cold Work	Reference
a. Hardness--Vickers at 27 °C	[74]	[76]	(19,20)
Rockwell H	[56]		(13)
Brinell HN	[45]		(11,13)
b. Crush Strength			

8. Chemical Properties (Promethium metal)

a. Thermodynamic Functions

	Value	Reference
1. So (cal/mole-deg) 300 °K	[17.1]	(13)
2. $\frac{H_t^\circ - H_o^\circ}{T}$ (cal/mole-deg) 300 °K	[6.07]	(13)
3. $\frac{F_t^\circ - H_o^\circ}{T}$ (cal/mole-deg) 300 °K	[11.0]	(13)

b. Chemical Reactions

Promethium metal can be expected to react in the same general fashion as other rare earth metals. Typical reactions might include the following:

$2\ Pm + 3/2\ O_2 \xrightarrow{>25\ °C} Pm_2O_3$ (10)

$2\ Pm + 3\ S \xrightarrow{500\ °C} Pm_2S_3$ (21)

$Pm + H_2 \xrightarrow{>25\ °C} PmH_x$ (21)

$Pm + 1/2\ N_2 \xrightarrow{900\ °C} PmN$ (21)

$Pm + 3\ H_2O \longrightarrow Pm(OH)_3 + 3/2\ H_2$ (20)

9. Biological Tolerances

Maximum Permissible Concentration, μ Ci/ml

	40 hr Week: Air	40 hr Week: Water	168 hr Week: Air	168 hr Week: Water	
Soluble	6×10^{-8}	6×10^{-3}	2×10^{-9}	2×10^{-4}	(22)
Insoluble	1×10^{-7}	6×10^{-3}	3×10^{-9}	2×10^{-4}	

10. Shielding Data — Reference (23)

Material	Shielding for 100X Attenuation, g/cm^2
U	2.0 to 50
Pb	1.5 to 59
W	1.7 to 66
Mo	4.8 to 93
Fe	15 to 103

(Thickness varies with source size and shape, and amount of other external shielding)

Shield Thickness cm of Uranium	Dose Rate at One Meter, mR/hr				
	10,000W	1000W	100W	10W	1W
0.01	2000	500	100	30	6
0.02	1000	300	70	20	3
0.05	700	200	30	6	1
0.1	400	90	20	3	0.4
0.2	300	60	10	2	0.2
0.5	200	40	6	0.9	0.1
1	70	20	3	0.4	0.04
2	10	3	0.5	0.07	0.008

B. Fuel Form (as produced): Sesquioxide (Pm_2O_3)

1. Composition

Constituent	Content, Wt%		Reference
	Minimum	Maximum	
Promethium	81	85	
Samarium	0.4	4	
Neodymium	0.4	1.7	
Yttrium	0	1.7	
Lead	0	1.7	
Aluminum	0	0.9	
Oxygen	14.0	14.7	

Constituent	Content, ppm by Activity Minimum	Maximum	Reference
			(1)

2. Specific Power (82 wt% Pm)

a.	0.2731 ± 0.0004 W/g	(2)
b.	761.6 ± 1.4 Ci/g	(2)

3. Radiation

   Same as for ^{147}Pm metal.

4. Half Lives

   Same as for ^{147}Pm metal.

Since little information is available on promethium and its compounds, most of the data given in Sections 5, 6, 7 and 8 of the following tables were obtained by interpolation from existing data for neodymium, samarium and other rare earths. The data listed in brackets were obtained by interpolation.

5. Compatibility with Materials of Containment (Pm_2O_3) (9)

6. Physical Properties (Pm_2O_3)

	Property		Value	Reference
a.	Density (g/cm^3)	A. Pm_2O_3	7.62	(14)
	(Theoretical,	B. Pm_2O_3	7.43	
	X-ray data.)	C. Pm_2O_3	6.84	
b.	Coefficient of linear thermal expansion		[9×10^{-6}]	(10)
c.	Heat Capacity (cal/mole-°C)		[$C_p = 29 + 0.00576T - \frac{415,000}{T^2}$]	(24)
d.	Melting Point (°C)		[2130]	(29)
e.	Boiling Point (°C)		[>3000]	(13)

		Value	Reference
f.	Phase Transition Temperature (°C)		
	C. Pm_2O_3 → B. Pm_2O_3	950 °C	(14)
	B. Pm_2O_3 → A. Pm_2O_3	>1000 °C	(14)
g.	Heat of Transition	-	
h.	Heat of Vaporization (kcal/mole)	[415]	(13)
i.	Heat of Fussion (kcal/mole)	-	
j.	Vapor Pressure (mmHg) for Lanthanum	[$\log P = 15.62 - \frac{39,800}{T}$]	(25)
k.	Thermal Conductivity (cal/sec-cm-°C)	[$k = 0.0045 + 1.414 \times 10^{-8} (1020-T)^2$]	(26)
l.	Thermal Diffusivity	-	
m.	Viscosity	-	
n.	Surface Tension	-	
o.	Total Hemispherical Emmissivity	-	
p.	Spectral Emmisivity	-	
q.	Crystallography		
	A. Pm_2O_3 hcp.	a = 3.806;c = 5.954	(14)
	B. Pm_2O_3 Monocl.	a = 14.15;b = 3.69;c = 8.78	(14)
	C. Pm_2O_3 bcc	a = 10.99	(14)
r.	Solubilities in H_2O Sol. Prod.	1×10^{-22} for $Pm(OH)_3$	(27)
s.	Diffusion Rates	-	

7. Mechanical Properties (Pm_2O_3)

		Value	Reference
a.	Hardness	-	
b.	Crush Strength	-	

8. Chemical Properties (Pm_2O_3)

	Value	Reference
a. Thermodynamic Properties		
1. ΔH_f° kcal/mole (298 °K)	[-433]	(13)
2. S° cal/mole-°C (298 °K)	[36.5]	(13)
3. ΔF_f° kcal/mole (298 °K)	[-413]	(28)

b. Chemical Reactions

Promethium oxide can be expected to react in the same general fashion
a as the oxides of samarium and neodymium. Typical reactions might include:

$$Pm_2O_3 + 6\ HCl_{(aq)} \rightarrow 2\ PmCl_3 \cdot X\ H_2O \quad (13)$$

$$Pm_2O_3 + 6\ HNO_3 \rightarrow 2\ Pm(NO_3)_3$$

$$Pm_2O_3 + HF \xrightarrow{700\ ^\circ C} 2\ PmF_3 + 3\ H_2O \quad (20)$$

$$Pm_2O_3 + 7C \xrightarrow{\geq 1000\ ^\circ C} 2\ PmC_2 + 3\ CO \quad (11)$$

9. Biological Tolerances

Same as for ^{147}Pm metal.

10. Shielding Data

Within limits of reporting, the same as for ^{147}Pm metal.

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