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OAK RIDGE NATIONAL LABORATORY

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CALCULATION OF ENERGY DEPOSITIONS AND DOSE RATES IN PROPOSED SHIELDING SURROUNDING THE TSR-II REACTOR

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JANUARY 1974

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ABSTRACT

The spherical distributions of dose rates and energy depositions due to neutrons and gamma rays in several kinds of shields surrounding the TSR-II reactor are presented. The distributions were calculated using ANISN.

These results are used to determine an adequate configuration for the proposed new shielding around the TSR-II when an ∿ 3-ft-diameter collimator is employed.

I. INTRODUCTION

A series of proposed beam shields for the TSR-II reactor[1] with a new large diameter beam hole (∿ 3 ft) has been investigated to determine heating and dose rate levels throughout the shields.

The ultimate shield must satisfy the following criteria:

1. Permissible gamma dose rate after shut down, both behind the shield and behind the beam shutter.
2. Permissible dose rate behind the shield while the reactor is operating to meet safety requirements at the 600-ft fence.
3. Permissible temperature rise in the shield under reactor operation.
4. Provide low background for measurements made in the beam hole behind relatively thick shields.
5. Low cost.

The calculations presented here investigate the first four criteria for several proposed shielding configurations.

II. CONFIGURATION OF THE TSR-II CORE AND OF THE SEVERAL PROPOSED SHIELDS

The configuration from the pressure vessel inward to the center of the core remains unaltered from the existing configuration. It is shown in Table 1 and Fig. 1 and the composition of the materials is shown in Table 2.

The configurations for the various proposed shields outside the reactor pressure vessel are shown in Table 3.

Cases 1 and 2 both consist of stainless steel-water multilayers and concrete. The only difference between them is the volume ratio of stainless steel and water in the multilayers.

Case 3 is the configuration at present used around the TSR-II.

Case 4 is a test configuration placed in front of the beam hole behind which measurements can reasonably be expected to be made. The dose rate behind this test shield should dominate those for cases 1-3.

Case 5 is a beam hole shutter shield, to be used after shut down.

Case 6 is the new proposed beam hole shutter, to be used after shut down.

III. RESULTS OF THE CALCULATIONS

Calculations with ANISN[2] were performed in spherical geometry using a 21 neutron - 18 gamma-ray group set expanded through P_3.

The fission neutron distribution obtained from a core calculation is shown in Fig. 2, which is normalized to one fission neutron integrated over the core. In order to obtain the results at 1 MWt operation, a normalizing factor of 8.06×10^{16} n/sec/core has to be used. Details of calculating this normalizing factor are shown in Appendix A.

Table 1. Configurations Inside the Pressure Vessel of the TSR-II for a Spherical Model Calculation

Zone No.	Thickness (in.)	Compositions (Volume Ratio)	Remarks
1	5 1/2	Aluminum (0.75), Water (0.23), Stainless Steel (0.02)	
2	3/8	Aluminum (0.170), Water (0.830)	
3	1	Aluminum (0.131), Water (0.394), Stainless Steel (0.0475), B_4C	Control Plate
4	1 1/2	Aluminum (0.354), Water (0.646)	
5	1/8	Aluminum (0.927), ^{235}U (3.257×10^{-4}), ^{238}U (2.43×10^{-5})	Fuel Plate
6	1/2	Aluminum (0.165), Water (0.835)	
7	5 1/2	Aluminum (0.361), Water (0.635), ^{235}U (1.3038×10^{-4}), ^{238}U (9.72×10^{-6})	Fuel
8	1/4	Aluminum (0.33), Water (0.67)	
9	1/2	Water (1.00)	
10	3/4	Aluminum (1.00)	
11	2	Water (1.00)	
12	3/8	Aluminum (1.00)	
13	3/4	Aluminum (1.00)	Pressure Vessel

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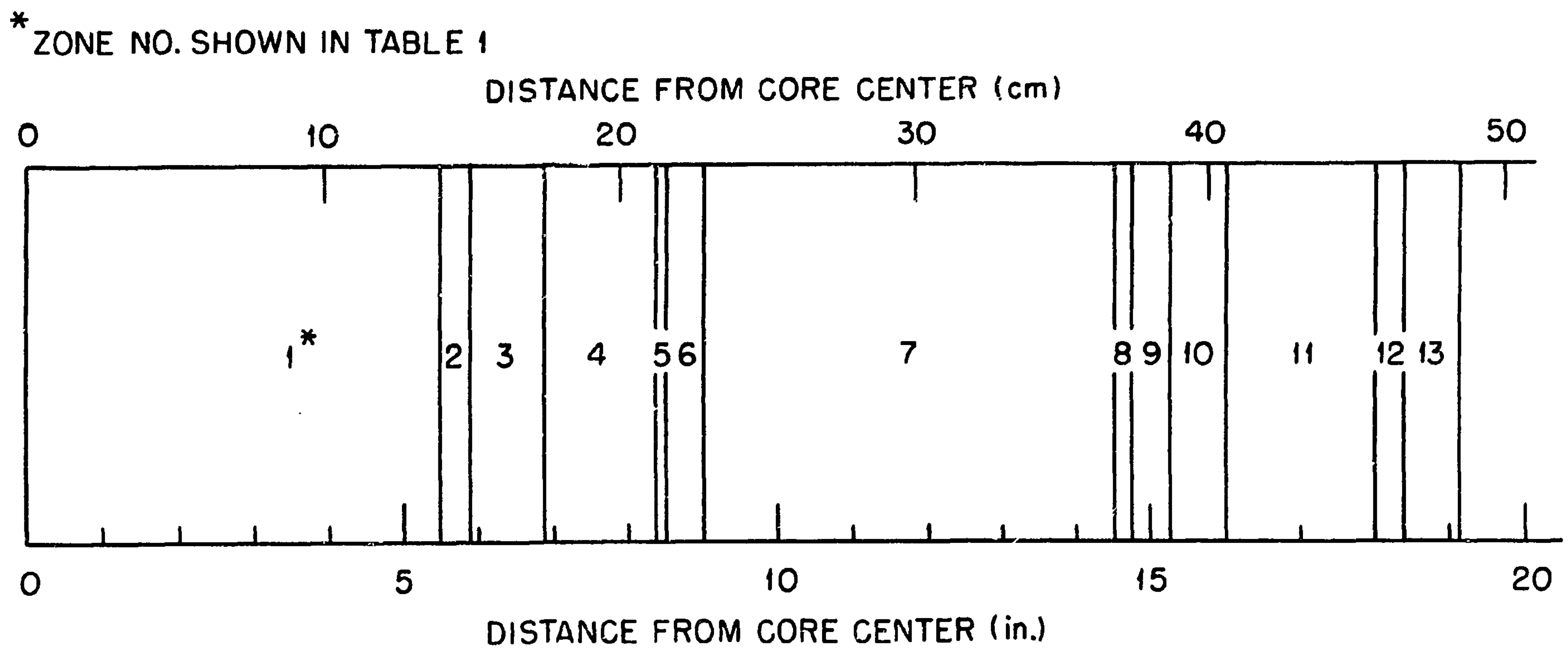

Fig. 1. Configuration Inside the Pressure Vessel of the TSR-II

Table 2. Composition of Materials Used in the Calculations

Material (Density)	Composition	(Weight Percent)
Aluminum Alloy ($2.767\ g/cm^3$)	Al	(98%)
	Mg, Fe, Si	(2%)
Stainless Steel 304 ($7.88\ g/cm^3$)	Fe	(69.871%)
	Cr	(18.46%)
	Ni	(9.725%)
	Mn	(1.394%)
	Si, C, O	(9.55%)
Light Water ($1.00\ g/cm^3$)	H	(11.2%)
	O	(88.8%)
Concrete ($2.31\ g/cm^3$)	H	(0.4%
	C	(10.4%)
	O	(48.9%)
	Si	(2.3%)
	Ca	(38.0%)

Table 3. Proposed Shielding Configurations Outside the Pressure Vessel of the TSR-II

Case No.	Zone No.	Thickness (in.)	Compositions (Volume Ratio)
1	14	1	Stainless Steel (1.0)
	15	8	Stainless Steel (0.65), Water (0.35)
	16	1	Stainless Steel (1.0)
	17	66	Concrete
2	14	1	Stainless Steel (1.0)
	15	8	Stainless Steel (0.35), Water (0.65)
	16	1	Stainless Steel (1.0)
	17	66	Concrete
3	14	17 1/8	Lead (0.5), Water (0.5)
	15	31 1/4	Water
4*	14	12	Steel
	15	120	Sodium
5**	14	10	Lead
6***	14	1/2	Stainless Steel
	15	11	Lead
	16	1/2	Stainless Steel

*Configuration to be considered as minimum test of a foreground measurement.

**Configuration of shutter for the beam hole.

***Proposed configuration of shutter for the new beam hole.

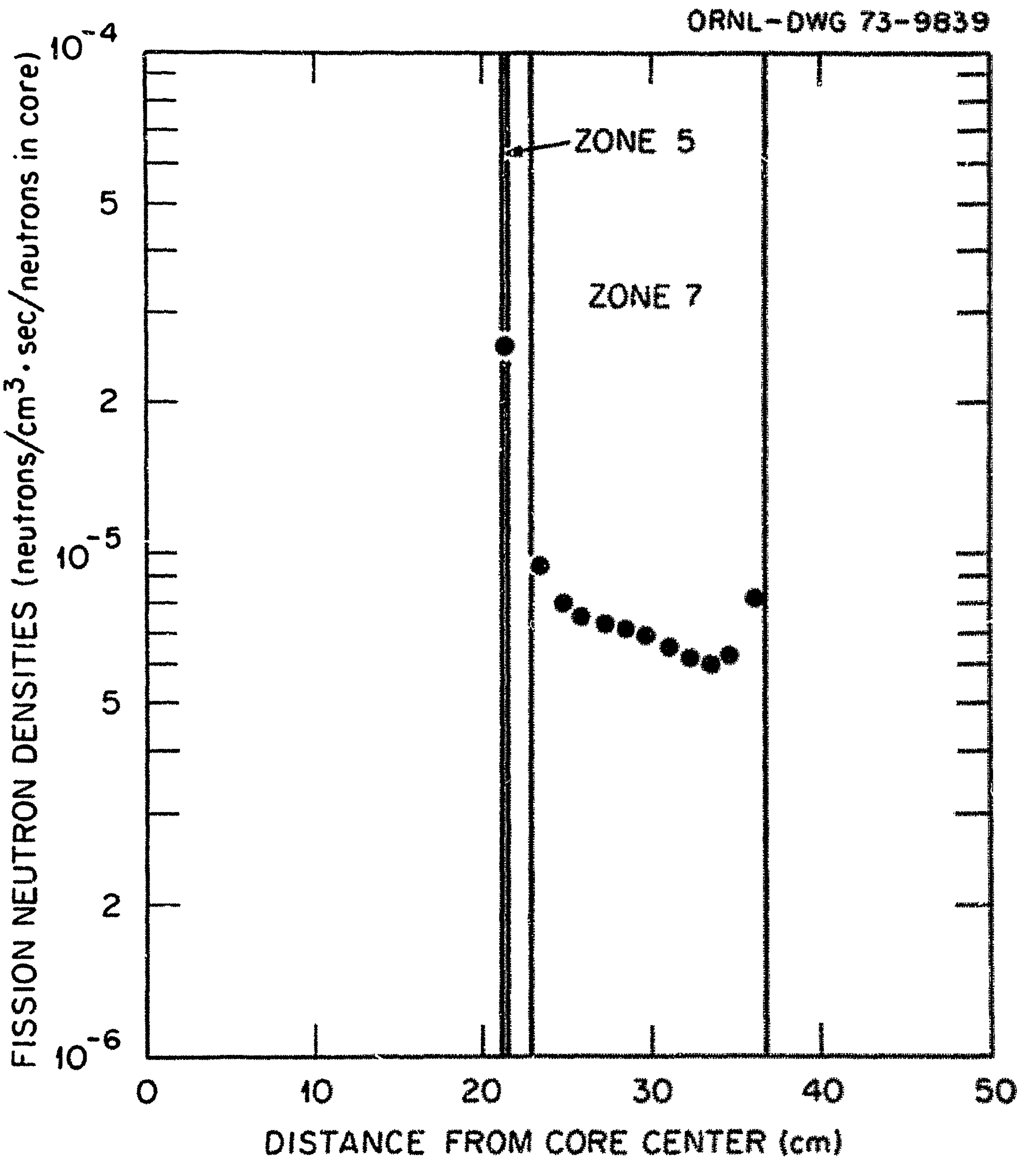

Fig. 2. Distribution of Fission Neutron Density

3.1. Heat Generation in the Shields

For the first three cases, energy deposition in the shield materials due to neutrons and gamma rays with the reactor operating were calculated by using a 39 group KERMA factor.[3] The 39 group KERMA factors for concrete, steel, and lead are shown in Tables 4 and 5. The calculated results are shown in Tables 6 and 7 for case 1 and in Figs. 3, 4, and 5. Since the energy deposition due to gamma rays is dominant in each case, the contribution of the neutrons can be neglected in calculating the heating rates in the shields.

3.2. Dose Rate Under Operation

The dose rate distribution in concrete for Case 1 is shown in Fig. 6. The dose rate at the outer surface of each shield for cases 1-4 is shown in Table 9.

3.3. Shut Down Dose Rate

To obtain the shut down fission product gamma-ray dose rate, intensities of the gamma rays after shut down were calculated using ORIGEN code[7] for the conditions following an operation of four cycles of 8 hr up and 16 hr down and then 8 hr up, the power during the up cycle being 1 MWt. Intensities of these source gamma rays are shown in Table 8.

The dose rate distribution for each case is calculated by assuming a flat source distribution in the core with the spectrum as shown in the table.

The results are shown in Table 9.

Table 4. Neutron KERMA Factors for 21 Group Set
(erg/cm/n)

Energy Group	Upper Energy (eV)	Concrete[4]	Steel[5]	Lead[5]
1	1.4918(7)[a]	2.69(-7)	3.40(-7)	1.24(-8)
2	1.0000(7)	1.52(-7)	1.34(-7)	9.80(-9)
3	6.7032(6)	1.10(-7)	5.84(-8)	8.06(-9)
4	4.4933(6)	1.11(-7)	3.54(-8)	7.58(-9)
5	3.0119(6)	6.67(-8)	2.51(-8)	5.84(-9)
6	2.0190(6)	6.08(-8)	1.71(-8)	3.53(-9)
7	1.3534(6)	6.63(-8)	1.09(-8)	2.36(-9)
8	9.0718(5)	3.77(-8)	7.90(-9)	1.79(-9)
9	5.5023(5)	3.75(-8)	6.93(-9)	1.19(-9)
10	3.3323(5)	2.17(-8)	3.26(-9)	1.07(-9)
11	2.0242(5)	1.43(-8)	2.81(-9)	7.27(-10)
12	1.2277(5)	7.75(-9)	1.50(-9)	4.20(-10)
13	4.0867(4)	2.85(-9)	1.71(-9)	1.48(-10)
14	1.1709(4)	8.85(-10)	2.74(-10)	6.95(-11)
15	3.3546(3)	2.35(-10)	7.43(-11)	4.50(-11)
16	7.4852(2)	5.27(-11)	2.10(-11)	4.13(-11)
17	1.6702(2)	1.19(-11)	8.36(-12)	4.41(-11)
18	3.7266(1)	2.80(-12)	8.88(-12)	4.90(-11)
19	8.3153(0)	9.22(-13)	1.61(-11)	8.22(-11)
20	1.8554(0)	8.36(-13)	3.50(-11)	1.75(-10)
21	4.1339(-1)	2.25(-12)	1.17(-11)	5.84(-10)

[a]Read as: 1.4919×10^7.

Table 5. Gamma-Ray KERMA Factors for 18 Group Set[6]
(MeV/cm/γ)

Energy Group	Upper Energy (eV)	Concrete	Steel	Lead
1	1.00(7)[a]	3.68(-1)	1.60(0)	4.00(0)
2	8.00(6)	3.10(-1)	1.29(0)	3.07(0)
3	7.00(6)	2.74(-1)	1.10(0)	2.51(0)
4	6.00(6)	2.37(-1)	9.11(-1)	1.99(0)
5	5.00(6)	2.01(-1)	7.34(-1)	1.51(0)
6	4.00(6)	1.74(-1)	6.10(-1)	1.19(0)
7	3.50(6)	1.56(-1)	5.31(-1)	9.90(-1)
8	3.00(6)	1.38(-1)	4.55(-1)	8.11(-1)
9	2.50(6)	1.1 (-1)	3. (-1)	6.64(-1)
10	2.00(6)	1.01(-1)	3.20(-1)	5.56(-1)
11	1.60(6)	8.33(-2)	2.62(-1)	4.83(-1)
12	1.20(6)	6.62(-2)	2. (-1)	4. (-1)
13	9.00(5)	4.90(-2)	1.58(-1)	4.70(-1)
14	6.00(5)	3.40(-2)	1.13(-1)	5.90(-1)
15	4.00(5)	1.83(-2)	7.43(-2)	1.13(0)
16	2.10(5)	1.16(-2)	9.19(-2)	2.88(0)
17	1.20(5)	1.49(-2)	2.21(-1)	3.84(0)
18	7.00(4)	3.13(-2)	4.96(0)	1.11(1)

[a]Read as: 1.00×10^{7}.

Table 6. Energy Deposition in Concrete (Case 1)

Radius of Mesh Point* (cm)	Energy Deposition in Concrete ($W/cm^3/MWt$)	
	Due to Gamma Rays	Due to Neutrons
76.52	2.04(-4)[a]	2.34(-5)
81.60	1.40(-4)	1.24(-5)
86.68	1.00(-4)	6.80(-6)
91.76	7.35(-5)	3.76(-6)
96.84	5.41(-5)	2.14(-6)
101.92	3.93(-5)	1.23(-6)
107.00	2.84(-5)	7.23(-7)
112.08	2.03(-5)	4.30(-7)
117.16	1.44(-5)	2.60(-7)
122.24	1.01(-5)	1.58(-7)
127.32	7.05(-6)	9.67(-8)
132.40	4.86(-6)	6.03(-8)
137.48	3.56(-6)	3.15(-8)
142.56	2.30(-6)	2.34(-8)
147.64	1.58(-6)	1.47(-8)
152.72	1.08(-6)	9.27(-9)
157.80	7.39(-7)	2.58(-9)
162.88	5.06(-7)	3.72(-9)
167.96	3.46(-7)	2.36(-9)
173.04	2.38(-7)	1.51(-9)
178.12	1.62(-7)	9.59(-10)
183.20	1.11(-7)	6.15(-10)
188.28	7.67(-8)	3.91(-10)
193.36	5.28(-8)	2.51(-10)
198.44	3.87(-8)	1.61(-10)
203.52	2.53(-8)	1.04(-10)
208.60	1.75(-8)	6.69(-11)
213.68	1.22(-8)	4.30(-11)
218.76	8.47(-9)	2.77(-11)
223.84	5.89(-9)	1.17(-11)
228.92	4.09(-9)	1.12(-11)
234.00	2.82(-9)	6.96(-12)
239.08	1.98(-9)	3.67(-12)

*Inner and Outer Radii of Concrete Shield are 73.98 cm and 241.62 cm, respectively.

[a]Read: 2.04×10^{-4}.

Table 7. Energy Deposition in Stainless Steel (Case 1)

Radius of Mesh Point (cm)	Energy Deposition in Steel ($W/cm^3/MWt$)	
	Due to Gamma Rays	Due to Neutrons
49.00*	2.05(-1)	6.34(-4)
49.85*	1.43(-1)	5.46(-4)
50.69*	1.07(-1)	4.63(-4)
52.04**	7.55(-2)	3.55(-4)
53.89**	4.99(-2)	2.45(-4)
55.74**	3.34(-2)	1.72(-4)
57.85**	2.31(-2)	1.22(-4)
59.43**	1.61(-2)	8.62(-5)
61.28**	1.13(-2)	6.13(-5)
63.12**	8.10(-3)	4.38(-5)
64.97**	5.80(-3)	3.13(-5)
66.82**	4.18(-3)	2.26(-5)
68.67**	3.00(-3)	1.64(-5)
70.51**	2.14(-3)	1.25(-5)
71.86***	1.59(-3)	1.06(-5)
72.71***	1.29(-3)	9.59(-6)
73.55***	1.07(-3)	8.54(-6)

*1-in. stainless steel inner and outer radii of which are 48.58 cm and 51.12 cm, respectively.

**8-in. stainless steel and water mixture, inner and outer radii of which are 51.12 cm and 71.44 cm, respectively. Volume ratio of stainless steel is 65%.

***1-in. stainless steel, inner and outer radii of which are 71.44 cm and 73.98 cm, respectively.

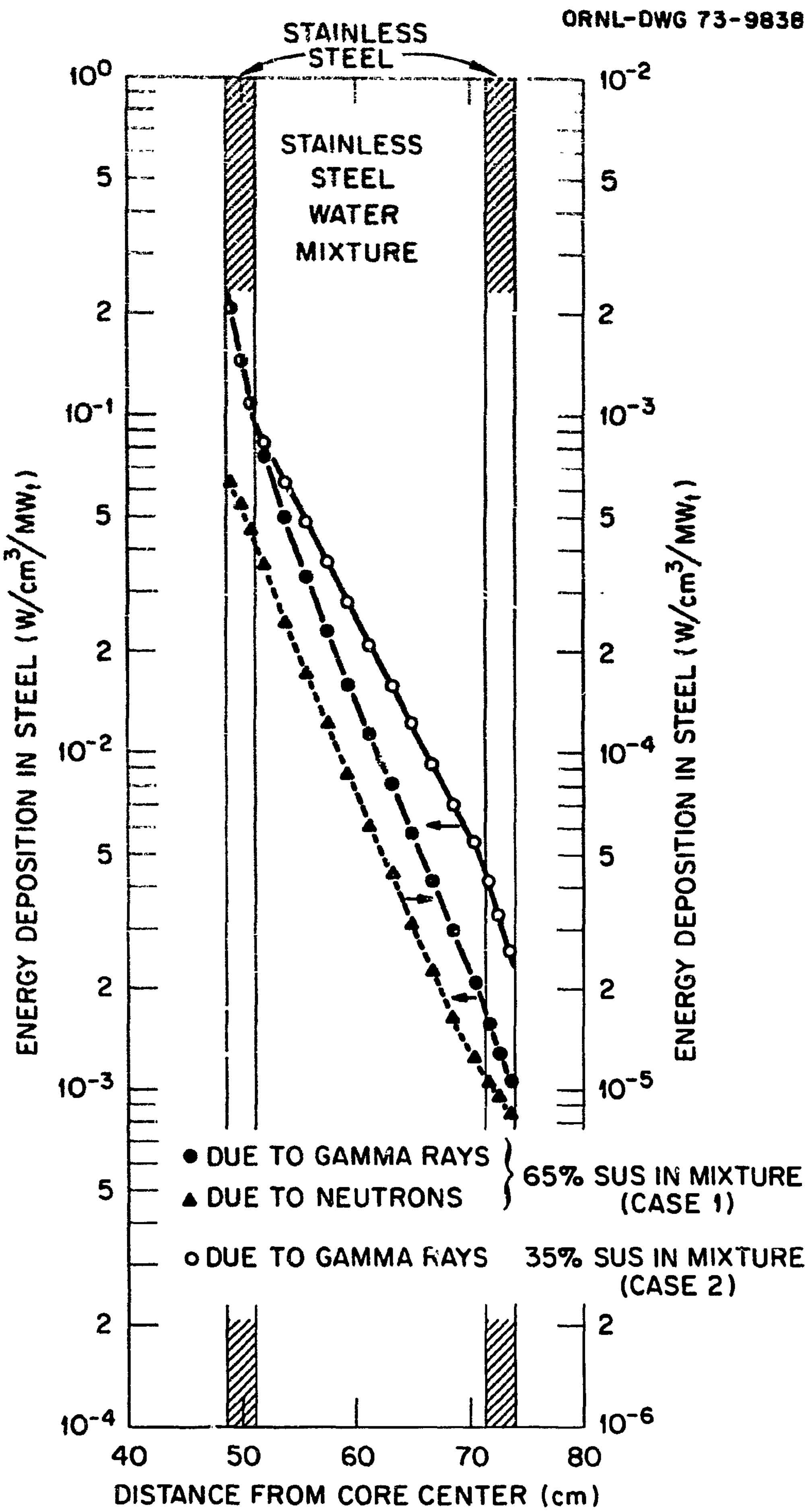

Fig. 3. Energy Deposition in Steel (Case 1 and 2)

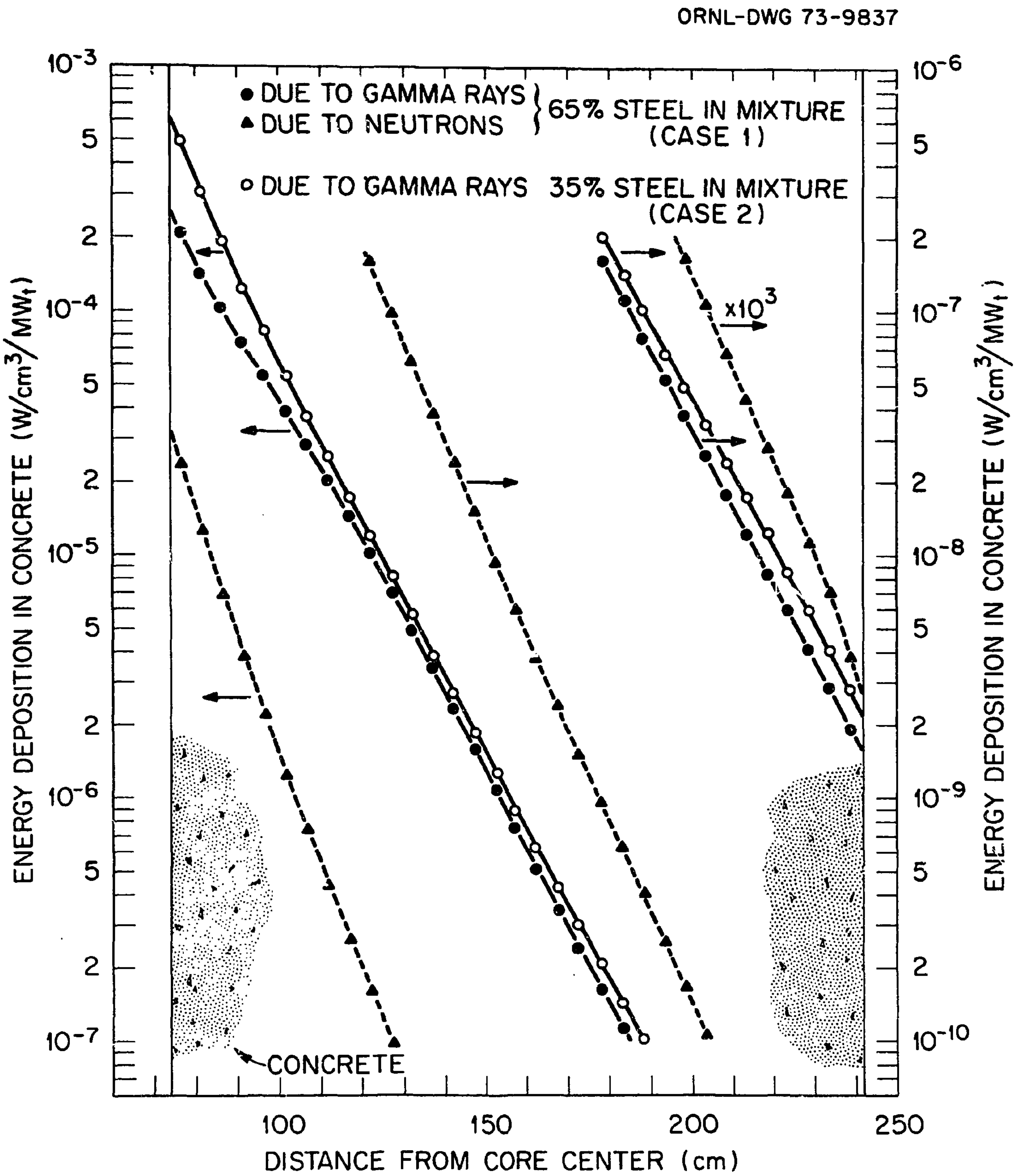

Fig. 4. Energy Deposition in Concrete (Case 1 and 2)

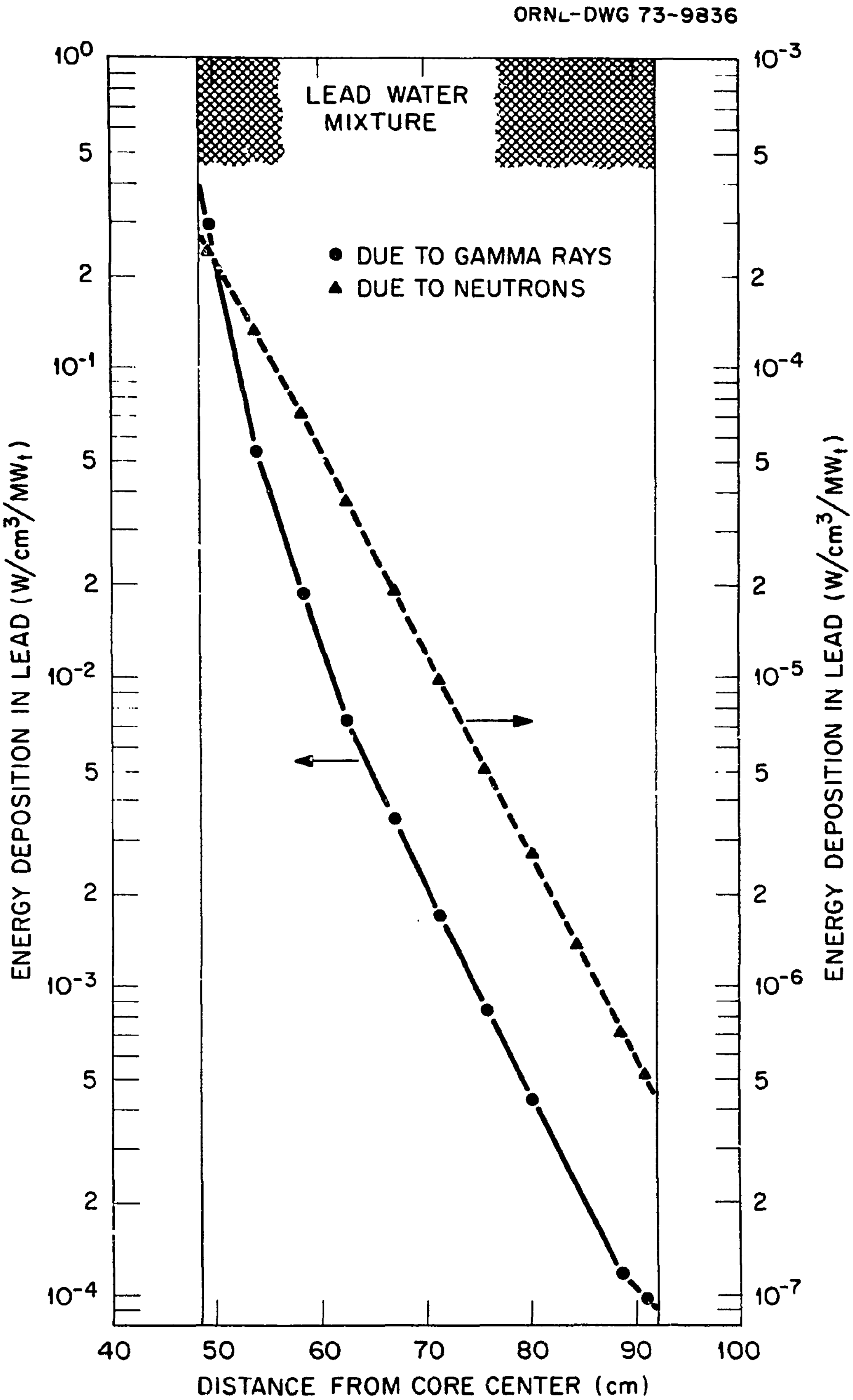

Fig. 5. Energy Deposition in Lead (Case 3)

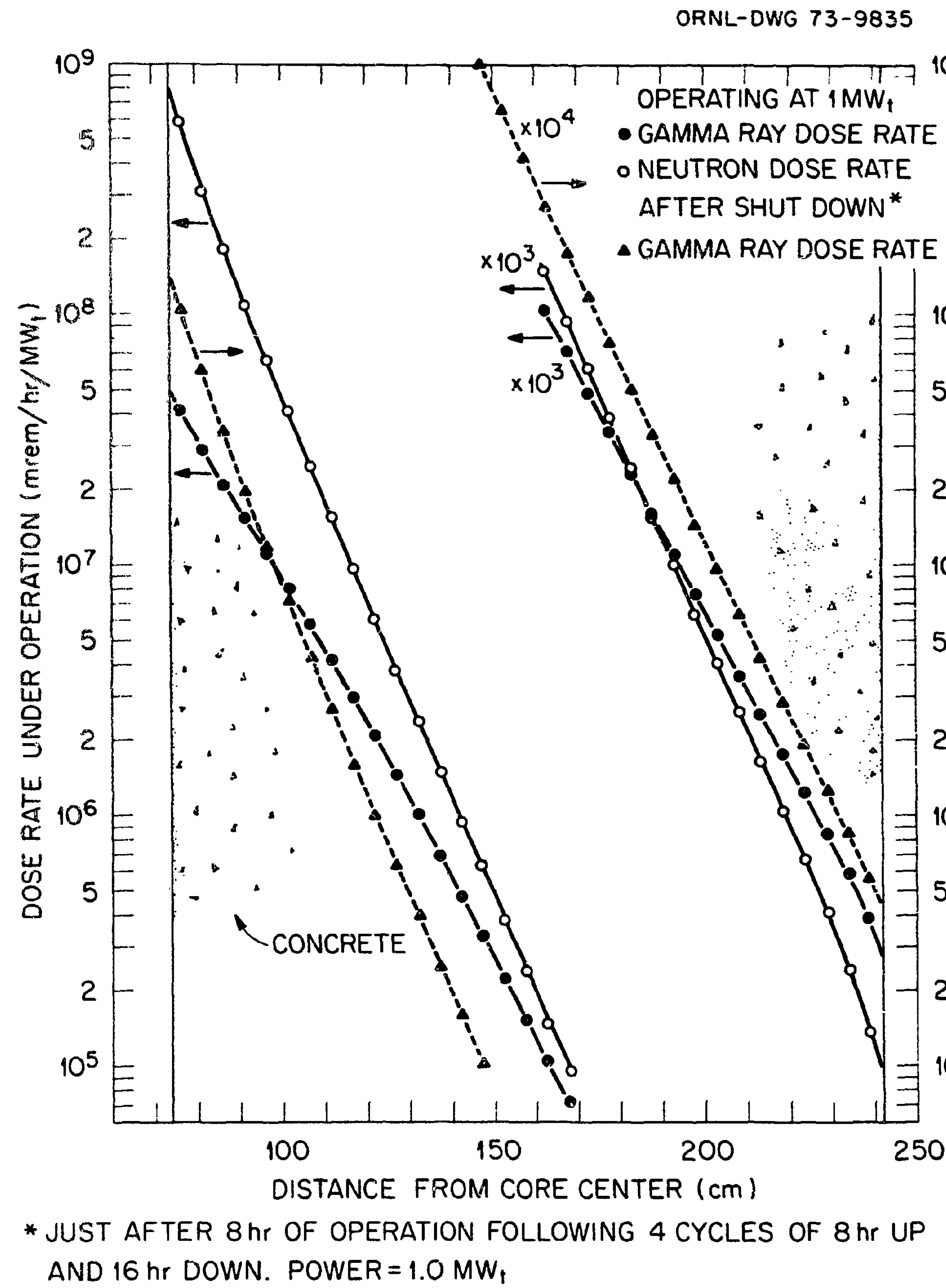

Fig. 6. Dose Rate Distribution in Concrete (Case 1)

Table 8. Energy Dependent Gamma Ray Intensities from the Core of the TSR-II after Shut Down*

Energy Range (MeV)	Intensities (γ/sec)
10.0-8.0	0
8.0-7.0	0
7.0-6.0	0
6.0-5.0	6.17(13)[a]
5.0-4.0	8.06(14)
4.0-3.5	1.76(14)
3.5-3.0	1.05(15)
3.0-2.5	2.17(15)
2.5-2.0	3.27(15)
2.0-1.6	6.73(15)
1.6-1.2	1.41(16)
1.2-0.9	1.42(16)
0.9-0.6	2.45(16)
0.6-0.4	1.63(16)
0.4-0.21	2.41(16)
0.21-0.12	1.26(15)
0.12-0.07	0
0.07-0.0	0

*Calculated conditions: After 8 hr of operation following 4 cycles of 8 hr up and 16 hr down. Power = 1.0 Mwt.

[a]Read: 6.17×10^{13}.

Table 9. Dose Rate at Outer Surface of Shields under Operation and after Shut Down

Case No.	Under Operation		After Shutdown
	Neutrons (mrem/h/MWt)	Gamma Rays (mrem/h/MWt)	Gamma Rays (mrem/h/MWt)
1	5.5×10^{1}	3.09×10^{2}	4.20×10^{-1}
2	7.59×10^{1}	4.72×10^{2}	1.65×10
3	8.83×10^{2}	3.64×10^{4}	2.11×10^{1}
4	2.76×10^{5}	1.06×10^{5}	
5*			5.79×10^{2}
6*			8.48×10^{1}
Modified Case**	5.0×10^{2}	1.00×10^{3}	1.58×10

*Shutters for beam hole.

**Same as case 1 but 5.0 feet concrete instead of 5.5 feet.

IV. CONCLUSIONS

The results shown in Figs. 3-5 (i.e., cases 1-3), when applied to a calculation of the temperature distribution in the shields, show that no serious temperature gradients or heating problems result.[8]

Under operation, the dose rates behind the shield for cases 1, 2, and Modified 1 (see Table 9) are all lower than the existing case 3, which has already met safety requirements at the fence.

Comparing these dose rates with those of case 4 shows that background should be no problem.

The gamma-ray dose rate after shut down (see Table 9) is seen to be dominated by the shutters (cases 5 or 6), and not by the shields (case 1-3, Modified 1). Since the dose rate behind the proposed shutter (case 6) is 85 mr/hr, personnel must wait a few minutes after shut down before venturing near the beam hole.

As a result of these calculations, and considering construction costs, the Modified case 1 shown in Table 9 has been proposed to be the shield built. It consists of 1 in. stainless steel, 8 in. stainless steel-water mixture containing 65% by volume stainless steel, 1 in. stainless steel, and 5 ft of ordinary concrete. The proposed beam hole shutter consists of 1/2 in. stainless steel, 11 in. lead, and 1/2 in. stainless steel.

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VI. APPENDIX

A. Normalizing Factor

Reactor Power: $P = 1.0$ MWt

Average neutrons per fission: $\bar{\nu} = 2.45$ m/fission

Conversion factor from watt to fission rate: $C = 3.29 \times 10^{10}$ fission/sec/watt

Normalizing factor: $f = P.C.\bar{\nu} = 8.06 \times 10^{16}$ n/sec/MWt