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CURIUM DATA SHEETS

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Request compliance with indicated action: Please make the following pen and ink correction to the table on page 4 of the subject report.

1st line, second column should read: 3.6×10^7 instead of 3.6×10^5

1st line, tenth column should read: 3.2×10^8 instead of 2.8×10^8

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ISOTOPES DEVELOPMENT CENTER

CURIUM DATA SHEETS

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CURIUM-244 DATA SHEETS

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A. CURIUM SESQUIOXIDE (Cm₂O₃)

²⁴⁴Cm half-life:¹ 18.12 years

1. Composition

a. Radionuclidic abundance

The isotopic composition of ²⁴⁴Cm products recovered from wastes generated by the processing of spent power reactor fuels is chosen as representative of the most probable fuel form for the next decade. The calculated isotopic composition is based on spent Diablo Canyon reference fuel as typical for a light-water reactor.²

Isotopic Composition of Curium Product^a

<u>Isotopic Mass</u>	<u>Wt %</u>	<u>Half-life (y)</u>
243	0.25	32.
244	91.77	18.12
245	7.16	8265.
246	0.82	4655.

^a Five years after reactor discharge. The ²⁴²Cm (half-life, 0.446 y) content (0.015 wt %) contributes <1% to the total heat output and is neglected along with minor amounts of ²⁴⁷Cm and ²⁴⁸Cm.

b. Radiochemical purity³

The ²⁴⁴Cm product will contain small amounts of fission products that are not removed in the chemical separations process. The gamma activities of the fission product impurities can be calculated and are tabulated in the table in Section A.3.c. (p. 4) in the column labeled "From Impurities." Almost all of the gamma rays above 1 MeV are from ¹⁴⁴Pr and ¹⁵²⁻¹⁵⁴Eu, and those below 1 MeV are primarily from ⁹⁵Zr-⁹⁵Nb, ¹⁴⁴Ce, ¹⁰⁶Rh, and ¹⁰³Ru-¹⁰³Rh. In addition, fission products will also be formed by the spontaneous fission of the ²⁴⁴Cm and ²⁵²Cf, which is present at an estimated maximum of 4×10^{-5} wt % of the ²⁴⁴Cm. The gamma activities from these spontaneous fission products are tabulated under the columns labeled "From Fission Products of ²⁴⁴Cm and ²⁵²Cf." Americium-243 and ²⁵²Cf which are formed in the reactor irradiation process are removed during chemical processing except for an estimated 0.5 wt % ²⁴³Am and $<4 \times 10^{-5}$ wt % ²⁵²Cf in the ²⁴⁴Cm product.

c. Chemical purity⁴

The following elemental impurity limits were set as objectives for the ²⁴⁴Cm process by Savannah River Plant during the CY 1968-1969 campaign:

<u>Elemental Impurities</u>	<u>Maximum Wt % of Cm</u>
Li + Na + K (total)	0.1
Si + Zn (total)	0.1
Fe + Cr + Ni (total)	0.2
²⁴⁰ Pu	a
Any other single impurity (except Am, Pu, Zr)	0.2
Total of all impurities (except Am, Pu, Zr)	1.0
Total of all impurities (except Pu)	3.0

^aPlutonium-240 as a decay product of ²⁴⁴Cm will be present in amounts increasing with time following chemical processing and should be taken into account.

d. Phase composition of various curium oxides⁵⁻⁹

CmO _{2.00}	CmO _{1.52-1.62} (C-type)
CmO _{1.81}	CmO _{1.50} (B- and A-type)
CmO _{1.71} (Cm ₇ O ₁₂)	

2. Specific Power and Power Density^{1,10-12}

- 2.58 W/g of 100% chemically pure ²⁴⁴Cm₂O₃ (100% ²⁴⁴Cm isotope)
2.37 W/g of 100% chemically pure ²⁴⁴Cm₂O₃^a
2.30 W/g of 97% chemically pure ²⁴⁴Cm₂O₃^a
- Specific power values are based on 80.9 Ci/g of ²⁴⁴Cm (100%) isotope and 35.0 W/kCi of ²⁴⁴Cm (2.83 W/g of ²⁴⁴Cm).
- Power density of 100% pure Cm₂O₃^a is 27.66 W/cm³ at 100% density (11.67 g/cm³).

^aIsotopic composition of curium as given in Section A.1.a.

3. Radiationa. Alpha particles^{1,10-12}

<u>Nuclide</u>	<u>Max E (MeV)</u>	<u>Av E (MeV)</u>	<u>Abundance (%)</u>	<u>W/kCi</u>	<u>Particles W⁻¹ sec⁻¹</u>
²⁴⁴ Cm	5.801	5.801	76.7	35.0	0.804 × 10 ¹²
	5.759	5.759	23.3		0.244 × 10 ¹²

The volume of helium from alpha decay as a function of decay time is given in the following table.

Volume of Helium ^a (cm ³ of He per g of ²⁴⁴ Cm)	Time	
	Years	Half-lives
6.15	1.8	0.1
11.8	3.6	0.2
17.3	5.4	0.3
22.1	7.2	0.4
26.9	9.1	0.5
31.2	10.9	0.6
35.3	12.7	0.7
39.1	14.5	0.8
42.6	16.3	0.9
45.9	18.1	1.0
59.3	27.1	1.5
68.9	36.2	2.0
80.3	54.3	3.0
86.1	72.4	4.0
88.9	90.5	5.0
91.7	181.0	10.0

^aStandard conditions.

b. Beta particles

None

c. Gamma³

The significant gamma emissions of product-grade ²⁴⁴Cm are listed in the following table. The gamma emissions result from the following:

- (1) Decay of curium nuclides and of ²⁴³Am (based on 0.25 wt % ²⁴³Cm, 91.77 wt % ²⁴⁴Cm, and 0.5 wt % ²⁴³Am).
- (2) Spontaneous fission of ²⁴⁴Cm and ²⁵²Cf (based on a maximum of 4×10^{-5} wt % ²⁵²Cf).
- (3) Decay of fission products resulting from the spontaneous fission of ²⁴⁴Cm and ²⁵²Cf.
- (4) Decay of fission products formed in the irradiation process and not removed in the chemical separation process.

Significant Gamma Rays of Curium-244 Product

Energy (MeV)	Abundance (photons per sec per W of ^{244}Cm product)								Total
	From Decay of Nuclides			From Spontaneous Fission		From Fission Products of		From Impurities	
	^{243}Cm	^{244}Cm	^{243}Am	^{244}Cm	^{252}Cf	^{244}Cm	^{252}Cf		
0.0-0.5	3.6×10^7	2.5×10^8	1.0×10^7	4.1×10^6	4.9×10^5	2.2×10^6	1.9×10^5	2.2×10^7	3.2×10^8
0.5-1.0	—	2.2×10^6	—	2.6×10^6	2.5×10^5	6.7×10^6	6.0×10^5	7.5×10^6	2.0×10^7
1.0-2.0	—	—	—	1.9×10^6	1.8×10^5	1.5×10^6	1.3×10^5	1.1×10^6	4.8×10^6
2.0-3.0	—	—	—	6.0×10^5	4.9×10^4	6.0×10^5	5.2×10^2	3.7×10^5	1.6×10^6
3.0-4.0	—	—	—	1.8×10^5	1.3×10^4	—	—	—	1.9×10^5
4.0-5.0	—	—	—	6.0×10^4	3.7×10^3	—	—	—	6.4×10^4
5.0-6.0	—	—	—	3.3×10^4	1.0×10^3	—	—	—	3.4×10^4
6.0-7.0	—	—	—	5.6×10^3	1.5×10^2	—	—	—	5.8×10^3

d. Bremsstrahlung

Negligible

e. Neutrons

- 4.04×10^6 n/sec.W of ^{244}Cm from spontaneous fission (half-life for spontaneous fission is 1.34×10^7 years).¹⁰⁻¹²
- 1.51×10^5 n/sec.W of ^{244}Cm from (α, n) reaction on oxygen in Cm_2O_3 .¹⁰
- 2.9×10^4 n/sec.W of ^{244}Cm due to spontaneous fission of ^{246}Cm (0.82%) from a spontaneous fission half-life of 1.66×10^7 years and 3.08 neutrons/fission.¹²⁻¹⁴
- 3.5×10^5 n/sec.W of ^{244}Cm from estimated maximum of ^{252}Cf content of 4×10^{-5} wt %.¹⁰
- The energy distribution of spontaneous fission neutrons from ^{244}Cm is given in the table on page 5.³
- The energy distribution of neutrons occurring as a result of the interaction of fast alpha particles from ^{244}Cm decay with oxygen atoms in Cm_2O_3 is given in the table on page 6.³

Energy Distribution of Spontaneous
Fission Neutrons from Curium-244

Energy (MeV)	Abundance (n/sec.W of ^{244}Cm)
0.3-0.4	1.51×10^5
0.4-0.6	3.13×10^5
0.6-0.8	3.20×10^5
0.8-1.0	2.77×10^5
1.0-1.2	2.84×10^5
1.2-1.4	2.80×10^5
1.4-1.6	2.44×10^5
1.6-1.8	2.19×10^5
1.8-2.0	1.98×10^5
2.0-2.2	1.80×10^5
2.2-2.4	1.65×10^5
2.4-2.6	1.58×10^5
2.6-2.8	1.30×10^5
2.8-3.0	1.08×10^5
3.0-3.2	1.01×10^5
3.2-3.4	0.97×10^5
3.4-3.6	0.93×10^5
3.6-3.8	0.75×10^5
3.8-4.0	0.79×10^5
4.0-4.4	1.04×10^5
4.4-4.8	0.86×10^5
4.8-5.2	0.65×10^5
5.2-5.6	0.50×10^5
5.6-6.0	0.40×10^5
6.0-6.4	2.95×10^4
6.4-6.8	2.12×10^4
6.8-7.2	1.47×10^4
7.2-7.6	1.12×10^4
7.6-8.0	0.90×10^4
8.0-8.8	1.01×10^4
8.8-9.6	2.95×10^3
9.6-10.4	3.1×10^3
10.4-11.2	2.05×10^3
11.2-12.8	1.40×10^3

Neutrons from (α, n) Reactions with Oxygen

Energy (MeV)	Abundance (n/sec.W of ^{244}Cm)
0.2	1.62×10^2
0.4	0.68×10^3
0.6	0.83×10^3
0.8	1.69×10^3
1.0	2.70×10^3
1.2	0.43×10^4
1.4	0.61×10^4
1.6	0.83×10^4
1.8	1.01×10^4
2.0	1.19×10^4
2.2	1.33×10^4
2.4	1.40×10^4
2.6	1.40×10^4
2.8	1.37×10^4
3.0	1.22×10^4
3.2	1.01×10^4
3.4	0.79×10^4
3.6	0.50×10^4
3.8	3.02×10^3
4.0	2.01×10^3
4.2	1.37×10^3
4.4	0.86×10^3
4.6	0.72×10^2

4. Critical Mass¹⁵

The critical mass of unreflected and reflected spheres of $^{244}\text{Cm}_2\text{O}_3$ has been calculated by C. W. Craven, Jr., at ORNL using the cross-section data available as of November 1965. The results, shown in the following table, agree within 10% of the results obtained in a replacement experiment at Los Alamos. The critical mass equation used is:

$$M_c = 2370/\rho^2 \quad (\text{kg})$$

where ρ = density of Cm_2O_3 .

Calculated Critical Mass of $^{244}\text{Cm}_2\text{O}_3$

Core		Reflector		Critical Mass (kg)	Critical Radius (cm)
Mixture	Density (g/cm ³)	Mixture	Thickness (cm)		
Cm_2O_3 ^a	10.60	Bare	-	21.1	7.8031
Cm_2O_3	9.01	Bare	-	29.2	9.1803
Cm_2O_3	10.60	Au-H ₂ O	4.0-15.0	11.9	6.4540
Cm_2O_3	10.60	Au-H ₂ O	2.0-7.5	13.5	6.7188
Cm_2O_3	10.60	Au-H ₂ O	0.5-2.0	16.5	7.1966

^aAssumed composition: 98.07 wt % ^{244}Cm and 1.93 wt % ^{241}Pu .

5. Compatibility

The compatibility of $^{244}\text{Cm}_2\text{O}_3$ with potential container materials has been studied at 750, 1250, 1650, 1800, 1850, and 2000°C for times up to 12,000 hr. In all of these tests, a $^{244}\text{Cm}_2\text{O}_3$ hot-pressed pellet was heated to the desired temperature while in contact with a specimen of the test material in a sealed capsule of the same material. Components from the system were then evaluated by metallographic, autoradiographic, or electron-beam microprobe techniques.

a. Tests at 750°C¹⁶

The following metals and alloys have been evaluated with $^{244}\text{Cm}_2\text{O}_3$ for 1000 and 10,000 hr at 750°C: Ni, Ni-10% Cr, Ni-7% Cr-16% Mo-5% Fe (Hastelloy N), Ni-20% Cr, Ni-16% Cr-16% Mo-6% Fe-3% W (Hastelloy C), Co-10% Cr, and Co-20% Cr-15% W-10% Ni (Haynes alloy No. 25).

In general, the results indicated good compatibility between $^{244}\text{Cm}_2\text{O}_3$ and all the materials tested. Metallographic observations are summarized in the table on page 8. Only Hastelloy N of the three commercial alloys showed any evidence of attack after 10,000 hr.

b. Tests at 1250°C¹⁷

The following materials were tested with $^{244}\text{Cm}_2\text{O}_3$ for 1000 and 10,000 hr at 1250°C: Nb, Nb-1% Zr, Ta, Ta-10% W, W, Mo, V, and Zr. After 10,000 hr, all materials except zirconium showed only limited reaction with $^{244}\text{Cm}_2\text{O}_3$ in the form of subsurface voids or intergranular penetration to <2 mils. Zirconium (both the specimen and capsule) completely reacted with $^{244}\text{Cm}_2\text{O}_3$ to form a compound of the type $\text{Zr}_x\text{Cm}_y\text{O}_z$ or Zr_xCm_y . Results from these tests are summarized in second table on page 8.

Summary of Metallographic Examination of
Materials Exposed to $^{244}\text{Cm}_2\text{O}_3$ at 750°C

Material	1,000-hr Test	10,000-hr Test
Nickel	Heavy porosity in grain boundaries of specimen, end plug, and capsule wall to maximum depth of 25 mils.	Specimen unaffected; end plug had heavy precipitation or void formation to 0.5 mil.
Ni-10% Cr	Surface reaction zone to maximum depth of 0.5 mil. Slight surface roughening.	Surface reaction zone to maximum depth of 0.5 mil. Some large voids in reaction zone.
Ni-20% Cr	Surface reaction zone to maximum depth of 0.5 mil. Slight surface roughening.	Surface reaction zone to maximum depth of 0.5 mil. Surface roughening.
Hastelloy N	Unaffected.	Surface reaction zone to maximum depth of 0.1 mil.
Hastelloy C	Surface roughening.	Unaffected.
Co-10% Cr	Surface roughening.	Surface roughening and slight attack to maximum depth of <0.5 mil.
Haynes 25	Very slight surface roughening.	Unaffected.

Summary of Metallographic Examination of
Materials Exposed to $^{244}\text{Cm}_2\text{O}_3$ at 1250°C

Material	1,000-hr Test	10,000-hr Test
Nb	Not examined.	Intergranular penetration and subsurface voids to maximum depth of ~2 mils. Surface roughening.
Nb-1% Zr	Not examined.	Intergranular penetration and subsurface voids to <2 mils.
Ta	Not examined.	Intergranular penetration and subsurface voids to maximum depth of <2 mils. Surface roughening.
Ta-10% W	Not examined.	Subsurface voids to depth of <1 mil.
Mo	Not examined.	Intergranular penetration and subsurface voids to maximum depth of 1.5 mils. Surface roughening.
V	Not examined.	Intergranular penetration and subsurface voids to depth of <2 mils. Surface roughening.
Zr	Not examined.	Complete reaction with Cm_2O_3 .

c. Tests at 1650°C¹⁸

The following materials were tested with $^{244}\text{Cm}_2\text{O}_3$ for 1000 and 10,000 hr at 1650°C: Ta, Ta-10% W, T-111, Mo, TZM, W, and W-26% Re. After 10,000 hr severe attack in the form of intergranular penetration and subsurface voids occurred in Ta-10% W and T-111. An autoradiograph of the Ta-10% W capsule showed that it was completely penetrated by ^{244}Cm (or $^{244}\text{Cm}_2\text{O}_3$) and evidence

of ^{244}Cm was found outside the capsule. The grain boundaries of T-111 (up to 30 mils) contained a phase rich in both ^{244}Cm and hafnium. The remaining materials, Ta, Mo, TZM, W, and W-26% Re, showed <1 mil attack, primarily along grain boundaries or as subsurface precipitate or void formation.

The crystal structure of the $^{244}\text{Cm}_2\text{O}_3$ used in these tests was the monoclinic B-type. When heated above 1600°C , it transforms reversibly to the hexagonal A-type. Metallographic examination of the $^{244}\text{Cm}_2\text{O}_3$ pellets indicated a well defined grain structure with a high degree of twinning (characteristic of a phase transformation during cooling) and some coalescing of voids, especially at grain boundary intersections. Grain size varied and was smaller in samples exposed to tantalum or tantalum alloys, indicating some dissolution which may have inhibited grain growth. Little redistribution of $^{244}\text{Cm}_2\text{O}_3$ occurred after 1000 hr, but more occurred after 10,000 hr. The results of the 1650°C test are summarized in the following table.

Summary of Metallographic Examination of
Materials Exposed to $^{244}\text{Cm}_2\text{O}_3$ at 1650°C

Material	1,000-hr Test	10,000-hr Test
Ta	Widmanstätten precipitate distributed throughout. Diffusion zone at surface of $^{244}\text{Cm}_2\text{O}_3$. No redistribution of $^{244}\text{Cm}_2\text{O}_3$.	Surface roughening and metallic particles in $^{244}\text{Cm}_2\text{O}_3$ indicating dissolution of Ta. Few subsurface voids at <1 mil in Ta. Complete redistribution of $^{244}\text{Cm}_2\text{O}_3$.
Ta-10% W	Grain boundary penetration to 1-2 mils. Metallic particles in $^{244}\text{Cm}_2\text{O}_3$. No redistribution of $^{244}\text{Cm}_2\text{O}_3$.	Complete penetration of capsule by $^{244}\text{Cm}_2\text{O}_3$. Complete redistribution of $^{244}\text{Cm}_2\text{O}_3$.
T-111	Grain boundary penetration to 5-10 mils. No redistribution of $^{244}\text{Cm}_2\text{O}_3$.	Grain boundary penetration to 30 mils. Complete redistribution of $^{244}\text{Cm}_2\text{O}_3$.
Mo	Grain boundary penetration and subsurface voids to <1 mil. No redistribution of $^{244}\text{Cm}_2\text{O}_3$.	Surface roughening. Large subsurface voids to 1-2 mils. Slight redistribution of $^{244}\text{Cm}_2\text{O}_3$.
TZM	Very slight attack (<0.1 mil). No redistribution of $^{244}\text{Cm}_2\text{O}_3$.	Surface roughening. Few subsurface voids to 1-2 mils. Complete redistribution of $^{244}\text{Cm}_2\text{O}_3$.
W	Voids or precipitation along grain boundaries to <0.5 mil. No redistribution of $^{244}\text{Cm}_2\text{O}_3$.	Heavy surface roughening and some tungsten mass transfer. Few subsurface voids (1-2 mils). Complete redistribution of $^{244}\text{Cm}_2\text{O}_3$.
W-26% Re	Not tested.	Slight surface roughening. Large subsurface voids to <0.5 mil. No redistribution of $^{244}\text{Cm}_2\text{O}_3$.

d. Tests at 1800°C^{19,20}

The following materials were exposed to $^{244}\text{Cm}_2\text{O}_3$ for 12,000 hr at 1800°C: Mo, Mo-46% Re, W, W-25% Re, and W-18% Mo-35% Re. Results were characterized by surface roughening (~3 mils or less, generally) and subsurface voids to 3 mils (10 mils for W-25% Re). Curia appeared to show a two-phase structure which could indicate loss of oxygen through the capsule wall. Results of these tests are summarized in the following table.

Summary of Metallographic Examination of
Materials Exposed to $^{244}\text{Cm}_2\text{O}_3$ at 1800°C

Material	Summary of Results for 12,000-hr Test
Mo	Heavy surface roughening and metallic particles in $^{244}\text{Cm}_2\text{O}_3$ indicating dissolution of molybdenum. Large subsurface voids (1-3 mils). No definite grain structure to $^{244}\text{Cm}_2\text{O}_3$, but many large voids and a two-color grey pattern.
Mo-46% Re	Medium-sized subsurface voids to <1 mil. Less cracking and voids in $^{244}\text{Cm}_2\text{O}_3$ compared with above.
W	Not examined.
W-25% Re	Heavy surface roughening. Large subsurface voids to 2-3 mils. Deep cracks (10-15 mils) in corner of capsule bottom, probably as a result of coalesced voids along grain boundaries.
W-18% Mo-35% Re	Heavy surface roughening and medium-to-large subsurface voids to depth of approximately 3 mils.

e. Tests at 1850°C¹⁸

The following materials were tested with $^{244}\text{Cm}_2\text{O}_3$ for 1000, 5000, and 10,000 hr at 1850°C: Ta, Ta-10% W, T-111, Mo, TZM, W, and W-26% Re. Results were characterized by surface dissolution and subsurface voids in the metal specimens. Mass transfer of metallic elements and redistribution of $^{244}\text{Cm}_2\text{O}_3$ were typical in the longer time.

Curia exposed to tantalum or tantalum alloys appeared to have been liquid during tests indicating the formation of a low melting phase. The alloys W-26% Re and TZM appeared to show the best overall resistance to attack. In none of the tests did the $^{244}\text{Cm}_2\text{O}_3$ have a definite grain structure and very often a two-phase structure was observed. Results are summarized in the following table.

Summary of Metallographic Examination of
Materials Exposed to $^{244}\text{Cm}_2\text{O}_3$ at 1850°C

Material	1,000-hr Test	5,000-hr Test	10,000-hr Test
Ta	Very shallow subsurface voids (<1 mil). Complete redistribution of $^{244}\text{Cm}_2\text{O}_3$.	Surface roughening. Shallow subsurface voids. Mass transfer of Ta. Complete redistribution of $^{244}\text{Cm}_2\text{O}_3$.	Same as 5000-hr test results except increased mass transfer of Ta.
Ta-10% W	Very shallow subsurface voids (<1 mil). Complete redistribution of $^{244}\text{Cm}_2\text{O}_3$.	Slight surface roughening and few subsurface voids. Mass transfer of Ta. Complete redistribution of $^{244}\text{Cm}_2\text{O}_3$.	Same as 5000-hr test results except increased evidence of mass transfer.
T-111	Few subsurface voids (1 mil). Complete redistribution of $^{244}\text{Cm}_2\text{O}_3$.	Surface roughening and mass transfer. Specimen joined to capsule in some areas. Few subsurface voids. Complete redistribution of $^{244}\text{Cm}_2\text{O}_3$.	Same as 5000-hr test results.
Mo	Grain boundary penetration and subsurface voids to <1 mil. Very slight redistribution of $^{244}\text{Cm}_2\text{O}_3$.	Surface roughening and mass transfer. Large subsurface voids to 1-2 mils. Few metallic particles in $^{244}\text{Cm}_2\text{O}_3$. Slight redistribution of $^{244}\text{Cm}_2\text{O}_3$.	Same as 5000-hr test except longer subsurface voids and complete redistribution of $^{244}\text{Cm}_2\text{O}_3$.
TZM	Surface roughening and subsurface voids to <1 mil. Slight redistribution of $^{244}\text{Cm}_2\text{O}_3$.	Surface roughening and mass transfer. Subsurface voids to 1-2 mils. Slight redistribution of $^{244}\text{Cm}_2\text{O}_3$.	Same as 5000-hr test results.
W	Surface roughening and metallic particles in $^{244}\text{Cm}_2\text{O}_3$. Very small grain boundary. Subsurface voids to <0.5 mil. No redistribution of $^{244}\text{Cm}_2\text{O}_3$.	Increased surface roughening and mass transfer. Grain boundary subsurface voids to 1 mil. Redistribution of $^{244}\text{Cm}_2\text{O}_3$.	Same as 5000-hr test except increased mass transfer and larger subsurface voids.
W-26% Re	Very slight surface attack, primarily along grain boundaries (0.1 mil). Redistribution of $^{244}\text{Cm}_2\text{O}_3$.	Surface roughening and subsurface voids to <1 mil. Redistribution of $^{244}\text{Cm}_2\text{O}_3$.	Same as 5000-hr test results.

f. Tests at 2000°C¹⁹⁻²¹

The following materials were tested with $^{244}\text{Cm}_2\text{O}_3$ for 1000 and 10,000 hr at 2000°C: Mo, Mo-46% Re, W, W-25% Re, W-18% Mo-35% Re, and Re. Results were characterized by surface roughening, mass transfer, and subsurface voids in the metallic components. Rhenium and Mo-46% Re appeared to show the best overall resistance to attack in the tests examined. Results are summarized in the following table.

Summary of Metallographic Examination of
Materials Exposed to $^{244}\text{Cm}_2\text{O}_3$ at 2000°C

Material	1,000-hr Test	10,000-hr Test
Mo	Surface roughening. Grain boundary attack to 2 mils. Metallic particles in $^{244}\text{Cm}_2\text{O}_3$.	Not examined.
Mo-46% Re	Subsurface precipitate or voids to <1 mil.	Surface roughening and large subsurface voids to 1 mil. Two-phase $^{244}\text{Cm}_2\text{O}_3$ structure.
W	Heavy grain boundary attack and/or subsurface void formation to 10 mils.	Not examined.
W-25% Re	Subsurface void formation to <1 mil.	Heavy surface roughening. Large subsurface voids to 1-2 mils. $^{244}\text{Cm}_2\text{O}_3$ penetration to 5 mils. Two-phase $^{244}\text{Cm}_2\text{O}_3$ structure.
W-18% Mo-35% Re	Subsurface void formation to <1 mil.	Not examined.
Re	Subsurface void formation to <1 mil.	Not examined.

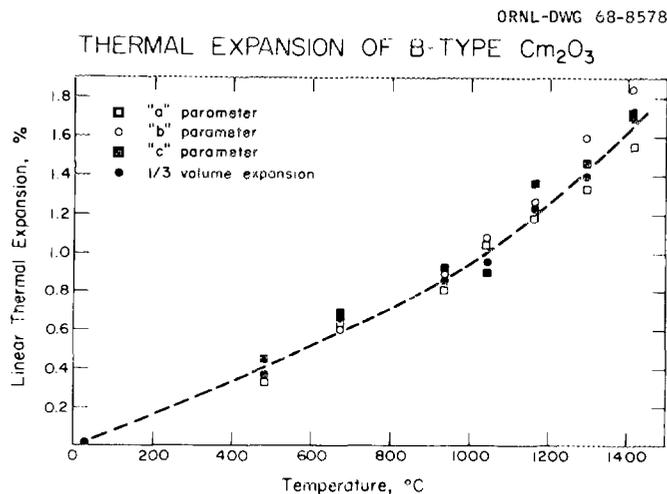
6. Thermophysical Properties

a. Density (calculated from lattice parameters)^{7,9}

C-type (bcc)	10.70 g/cm ³ at room temperature
B-type (monoclinic)	11.67 g/cm ³ at room temperature
B-type (monoclinic)	10.9 g/cm ³ at 1600°C
A-type (hex)	11.4 g/cm ³ at 1640°C

b. Coefficient of thermal expansion⁹

B-type (monoclinic) Cm_2O_3



Thermal Expansion of Monoclinic B-Type Cm_2O_3 .
Volume expansion is approximately linear to
1000°C with a coefficient of $28.8 \times 10^{-6}/^\circ\text{C}$.

c. Specific heat and enthalpy

- (1) Specific heat in cal/g.^{°C}
- (2) Enthalpy

d. Temperatures of phase transformations

- (1) Phase transitions^{6,7,9,22}
 - C-type Cm₂O₃ (bcc) transforms irreversibly to B-type Cm₂O₃ (monoclinic) between 800-1300°C depending on degree of crystallinity of cubic form.
 - B-type Cm₂O₃ (monoclinic) transforms reversibly to A-type Cm₂O₃ (hexagonal) at 1600°C.
 - A-type Cm₂O₃ (hexagonal) transforms reversibly to H-type Cm₂O₃ (hexagonal) at 2000 ± 20°C.
- (2) Melting point²²⁻²⁴
 - 2265 ± 20°C
 - 2180°C (production oxide)
- (3) Boiling point⁶
 - 3700 ± 200°C
- (4) Thermogravimetric analytical work on the decomposition of CmO₂ to Cm₂O₃ at SRL confirmed previous work at ORNL and indicated some variations from earlier SRL results. Stable oxide phases and temperature ranges of stability in various atmospheres are:^{5,6,8,9,22}

Phase	Type	Composition	Range of Stability in (°C)		
			Oxygen	Helium	4% H ₂ -96% He
CmO ₂		CmO _{2.0}	<380	<400	<250
Delta		CmO _{1.81}	445-480	Unstable	Unstable
Cm ₇ O ₁₂		CmO _{1.71}	500-700	450-520	Unstable
Cm ₂ O ₃	C	CmO _{1.62-1.52}	700-800	600-900	530-750
Cm ₂ O ₃	B	CmO _{1.50}	{ <250 520-1600	<950	<850
Cm ₂ O ₃	A	CmO _{1.50}		>1600	<2000

The range of stability of curium oxide compounds in oxygen, helium, and 4% H₂-96% He is only qualitative and the references should be consulted for further details.

e. Latent heats of phase transformations⁶

ΔH fusion	29 kcal/mole (Richard's rule)
ΔH° vaporization	133.0 ± 2.7 kcal/mole of gas between 1600 and 2250°C

f. Vapor pressure⁶

$$\log_{10} P_E \text{ (atm)} = (7.32 \pm 0.26) - [(29,050 \pm 590)/T \text{ (}^\circ\text{K)}]$$

at 1800-2600°K where P_E is an artificial pressure of $\text{Cm}_2\text{O}_3(\text{g})$. The vapor species in the vaporization reaction have not been identified, but the most prominent are believed to be $\text{CmO}(\text{g})$ and $\text{O}(\text{g})$. P_E is related to the actual vapor pressure P_T as follows:

$$P_T = 2[(M_{\text{CmO}}/M_{\text{Cm}_2\text{O}_3})^{1/2} + (M_{\text{O}}/M_{\text{Cm}_2\text{O}_3})^{1/2}]P_E = 1.567 P_E$$

where M = moles of the designated species.

g. Thermal conductivity²⁵

The following equation was derived from data by a method of least mean squares:

$$1/K = 37.795 + 0.01659 T$$

where K at theoretical density is in $\text{W/cm.}^\circ\text{C}$ and T is in $^\circ\text{K}$. The data covered the range of 500-1100°C. The useful range of the equation is 200-1400°C.

Thermal Conductivity (W/cm.°C)	Temperature (°C)
0.02193 ± 0.00326	200
0.02043 ± 0.00193	400
0.01914 ± 0.00101	600
0.01880 ± 0.00043	800
0.01698 ± 0.00048	1000
0.01608 ± 0.00084	1200
0.01526 ± 0.00118	1400

h. Thermal diffusivity²²

Thermal Diffusivity (cm ² /sec)	Temperature (°C)	Density (g/cm ³)
0.00516	100	11.05
0.00505	200	11.02
0.00495	300	11.00
0.00485	400	10.97
0.00476	500	10.94
0.00467	600	10.91
0.00458	700	10.88
0.00450	800	10.85
0.00442	900	10.81
0.00434	1000	10.77
0.00427	1100	10.73
0.00419	1200	10.68
0.00412	1300	10.62
0.00406	1400	10.56

The following equation was derived from these data:

$$\alpha = (0.0404T + 190)^{-1}$$

where α is thermal diffusivity in cm²/sec and T is in °C.

- i. Viscosity
- j. Surface Tension
- k. Total hemispherical emittance
- l. Spectral emissivity²⁶

• 0.20 to 0.50 (for ThO₂)

The precise value is a function of the roughness of the material surface, the presence of impurities, and the effects of radiation.

m. Crystallography

- (1) Cubic, related to fcc structure of CmO₂, possibly CmO_{1.81}, obtained on heating at 450°C in oxygen.
a = 5.435 ± 0.001 Å at room temperature.⁹

- (2) Rhombohedral cell with $a = 6.677 \pm 0.004 \text{ \AA}$ and $\alpha = 99.52 \pm 0.007^\circ$ with composition of $\text{CmO}_{1.76}$ obtained by thermal reduction in oxygen at 475°C .⁹
- (3) Cubic with superstructure, related to bcc structure of C-type Cm_2O_3 , 5.459 \AA with composition of $\text{CmO}_{1.72}$ obtained in oxygen at 700°C .⁹
- (4) Body-centered cubic, C-type rare-earth oxide structure with variable lattice parameter, produced by reducing CmO_2 .⁷ $a = 10.922 \pm 0.001$ ($\text{CmO}_{1.64}$) to 10.997 ± 0.003 ($\text{CmO}_{1.52}$) at room temperature.
- (5) Monoclinic B-type Cm_2O_3 produced irreversibly by heating C-type Cm_2O_3 in a reducing or helium atmosphere $800\text{--}1300^\circ\text{C}$, composition $\text{CmO}_{1.50}$.⁹ $a = 14.276 \pm 0.008 \text{ \AA}$, $b = 3.656 \pm 0.001 \text{ \AA}$, $c = 8.913 \pm 0.004 \text{ \AA}$, and $\beta = 100.39 \pm 0.03^\circ$.
- (6) Hexagonal, A-type rare-earth oxide structure, obtained by reversible transformation or reaction of B-type Cm_2O_3 on noble metals on heating at 1600°C .⁹ $a = 3.845 \pm 0.005 \text{ \AA}$ at 1650°C on iridium in 4% H_2 -96% He and $c = 6.092 \pm 0.005 \text{ \AA}$ at 1650°C on iridium in 4% H_2 -96% He.

n. Solubilities²⁴

The solubility in air-saturated sea water is $3.4 \pm 1.4 \times 10^{-3}$ mg/liter. The maximum solubility was reached in a few hours and remained constant up to 1032 hr.

The solubility in air-saturated distilled water is $9.06 \times 10^{-4} t^{1.913}$ where t is time in hours. The solubility continued to increase until the experiment was terminated at 1032 hr. The pH of the solution decreased up to the end and could have accounted for the solubility increase. The increase in acidity may have been due to the formation of a nitrogen acid or sulfuric acid in combination with radiation. Air containing N_2 and traces of SO_2 was bubbled through the water to maintain a saturated solution.

o. Diffusion Rates^{27,28}

The average concentration of helium (C_{av}) within a monoclinic B-type $^{244}\text{Cm}_2\text{O}_3$ solid body, as derived from a spherical model, is given by

$$C_{\text{av}} = P/15 D' \quad (\text{cm}^3/\text{cm}^3)$$

where P is the rate of helium generation within the body and D' is the effective steady-state diffusion-release parameter. At

temperature below 1620°C, the diffusion parameter, D' , is controlled by two processes which are additive and is obtained by adding values calculated from

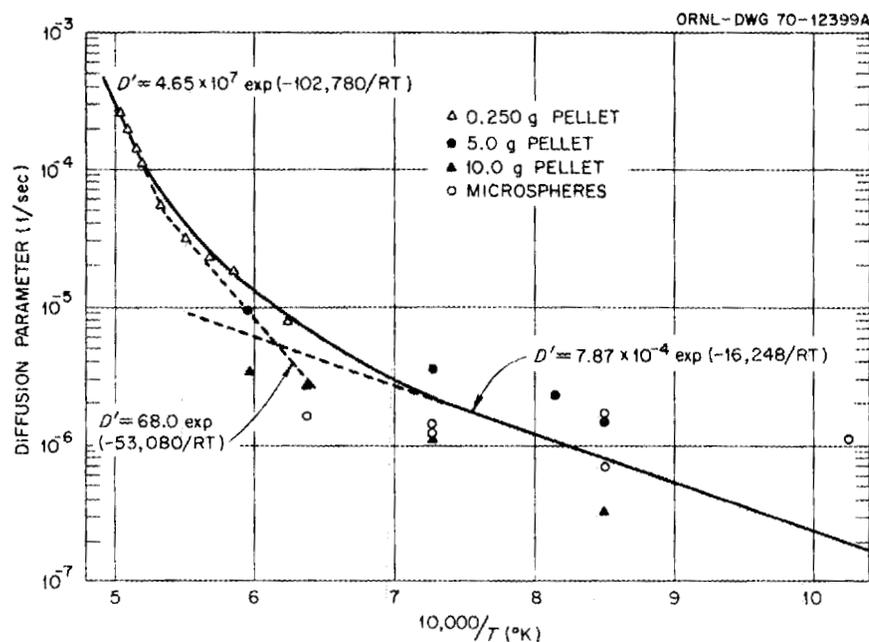
$$D' = 7.87 \times 10^{-4} \exp(-16,248/RT^{\circ}\text{K}), \text{ predominate } <1300^{\circ}\text{C}, \text{ and}$$

$$D' = 68.0 \exp(-53,080/RT^{\circ}\text{K}), \text{ predominate } 1300\text{--}1620^{\circ}\text{C}.$$

At temperatures above 1620°C the diffusion parameter is significantly different, presumably due to formation of the hexagonal A-type structure, and is given by

$$D' = 4.65 \times 10^7 \exp(-102,730/RT^{\circ}\text{K}), \text{ predominate } >1620^{\circ}\text{C}.$$

The diffusion parameter, D' , is independent of the geometry of the fuel form. The results of steady-state helium release determinations from 700 to 1800°C are shown in the following figure.



Helium Diffusion Parameter in $^{244}\text{Cm}_2\text{O}_3$ as a Function of Reciprocal Absolute Temperature.

7. Mechanical Properties

- a. Hardness
- b. Crush strength²⁹

1900 kg/cm² (for CeO₂)

8. Chemical Properties

a. Heat and free energy of formation, entropy

(1) Heat of formation^{30,31}

<u>Phase</u>	<u>$-\Delta H_f^\circ$ (298°K), kcal/mole</u>
CmO _{1.50}	215 ± 7 (est)
CmO _{1.71}	218 ± 10 (est)
CmO _{1.83}	225 ± 10 (est)
CmO _{2.00}	236 ± 8 (est)

(2) Free energy of formation of CmO_{1.50}³⁰

$$\Delta G_f^\circ (298^\circ\text{K}) = -205 \pm 7 \text{ kcal/mole (calc)}$$

(3) Entropy of CmO_{1.50}³²

$$S_{298}^\circ = 19.2 \text{ eu (est)}$$

b. Chemical reactions and reaction rates^{7,9}(1) Oxidation of B-type Cm₂O₃ in oxygen (1 atm)

While C-type Cm₂O₃ oxidizes slowly at room temperature in an atmosphere containing oxygen, the B-type Cm₂O₃ does not oxidize below 250°C. Both forms of Cm₂O₃ oxidize readily between 250 and 520°C to form CmO_{1.71} or CmO₂. The CmO₂ is the more stable product below 360°C and CmO_{1.71} is the more stable oxidation product above 360°C. While the C-type curium oxide can accommodate excess oxygen above 520°C, the B-type Cm₂O₃ resists oxidation above 520°C. Large compacts of B-type Cm₂O₃ may have enough self-heating to remain above 520°C and hence could be resistant to further oxidation.

(2) Nitrogen — no reaction³³(3) Water — possible hydration reaction³³(4) Inorganic acids — soluble in acids³³9. Biological Tolerances³⁴

Maximum permissible body burdens and maximum permissible concentrations of ²⁴⁴Cm in air and water are shown in the following table.

Maximum Permissible Body Burdens and Maximum Permissible Concentrations
for Radionuclides in Air and in Water for Occupational Exposure^{3,4}

Radionuclide and type of decay	Organ of reference (critical organ underscored)	Max permissible burden in total body, q(μ Ci)	Max permissible concentrations, μ Ci/cm ³				
			For 40-hr week		For 168-hr week		
			Water	Air	Water	Air	
²⁴⁴ Cm (α , γ)	(Sol) {	Bone	0.1	2×10^{-4}	9×10^{-12}	7×10^{-5}	3×10^{-12}
		Liver	0.2	3×10^{-4}	10^{-11}	9×10^{-5}	4×10^{-12}
		Kidney	0.2	4×10^{-4}	2×10^{-11}	10^{-4}	6×10^{-12}
		Total Body	0.3	6×10^{-4}	3×10^{-11}	2×10^{-4}	9×10^{-12}
		GI (LLI) ^a		8×10^{-4}	2×10^{-7}	3×10^{-4}	6×10^{-8}
	(Insol) {	Lung			10^{-10}		3×10^{-11}
	GI (LLI) ^a		8×10^{-4}	10^{-7}	3×10^{-4}	5×10^{-8}	

^aThe abbreviations GI and LLI refer to the gastrointestinal tract and lower large intestine, respectively.

10. Shielding Data¹⁰

Gamma dose rates with water, iron, lead, and uranium shielding are given in Figs. 1-5 for ²⁴⁴Cm power sources of 100, 200, 500, 1000, 2000, 5000, 10,000, and 20,000 W. Neutron dose rates with water shielding are given in Fig. 6. Neutron dose rates on shielding with Be, CH, CH₂, or LiH can be estimated by using Fig. 6 in conjunction with Fig. 7.

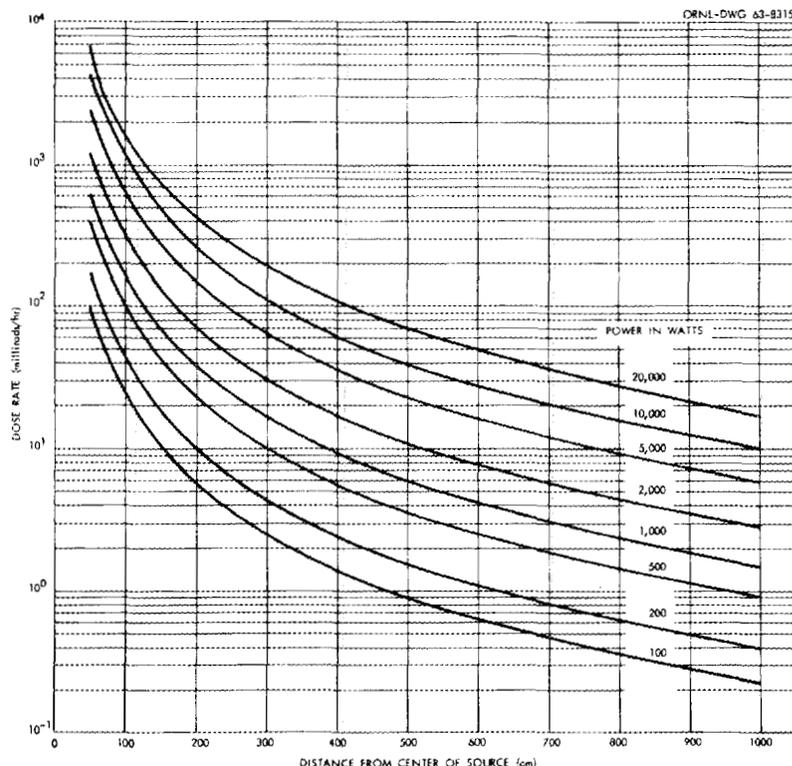


Fig. 1. Gamma Dose Rates from Unshielded Isotopic Power Sources of ²⁴⁴Cm as a Function of Distance from Center of Source.

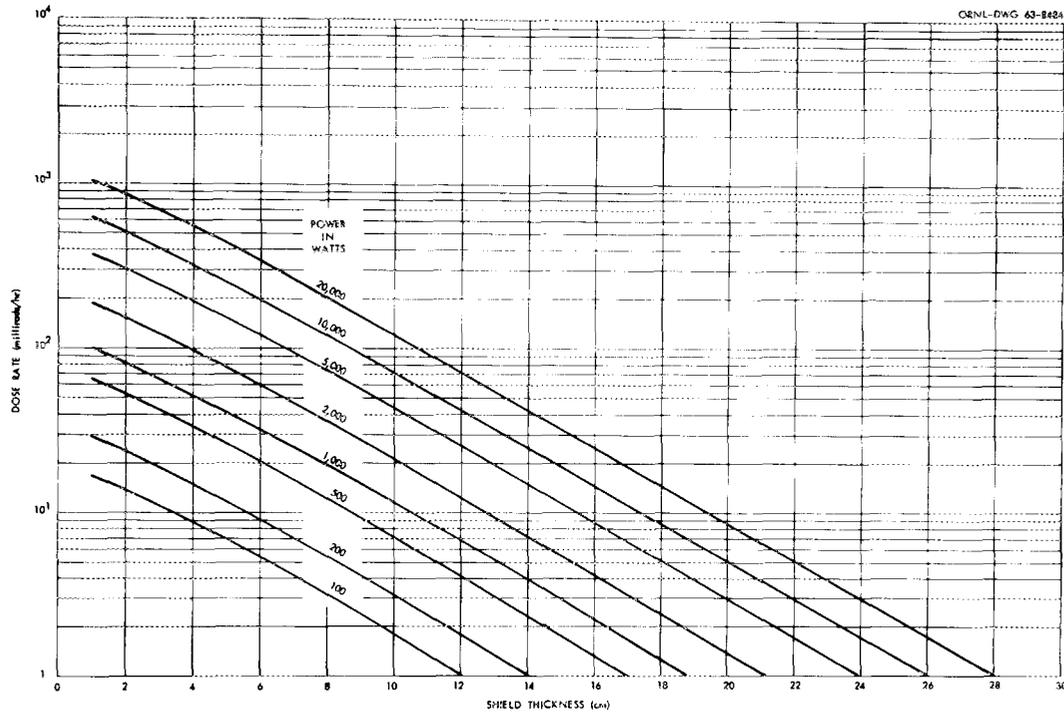


Fig. 2. Gamma Dose Rates from Iron-Shielded Isotopic Power Sources of ^{244}Cm . Center of source to dose point separation distance is 100 cm.

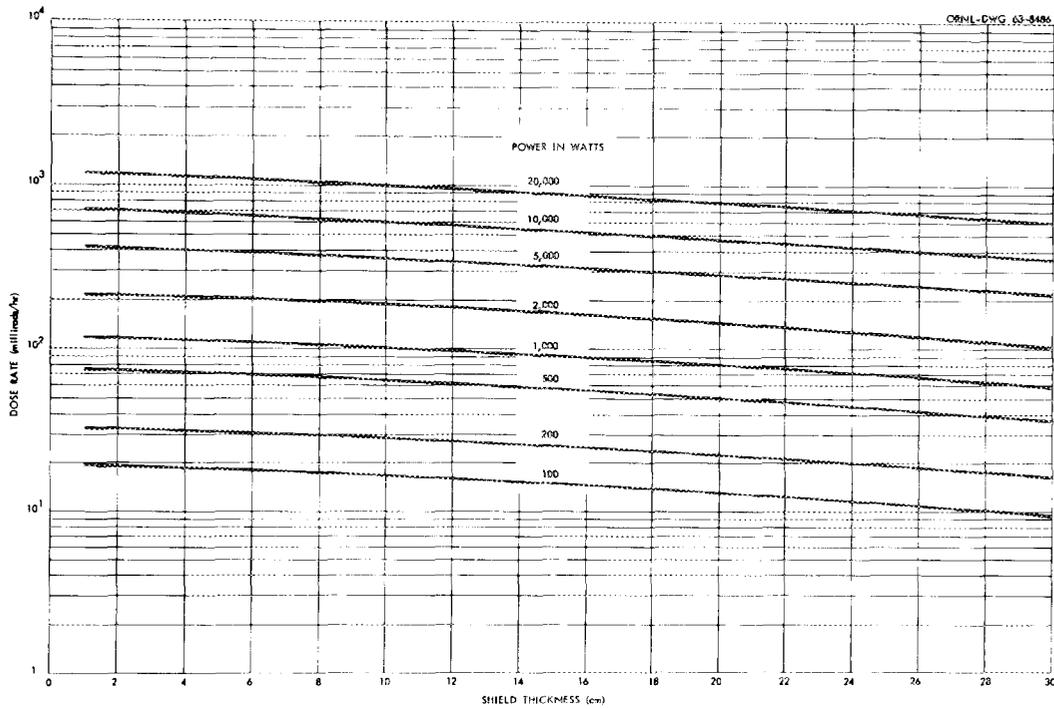


Fig. 3. Gamma Dose Rates from Water-Shielded Isotopic Power Sources of ^{244}Cm . Center of source to dose point separation distance is 100 cm.

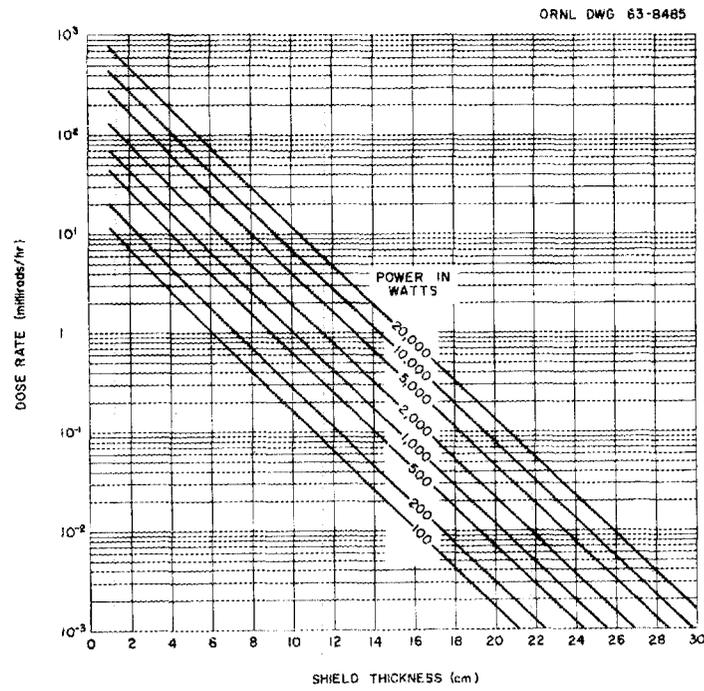


Fig. 4. Gamma Dose Rates from Lead-Shielded Isotopic Power Sources of ^{244}Cm . Center of source to dose point separation distance is 100 cm.

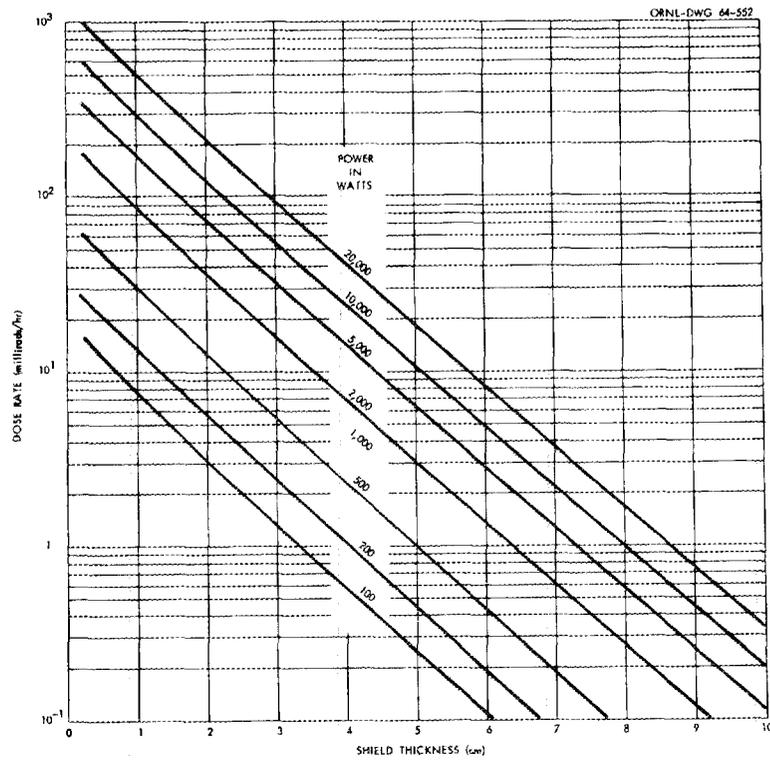


Fig. 5. Gamma Dose Rates from Uranium-Shielded Isotopic Power Sources of ^{244}Cm . Center of source to dose point separation distance is 100 cm.

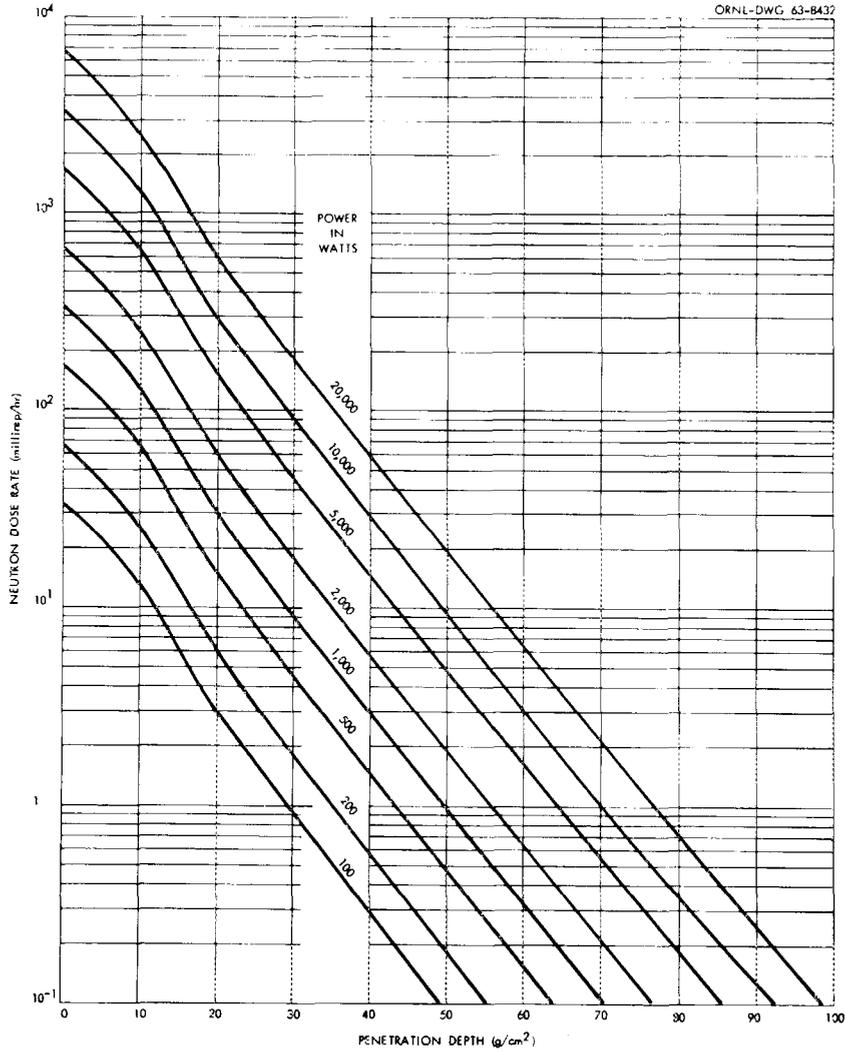


Fig. 6. Neutron Dose Rates from Water-Shielded Isotopic Power Sources of ²⁴⁴Cm as a Function of Penetration Depth of Shielding Material. Center of source to dose point separation distance is 100 cm.

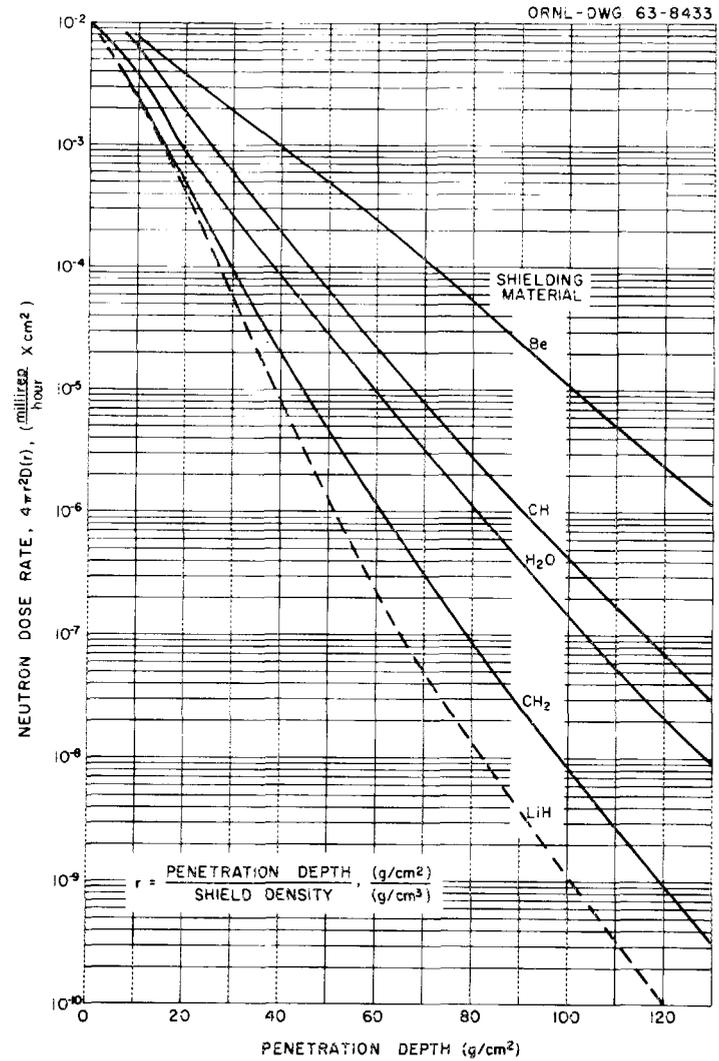


Fig. 7. Fast Neutron Dose Rate (Multiplied by $4\pi r^2$) in Various Materials as a Function of Penetration Depth from a Unit Point Isotropic Fission Source.

B. CURIUM-244 METAL

1. Composition

- a. Radionuclidic abundance — See Section A.1.a.
- b. Radiochemical purity — See Section A.1.b.
- c. Chemical purity — See Section A.1.c.

2. Specific Power^{1,10-12,35}

- a. 2.83 W/g of ^{244}Cm (100% ^{244}Cm isotope).
 2.60 W/g of pure curium element (91.77% ^{244}Cm plus curium isotopic abundances given in Section A.1.a).
 2.52 W/g of curium product (97% chemically pure, see Section A.1.c).
- b. Specific power values are based on 80.93 Ci/g of ^{244}Cm (100%) and 34.97 W/kCi of ^{244}Cm .
- c. Power density is 35.1 W/cm³ of chemically pure curium element (91.77% ^{244}Cm plus curium isotopic abundances given in Section A.1.a) and 34.0 W/g of curium product (97% chemically pure, see Section A.1.c).

3. Radiation

See Section A.3.

4. Critical Mass^{36,37}

The critical radii and masses of ^{244}Cm metal have been calculated at BNWL.

Density (g/cm ³)	H/M	k_{∞}	Bare Critical		Water Reflected ^a Critical		Steel Reflected ^a Critical	
			Radius (cm)	Mass (kg)	Radius (cm)	Mass (kg)	Radius (cm)	Mass (kg)
13.5	0	2.4552	7.430	23.20	7.303	22.02	6.31	14.21
10.872	0.5	1.7440	10.667	55.27	10.466	52.21	—	—
9.055	1.0	1.3993	15.727	147.54	15.432	139.39	—	—
7.758	1.5	1.1747	25.813	558.92	—	—	22.817	368.025
6.787	2.0	1.0143	102.825	30,907.43	—	—	—	—

^a20-cm reflector.

5. Compatibility^{35,38,39}

- Severe interaction of curium with tantalum container when in contact for 10 min at 950°C.
- Molten curium dissolves appreciable amount of tantalum.
- Extensive solubility in tungsten at temperatures up to 1795°C.
- Interaction at melting point of curium with tungsten is low.

6. Thermophysical Propertiesa. Density^{35,40}13.51 g/cm³ of metal12.66 g/cm³ of high-temperature formb. Coefficient of thermal expansion⁴¹

$$\alpha_a = 7.5 \times 10^{-6}/^{\circ}\text{C} \text{ (for Am)}$$

$$\alpha_c = 6.2 \times 10^{-6}/^{\circ}\text{C} \text{ (for Am)}$$

c. Specific heat and enthalpy⁴²

(1) Specific heat

<u>Specific Heat</u> (cal/g.°C)	<u>Temperature</u> (°K)
0.0265	300
0.0264	400
0.0262	500
0.0259	600
0.0257	700
0.0255	800
0.0253	900
0.0251	1000
0.0250	1100
0.0249	1200
0.0248	1300
0.0246	1400
0.0245	1500
0.0244	1600
0.0242	1700
0.0241	1800
0.0240	1900
0.0238	2000

(2) Enthalpy⁴²

$H_T^\circ - H_{298}^\circ$ (kcal/gfw)	Temperature (°K)
0.0119	300
0.6514	400
1.2860	500
1.9150	600
2.5384	700
3.1566	800
3.7703	900
4.3799	1000
4.9859	1100
5.5885	1200
6.1880	1300
6.7843	1400
7.3774	1500
7.9674	1600
8.5541	1700
9.1377	1800
9.7180	1900
10.2952	2000

d. Temperatures of phase transformations

(1) Melting point^{35,38}

1340 ± 40°C

1350 ± 60°C

(2) Boiling point³⁹

3525 ± 130°C

e. Latent heats of phase transformations³⁹ ΔH fusion 3.5 kcal/mole (Richard's rule) $\Delta H_{600^\circ K}^\circ$ vaporization 82.6 ± 2.7 kcal/molef. Vapor pressure³⁹ $\log_{10} P = 4.74 \pm 0.37 [(18,060 \pm 589)/T]$

(T is in °K and P is in atm)

g. Thermal conductivity⁴³

0.1 W/cm.°K at 300°K (est)

h. Thermal diffusivity

0.0668 cm²/sec at 26°C

This value was calculated by dividing the thermal conductivity by the product of the specific heat and density.

i. Viscosity⁴⁴

4.76 centipoises at 1340°C (calc)

j. Surface tension⁴⁵

1300 dyn/cm (for U)

k. Total hemispherical emittance⁴⁶

0.37 at 89°C (for Pu)

l. Spectral emissivity²⁶

0.55 (for Er)

A higher value of 0.9 can be assumed if the metal surface is oxidized or if impurities are present.

m. Crystallography³⁵

Double hexagonal close packed, $a = 3.496 \pm 0.003 \text{ \AA}$ and
 $c = 11.331 \pm 0.005 \text{ \AA}$

n. Solubilities³³

Reacts strongly with water

o. Diffusion rates

7. Mechanical Properties⁴⁷

a. Hardness

Vicker's 97.7 (for Dy)

b. Crush strength

7741 kg/cm² (for Tm)

8. Chemical Properties

a. Heat and free energy of formation, entropy

- (1) Heat of formation -- Zero, by definition of standard state
- (2) Free energy of formation -- Zero, by definition of standard state
- (3) Entropy⁴⁸ -- $S_{298}^{\circ} = 18 \text{ cal/}^{\circ}\text{C.mole}$ (est)

b. Chemical reactions and reaction rates

- (1) Oxygen at room temperature -- slow³⁵
- (2) Oxygen at elevated temperature -- fast^{36,37}
- (3) Nitrogen at room temperature -- very slow⁴⁹
- (4) Nitrogen at elevated temperature -- slow⁴⁹
- (5) Water at room temperature -- fast³³
- (6) Hydrogen at room temperature -- slow³³
- (7) Hydrogen at elevated temperature -- fast³³
- (8) 1 N HCl at 25°C -- rapid⁵⁰

9. Biological Tolerances

Maximum permissible body burden and maximum permissible concentrations of ^{244}Cm in air and in water are given under Section A.9.

10. Shielding Data

The dose rates are given under Section A.10.

C. CURIUM OXYSULFIDE (Cm₂O₂S)

1. Composition

- a. Radionuclidic abundance — See Section A.1.a.
- b. Radiochemical purity — See Section A.1.b.
- c. Chemical purity — See Section A.1.c.

2. Specific Power^{1,10-12}

- a. 2.30 W/g of 100% pure Cm₂O₂S^a
2.23 W/g of 97% pure Cm₂O₂S^a
- b. Specific power values are based on 80.93 Ci/g of ²⁴⁴Cm and 34.97 W/kCi of ²⁴⁴Cm.
- c. Power density
22.9 W/cm³ of pure Cm₂O₂S^a
22.2 W/cm³ of 97% Cm₂O₂S^a

^aIsotopic curium composition in Section A.1.

3. Radiation

The radiation is given under Section A.3.

4. Critical Mass

See Section A.4.

5. Compatibility⁵¹

Compatibility tests of ²⁴⁴Cm₂O₂S with materials of containment have not been conducted; however, qualitative data are available for Ce₂O₂S in contact with superalloys and refractory metals which are expected to be indicative of the ²⁴⁴Cm₂O₂S. The superalloys Hastelloy X, Haynes alloy No. 25, Ni-o-nel, and N-155 were tested at 1000°C for 1000 hr. The results showed only slight reaction in all cases except N-155 which showed major reaction. The refractory metals Mo, Ta, W, and TZM alloy were tested at both 1000°C and 1850°C for 1000 hr. In the 1000°C tests, tungsten showed no reaction and Mo, Ta, and TZM only slight reaction. At 1850°C, molybdenum and tungsten showed slight reaction and tantalum a major reaction; TZM was not tested.

- i. Viscosity
- j. Surface tension
- k. Total hemispherical emittance
- l. Spectral emissivity²⁶

0.20 to 0.57 (for ThO₂)

The emissivity value depends on the roughness of the material surface, radiation effects, and the presence of impurities.

- m. Crystallography⁵² (for Pu₂O₂S)

Hexagonal, $a = 3.927 \text{ \AA}$ and $c = 6.769 \text{ \AA}$. The cell constants should be slightly smaller for Cm₂O₂S due to the actinide contraction.

- n. Solubilities⁵⁵

- (1) Soluble in strong acids (Ce₂O₂S)
- (2) Insoluble in acetic acid (Ce₂O₂S)

- o. Diffusion rates

7. Mechanical Properties

- a. Hardness
- b. Crush strength

8. Chemical Properties

- a. Heat and free energy of formation, entropy

- (1) Heat of formation⁵⁴

$$\Delta H_f^\circ = -430 \text{ kcal/mole (approximated by Ce}_2\text{O}_2\text{S)}$$

- (2) Free energy of formation⁵⁴

$$\Delta G_f^\circ = -414 \text{ kcal/mole (calculated by } \Delta G_f^\circ = \Delta H_f^\circ - T\Delta S_f^\circ)$$

- (3) Entropy⁵⁶

$$S_{298}^\circ = 34.3 \text{ eu (calculated by Latimer's method)}$$

b. Chemical reactions and reaction rates⁵⁵

- (1) Air at room temperature -- slow
- (2) Air at elevated temperature -- fast
- (3) Water at room temperature -- no reaction
- (4) Inorganic acids at room temperature -- reacts

9. Biological Tolerances

Maximum permissible body burdens and maximum permissible concentrations of ^{244}Cm in air and in water are given in the $^{244}\text{Cm}_2\text{O}_3$ form, Section A.9.

10. Shielding Data

The radiation dose rates are given under the $^{244}\text{Cm}_2\text{O}_3$ form, Section A.10.

D. CURIUM FLUORIDE (CmF₃)

1. Composition

- a. Radionuclidic abundance — See Section A.1.a.
- b. Radiochemical purity — See Section A.1.b.
- c. Chemical purity — See Section A.1.c.

2. Specific Power and Power Density^{1,10-12,57}

- a. 2.11 W/g of 100% pure CmF₃^a
2.04 W/g of 97% pure CmF₃^a
- b. Specific power values are based on 80.93 Ci of ²⁴⁴Cm (100%)
and 34.97 W/kCi of ²⁴⁴Cm.
- c. Power density
20.8 W/cm³ of 100% pure CmF₃^a
20.1 W/cm³ of 97% pure CmF₃^a

^aIsotopic curium composition given in Section A.1.

3. Radiation

The radiation is given under Section A.3.

4. Critical Mass

The critical mass is given under Section A.4.

5. Compatibility⁵¹

Compatibility tests of ²⁴⁴CmF₃ with materials of containment have not been conducted; however, qualitative data are available for CeF₃ in contact with superalloys and refractory metals which are expected to be indicative of the ²⁴⁴CmF₃. The superalloys Hastelloy X, Haynes alloy No. 25, Ni-o-nel, and N-155 and the refractory metals Mo, Nb, Ta, and W were tested at 1000°C for 1000 hr. The results showed no reaction with the metals with the exception of Hastelloy C and tungsten which showed only a slight reaction.

6. Thermophysical Properties

- a. Density⁵⁷
9.85 g/cm³

h. Thermal diffusivity

<u>Thermal Diffusivity</u> (cm ² /sec)	<u>Temperature</u> (°C)
0.0379	0
0.0319	100

Calculated by dividing the thermal conductivity by the product of the specific heat and the room temperature density.

i. Viscosity⁶³ (for BaCl₂)

$$\eta = 1.643 \times 10^{-3} \exp(-20,030/RT) \text{ antipoise}$$

j. Surface tension⁶⁴ (for UF₄)

$$\sigma = 447 - (19.2 \times 10^{-2} T) \text{ (°K) dynes/cm}$$

k. Total hemispherical emittance

A value of 0.9 can be assumed.

l. Spectral emissivity

m. Crystallography⁵⁷

Hexagonal, LaF₃-type, space group P6₃/mmc, a = 4.041 ± 0.001 Å and c = 7.179 ± 0.002 Å.

n. Solubilities

o. Diffusion rates

7. Mechanical Properties

a. Hardness

b. Crush strength

8. Chemical Propertiesa. Heat and free energy of formation, entropy⁴⁸

(1) Heat of formation

$$\Delta H_f^\circ = -357 \text{ kcal/mole (estimated from other actinide data)}$$

(2) Free energy of formation

$$\Delta G_f^\circ = -339 \text{ kcal/mole}$$

(3) Entropy

$$S_{298}^{\circ} = 29 \text{ eu}$$

b. Chemical Reactions and reaction rates³³

- (1) Air at room temperature -- no reaction
- (2) Air at elevated temperature -- forms oxyfluoride
- (3) Nitrogen -- no reaction
- (4) Water -- insoluble
- (5) Inorganic acids -- insoluble in weak inorganic acid

9. Biological Tolerances

Maximum permissible body burdens and maximum permissible concentrations of ^{244}Cm in air and in water are given under Section A.9.

10. Shielding Data

The dose rates are given under Section A.10.

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