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UC-4 — Chemistry

CESIUM-137 DATA SHEETS

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OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

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ISOTOPES DEVELOPMENT CENTER

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Isotopes Division

DECEMBER 1967

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee
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CURIUM DATA SHEETS

I. CURIUM-244

REFERENCE COLUMN

A. CURIUM-244 METAL

HALF-LIFE: 18.1 y — 1

1. Composition

a. Radionuclidic abundance — 2

Element	Minimum, %	Maximum, %
Cm	99.5	99.8
Am	0.5	0.2

An average ^{244}Cm product will have the following analysis:

Isotope	% Abundance
^{244}Cm	95.5
^{245}Cm	1.6
^{246}Cm	2.7
^{243}Am	0.2

b. Radiochemical purity

Because of their long half-lives, the ^{245}Cm ($T_{1/2}$ = 8000 y), ^{246}Cm ($T_{1/2}$ = 6600 y), and ^{243}Am ($T_{1/2}$ = 8000 y) impurities act as inert diluents and contribute 0.1% of the total source power.

The radiations from these impurities are weak gammas or alpha particles and can be neglected because they are readily shielded. The prompt gammas and neutrons from the spontaneous fission will be only a few percent of that obtained from spontaneous fission of ^{244}Cm.

Since the ^{244}Cm decays to ^{240}Pu, the plutonium content in a 100% ^{244}Cm sample will slowly build up after the final purification step as shown in the following table.

Time, months	^{240}Pu, %
0	0
7.2	2.3
18	5.6
36	10.8
90	25.2

CESIUM CHLORIDE (CsCl)

REFERENCE COLUMN

The ratio of ^{134}Cs to ^{137}Cs activities will decrease by a factor of ~2.0 every two years after discharge of the fuel from the reactor.

2. Specific Power 2, 3, 4

a. 0.120 watt/g of pure CsCl
0.119 watt/g of 99% CsCl–1% RbCl

b. 25.1 curies of ^{137}Cs per gram of pure CsCl
24.85 curies of ^{137}Cs per gram of 99% CsCl–1% RbCl

3. Radiation

a. Alpha particles — None

b. Beta particles 5

Nuclide	Max E, Mev	Avg E, Mev	Abundance, %	w/kilocurie	Particles w^{-1} sec^{-1}
^{137}Cs	1.18	0.42	8	1.23	0.619×10^{12}
	0.52	0.19	92		7.11×10^{12}

c. Gamma 5

Nuclide	Energy, Mev	Abundance, %	w/kilocurie	Particles w^{-1} sec^{-1}
^{137m}Ba	0.662	83.5	3.61	6.46×10^{-12}
Total gamma power			3.61	
Total beta power			1.23	
Total gamma and beta power			4.84	

d. Bremsstrahlung 5

Bremsstrahlung radiation from the 1.18-Mev beta particles is negligible compared to the shielding required for the 0.662-Mev gamma photons.

The bremsstrahlung radiation from the 0.52-Mev beta particles will be similar to that from the 0.545-Mev beta particles of ^{90}Sr calculated in Ref. 5. These values are given in Appendix 1, Table 1.

The bremsstrahlung radiation from the 1.18-Mev beta particles of ^{137}Cs will be similar to that from the 0.968-Mev beta particles of ^{170}Tm calculated in Ref. 5.

These values are given in Appendix 1, Table 2. More accurate values of the bremsstrahlung spectrum can be calculated from the computer program given in Ref. 5.

e. Neutron — none

4. Critical Mass

Cesium-137 and ^{137}Ba are not fissionable.

5. Compatibility With Materials of Containment

A CsCl source which was encapsulated in stainless steel and contained 1540 curies of ^{137}Cs showed no signs of reaction after being opened nine years later. The source operated at slightly above ambient room temperature. 6

6. Thermophysical Properties

a. Density

Density of CsCl versus temperature 7

Temperature, °C	Density, g/cm³ cubic	fcc	liquid
25	3.999		
100	3.952		
200	3.897		
300	3.827		
400	3.758		
469	3.709	3.153	
500		3.141	
600		3.095	
645		3.072	2.792

Density of molten CsCl in g/cm³

$$\rho = 3.4782 - (1.0650 \times 10^{-3}\ t)$$ 8

(temperature range 670-905°C)

b. Coefficients of thermal expansion

$4.78 \times 10^{-5}/°C$ 9

(temperature range 50-150°C)

CESIUM CHLORIDE (CsCl)

REFERENCE COLUMN

c. Specific heat and enthalpy

(1) Specific heat in cal g^{-1} $°C^{-1}$ — 10

CsCl (solid, alpha)

$7.59 \times 10^{-2} + (7.29 \times 10^{-6}\ T) - (2.71 \times 10^{2}\ T^{-2})$

(temperature range 385.2-740.5°K)

CsCl (solid, beta)

$4.78 \times 10^{-3} + (1.05 \times 10^{-4}\ T) - (5.29 \times 10^{2}\ T^{-2})$

(temperature range 753.7-904.9°K)

CsCl (liquid)

$8.23 \times 10^{-2} + (2.54 \times 10^{-5}\ T)$

(temperature range 923.6-1168.0°K)

(2) Enthalpy in calories/mole — 10

CsCl (solid, alpha)

$H_T - H_{273.15} = -3705 + 12.78\ T + (6.14 \times 10^{-4}\ T^2) + (4.56 \times 10^{4}\ T^{-1})$

(temperature range 385.2-740.5°K, ±0.5%)

CsCl (solid, beta)

$H_T - H_{273.15} = 1365 + 0.805\ T + (8.82 \times 10^{-3}\ T^2) + (8.91 \times 10^{4}\ T^{-1})$

(temperature range 753.7-904.9°K, ±0.5%)

CsCl (liquid)

$H_T - H_{273.15} = -0.69 + 13.86\ T + (2.14 \times 10^{-3}\ T^2)$

(temperature range 923.6-1168.0°K, ±0.5%)

d. Temperature of phase transformations

(1) Melting point — 645°C — 11

(2) Boiling point — 1300°C — 11

(3) Melting temperatures of $CsCl-BaCl_2$ mixtures — 12

Mole % CsCl	Temperature, °C
50	725
60	630
70	614
80	590
90	599
100	657
86.5	568

CESIUM CHLORIDE (CsCl)

REFERENCE COLUMN

e. Latent heats of phase transformations

ΔH transition (469°C)	1.8 kcal/mole, cubic to fcc	7
ΔH fusion	4.9 ± 0.1 kcal/mole	13
ΔH vaporiation	38.2 ± 2.0 kcal/mole	13

f. Vapor pressure

$$\log P_{mm} = 11.346 - \frac{11.076 \times 10^3}{T} + \frac{5}{2} \log \frac{1000}{T}$$ 14

(T is in °K)

g. Thermal conductivity

cal cm^{-1} sec^{-1} $°C^{-1}$	Temperature, °C	15
0.001456	46	
0.001365	89	

Determined on 87.9% theoretically dense pellets of CsCl.

h. Thermal diffusivity

cm^2/sec	Temperature, °C
0.0050	46
0.0047	89

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

i. Viscosity

η, centipoise	Temperature, °C	16
1.45	667	
1.06	727	
0.84	777	
0.68	827	
0.56	877	
0.52	897	

j. Surface tension

dyn/cm	Temperature, °C	17
89.2	664	
81.9	771	
73.7	881	
66.4	979	
61.6	1035	
56.3	1080	

CESIUM CHLORIDE (CsCl)

REFERENCE COLUMN

k. Total hemispherical emittance

l. Spectral emissivity

A value of 0.9 can be assumed.

m. Crystallography

cubic, body centered

a = 4.113 kX 18

n. Solubilities 18

g per 100 g water	Temperature, °C
162.3	0.7
197.2	29.9
229.4	60.2
259.6	89.5
290.0	119.4

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 formation

ΔH°_f = -106.3 kcal/mole 11

(2) Free energy of formation

ΔF°_f = -99.6 kcal/mole 11

(3) Entropy

S°_{298} = 23.9 eu 11

b. Chemical reactions and reaction rates (oxygen, nitrogen, water, steam, hydrogen, liquid metals, other) 18

(1) Oxygen -- no reaction

(2) Nitrogen — no reaction

(3) Water -- soluble

(4) Inorganic acids -- soluble

CESIUM CHLORIDE (CsCl)

REFERENCE COLUMN

9. Biological Tolerances 19

Maximum permissible body burdens and maximum permissible concentrations of ^{137}Cs in air and in water were taken from Ref. 19 and are given in the table on the following page.

10. Shielding Data

Gamma dose rates from ^{137}Cs power sources of 100, 200, 500, 1000, 2000, 5000, 10,000, and 20,000 watts with iron, lead, and uranium shielding are given in Figs. 1-8. Extra shielding is required when ^{134}Cs impurity is present in the ^{137}Cs source because of the higher energy gamma photons of ^{134}Cs compared to ^{137}Cs.

Maximum Permissible Body Burdens and Maximum Permissible Concentrations for Radionuclides in Air and in Water for Occupational Exposure[19]

Radionuclide and type of decay	Organ of reference (critical organ underscored)	Max. permissible burden in total body, q(μc)	Maximum permissible concentrations, μc/cm³ For 40-hr week Water	For 40-hr week Air	For 168-hr week Water	For 168-hr week Air
$_{55}Cs^{137}$	Total Body	30	4×10^{-4}	6×10^{-8}	2×10^{-4}	2×10^{-8}
(β^-,γ,e^-)	Liver	40	5×10^{-4}	8×10^{-8}	2×10^{-4}	3×10^{-8}
	Spleen	50	6×10^{-4}	9×10^{-8}	2×10^{-4}	3×10^{-8}
	Muscle	50	7×10^{-4}	10^{-7}	2×10^{-4}	4×10^{-8}
(Sol)	Bone	100	10^{-3}	2×10^{-7}	5×10^{-4}	7×10^{-8}
	Kidney	100	10^{-3}	2×10^{-7}	5×10^{-4}	8×10^{-8}
	Lung	300	5×10^{-3}	6×10^{-7}	2×10^{-3}	2×10^{-7}
	GI (SI)*		0.02	5×10^{-6}	8×10^{-3}	2×10^{-6}
(Insol)	Lung			10^{-8}		5×10^{-9}
	GI (LLI)*		10^{-3}	2×10^{-7}	4×10^{-4}	8×10^{-8}

*The abbreviations GI, SI, and LLI refer to gastrointestinal tract, small intestine, and lower large intestine, respectively.

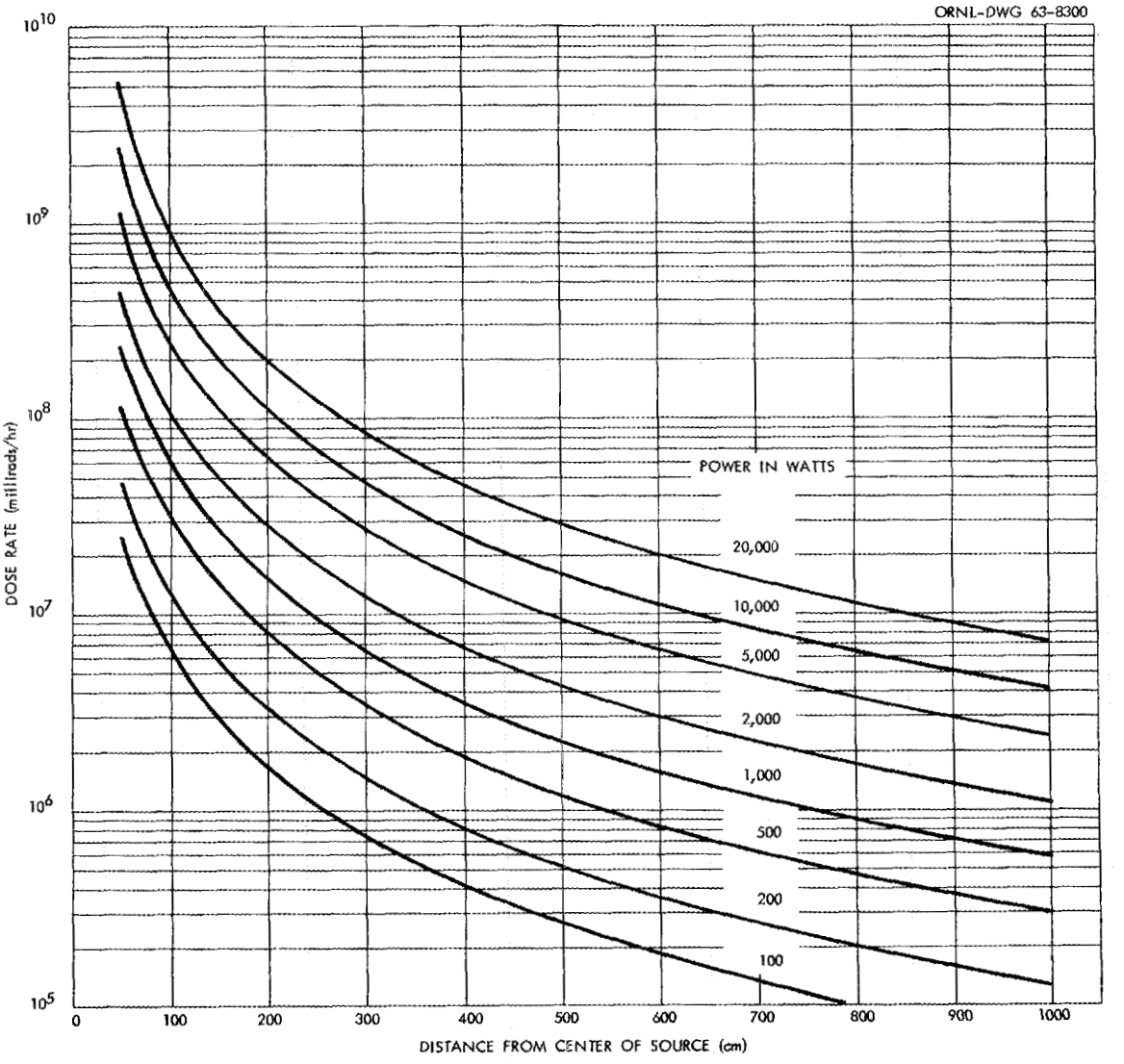

Fig. 1. Gamma Dose Rates from Unshielded Isotopic Power Sources of Cesium-137 as a Function of Distance from Center of Source.

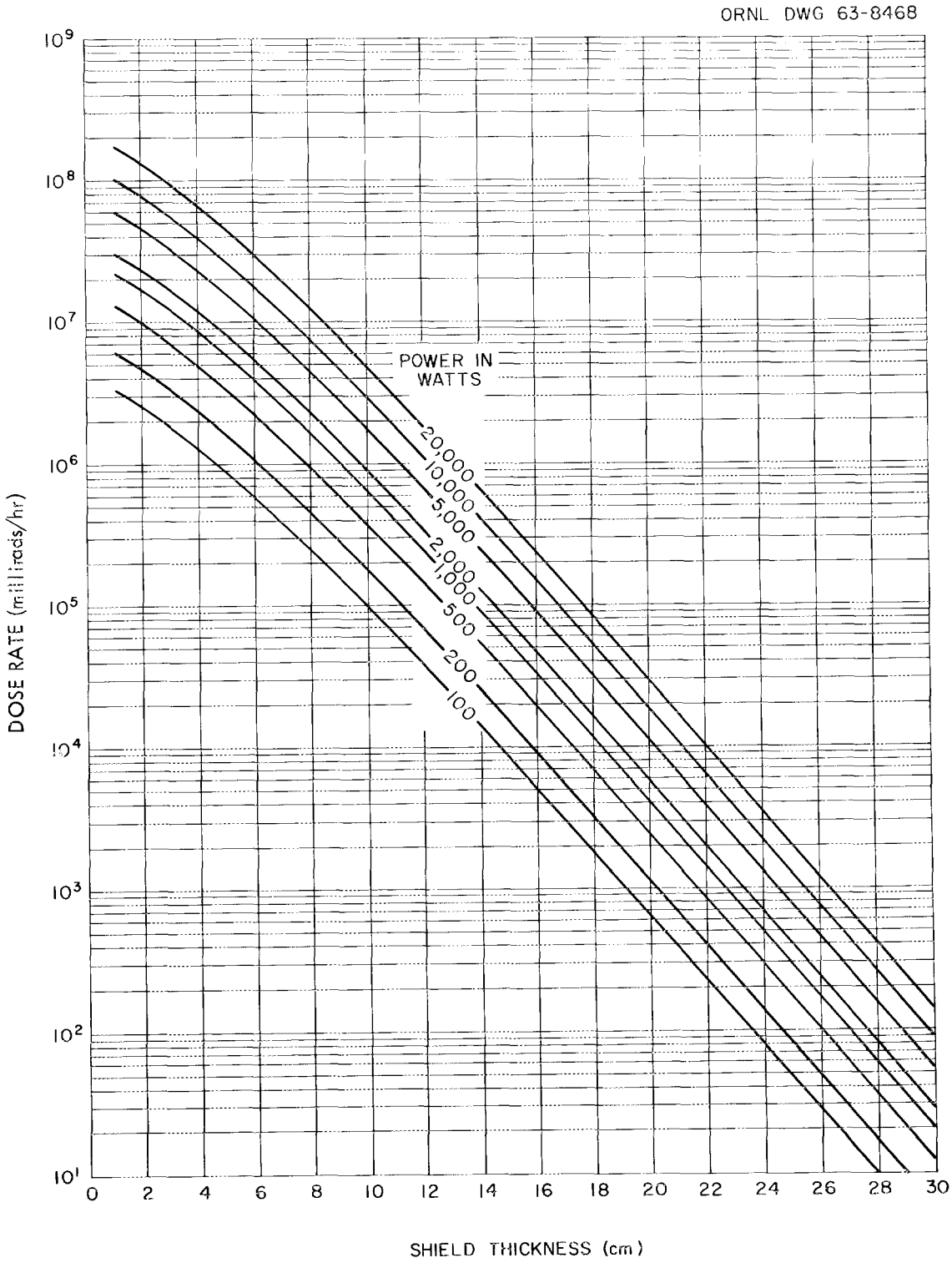

Fig. 2. Gamma Dose Rates from Iron-Shielded Isotopic Power Sources of Cesium-137. Center of source to dose point separation distance = 100 cm.

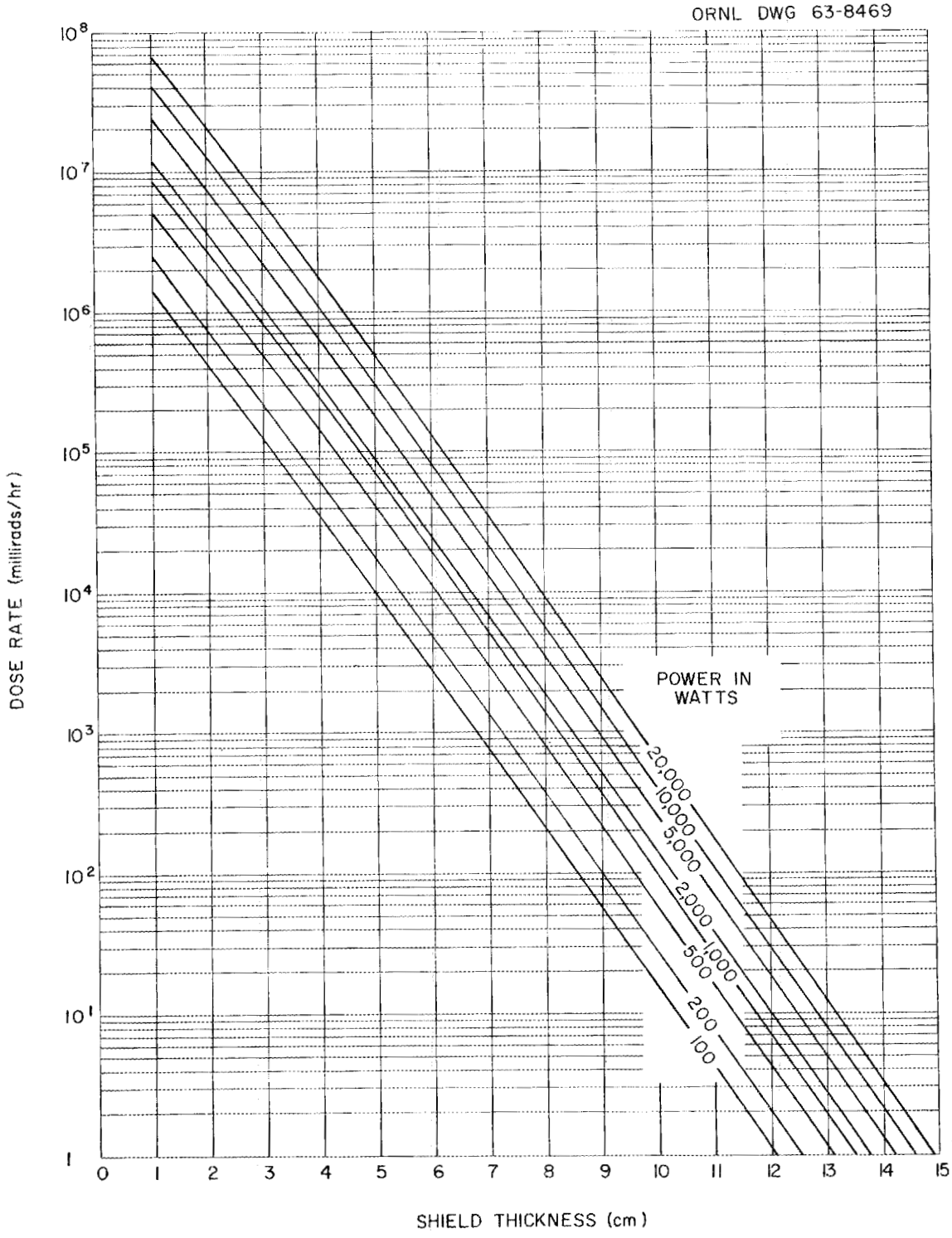

Fig. 3. Gamma Dose Rates from Lead-Shielded Isotopic Power Sources of Cesium-137. Center of source to dose point separation distance = 100 cm.

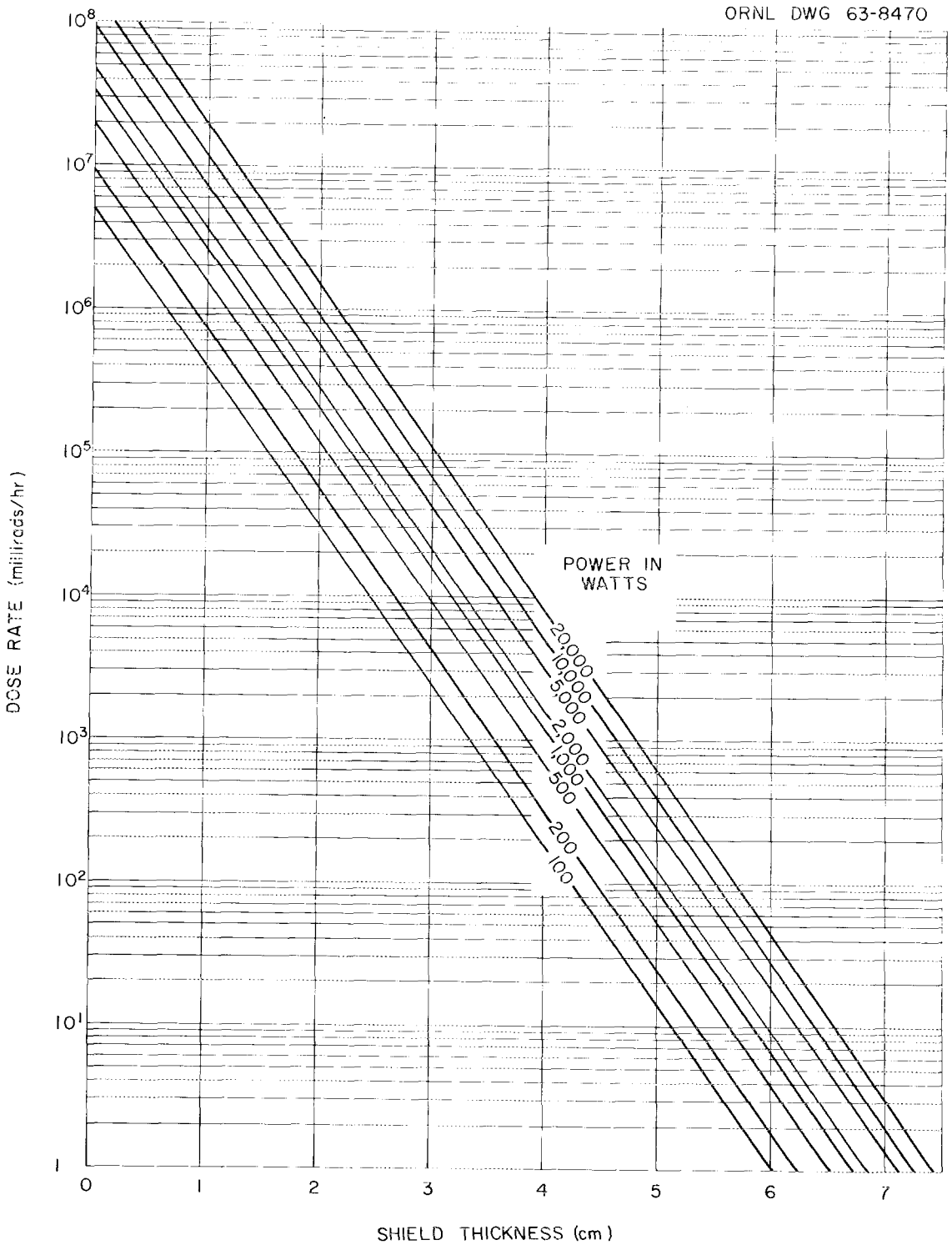

Fig. 4. Gamma Dose Rates from Uranium-Shielded Isotopic Power Sources of Cesium-137. Center of source to dose point separation distance = 100 cm.

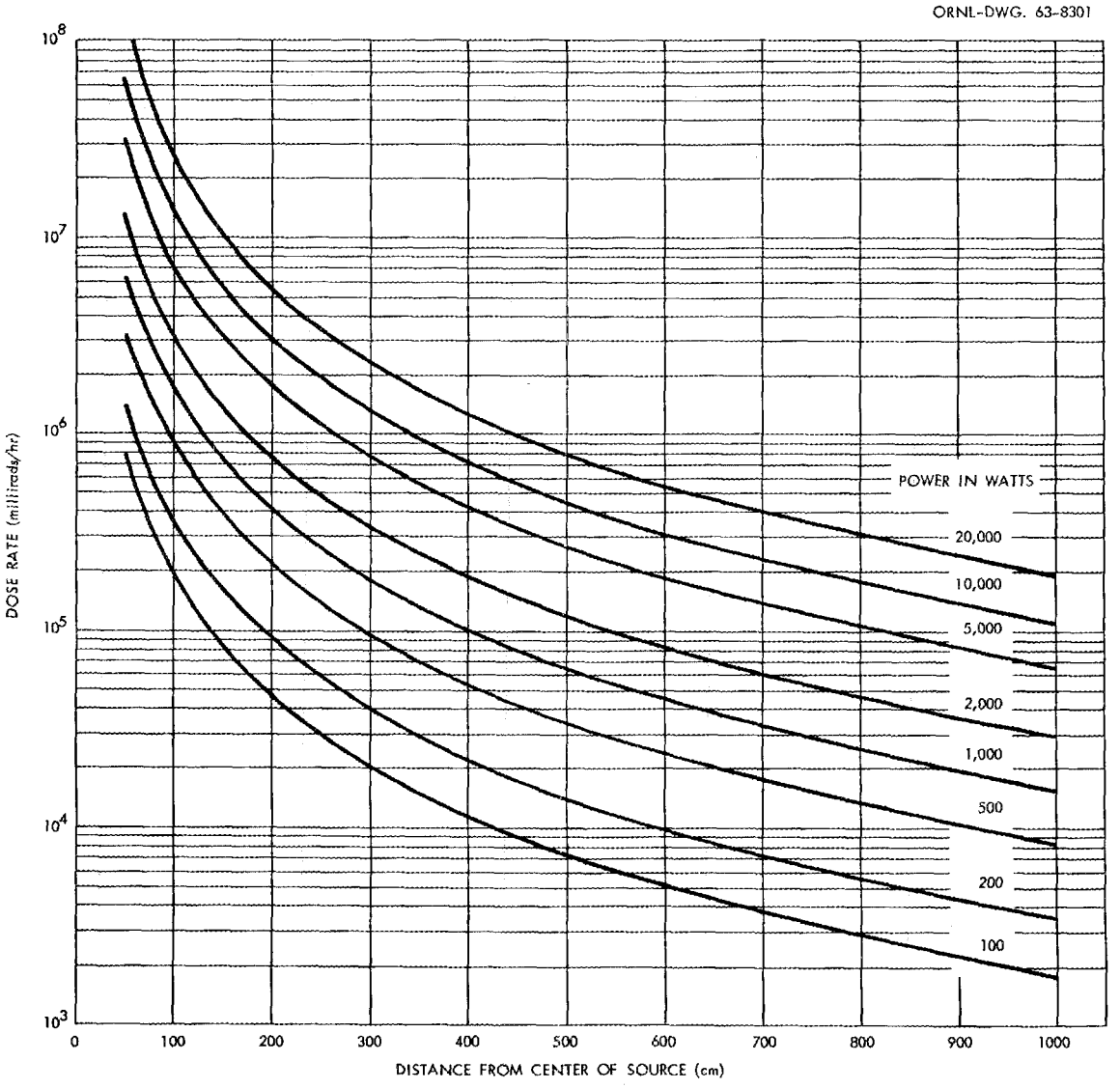

Fig. 5. Gamma Dose Rates Contributed by a 1% Impurity of Cesium-134 in Cesium-137 Isotopic Power Sources as a Function of Distance from Center of Source. Cesium-134 is assumed to contribute 1% of the beta activity due to cesium-137; refer to Fig. 1.

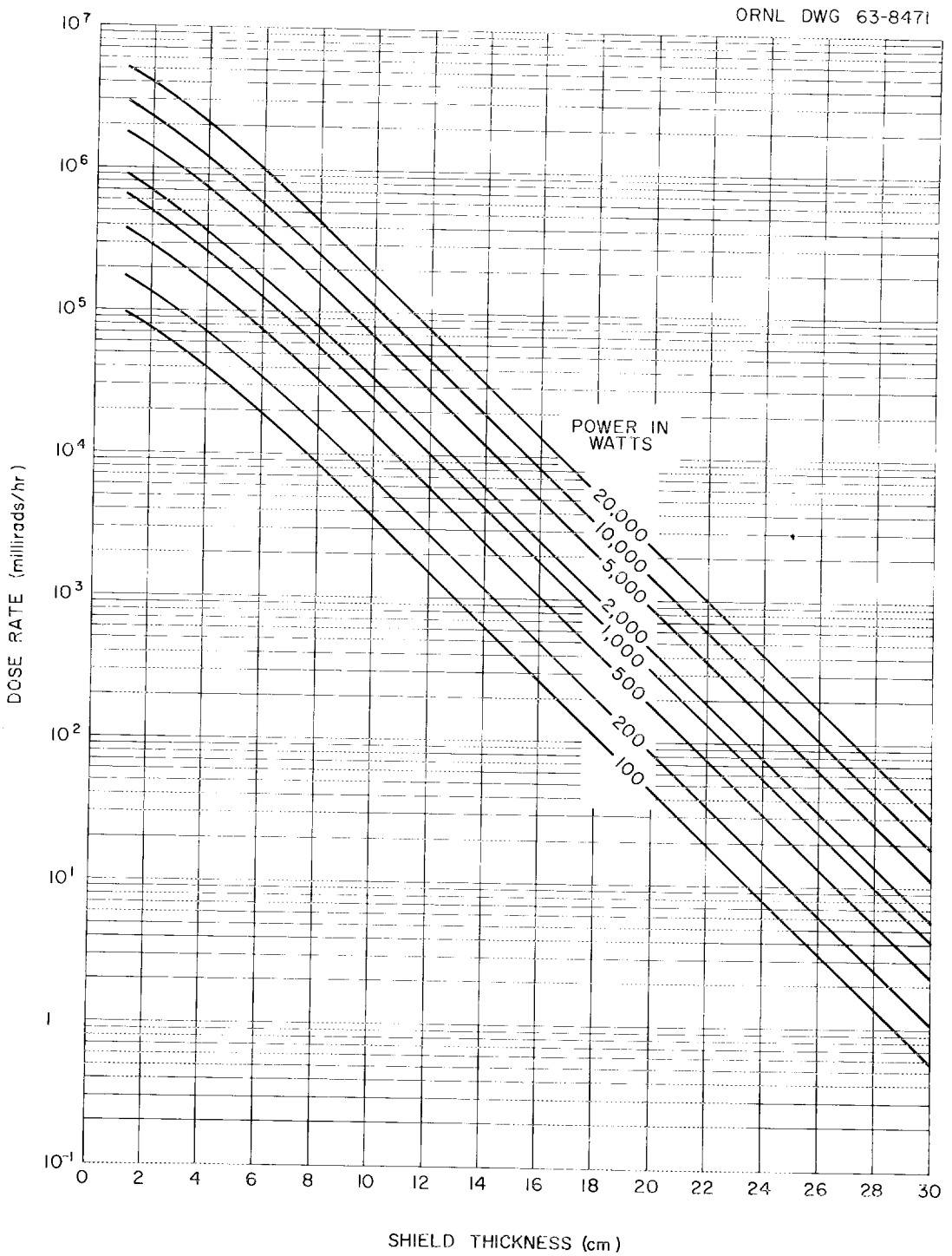

Fig. 6. Gamma Dose Rates Contributed by a 1% Impurity of Cesium-134 in Iron-Shielded Isotopic Power Sources of Cesium-137. Center of source to dose point separation distance = 100 cm. Cesium-134 is assumed to contribute 1% of the beta activity due to cesium-137; refer to Fig. 2.

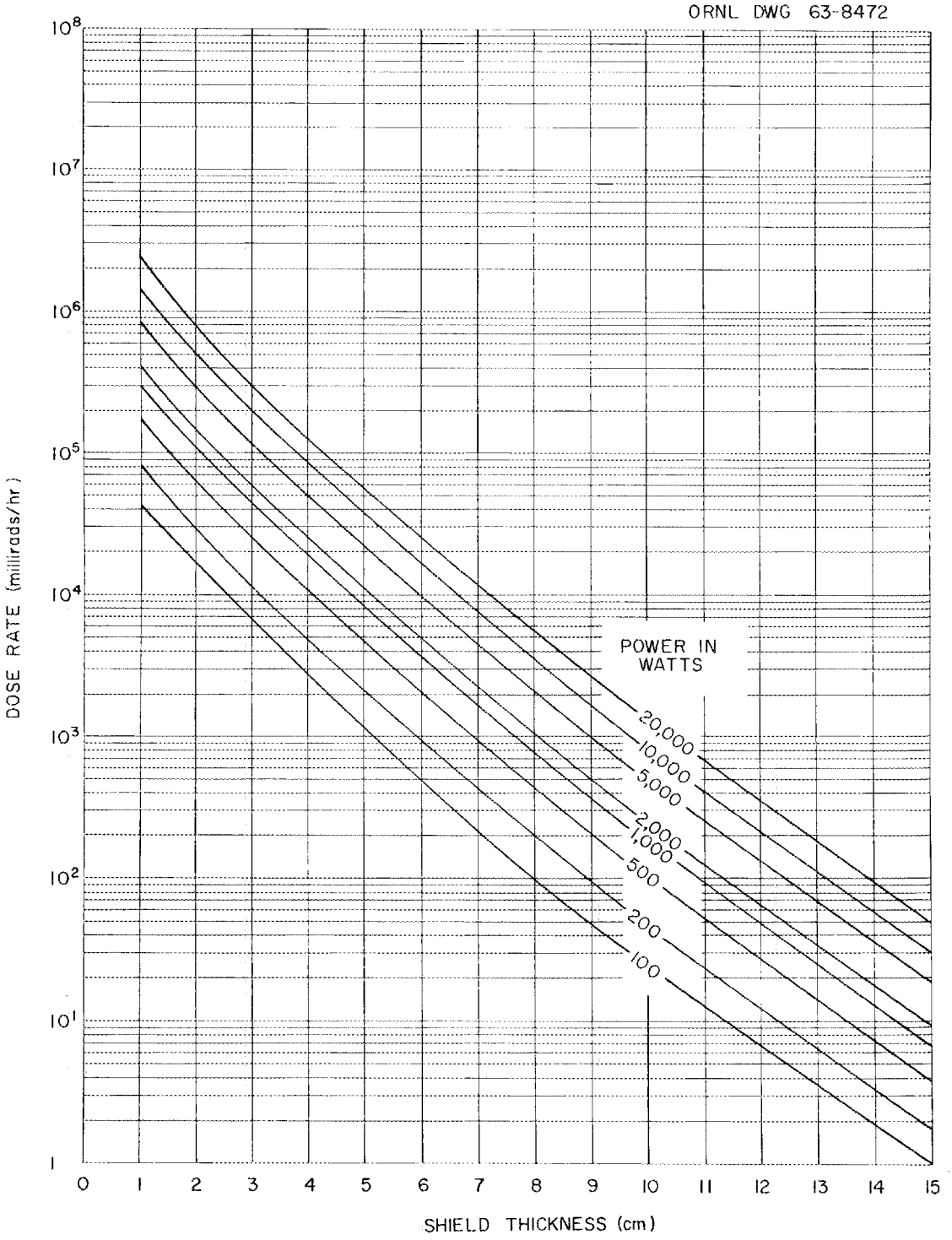

Fig. 7. Gamma Dose Rates Contributed by a 1% Impurity of Cesium-134 in Lead-Shielded Isotopic Power Sources of Cesium-137. Center of source to dose point separation distance = 100 cm. Cesium-134 is assumed to contribute 1% of the beta activity due to cesium-137; refer to Fig. 3.

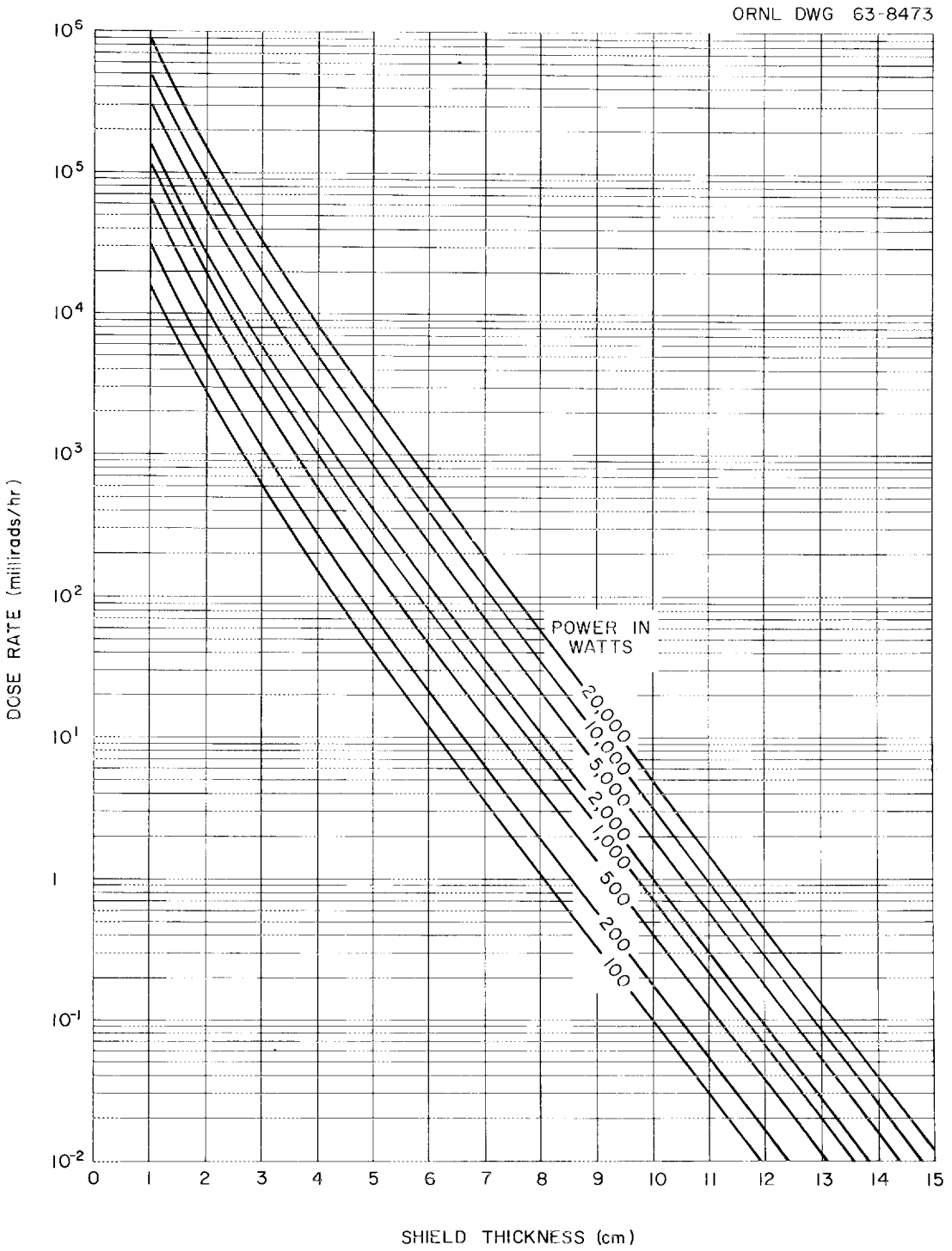

Fig. 8. Gamma Dose Rates Contributed by a 1% Impurity of Cesium-134 in Uranium-Shielded Isotopic Power Sources of Cesium-137. Center of source to dose point separation distance = 100 cm. Cesium-134 is assumed to contribute 1% of the beta activity due to cesium-137; refer to Fig. 4.

REFERENCE COLUMN

B. CESIUM SULFATE (Cs_2SO_4)

1. Composition

a. Radionuclidic Abundance

The cesium product contains >99% cesium and <1% rubidium. The radionuclidic abundances are given in Section I.A.1.

b. Radiochemical Purity

The principal radiochemical impurity in the ^{137}Cs fission product is ^{134}Cs ($T_{1/2}$ = 2.1 y), whose content in aged wastes is 2-5% of the ^{137}Cs activity. The ratio of ^{134}Cs to the ^{137}Cs activities will decrease by a factor of ~2.0 every two years as a result of decay.

2. Specific Power

a. 0.111 watt/g of pure Cs_2SO_4
0.110 watt/g of 99% Cs_2SO_4–1% RbS_2O_4

b. 23.3 curies of ^{137}Cs per gram of pure Cs_2SO_4 2, 3, 4
23.1 curies of ^{137}Cs per gram of 99% Cs_2SO_4–1% Rb_2SO_4

3. Radiation

The radiation is given under Section I.A.3.

4. Critical Mass

Cesium-137 and ^{137}Ba are not fissionable.

5. Compatibility With Materials of Containment

6. Thermophysical Properties

a. Density

4.243 grams/cm^3 – density of pure Cs_2SO_4 20

4.24 grams/cm^3 – density of 99% Cs_2SO_4–1% Rb_2SO_4

b. Coefficients of thermal expansion

c. Specific heat and enthalpy

(1) Specific heat

0.088 cal g^{-1} $°C^{-1}$ 21

(2) Enthalpy in calories

CESIUM SULFATE (Cs_2SO_4)

REFERENCE COLUMN

d. Temperatures of phase transformations

(1) Melting point – 1019°C — 20

(2) Boiling point

e. Latent heats of phase transformations

ΔH (fusion) 15 kcal/mole — 21

(estimated from Na_2SO_4 and K_2SO_4)

f. Vapor pressure

g. Thermal conductivity

h. Thermal diffusivity

i. Viscosity

j. Surface tension

dyn/cm	Temperature, °C	
111.3	1036	17
105.0	1105	
97.3	1221	
87.4	1423	
83.0	1530	

k. Total hemispherical emittance

l. Spectral emissivity

A value of 0.9 can be assumed.

m. Crystallography

rhombic (K_2SO_4 type) — 18

a = 6.24 kX

b = 10.93 kX

c = 8.23 kX

n. Solubilities

g per 100 g water	Temperature, °C	
167.6	0.7	18
184.4	30.4	
199.4	59.5	
214.8	89.8	
224.5	108.6	

CESIUM SULFATE (Cs_2SO_4)

REFERENCE COLUMN

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 formation

$\Delta H^\circ_f = -339.4$ kcal/mole — 13

(2) Free energy of formation

$\Delta F^\circ_f = -310.6$ kcal/mole — 20, 22

(calculated by $\Delta F^\circ_f = \Delta H^\circ_f - T\Delta S^\circ_f$)

(3) Entropy

$S^\circ_{298} = 49.2$ eu — 22

(calculated by W. Latimer's method)

b. Chemical reactions and reaction rates (oxygen, nitrogen, water, steam, hydrogen, liquid metals, other) — 18

(1) Oxygen — no reaction

(2) Nitrogen — no reaction

(3) Water — soluble

(4) Inorganic acids — soluble

9. Biological Tolerances

Maximum permissible body burdens and maximum permissible concentration of ^{137}Cs in air and water are given under the CsCl Source Form, Section I.A.9. — 19

10. Shielding Data

The shielding requirements are presented under the CsCl Source Form, Section I.A.10.

REFERENCE COLUMN

C. CESIUM BOROSILICATE GLASS ($Cs_2O \cdot B_2O_3 \cdot 4.2SiO_2$)

1. Composition

a. Radionuclidic Abundance

The cesium product contains >99% cesium and <1% rubidium. The radionuclidic abundances are given in Section I.A.1.

b. Radiochemical Purity

The principal radiochemical impurity in the ^{137}Cs fission product is ^{134}Cs ($T_{1/2}$ = 2.1 y), whose content in aged wastes is 2-5% of the ^{137}Cs activity. The ratio of ^{134}Cs to ^{137}Cs activities will decrease by a factor of ~2.0 every two years as a result of decay.

2. Specific Power

a. 0.065 watt/g of pure cesium glass — 4
0.064 watt/g of 99% cesium glass—1% rubidium glass

b. 13.6 curies of ^{137}Cs per gram of cesium glass — 2, 3, 4
13.5 curies of ^{137}Cs per gram of 99% cesium glass—1% rubidium glass

3. Radiation

The radiation is given under Section I.A.3.

4. Critical Mass

Cesium-137 and ^{137}Ba are not fissionable.

5. Compatibility With Materials of Containment

6. Thermophysical Properties

a. Density

3.1 grams/cm^3 — density of pure cesium glass — 23

3.1 grams/cm^3 — density of 99% cesium glass—1% rubidium glass

b. Coefficient of thermal expansion

7.0×10^{-6}/°C for 1.24 Rb_2O-1.08 B_2O_3-7.64 SiO_2 glass — 24

CESIUM BOROSILICATE GLASS ($Cs_2O \cdot B_2O_3 \cdot 4.2SiO_2$)

REFERENCE COLUMN

c. Specific heat and enthalpy

(1) Specific heat in cal g^{-1} $°C^{-1}$

0.148 at 298°C — 25

(2) Enthalpy in calories/mole

d. Temperature of phase transformations

(1) Softening point — 1200-1300°C — 23

(2) Boiling point

e. Latent heats of phase transformations

f. Vapor pressure

At 1200°C cesium glass will volatilize at the rate of 35 mg of $Cs_2O \cdot B_2O_3$ per cm^2/hr. — 23

g. Thermal conductivity — 26

cal cm^{-1} sec^{-1} $°C^{-1}$	Temperature, °C
0.00367	115
0.00424	209
0.00600	352
0.00792	448

These values are for Pyrex glass.

h. Thermal diffusivity

0.0117 cm^2/sec at 298°C

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

i. Viscosity

j. Surface tension

k. Total hemispherical emittance

l. Spectral emissivity

m. Crystallography

Glass shows no long-range X-ray structure.

n. Solubilities

The leach rate of cesium glass is 0.2 mg cm^{-2} day^{-1} of $Cs_2O \cdot B_2O_3$. — 23

CESIUM BOROSILICATE GLASS ($Cs_2O \cdot B_2O_3 \cdot 4.2SiO_2$)

REFERENCE COLUMN

o. Diffusion rates

7. Mechanical Properties

a. Hardness

5-7 on Mohs scale — 27

b. Crush strength

3500-7000 kg/cm^2 at room temperature — 27 (silicates)

8. Chemical Properties

a. Heat and free energy of formation, entropy

(1) Heat of formation of $Cs_2O \cdot B_2O_3 \cdot 4.2SiO_2$

$\Delta H^\circ_f = -1317$ kcal/mole — 22, 25

(estimated from the ΔH°_f's of the individual oxides and the Na-B compounds)

(2) Free energy of formation

$\Delta F^\circ_f = -1237$ kcal/mole — 22, 25

(calculated by $\Delta F^\circ_f = \Delta H^\circ_f - T\Delta S^\circ_f$)

(3) Entropy

$S^\circ_{298} = 95.4$ eu — 22

(estimated by summing the individual oxides)

b. Chemical reactions and reaction rates (oxygen, nitrogen, water, steam, hydrogen, liquid metals, other) — 23

(1) Oxygen — no reaction

(2) Nitrogen — no reaction

(3) Water — 0.2 mg cm^{-2} day^{-1} of cesium

(4) Inorganic acids — soluble

9. Biological Tolerances

Maximum permissible body burdens and maximum permissible concentration of ^{137}Cs in air and water are given under the CsCl Source Form, Section I.A.9. — 19

10. Shielding Data

The shielding requirements are presented under the CsCl Source Form, Section I.A.10.

APPENDIX I

Table 1. Production of Bremsstrahlung Photons From Strontium-90 Beta in Strontium Oxide Matrix (Ref. 5)

Maximum beta-particle energy	0.545 Mev
Average beta-particle energy	0.201 Mev

Bremsstrahlung energy group, Mev	Within ΔE energy group	
	Photons/beta particle	Photons w^{-1} sec^{-1}
0.020 ± 0.01	1.378×10^{-2}	9.80×10^{10}
0.040 ± 0.01	5.523×10^{-3}	3.93×10^{10}
0.060 ± 0.01	2.998×10^{-3}	2.13×10^{10}
0.080 ± 0.01	1.841×10^{-3}	1.31×10^{10}
0.100 ± 0.01	1.208×10^{-3}	8.59×10^{9}
0.120 ± 0.01	8.239×10^{-4}	5.86×10^{9}
0.140 ± 0.01	5.759×10^{-4}	4.09×10^{9}
0.160 ± 0.01	4.086×10^{-4}	2.91×10^{9}
0.180 ± 0.01	2.923×10^{-4}	2.08×10^{9}
0.200 ± 0.01	2.099×10^{-4}	1.49×10^{9}
0.220 ± 0.01	1.505×10^{-4}	1.07×10^{9}
0.240 ± 0.01	1.074×10^{-4}	7.64×10^{8}
0.260 ± 0.01	7.604×10^{-5}	5.41×10^{8}
0.280 ± 0.01	5.315×10^{-5}	3.78×10^{8}
0.300 ± 0.01	3.654×10^{-5}	2.60×10^{8}
0.320 ± 0.01	2.458×10^{-5}	1.75×10^{8}
0.340 ± 0.01	1.609×10^{-5}	1.14×10^{8}
0.360 ± 0.01	1.016×10^{-5}	7.22×10^{7}
0.380 ± 0.01	6.135×10^{-6}	4.36×10^{7}
0.400 ± 0.01	3.491×10^{-6}	2.48×10^{7}
0.420 ± 0.01	1.835×10^{-6}	1.30×10^{7}
0.440 ± 0.01	8.638×10^{-7}	6.14×10^{6}
0.460 ± 0.01	3.456×10^{-7}	2.46×10^{6}
0.480 ± 0.01	1.065×10^{-7}	7.57×10^{5}
0.500 ± 0.01	2.007×10^{-8}	1.43×10^{5}
0.520 ± 0.01	1.000×10^{-9}	7.11×10^{3}
0.540 ± 0.01	0.000	
Total bremsstrahlung energy, Mev/beta particle	1.411×10^{-3}	

APPENDIX I

Table 2. Production of Bremsstrahlung Photons From Thulium-170 Beta 1 in Thulium Oxide Matrix (Ref. 5)

Maximum beta-particle energy	0.968 Mev
Average beta-particle energy	0.326 Mev

Bremsstrahlung energy group, Mev	Within ΔE energy group	
	Photons/beta particle	Photons w^{-1} sec^{-1}
0.050 ± 0.025	5.736×10^{-2}	3.55×10^{10}
0.100 ± 0.025	2.085×10^{-2}	1.29×10^{10}
0.150 ± 0.025	1.026×10^{-2}	6.35×10^{9}
0.200 ± 0.025	5.686×10^{-3}	3.52×10^{9}
0.250 ± 0.025	3.340×10^{-3}	2.07×10^{9}
0.300 ± 0.025	2.020×10^{-3}	1.25×10^{9}
0.350 ± 0.025	1.236×10^{-3}	7.65×10^{8}
0.400 ± 0.025	7.551×10^{-4}	4.67×10^{8}
0.450 ± 0.025	4.562×10^{-4}	2.82×10^{8}
0.500 ± 0.025	2.696×10^{-4}	1.67×10^{8}
0.550 ± 0.025	1.542×10^{-4}	9.54×10^{7}
0.600 ± 0.025	8.410×10^{-5}	5.21×10^{7}
0.650 ± 0.025	4.296×10^{-5}	2.66×10^{7}
0.700 ± 0.025	2.000×10^{-5}	1.24×10^{7}
0.750 ± 0.025	8.138×10^{-6}	5.04×10^{6}
0.800 ± 0.025	2.680×10^{-6}	1.66×10^{6}
0.850 ± 0.025	6.111×10^{-7}	3.78×10^{5}
0.900 ± 0.025	6.278×10^{-8}	3.89×10^{4}
0.950 ± 0.025	2.196×10^{-10}	1.36×10^{2}
Total bremsstrahlung energy, Mev/beta particle	1.033×10^{-2}	

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