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CALCULATIONS OF THE EFFECT OF THE AIR-GROUND INTERFACE ON THE TRANSPORT OF FISSION NEUTRONS THROUGH THE ATMOSPHERE

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ABSTRACT

Two-dimensional discrete ordinates calculations of neutron transport in an air-over-ground geometry have been performed for three different ground compositions. Results for a neutron fission source at 92 meters above the interface are compared with infinite air results. The calculated values of dose and thermal flux for both a fission and a Godiva leakage spectrum are compared with results from Operation BREN. Although the ground interface has a significant effect on the transport, the hydrogen content of the ground also has a large effect. Agreement between calculations and the BREN results is satisfactory when the Godiva leakage spectrum is used.

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The development of the two-dimensional anisotropic scattering discrete ordinates transport code DOT[1] has made it possible to further investigate neutron transport in an air-over-ground geometry. The use of a deterministic solution of the transport equation permits the determination of the effect on neutron distributions of the interface perturbation, as compared to infinite-medium results, and of the effect of the composition of the ground in an atmospheric transport problem. Calculations have been performed for a fission source 92 meters above the air-ground interface for three different ground compositions. The results of the calculations are compared with infinite-medium calculations and with measurements of dose and thermal flux made during operation BREN.[2] The effect of altering the source spectrum used in the calculations from a Cranberg fission spectrum to a Godiva spectrum is also shown.

Calculations were performed in a finite cylindrical (r,z) geometry with the size of the cylinder determined by the requirement of a reasonable running time (approximately 4 hr). The cylinder height was 750 meters and had a diameter of 2600 meters. The calculations contained 2790 spatial mesh points, 27 neutron energy groups, a P_3 approximation to the elastic scattering cross section, and an S_8 angular segmentation (48 angles). Albedo conditions were applied to the exterior boundaries such that emergent neutrons were returned isotropically in proportion to calculated albedos. This boundary condition essentially removes the effect of neutron leakage on the finite geometry results.

Composition of the air and of the three different grounds is shown in Table 1. The density of 1.07 mg/cc for the air was chosen so that the calculations could be compared with BREN experimental results directly. It should be noted that dry ground has no bound water (0% hydrogen) and is therefore not a realistic representation of any soil. The dose was calculated using the flux-to-dose conversion factors of Henderson.[3]

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[1] F. R. Mynatt, A User's Manual for DOT, a Two-Dimensional Discrete Ordinates Transport Code with Anisotropic Scattering, K-1694 (to be published).

[2] J. A. Auxier, F. F. Haywood, and L. W. Gilley, General Correlative Studies-Operation BREN, CEX-62.03 (1963).

[3] B. J. Henderson, Conversion of Neutron and Gamma-Ray Flux to Absorbed Dose Rate, XDC 59-8-179 (1959).

Table 1. Air and Ground Compositions

Material	Composition (at. %) H	O	N	Al	Si	Density (g/cc)
Air	0.05	20.95	79.0			1.07(-3)
Dry Ground	0	73.6		8.3	18.1	1.58
Wet Ground	13.8	63.4		7.2	15.6	1.58
Water	66.66	33.33				1.00

Figure 1 shows a comparison of $4\pi R^2$ dose versus range for the various ground configurations and for infinite air.[4] The fission source height was 92 meters and the detector height was 1 meter from the interface. There appears to be an anomaly in the air-over-ground calculations for ranges between 200 and 500 meters. It is suspected that this "structure" is associated with the discrete angular and spatial mesh; however, it is believed that this structure does not seriously alter the conclusions that may be drawn from the calculations. Investigation of this structure has shown that it also appears in an air-over-air calculation (see Fig. 2). The comparison with a one-dimensional calculation indicates that a smooth curve should be drawn through the structure. That there are possible ray effects is partially demonstrated by results shown in Fig. 2, which indicate a shifting of the location of the anomaly when a different quadrature is used. Further investigation is needed.

Perhaps the most significant effect of the ground interface on the fast-neutron-dose distribution is that it causes an appreciable decrease in the dose everywhere and also shortens the apparent relaxation length in $4\pi R^2$ times dose at large distances. Varying the composition of the ground does not appear to affect the relaxation length, but increasing the hydrogen content decreases the fast-neutron dose about a factor of 2 between 0% hydrogen and all water.

[4] E. A. Straker, Calculations of the Transport of Neutrons from Fission and 14-MeV Point Sources in an Infinite Medium of Air, ORNL TM-1547 (1966).

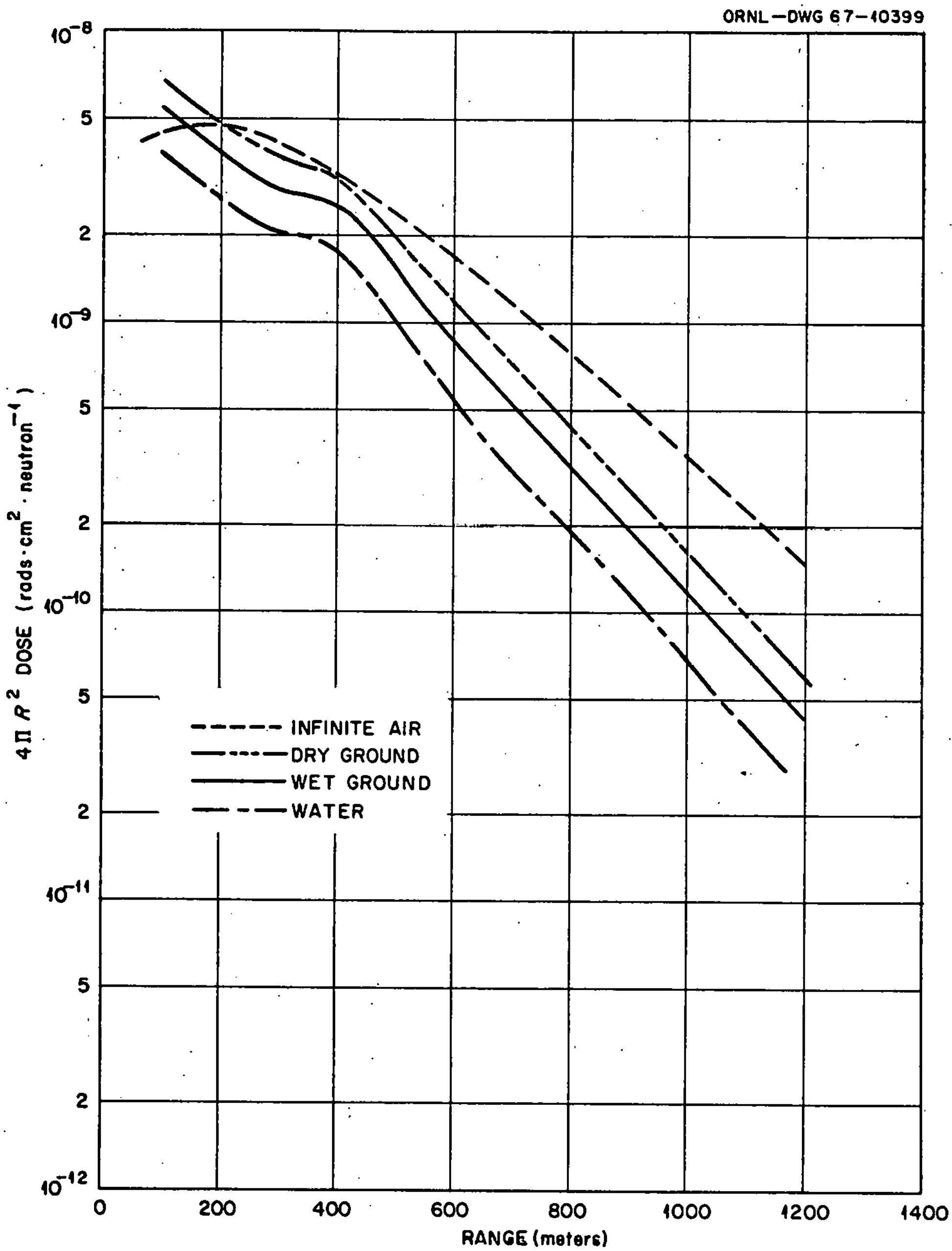

Fig. 1. $4\pi R^2$ Dose at 1 meter Above the Interface Due to a Fission Source at a Height of 92 meters.

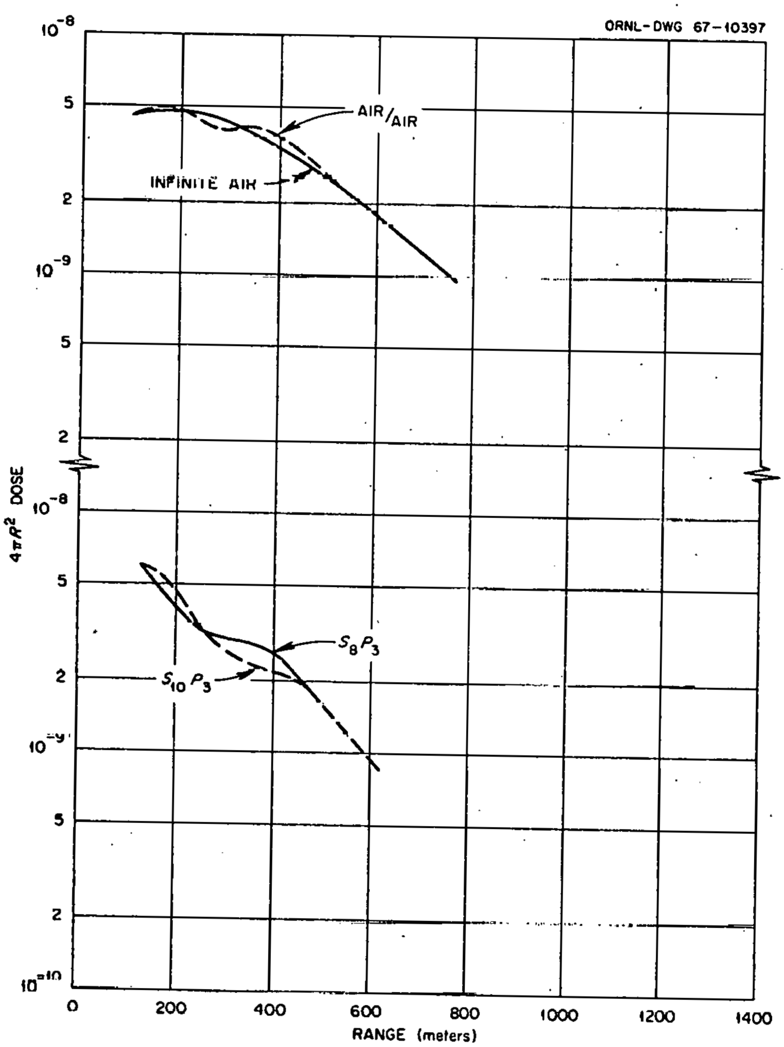

Fig. 2. Results of Various Calculations of $4\pi R^2$ Dose in the Region of the Structure.

Figure 3 compares the spatial distribution of $4\pi R^2$ times the thermal flux (energies below 0.4 eV) for the four cases. In the range 0 to 400 meters introduction of the interface with hydrogen in it causes an order of magnitude increase in the thermal flux over that for both the infinite air and 0% hydrogen. The thermal flux distribution with the interface present also has a shorter relaxation length at large distances than that for the infinite air case. The thermal flux for the water case is comparable with the infinite-air values at 1200 meters even though the fast-neutron dose rate is approximately a factor of 6 lower. This indicates that there is no correlation as a function of range for the neutron spectra in the two cases. Thus there is no consistent correlation that can be made between the infinite-medium calculations and the interface calculations.

Neutron spectra at 1000 meters for the four cases are shown in Fig. 4. All the spectra exhibit a 1/E shape for eV and keV energies, but there are significant differences in the thermal and MeV spectra. (This is consistent with the relative variations of dose and thermal flux.) Table 2 gives the fraction of neutrons in the thermal, 1/E, and MeV energy ranges. It is noted that dry ground shifts the spectrum little but that moist ground has a large effect on the energy distribution.

Table 2. Energy Distribution of Neutrons at 1012 meters from the Source

	% Thermal ($E < 0.4$ eV)	% 1/E (0.4 eV $< E < 0.1$ MeV)	% MeV ($E > 0.1$ MeV)	Total Number of Neutrons
Infinite Air	5.02	71.58	23.4	6.2(-2)
Dry Ground	4.9	64.5	30.6	1.95(-2)
Wet Ground	25.84	46.0	28.16	1.52(-2)
H_2O	45.3	30.0	24.7	9.87(-3)

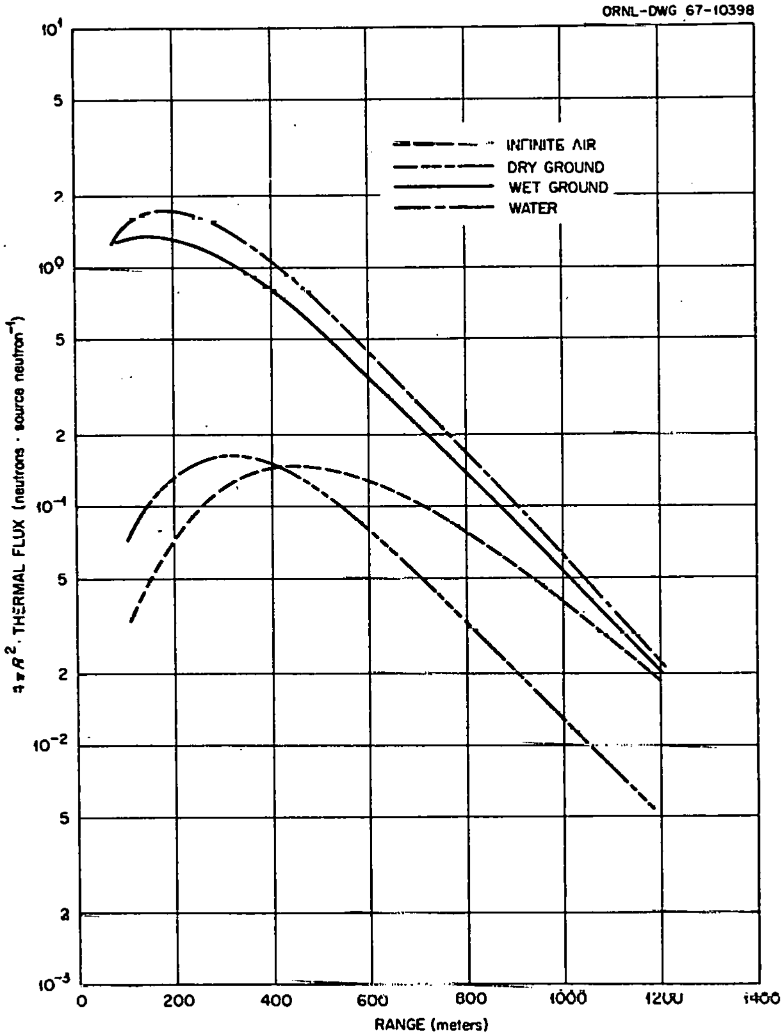

Fig. 3. $4\pi R^2$ Thermal Flux at 1 meter Above the Interface Due to a Fission Source at a Height of 92 meters.

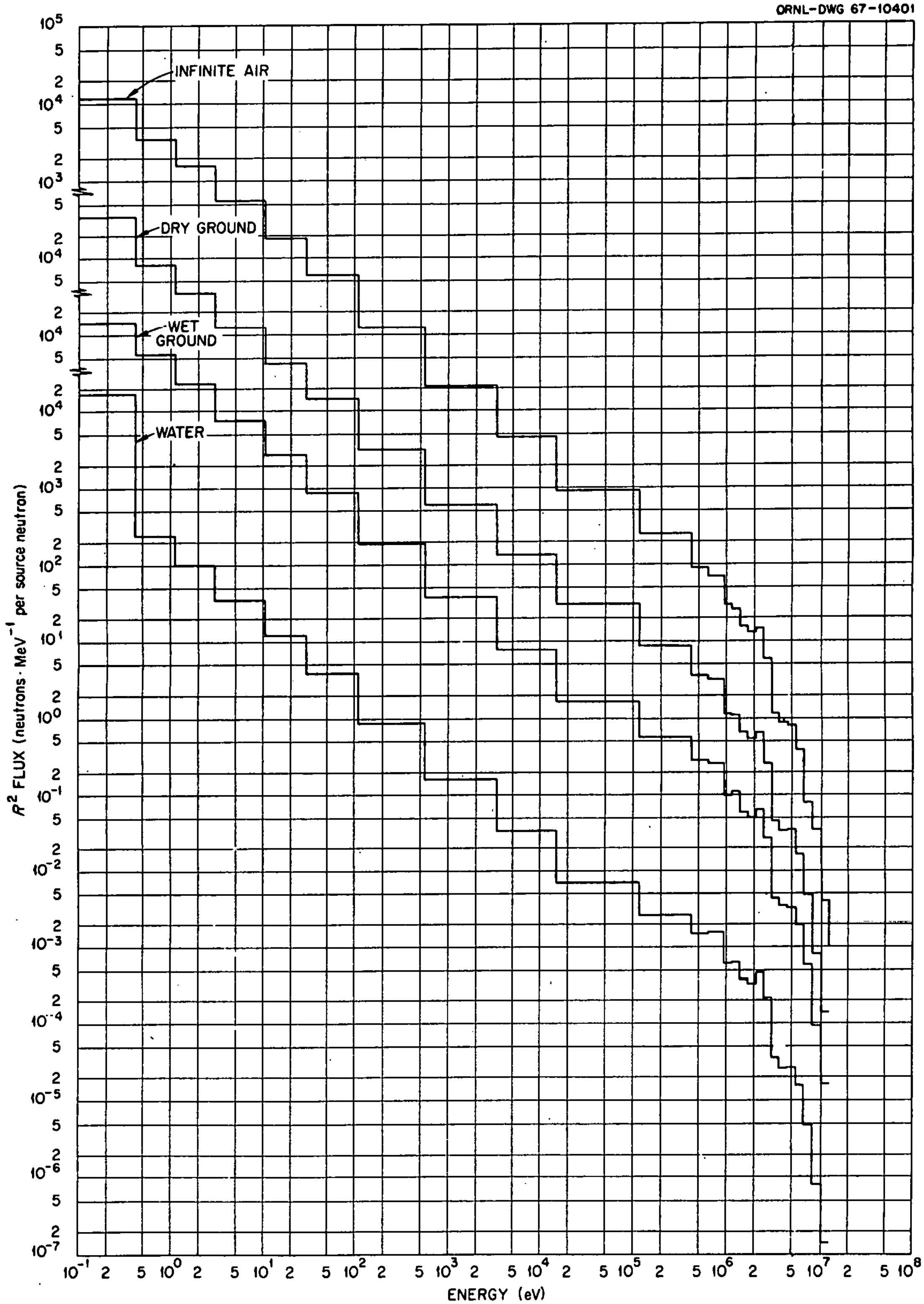

Fig. 4. Effect of Ground Composition on the Neutron Spectra at 1000 meters. The fission source is at 92 meters above the interface.

The spectra shown in Fig. 4 are for one range only. In order to more fully illustrate the changes in spectra, Figs. 5-9 are included. Figure 5 illustrates the change in the total number of neutrons with range for the four configurations. Figures 6-9 show the number of neutrons in the MeV, 1/E, and thermal energy groups as a function of range. It is noted that the spectrum for the infinite air case has essentially reached equilibrium at a range of 1000 to 1200 meters, whereas the spectra for the air-over-ground cases reach equilibrium at a much shorter range. It should also be noted that even though the spectra comes into equilibrium at short ranges for the various ground compositions, the spectra are quite different.

Comparison of the dose data from the BREN experiment[5,6] with the calculations for a fission source at 300 ft above wet ground is shown in Fig. 10. Data for several detector heights are shown and the data consistently fall below the calculated values. A repeat calculation for a Godiva source spectrum is also shown in Fig. 10. The difference in the leakage spectrum significantly changes the dose distribution. The fission and Godiva source spectra are shown in Fig. 11. Figure 12 compares the measured thermal flux[6] with the calculations. The calculation of thermal flux for a fission spectrum is much too high, but there is better agreement when the Godiva spectrum is used. Although the hydrogen content in the ground has a strong influence on the thermal flux, it is not likely that the uncertainty in the water content alone could account for the total disagreement. Part of the disagreement may be due to experimental errors in power calibration but no attempt was made to correct the data for possible normalization errors.

The use of the two-dimensional discrete ordinates transport code to perform calculations in a realistic air-over-ground geometry has made it possible to determine the quantitative effect of ground composition on neutron transport. The effect of the interface depends strongly on the

[5] F. J. Muckenthaler et al., An Eveluation of Simple Iron-Water Radiation Shields and Radiation Measurements within Concrete-Lined and Capped Pits, CEX 62.30 (1964) (Classified).

[6] F. F. Haywood, J. A. Auxier, and E. T. Loy, An Experimental Investigation of the Spatial Distribution of Dose in an Air-Over-Ground Geometry, CEX 62.14 (October 2, 1964).

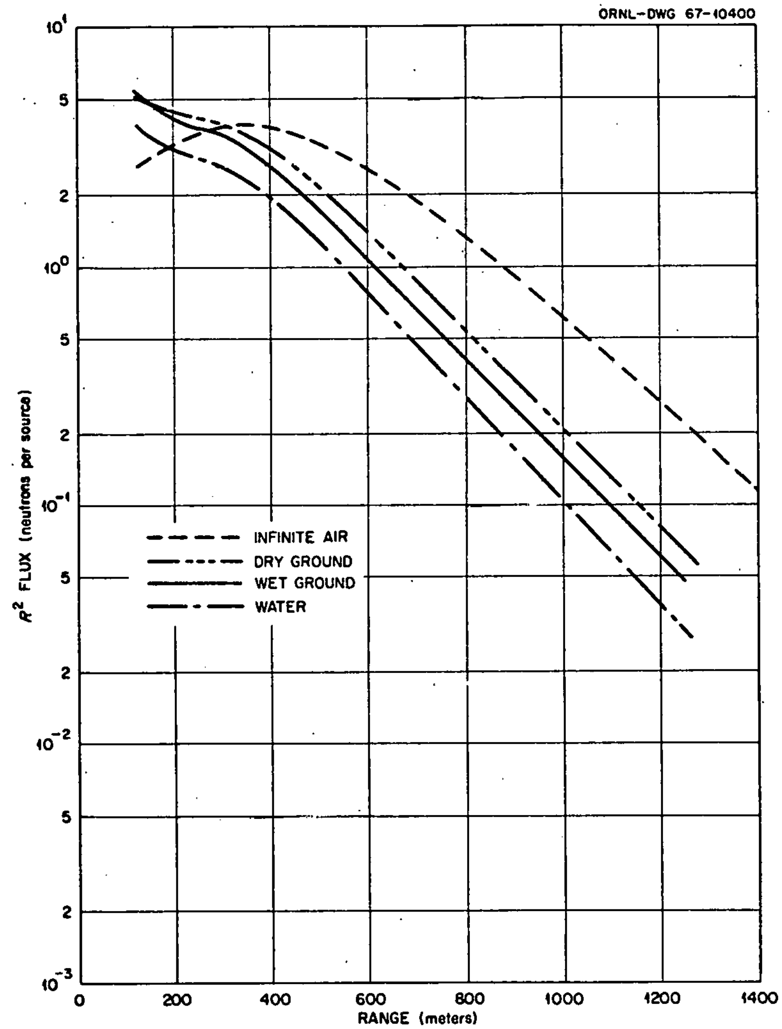

Fig. 5. Total Neutron Flux Versus Range for the Four Ground Compositions.

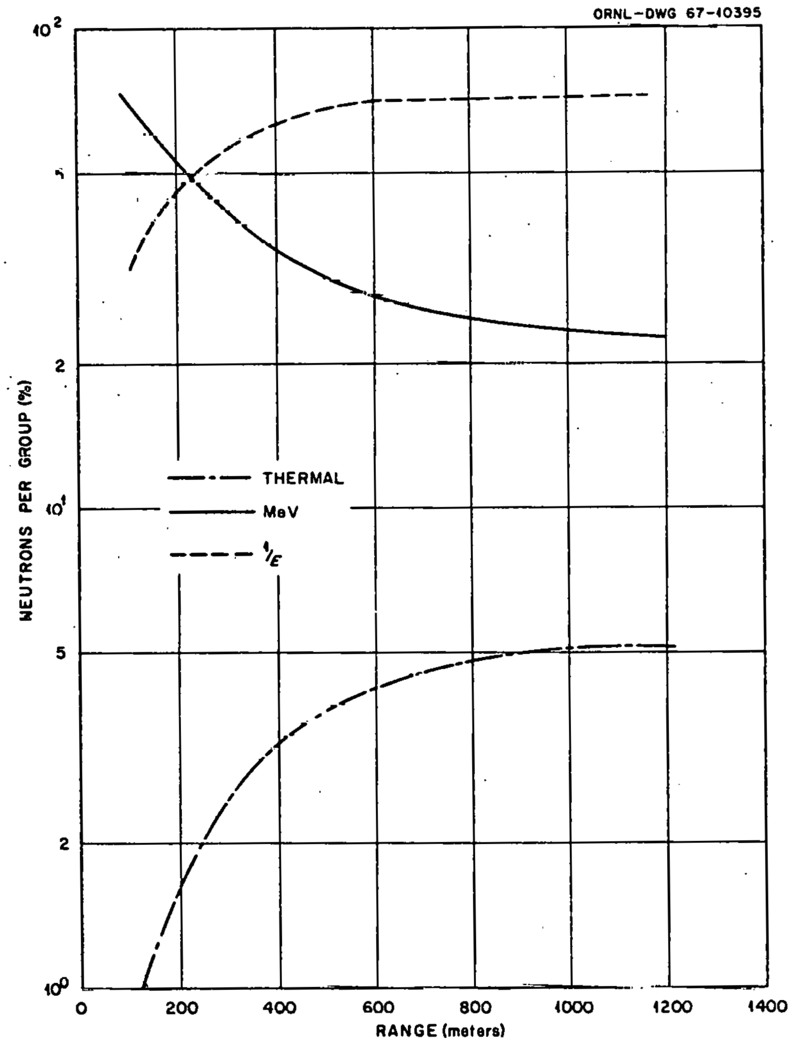

Fig. 6. Percent Neutrons in MeV, 1/E, and Thermal Groups Versus Range for Air Over Air.

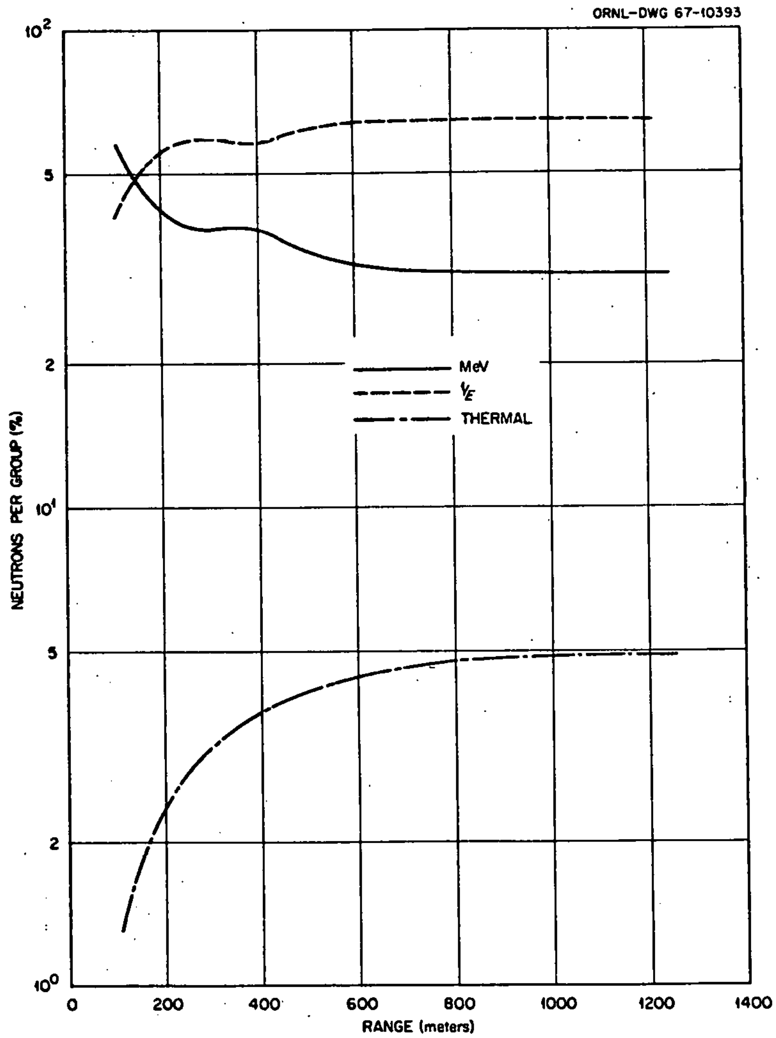

Fig. 7. Percent Neutrons in MeV, 1/E, and Thermal Groups Versus Range for Air Over Dry Ground.

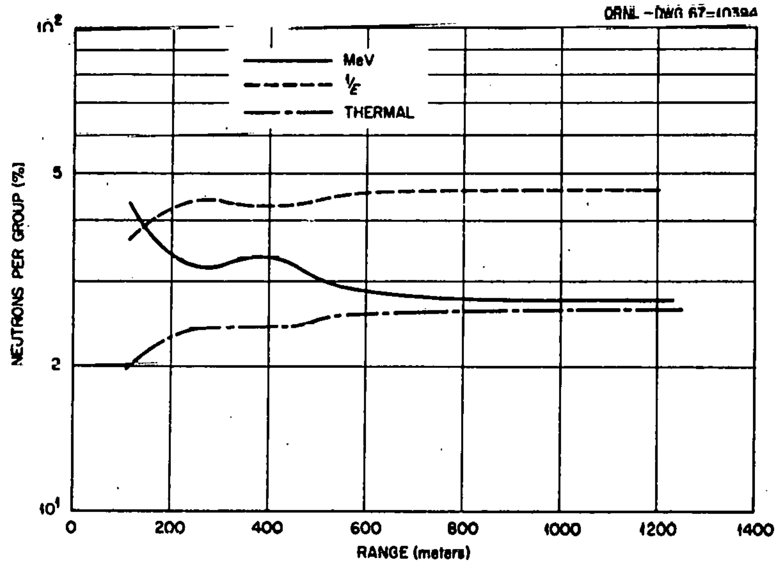

Fig. 8. Percent Neutrons in MeV, 1/E, and Thermal Groups Versus Range for Air Over Wet Ground.

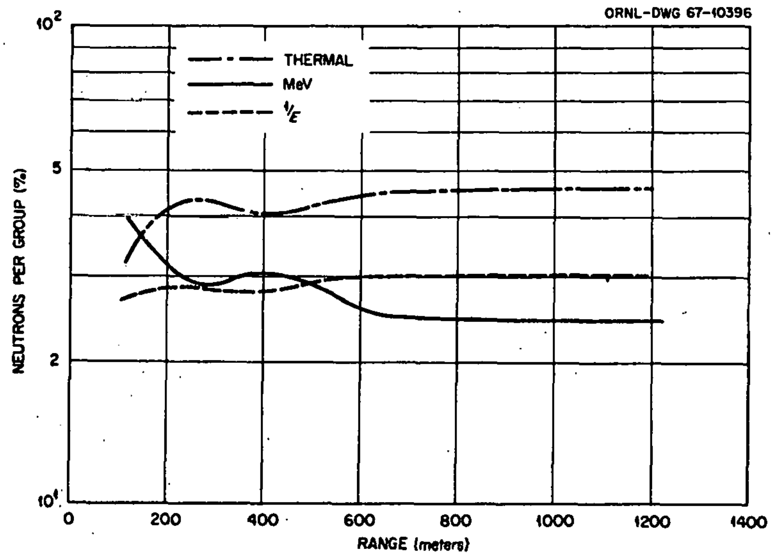

Fig. 9. Percent Neutrons in MeV, 1/E, and Thermal Groups Versus Range for Air Over Water.

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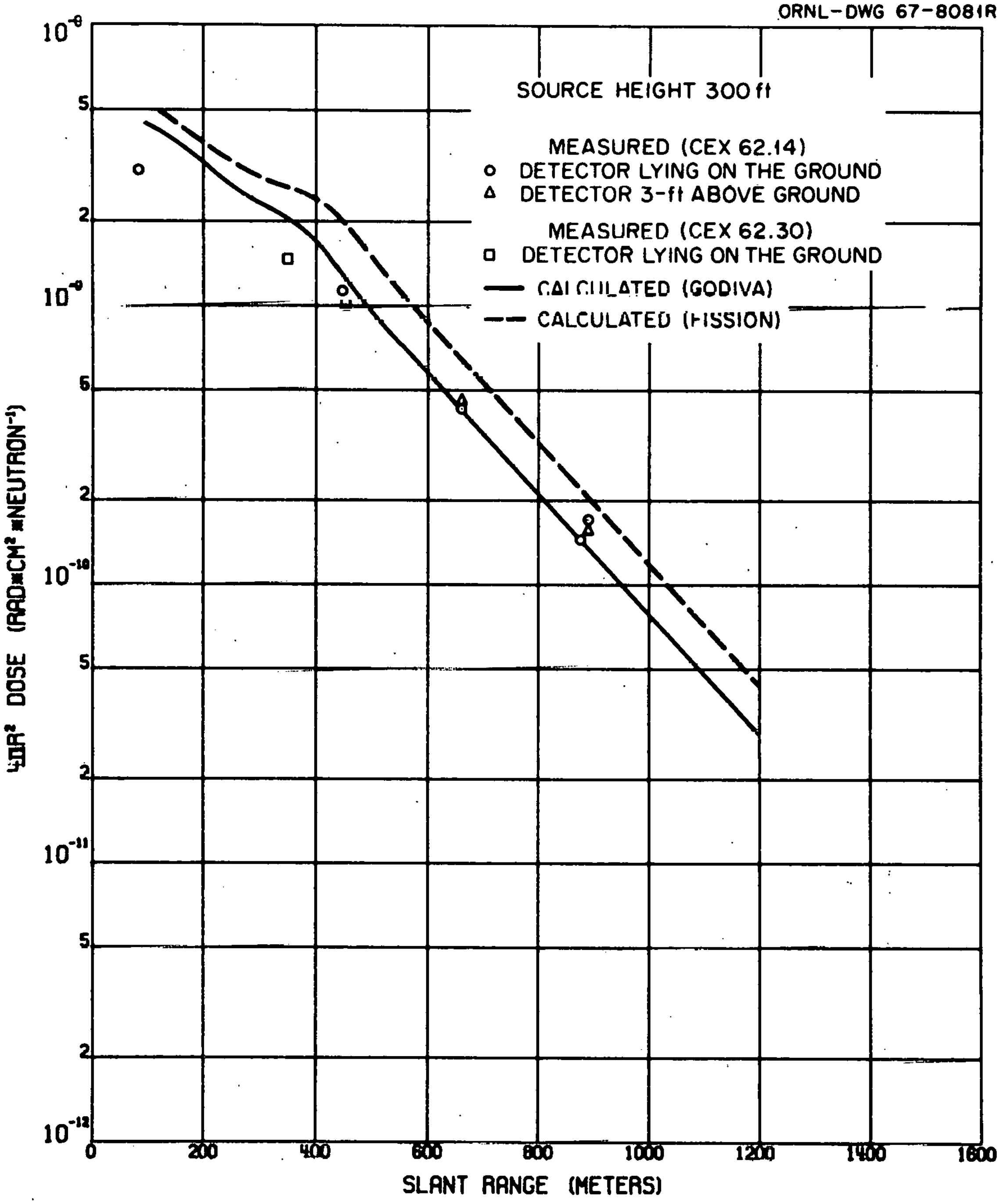

Fig. 10. $4\pi R^2$ Dose Versus Range for Reactor at 300 ft Above Wet Ground.

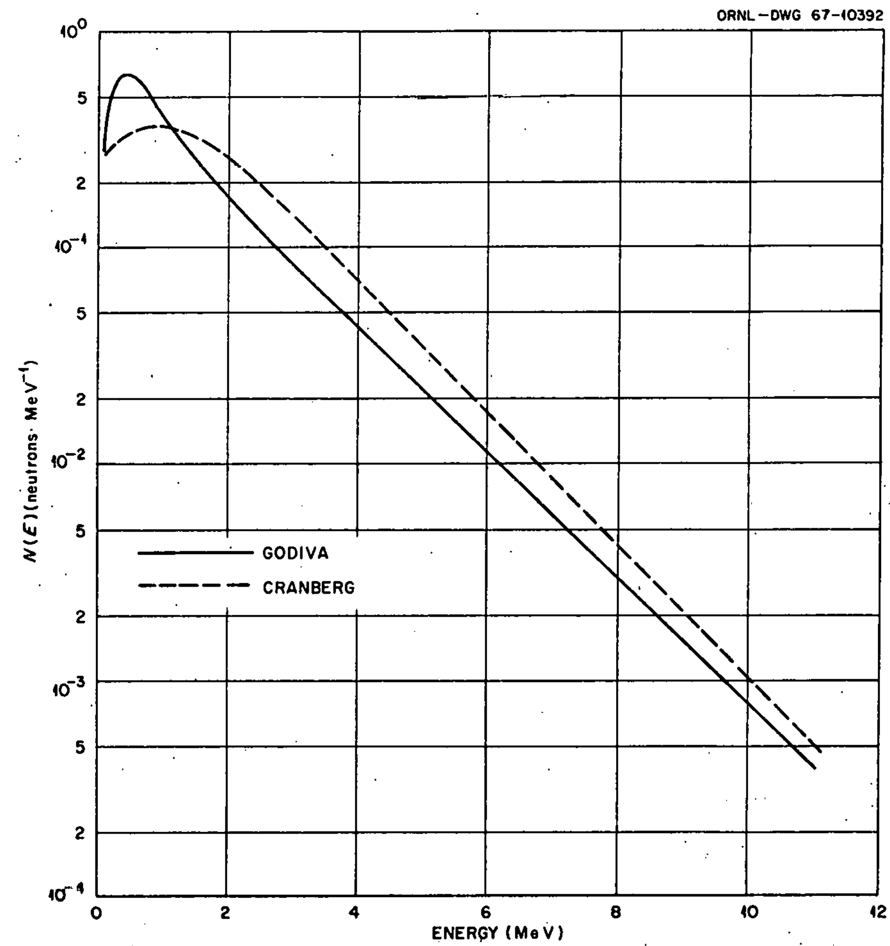

Fig. 11. Fission and Godiva Leakage Spectrum.

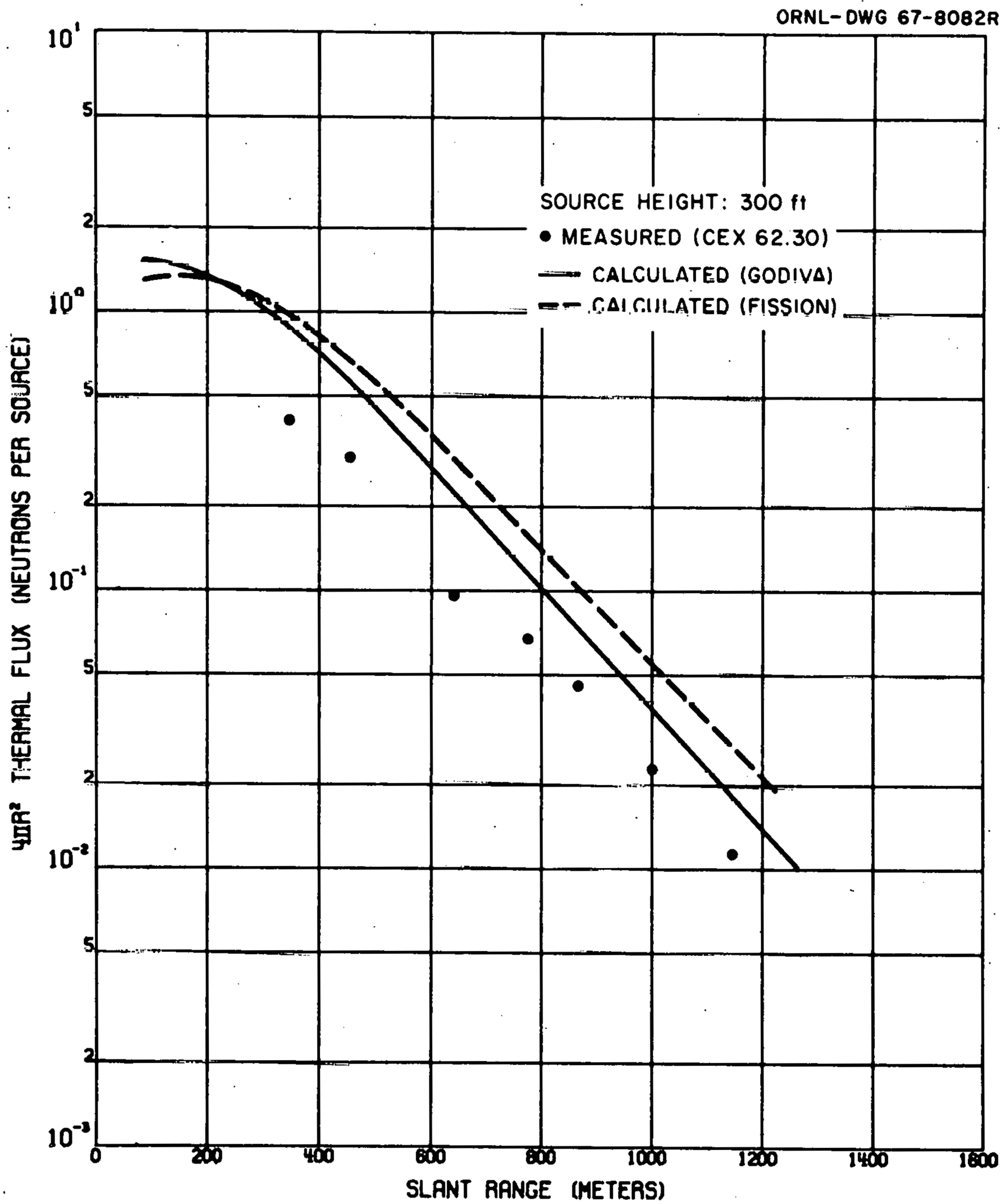

Fig. 12. $4\pi R^2$ Thermal Flux Versus Range for Reactor at 300 ft Above Wet Ground.

amount of water present in the ground with the largest differences appear- in the thermal flux distribution. Comparison of the calculations with experimental data is satisfactory when the actual reactor leakage spectrum is used.

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