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Neutron Physics Division

GROUND HEATING DUE TO A POINT SOURCE OF 12.2- TO 15-MeV NEUTRONS AT AN ALTITUDE OF 50 FEET

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Abstract

The heat deposited in the ground as a function of range, ground depth, and time due to the neutrons and their secondary gamma rays from a 12.2- to 15-MeV neutron source has been determined. The source was situated at an altitude of 50 feet above the ground in air of uniform density (1.10 gm/ℓ). Both Monte Carlo and discrete ordinates methods were used to transport the neutrons and gamma rays through the atmosphere and into the ground. The importance of low-energy neutrons and the secondary gamma rays to the total heat deposited is shown.

*Mathematics Division

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The heat deposited in the ground or in a concrete structure due to neutrons and their secondary gamma rays is of interest in silo shielding studies. In order to obtain an estimate of both the magnitude and rate of the heat deposited, a reanalysis of previous air-over-ground transport calculations,[1] in addition to new calculations, has been made. The results are presented for a 12.2- to 15-MeV band source at a height of 50 ft above the ground.

New calculations were made with time-dependent versions of the 05R[2] and OGRE[3] Monte Carlo codes to obtain the time distribution of energy deposited in volume elements in the ground. Only neutrons with energies greater than 0.11 MeV and their secondary gamma rays were considered. For the determination of heat deposited in concrete, the flux-to-kerma factors for concrete (see Table I) were used with the flux distribution in the ground; this is a reasonable approximation since the ground contained approximately the same amount of water as structural concrete.

Figure 1 shows the intensity versus range for the amount of heat deposited in the top 2 cm of the ground by fast neutrons and their secondary gamma rays for ranges out to 1200 meters. Fig. 2 shows the distribution of the heat deposited by neutrons and secondary gamma rays as a function of depth at a slant range of 300 meters. The heat deposited for secondary gamma rays is very large in the first 2 cm because of the slant angle at which most of the air inelastic gamma rays strike the ground.

TABLE I. CONCRETE KERMA FACTORS[a]

Group	Neutrons Upper Energy (eV)	Concrete Kerma (ergs/gm)(n/cm^2)	Gamma Rays Group	Gamma Rays Upper Energy (MeV)	Gamma Rays Concrete Kerma (ergs/gm)(γ/cm^2)
1	15.9(+6)*	1.58(-7)	1	10.0	2.65(-7)
2	12.2(+6)	1.17(-7)	2	8.0	2.18(-7)
3	10.0(+6)	8.2(-8)	3	6.5	1.8(-7)
4	8.18(+6)	7.05(-8)	4	5.0	1.46(-7)
5	6.36(+6)	5.75(-8)	5	4.0	1.18(-7)
6	4.96(+6)	5.4(-8)	6	3.0	9.8(-8)
7	4.06(+6)	5.8(-8)	7	2.5	8.4(-8)
8	3.01(+6)	4.1(-8)	8	2.0	7.15(-8)
9	2.46(+6)	3.2(-8)	9	1.66	6.15(-8)
10	2.35(+6)	3.5(-8)	10	1.33	5.05(-8)
11	1.83(+6)	3.12(-8)	11	1.0	4.1(-8)
12	1.11(+6)	2.61(-8)	12	0.8	3.3(-8)
13	5.50(+5)	1.48(-8)	13	0.6	2.42(-8)
14	1.11(+5)	3.55(-9)	14	0.4	1.68(-8)
15	3.35(+3)	1.58(-10)	15	0.3	1.20(-8)
16	5.83(+2)	2.85(-11)	16	0.2	8.0(-9)
17	1.01(+2)	7.1(-12)	17	0.1	1.20(-8)
18	1.90(+1)	5.0(-12)	18	0.05	5.0(-8)
19	1.07(+1)	6.35(-12)			
20	3.06(+1)	1.02(-11)			
21	1.12(+1)	1.63(-11)			
22	0.414(+0)	3.62(-11)			

[a]Taken from reference 4.

*Read as 15.9 x 10^6.

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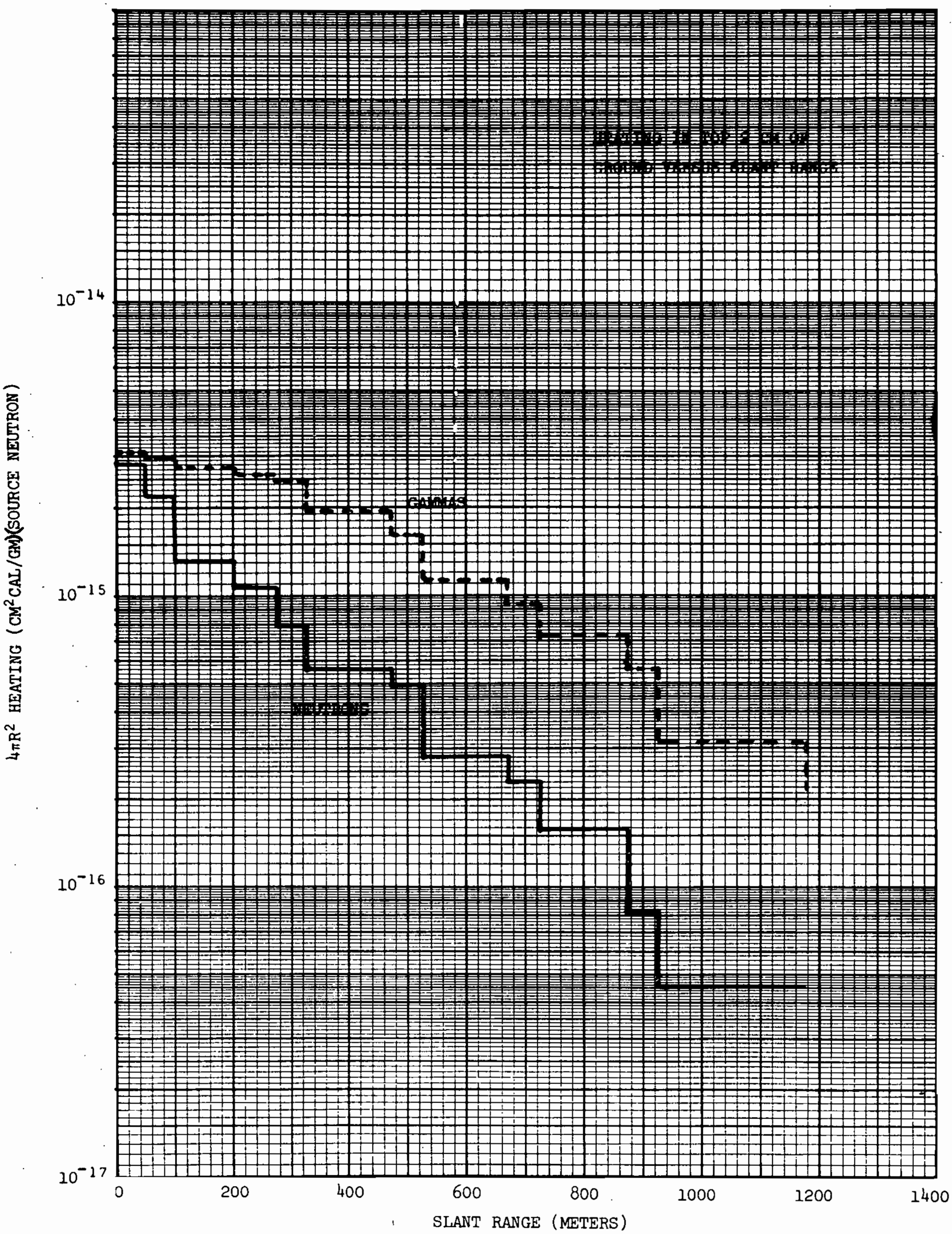

Fig. 1. $4\pi R^2$ Heating in the Top 2 cm of the Ground Versus Slant Range. —— Neutrons, ---- Gamma Rays.

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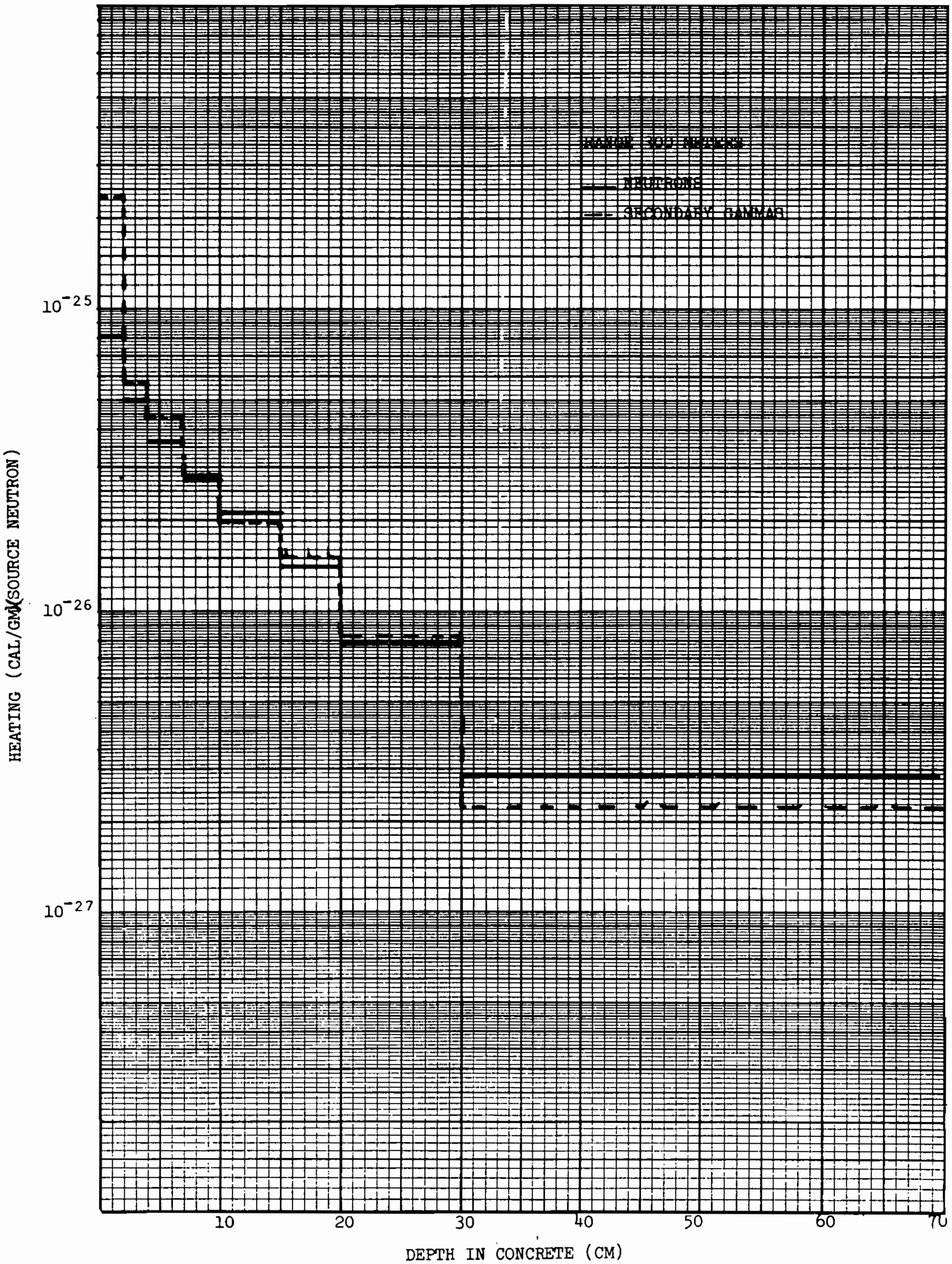

Fig. 2. Heating Versus Depth in the Ground at a Slant Range of 300 Meters. ——— Neutrons, ---- Gamma Rays.

The time distribution of the heat deposited at a slant range of 300 meters for depths in the range of 0-2, 2-4, and 10-15 cm is shown in Fig. 3 for neutrons and Fig. 4 for gamma rays. Note that the heating rates due to neutrons become more spread out in time at the greater depths and that the shape of the heating rate curve for gamma rays tends to become more like the curve for neutron heating rate as the depth is increased. Thus, as the depth in the ground is increased the heating rate is determined less by the direct radiation components and more by the scattered component. Both of these effects are due to the peaked angular distribution of the radiation field in the source-receiver direction.

To estimate the amount of heat produced by low-energy neutrons (<0.11 MeV) and their secondary gamma rays, the results of DOT calculations[1] were edited to obtain the energy deposited by neutrons of all energies and their secondary gamma rays as a function of depth. For a slant range of 300 meters, Fig. 5 compares the total heat deposited from all radiation with the heat due to fast neutrons and their secondary gamma rays. The contribution from low-energy neutrons is less than 5%; however, the contribution from secondary gamma rays due to thermal neutron capture becomes the dominating source of heat as the depth into the ground increases. For the 0-2 cm depth interval, the Monte Carlo results (heating due to fast neutrons and their secondary gamma rays) are higher than the discrete ordinates results (heating due to all neutrons and their secondary gamma rays). This disagreement is due to a larger contribution from inelastic gamma-ray induced heat in the Monte Carlo calculation than that calculated by discrete ordinates.

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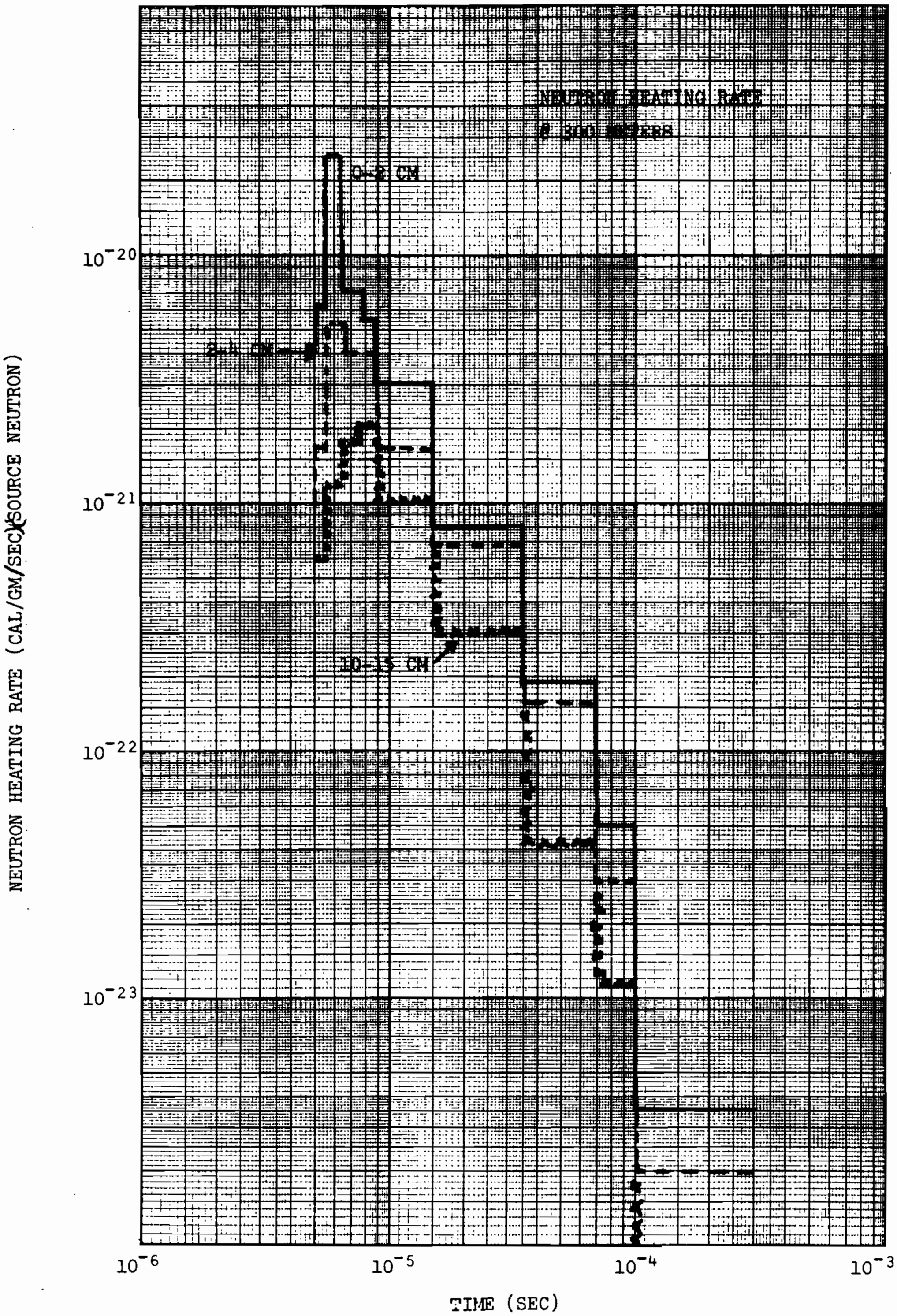

Fig. 3. Neutron Heating Rate Versus Time at a Slant Range of 300 Meters For Depths of 0-2 cm ——, 2-4 cm ----, 10-15 cm xxxx.

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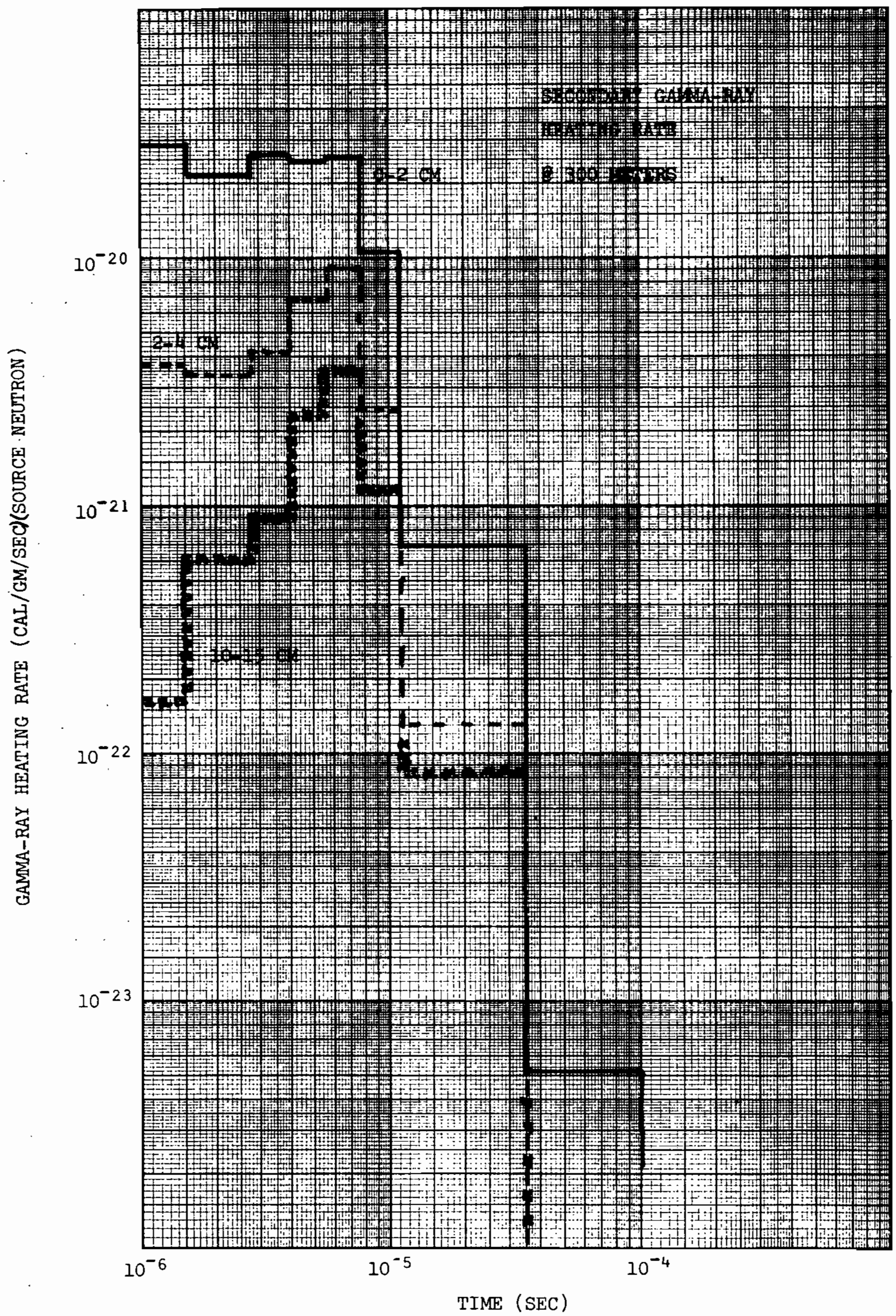

Fig. 4. Secondary Gamma-Ray Heating Rate Versus Time at a Slant Range of 300 Meters for Depths of 0-2 cm ——, 2-4 cm ----, 10-15 cm xxxx.

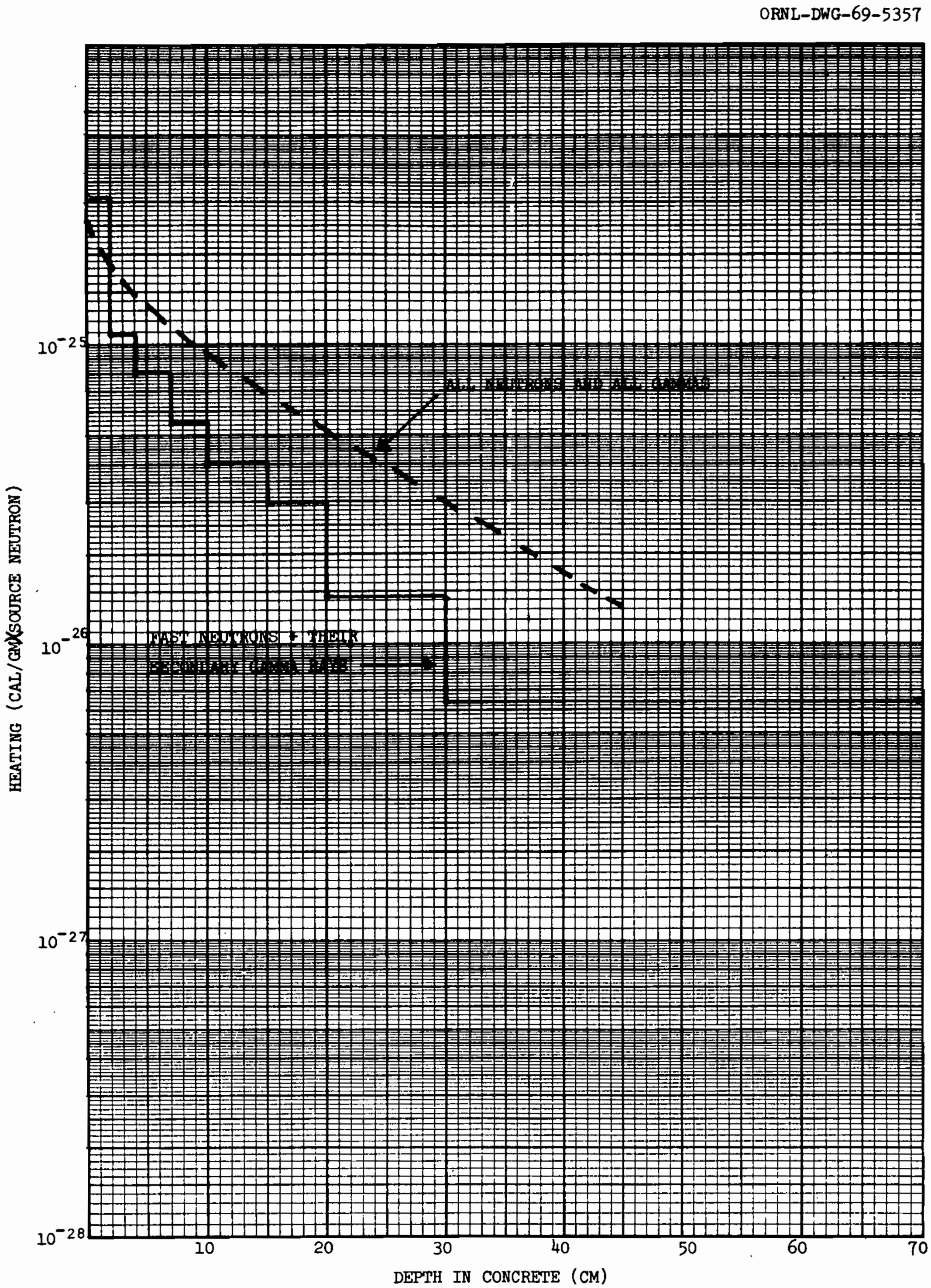

Fig. 5. Total Heating Rate Versus Depth at a Slant Range of 300 Meters —— Fast Neutrons and Their Secondary Gamma Rays (Monte Carlo results); ---- All Neutrons and Secondary Gamma Rays (Discrete Ordinates results).

Since the secondary gamma rays from a fission source are lower in magnitude, the 12.2- to 15-MeV source results should produce the maximum heating rate for any particular source spectrum. The results presented here should provide a reasonable estimate of the amount of heat deposited in shields and should indicate if further generation of time-dependent heating rates for other source energies are needed.

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