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NUCLEAR WEAPONS FREE-FIELD ENVIRONMENT RECOMMENDED FOR INITIAL RADIATION SHIELDING CALCULATIONS

J. A. Auxier, Z. G. Burson, R. L. French,
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This report has been prepared by a special working group convened and given administrative support by the ad hoc Subcommittee on Radiation Shielding which is part of the National Academy of Sciences' Advisory Committee on Civil Defense. This report should not be attributed to the Advisory Committee on Civil Defense or the National Academy of Sciences.

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NUCLEAR WEAPONS FREE-FIELD ENVIRONMENT RECOMMENDED FOR INITIAL RADIATION SHIELDING CALCULATIONS*

J. A. Auxier, Z. G. Burson,† R. L. French,††
F. F. Haywood, L. G. Mooney,†† and E. A. Straker†††

ABSTRACT

A review of the individual components of the initial nuclear radiation field from an intermediate yield thermonuclear weapon has been completed. The purpose of this work was to develop criteria for use by persons interested in determining initial radiation protection or dose transmission factors for civil defense structures. Parameters which were investigated included energy and angular distributions of neutrons and gamma rays at the source as well as those incident on the shield; transmission of neutrons and gamma rays through shielding material; triple point overpressure as a function of angle of incidence at the point of interest; and dose as a function of distance, weapon yield, and overpressure. Data are presented for the above parameters. In addition, the recommended criteria for calculating initial radiation protection or dose transmission factors are given.

ACKNOWLEDGMENTS

The working group wishes to express its sincere appreciation to the Radiation Shielding Subcommittee of the National Academy of Sciences' Committee on Civil Defense for their discussions and suggestions which helped shape this study. The cooperation of the administrations of Radiation Research Associates, Inc. and EG&G, Inc., Las Vegas Office, as well as the Health Physics and Neutron Physics Divisions of the Oak Ridge National Laboratory are greatly appreciated. The technical assistance of numerous associates made this study feasible. Finally, we wish to express our appreciation to L. J. Deal, Chief of the Civil Effects Branch of the Division of Biology and Medicine, U. S. Atomic Energy Commission, for his continued support and encouragement.

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†EG&G, Inc.
††Radiation Research Associates, Inc.
†††Science Applications, Inc.

I. SUMMARY

The important components and characteristics of the radiation environment due to initial nuclear radiations from nuclear weapons are discussed from the viewpoint of those persons concerned with shielding for civil defense purposes. Certain guidelines used in establishing the criteria which are recommended were stipulated by the Subcommittee on Shielding of the Committee on Civil Defense of the National Academy of Sciences. Based on these guides the authors reviewed the information developed during the past decade and then composed this report.

Separate normalized energy and angular distribution parameters, air-ground secondary gamma rays and fission-product gamma rays based on the following criteria are recommended for calculating initial radiation protection or dose attenuation factors:

1. A fission to fusion energy yield ratio of 50/50.
2. A "typical" intermediate yield thermonuclear neutron spectrum leaking from the weapon.
3. A "halo-source," i.e., because the direction to the detonation cannot be known in advance, the detonation is assumed to have occurred in a ring around the observer (equal probabilities in all azimuthal directions).
4. Angular distribution of the radiation at the shield be chosen such that the source would appear at an angle of elevation of 45° above the horizontal plane of the detector.
5. A source-detector distance of 1200 m in an infinite air medium.
6. To aid in the understanding of the criteria, dose as a function of psi is given for several cases for selected burst heights.

Criteria 3 - 5 are applicable only in determining the normalized energy-angular distribution; the actual intensities of the three radiation components should be developed for the actual burst heights and separation distances of interest.

General recommendations for application are also given. However, all considerations given herein are intended to serve as a point of departure and it is assumed that further work in the field may indicate the need for changes in these criteria. For example, the detailed treatment of the shelter entrance-way problems may require further investigation of the angular distributions recommended.

II. INTRODUCTION

Over the past decade, the Radiation Shielding Subcommittee of the National Academy of Sciences' Advisory Committee on Civil Defense has developed extensive criteria and engineering methods for fallout radiations. However, for the initial radiations (both neutrons and gamma rays), such criteria have been delayed because of the complexities of the problem and the lack of some important input data. Now it appears that the problem is manageable if the criteria are chosen properly. The Subcommittee assigned to a working group composed of the authors of this report, the responsibility of writing the criteria to be used as input to shielding calculations for the initial radiations from nuclear weapons.

In preliminary reports and discussions with the Subcommittee a set of controlling guidelines was established. These included the following:

1. The criteria should be unclassified.
2. The criteria should be as simple as possible but sufficient to provide meaningful answers to real shielding problems.
3. Three classes of radiation, neutrons, gamma rays from fission products, and gamma rays from neutron interactions, should be considered separately.
4. A weapon yield of 300 KT should be assumed as typical of those of greatest importance, with lesser emphasis on 40 KT and 1 MT.
5. The ranges of primary interest should be defined by those ranges for which the maximum overpressure was between 5 and 30 psi.
6. The environment can be described by one normalized energy and angular distribution for each radiation component for all conditions.
7. Typical intensity curves for the radiation field should be given as an example.

The working group has endeavored to identify the critical parameters and to indicate their relative importance. The recommended criteria are based on a survey of both classified and unclassified sources of weapons radiation data as well as the extensive experience of the subcommittee members in this field. Justification of the criteria is based on unclassified data and reports; in one or two instances no justification other than a consensus of educated guesses was possible, but these are discussed at the appropriate point in the text. All data reproduced herein or reanalyzed and presented in new forms are unclassified. The information presented is intended to serve as the point of departure for actual shielding calculations of interest in civil defense. Since this report is intended to be useful primarily to shielding experts, the reader is assumed to have a high degree of familiarity with this field.

III. SPECTRA

A. Source Leakage Spectra

It is desirable to choose a source spectrum that will produce a radiation field at the point of interest (outside of a shield to be considered) representative of real conditions to be encountered. For simplicity of application to shielding calculations, a single neutron spectrum is desirable.

Initially a study was made to evaluate the variation of radiation dose at one mile ($\sim$ 1600 m) as a function of the neutron spectrum at the source. Sources composed of "14 MeV" and "fission" neutrons of varying proportions were selected. The sources were normalized to a unit leakage neutron. A third neutron source, consisting of a "typical" thermonuclear" spectrum, was chosen for comparison. The purpose of this initial study was to examine the sensitivity of dose to the neutron spectrum at the source. Therefore, the fission-product gamma rays are not included.

The combined neutron and air-secondary gamma-ray tissue doses (rads) were determined at 1600 m, both in a free-field location and beneath a 60 cm slab of standard concrete. Normal incidence was assumed and the results are given in Table 1. The results in Table 1 were obtained from many sources of information;[1-6] they are simply representative values and are not to be used quantitatively. Nevertheless, it is seen that the final radiation levels are not very sensitive to the neutron spectrum at the source.

A typical thermonuclear (TN) spectrum produced radiation levels nearly midway between the two extremes (pure 14 MeV or pure fission). Since neither of these two extremes is likely, it is recommended that the TN spectrum be used as a standard.

The TN spectrum, presumably representing the leakage spectrum from a "typical" intermediate yield thermonuclear weapon, was transmitted to C. E. Clifford from B. C. Diven[7] and subsequently used in transport calculations.[1,8,9] It is reproduced in Table 2 and Fig. 1. For reference, typical TN spectra for low- and high-yield devices are also given in Table 2. It is expected[10] that similar neutron spectra will appear in the next revision of The Effects of Nuclear Weapons.

Table 1. Combined Neutron and Air-Secondary Gamma Ray Doses in Rads (normalized to intermediate thermonuclear yield) at a Slant Range of 1600 Meters in Infinite Air

Source Composition* (Leakage Fraction) "14 MeV"	Fission	Free-Field Dose at Interface†	Dose Under 60 cm of Standard Concrete†
1.00	0	1.63	1.98
0.50	0.50	1.18	1.25
0.40	0.60	1.09	1.11
0.30	0.70	1.00	0.96
0.25	0.75	0.96	0.87
0.20	0.80	0.91	0.81
0.15	0.85	0.87	0.74
0.10	0.90	0.83	0.67
0.05	0.95	0.78	0.57
0	1.00	0.74	0.52
Thermonuclear (Intermediate Yield)		1.00	1.00

*Sources ("14 MeV", and fission) normalized to a unit leakage neutron.

†Note that each column is independently normalized to the thermonuclear case.

Table 2. Neutron Leakage Spectra of Thermonuclear Devices

Neutrons/Group

Energy Interval (MeV)	Low Yield	Intermediate Yield	High Yield
12.2–15	0.0158	0.0706	0.0240
10.0–12.2	0.0064	0.0256	0.0106
8.18–10.0	0.0048	0.0141	0.0085
6.36–8.18	0.0068	0.0147	0.0102
4.96–6.36	0.0100	0.0180	0.0110
4.06–4.96	0.0125	0.0170	0.0107
3.01–4.06	0.0267	0.0260	0.0180
2.46–3.01	0.0238	0.0190	0.0164
2.35–2.46	0.0058	0.0050	0.0037
1.86–2.35	0.0325	0.0280	0.0220
1.11–1.86	0.0750	0.0620	0.0537
0.55–1.11	0.0917	0.0850	0.0745
0.111–0.55	0.1167	0.1020	0.1453
3.35(−3)*–0.111	0.2083	0.355	0.5590
5.83(−4)–3.35(−3)	0.2750	0.1220	0.0287
1.01(−4)–5.83(−4)	0.0833	0.0240	0.0041
2.9(−5)–1.01(−4)	0.0078	0.002	0.0

*Reads 3.35×10^{-3}

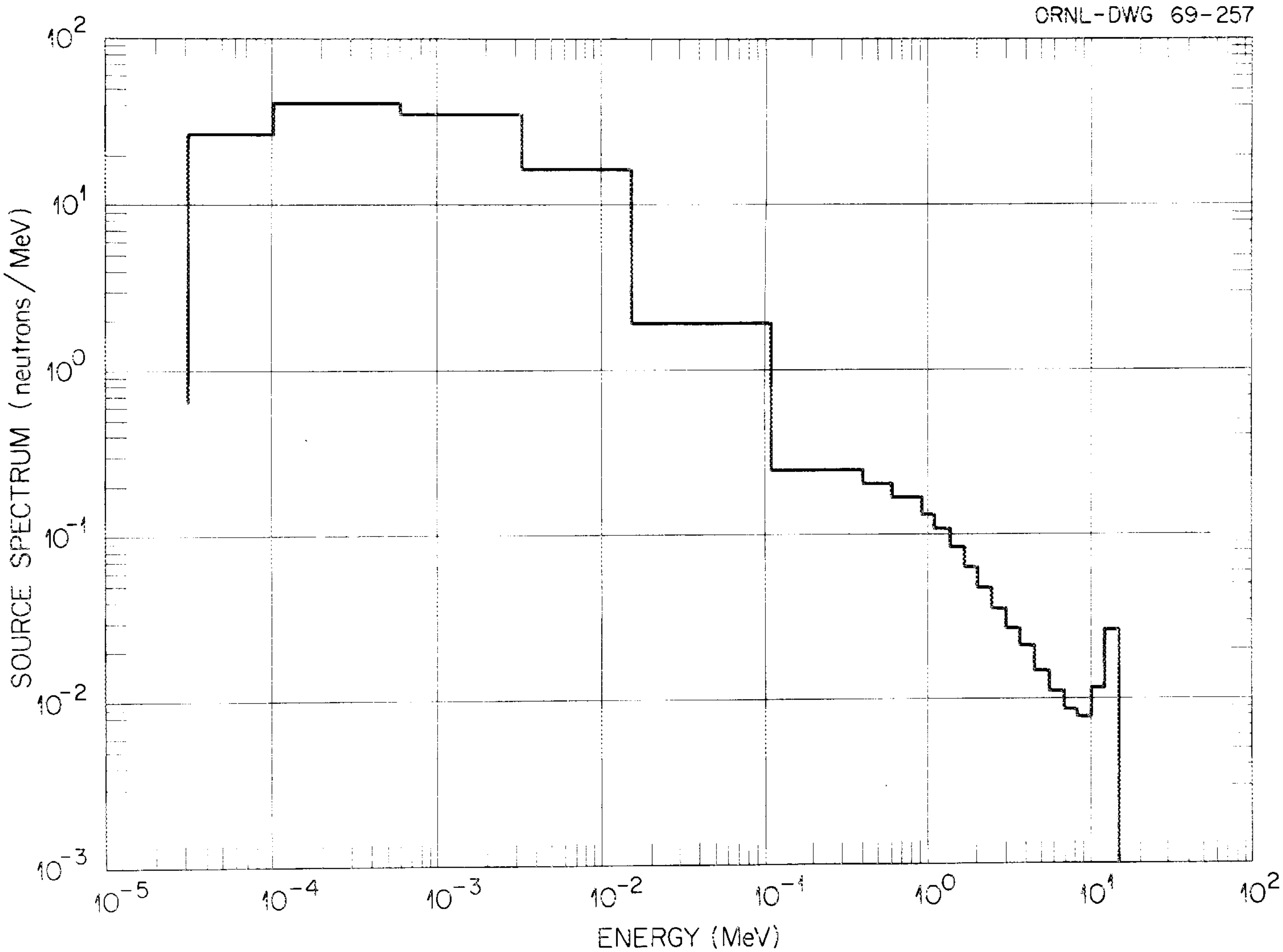

Figure 1. Energy Distribution of Neutrons Emitted from a Representative Intermediate Yield Thermonuclear Weapon

The fission-product gamma-ray energy spectrum emitted at the source is assumed to be that measured by Fisher and Engle[11] in the time interval 0.2-0.5 sec after fission of ^{235}U. This spectrum is assumed to be representative of that for all time intervals of interest after fission because of the insignificant change shown in the measured data for longer times. The spectrum is shown in Fig. 2.

B. Incident Spectra at the Shield

Both the neutron and secondary gamma-ray spectra from a typical TN source vary slowly with range for ranges greater than approximately 600 m. Also it has been shown[12] that the ground has little effect on the fast neutron spectra and on the gamma-ray spectra; therefore, spectra for infinite air may be used as a reasonable approximation.

For the intermediate yield TN source, total fluence in several energy groups is shown versus range in infinite air for neutrons in Figs. 3 and 4 and for air-secondary gamma rays in Fig. 5. For the distances of interest, only small changes in the energy distribution are observed, as evidenced by the curves in Figs. 3-5 being nearly parallel. These data are from ORNL-4464.[1]

The closest distance of practical interest is about 525 m (40 KT, 100 psi); the farthest distance is about 4000 m (1 MT, 10 psi). However, the conditions where initial radiation shielding technology will be the most useful are those where initial radiation becomes the limiting criterion and these, in general, are high overpressures from low yield weapons. The ranges of interest then become approximately 900 m (40 KT, 30 psi) to 1700 m (300 KT, 30 psi). Therefore, spectrum at 1200 m is recommended as reasonably representative of all cases of interest. Strictly speaking, equilibrium is not obtained in any of the three components, particularly for neutrons above 8 MeV*. However, it was felt that changes in the spectra at greater distances were not in themselves worthy of further considerations.

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*Source neutrons greater than 8 MeV make up 8.5% of the leakage spectrum for an intermediate yield TN weapon. Neutrons above 8 MeV at 1200 m represent less than 1% of the total fluence at that point.

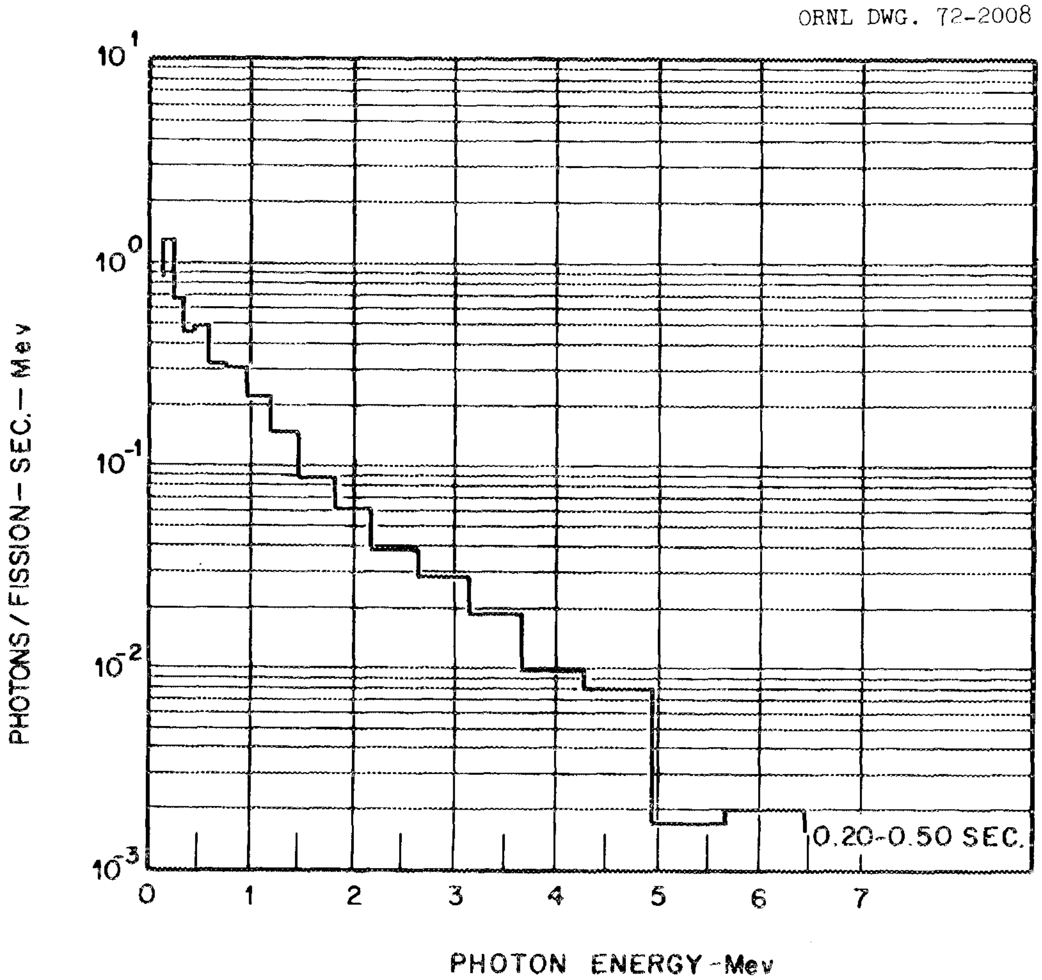

Figure 2. Energy Distribution of Gamma Rays Emitted During the Time Interval 0.2-0.5 Seconds Following ^{235}U Fission[11]

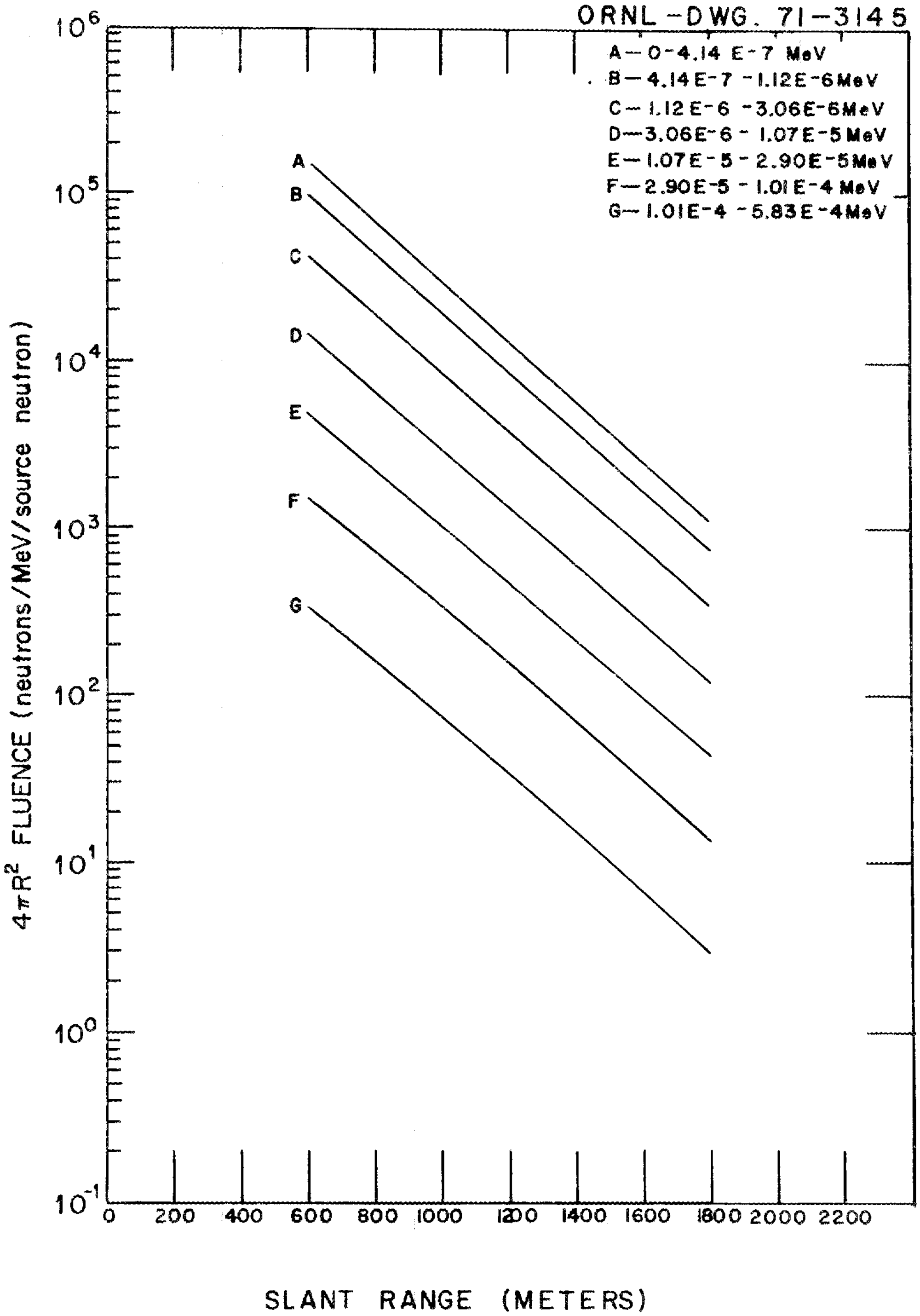

Figure 3. Neutron Spectral Distribution Below 5.83×10^{-4} MeV as a Function of Slant Range from an Intermediate Yield Thermonuclear Weapon

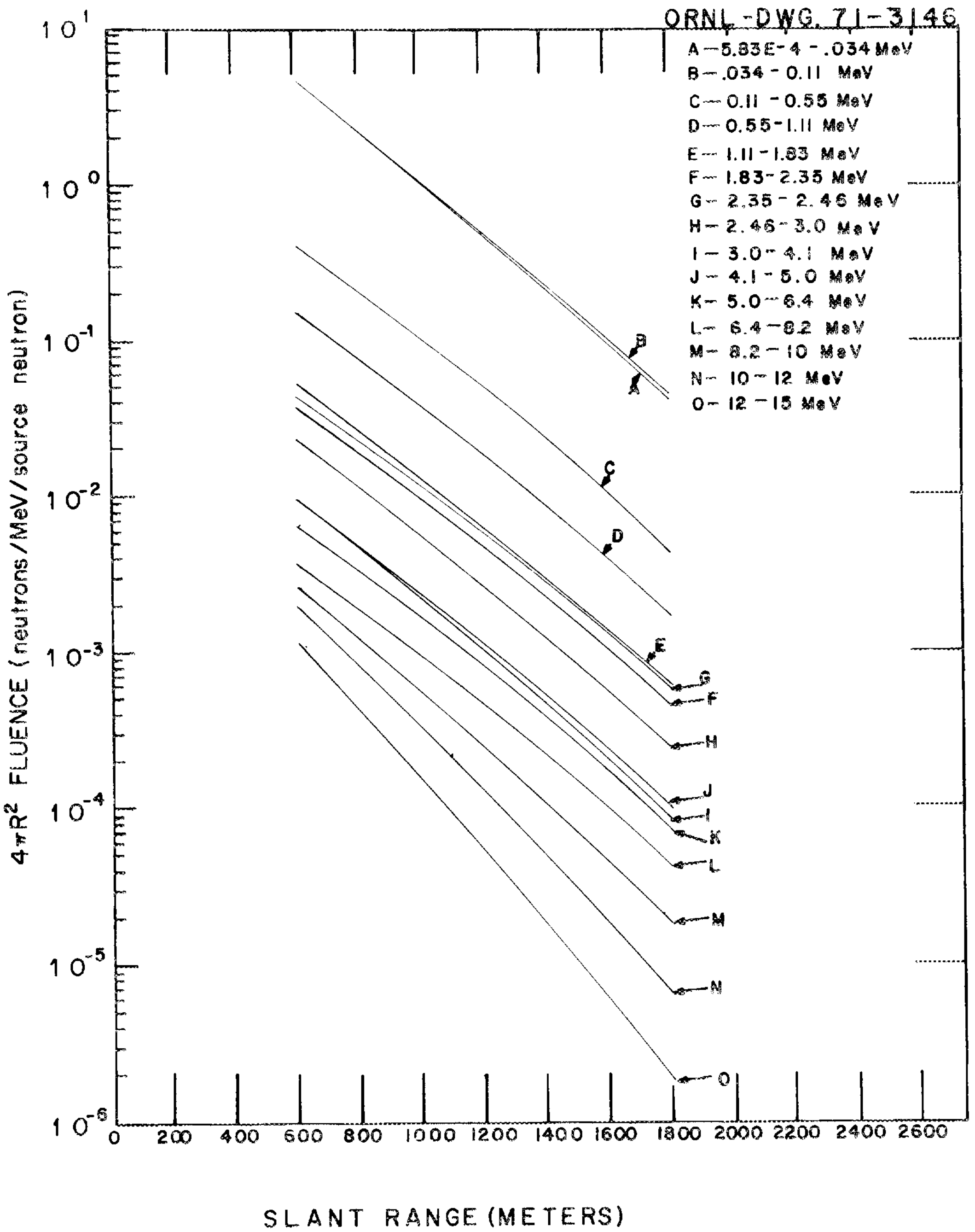

Figure 4. Neutron Spectral Distributions Above 5.83 x 10^{-4} MeV as a Function of Slant Range from an Intermediate Yield Thermonuclear Weapon

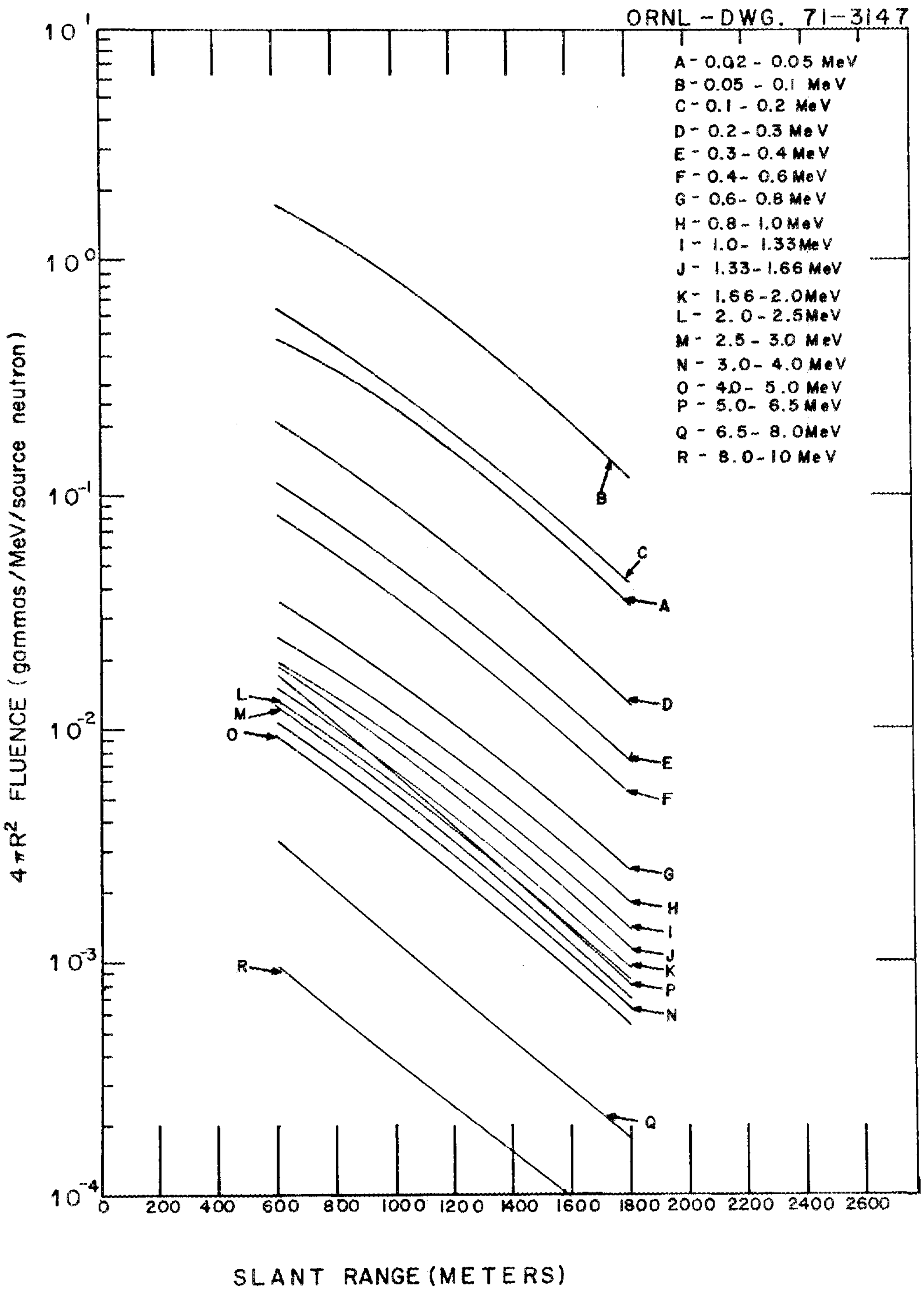

Figure 5. Air-Secondary Gamma-Ray Spectral Distributions as a Function of Range from an Intermediate Yield Thermonuclear Weapon

Angular distributions for the fission-product gamma rays change slowly with range for distances greater than 1200 m for a static point source.[13] However, the source is moving vertically with time after detonation, resulting in a distribution continuously changing relative to the source-detector axis at the instant of detonation. It is necessary to calculate the effects of the coordinate system rotation with time and to describe the resultant distribution in terms of the original axis at the time of detonation.

Approximate energy and angular distributions of fission-product gamma rays obtained for a rising source for an initial elevation of 45° based on the technique given in reference 9 will be used. These data are derived for a detector located at the 100 psi overpressure range and are relatively insensitive to weapon yield. These data are recommended for use as being representative, or conservative, for lower overpressures of interest.

IV. ANGULAR DISTRIBUTIONS

A. Burst Elevation Angle Selection

For purposes of determining a representative burst elevation angle, the angles (above the horizon) versus overpressure to produce the triple point (point at which incident and reflected shock waves coincide at the air-ground interface)[14] were examined. As shown in Fig. 6, the overpressure ranges of interest, 5 to 30 psi, correspond to angles from 30° to 45°. For simplicity a single angle of 45° is recommended. A smaller angle (burst nearer the surface) would produce a radiation field with intensities more normal to a vertical shield, but more tangential to a horizontal shield. A single angle of 45° appears to be realistic and practical for a wide range of shelters.

B. Polar Angular Distribution

Dose-angular distribution data from Straker[1] for an infinite air medium are plotted for the TN source in Figs. 7 and 8. The dose-angular distributions for neutrons and air-secondary gamma rays do not change rapidly with distance. These same distributions are presented in a different manner in Fig. 9 for a TN source at a distance of 1200 m. Note that the secondary gamma dose is strongly peaked in the forward direction, although not enough to warrant an assumption that it is monodirectional.

It is recommended that the polar angle distributions for neutron and secondary gamma rays be chosen according to the above curves for a detonation occurring at an angle of 45° above the horizontal. It is further recommended that fission-product gamma-ray energy and angular distributions be those given later in Table 13. These are also based on a burst elevation angle of 45°.

C. Azimuthal Angular Direction

For a given burst direction it is reasonable to assume that the azimuthal angle distributions (i.e., in the horizontal plane) are the same, with respect to the burst axis, as the polar angle distributions specified above. However, since there is no realistic basis for specifying a single

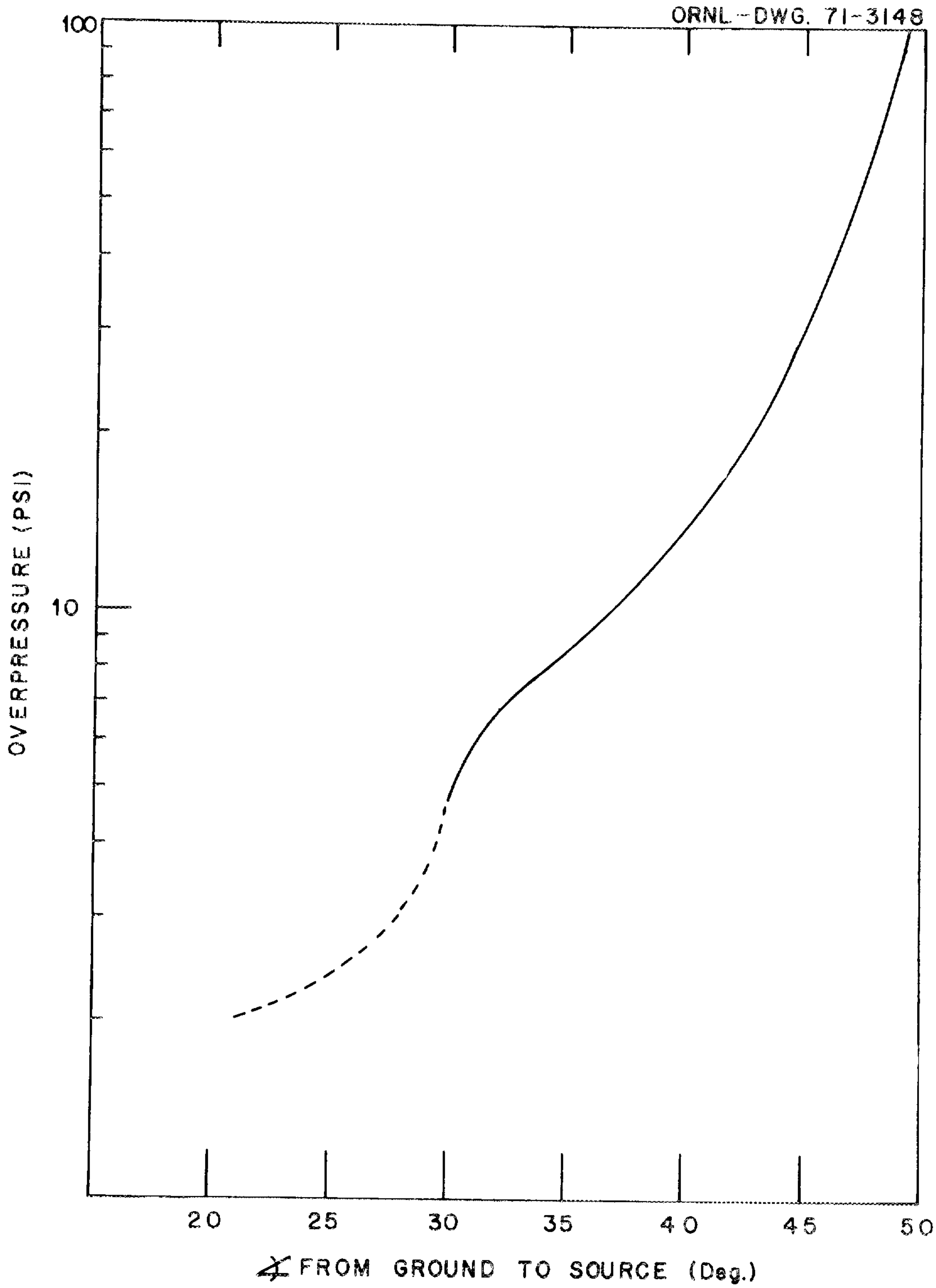

Figure 6. Triple Point Overpressure vs Angle from Ground to Source

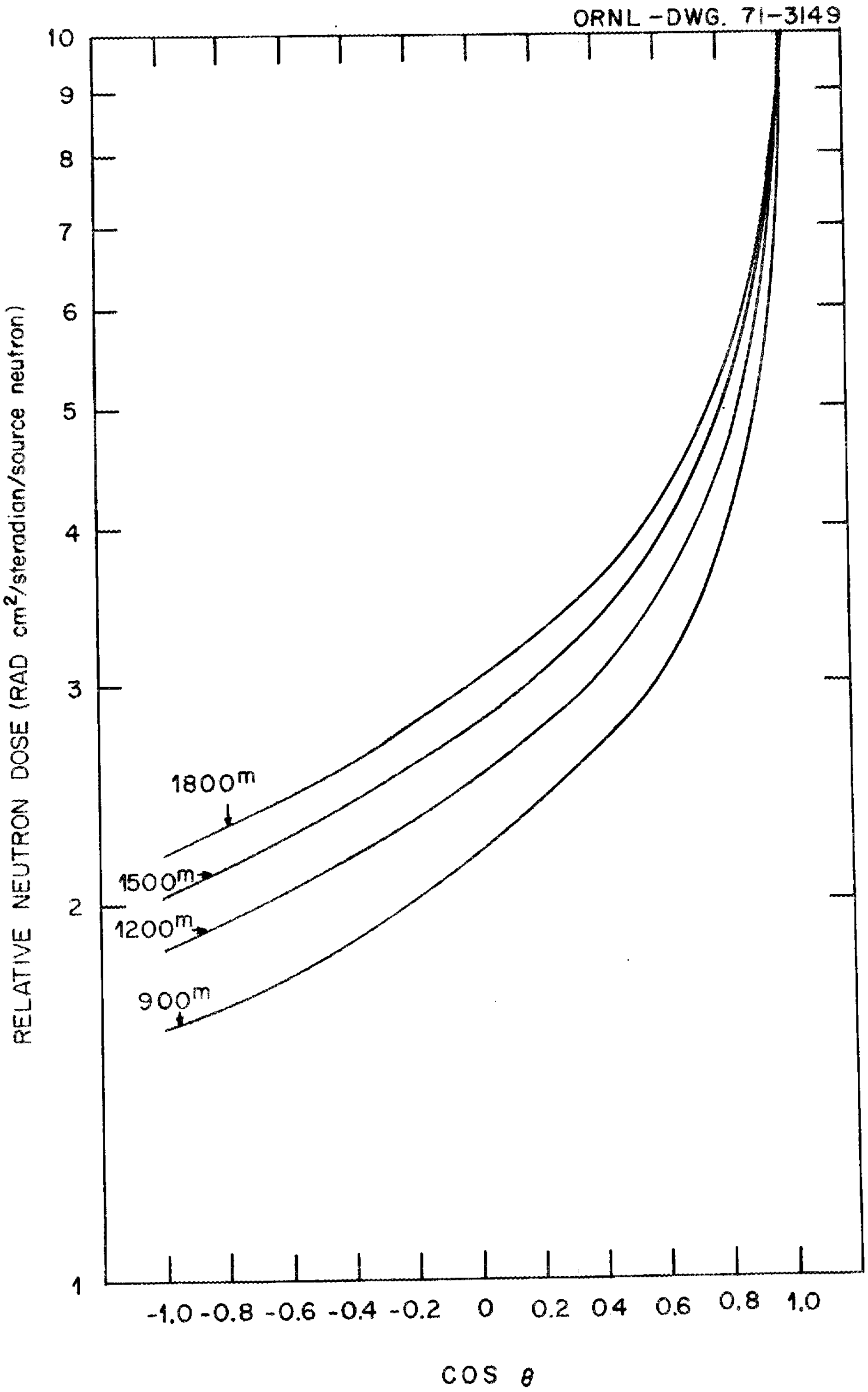

Figure 7. Angular Distribution of Neutron Dose from a Thermonuclear Weapon in Infinite Air

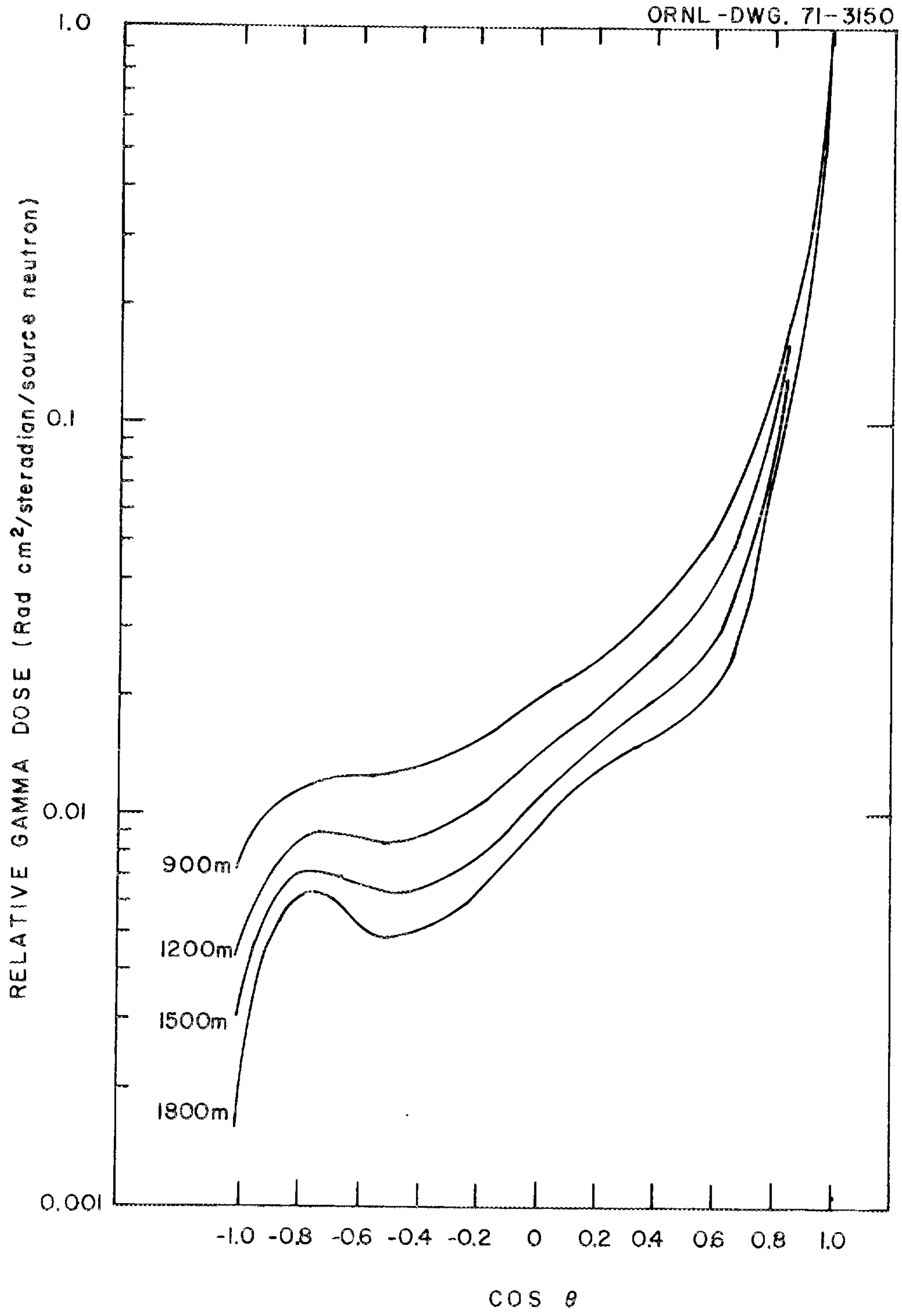

Figure 8. Angular Distribution of Secondary Gamma Dose from a Thermonuclear Weapon in Infinite Air

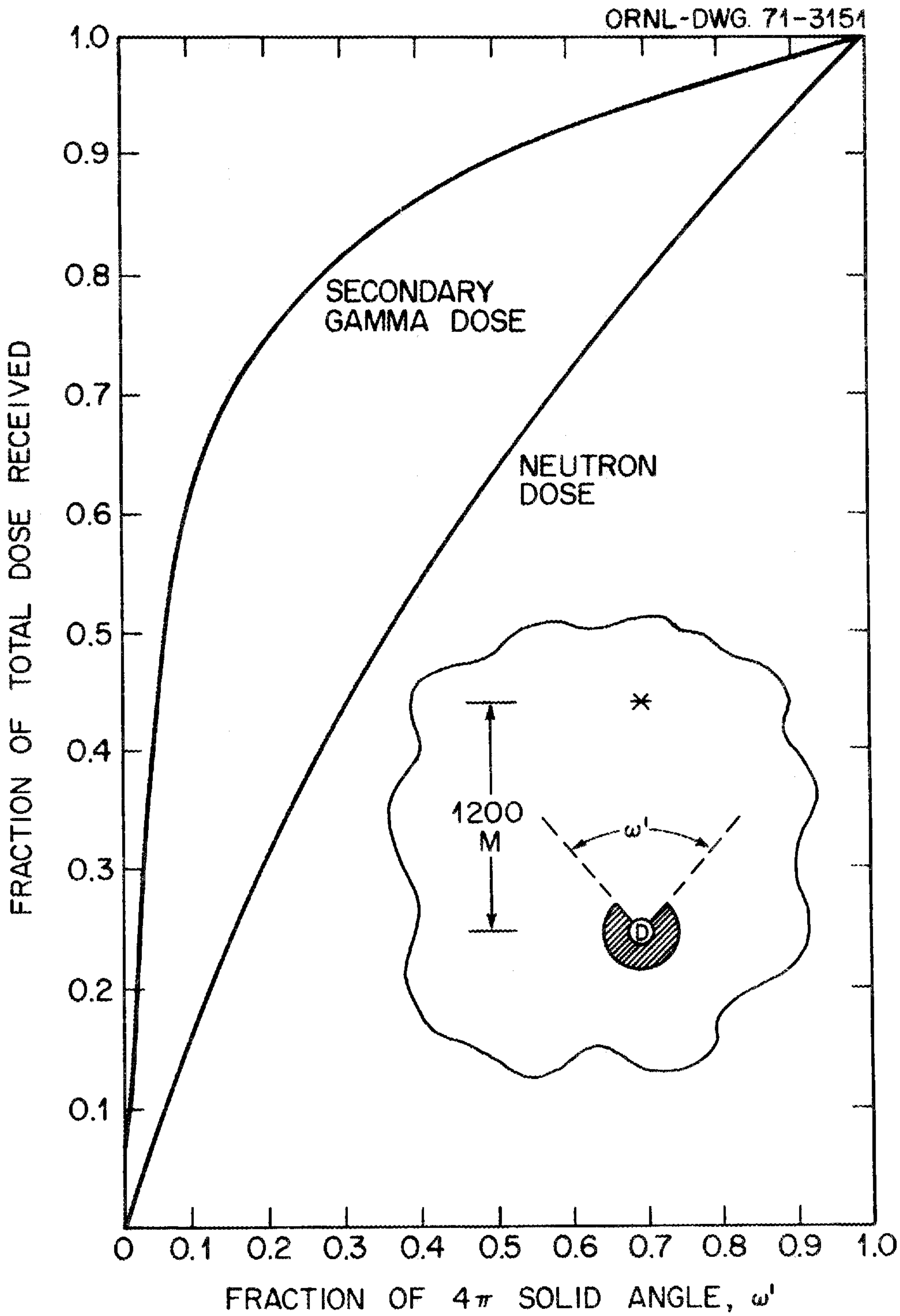

Figure 9. Angular Distribution of Neutron and Secondary Gamma Dose 1200 m from a Thermonuclear Weapon

source direction for the general case, it is recommended that an equal probability be assigned to all directions. This results in an isotropic azimuthal angle distribution as would be generated by a "halo" source, i.e., a source distributed on the circumference of an elevated circle centered about the detector.

Results of sensitivity studies performed to support the above recommendation are summarized in Table 3. The neutron transmission factors were calculated using Monte Carlo data for a fission-like neutron spectrum incident upon concrete.[15] The air-secondary and fission-product gammas were approximated by 2 and 1 MeV gammas, respectively, and Raso's Monte Carlo penetration data for concrete[16] were used to calculate the factors. All results are based on the total penetration through a vertical infinite slab.

The point source is a "worst case" whereas the halo source represents, for a given burst elevation, the average of all possible cases. For moderate wall thicknesses, the worst case differs from the average case by as much as a factor of 2. The less conservative but more realistic "halo" source is recommended.

Table 3. Dose Transmission Factors for Various Radiation Distributions Incident Upon a Vertical Infinite Slab of Concrete

D/Do

Slab Thickness (in.)	Radiation Source	Burst Elevation 0°	Burst Elevation 45°
	Neutrons		
0	Point	1.0	1.0
	Halo	1.0	1.0
5	Point	0.340	0.235
	Halo	0.281	0.142
10	Point	0.132	*
	Halo	0.071	*
	Air-Secondary Gammas		
0	Point	1.0	1.0
	Halo	1.0	1.0
5	Point	0.394	0.271
	Halo	0.249	0.168
10	Point	0.129	*
	Halo	0.071	*
	Fission-Product Gammas		
0	Point	1.0	1.0
	Halo	1.0	1.0
5	Point	*	0.281
	Halo	*	0.178

*Not Calculated

V. INTENSITY RELATIONSHIPS

The energy-angular distribution of the radiation field has been specified independent of a specific overpressure or intensity. However, in order to determine representative dose levels, specific intensities are determined for a selected burst height.

To examine the general problem of defining the standard free-field conditions of initial radiation, the relationships of yield, radiation dose, range, and overpressure were studied. The five primary assumptions were:

1. A fission/fusion ratio of 50/50 (in terms of energy yield).
2. The triple point burst height* for each overpressure of interest.
3. A neutron spectrum from a typical intermediate yield TN weapon.
4. Air density of 1.11 mg/cc.
5. All doses given as single collision absorbed dose in a small sample of tissue located in air.

From Fig. 3.67 in The Effects of Nuclear Weapons[14] the relationship between burst heights, slant ranges, and overpressure levels were obtained. For the fission-product gamma radiation dose calculations, state-of-the-art models fully described in a recent classified study[17] were used. The fission-product model, which incorporates Monte Carlo data for gamma-ray transport in infinite air,[13] takes into account decay rates, cloud rise, hydrodynamic enhancement of the gamma-ray dose, and interface effects. The neutron and secondary gamma-ray models, described in reference 8 are based on Straker's discrete-ordinates calculations of neutron and air-ground secondary gamma-ray transport in an air-over-ground geometry for a source height of 100 m. The models include adjustments for other burst heights and extrapolate the data to larger slant ranges.

*This burst height was chosen for the point on the ground, for each overpressure considered, at which the mach stem originates (triple point).

Neutron and air-secondary gamma-ray doses scale directly with yield. Fission-product gamma-ray doses were obtained (partly by extrapolation) from results of a previous study.[17] Doses from the three radiation components are given in Figs. 10, 11, and 12, and in Table 4 as a function of slant range for the triple point burst heights. Overpressure, range, and yield relationships are shown in Table 5.

It is seen from Figs. 10-12 and Table 4 that fission-product gamma rays are important for high-yield weapons whereas neutrons are important for low yield weapons. It should be emphasized that single collision dose in tissue has been calculated for neutrons.

As an example of the shielding that might be necessary, to reduce the free-field total dose to interior doses of 5 or 50 rads, dose transmission factors for the various cases are presented in Table 6. For a burst at the triple point burst height, note that radiation is of no concern below 20 psi for a 1 MT weapon, below 15 psi for a 300 KT weapon and at 5 psi for a 40 KT weapon. For lower burst heights these values are quite different; for example, for a 100 m burst height and 300 KT weapon there is a radiation problem even for overpressures of 5-10 psi.

Shown in Table 7 are radiation doses for a 300 KT weapon detonated at the triple point burst height and at 100 m. Dose components for the latter case are given in Fig. 13. Doses are more than a factor of 10 higher for the lower burst height at a given overpressure level. Thus the triple point burst height chosen here is non-conservative for estimating exposures at a fixed overpressure.

Because of the possibility that the shock wave might disturb the shield before the fission product dose was delivered, time-dependent calculations based on techniques described in reference 17 are included for the fission-product dose. These calculations include (1) the time of the shock front arrival at the various overpressure ranges, and (2) the percent of the total fission-product exposure before and after shock front arrival. The results of these calculations are summarized in Table 8 and are applicable for a burst height of 100 m. These results do not correspond to the same conditions in Tables 4-7, but are included to indicate trends.

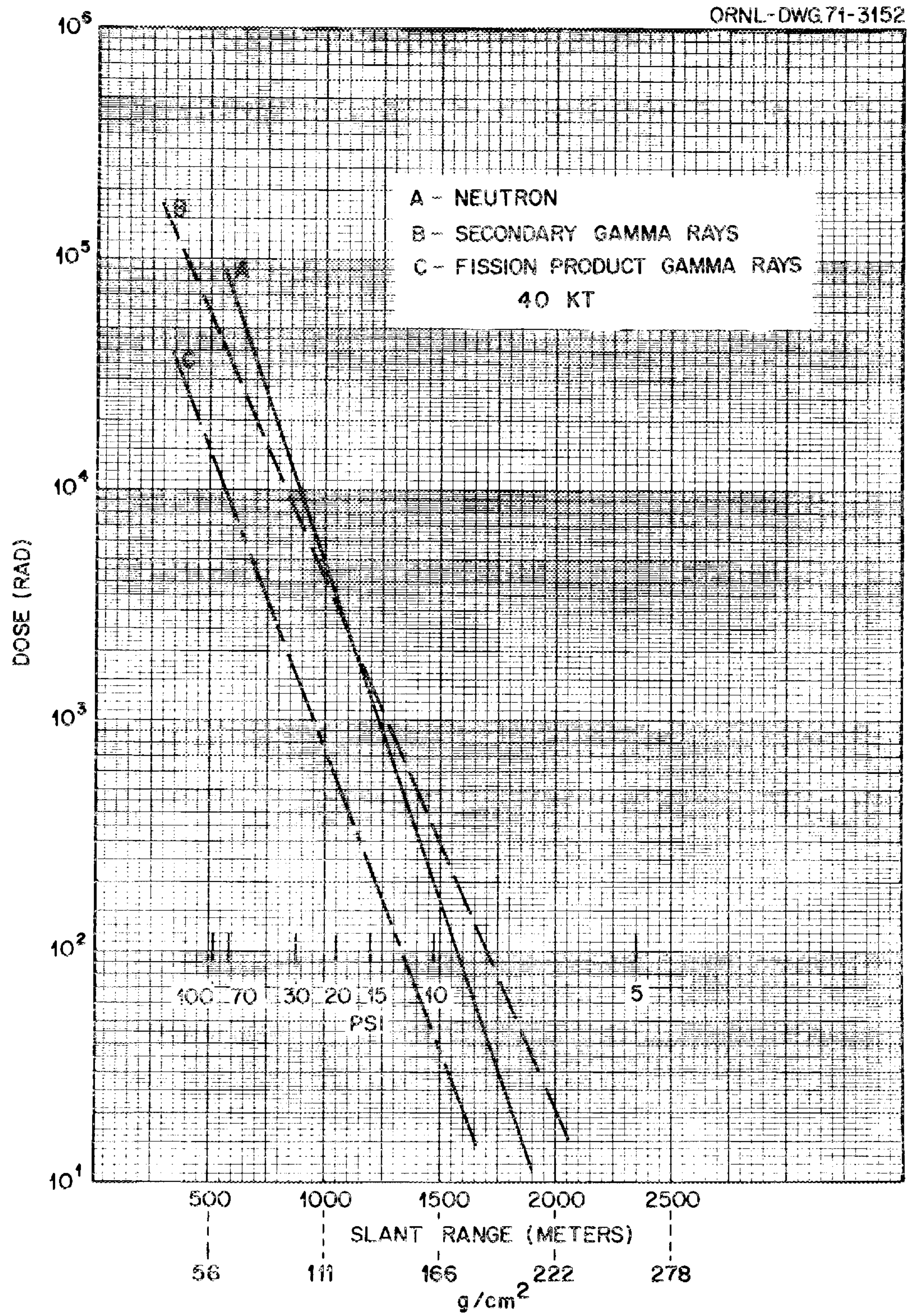

Figure 10. Dose Components from 40 KT Weapon Detonated at Triple Point Burst

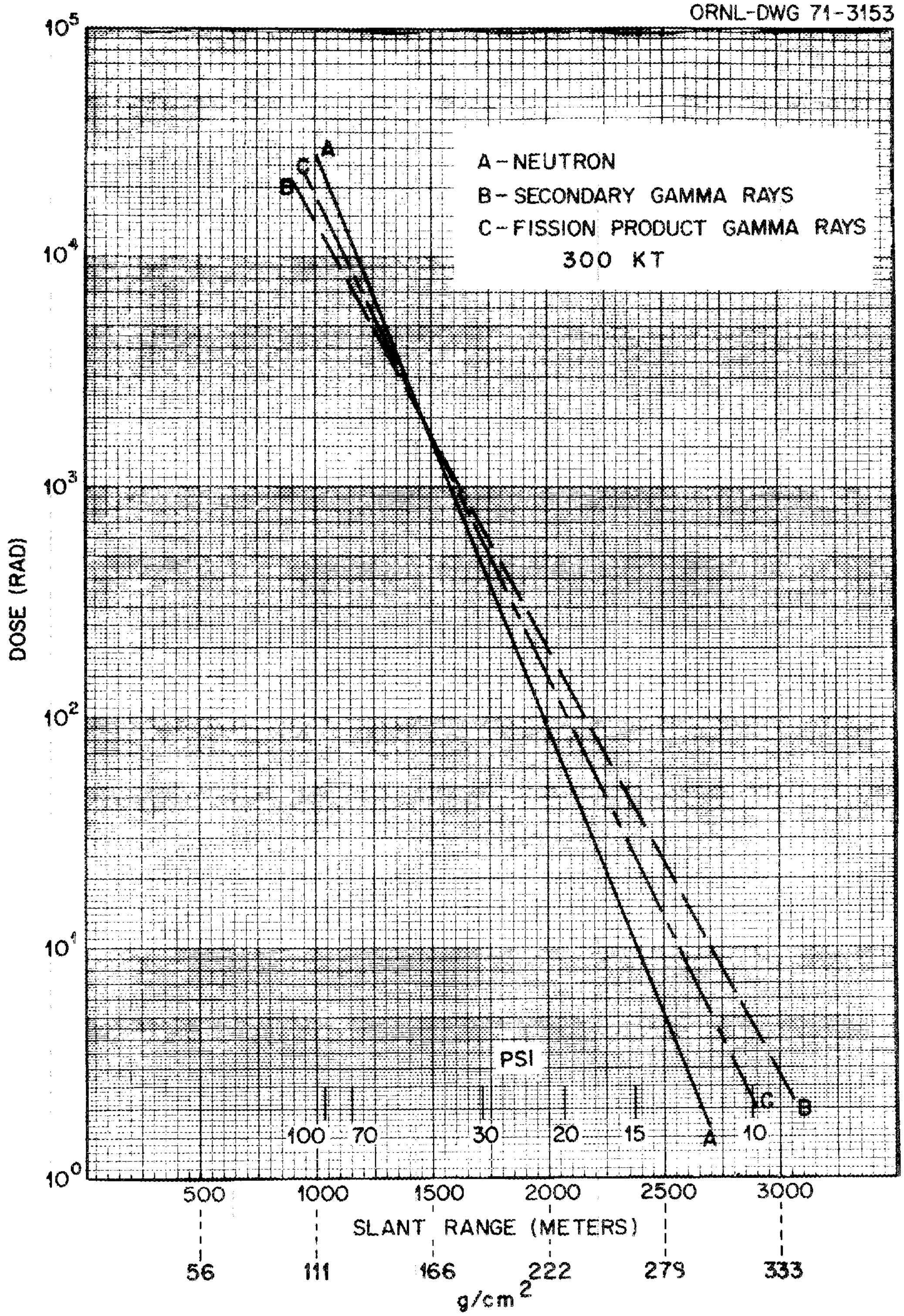

Figure 11. Dose Components from 300 KT Weapon Detonated at Triple Point Burst

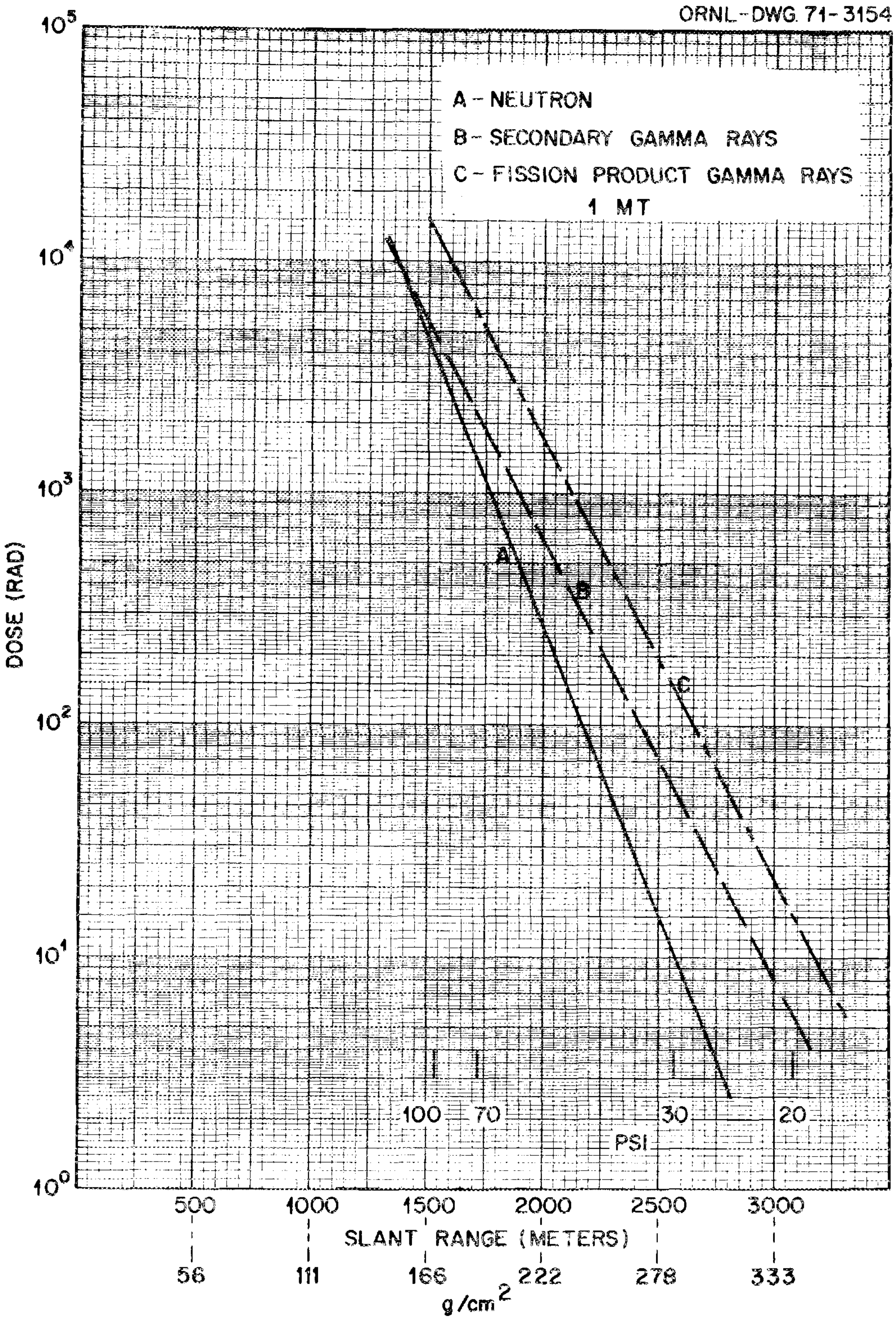

Figure 12. Dose Components from 1 MT Weapon Detonated at Triple Point Burst

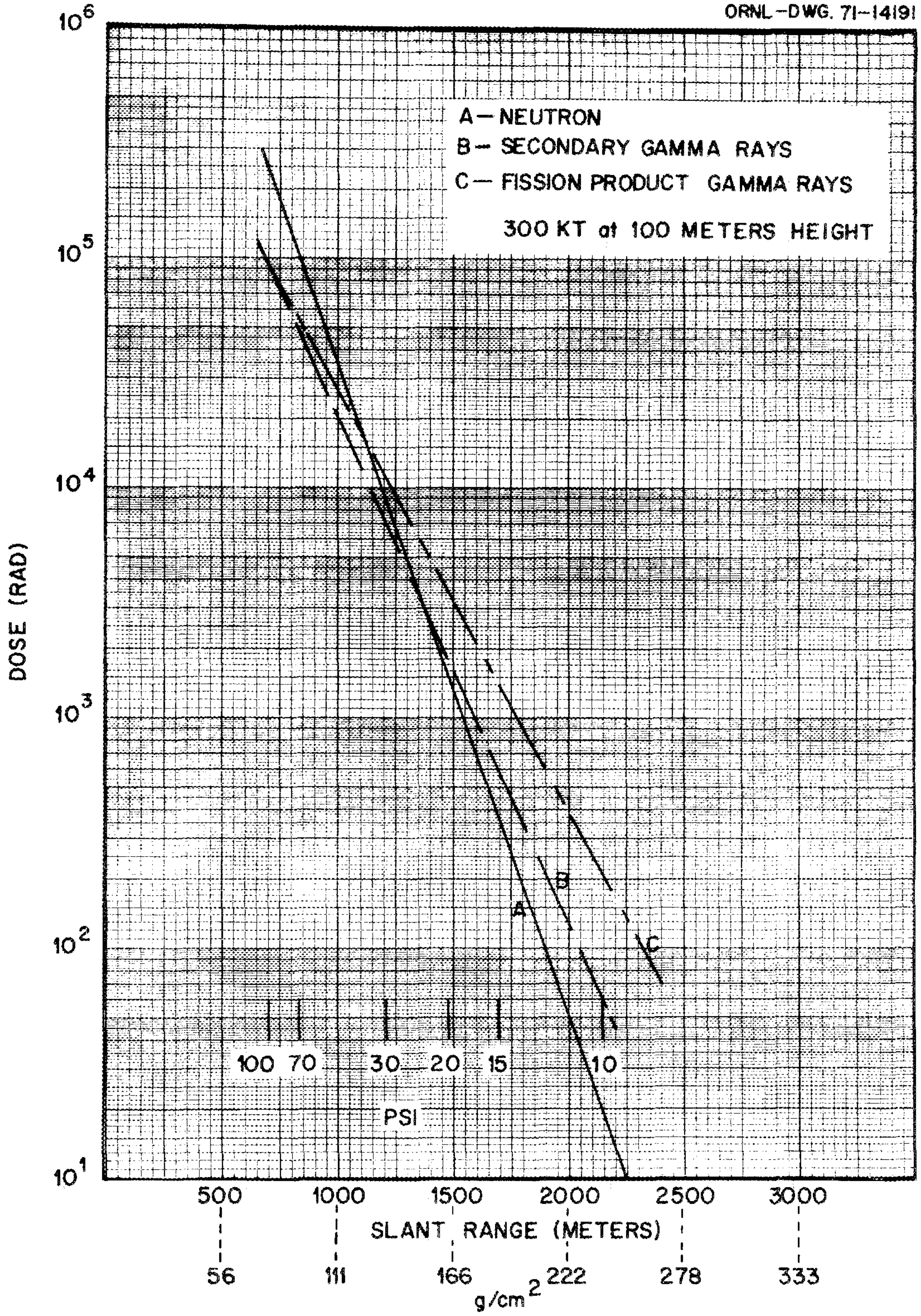

Figure 13. Dose Components from 300 KT Weapon Detonated at a Height of 100 m

Table 4. Initial Radiation Dose Components at Various Ranges of Overpressure from TN Weapons Detonated at Triple Point Burst Heights

Weapon Yield	Radiation Component	Overpressure (psi) 5	10	15	20	30	70	100
40 KT	Range (m)	2,358	1,470	1,204	1,053	879	587	528
					DOSE (RADS)			
	Neutrons	~1.0	200	1,300	3,700	12,000	85,000	350,000
	Secondary-Gamma	4.0	320	1,300	3,000	8,000	40,000	55,000
	Fission-Product-Gamma	<1.0	45	200	560	1,600	10,000	15,000
	TOTAL	5.0	565	2,800	7,260	21,600	135,000	420,000
300 KT	Range (m)	4,624	2,884	2,362	2,064	1,715	1,150	1,037
					DOSE (RADS)			
	Neutrons		<1.	11	60	430	12,000	24,000
	Secondary-Gamma		5.	40	150	670	7,800	13,000
	Fission-Product-Gamma		2.5	25	100	560	8,400	14,000
	TOTAL		8.0	76	310	1,660	28,200	51,000
1 MT	Range (m)	6,901	4,304	3,525	3,080	2,500	1,716	1,547
					DOSE (RADS)			
	Neutrons			<1	<1	10	1,400	3,800
	Secondary-Gamma			1	6	58	2,200	4,800
	Fission-Product-Gamma			2	16	160	6,000	13,000
	TOTAL			3	22	228	9,600	21,600

Table 5. Slant Ranges and Triple Point Burst Height for Various Overpressures from Different Weapon Yields

(meters)

Overpressure (psi)	Yield: 40 KT		300 KT		1 MT	
	Slant Range	Burst Height	Slant Range	Burst Height	Slant Range	Burst Height
5	2358	1210	4624	2350	6901	3510
10	1470	900	2884	1760	4304	2620
15	1204	785	2362	1530	3525	2290
20	1053	720	2064	1400	3080	2090
30	879	625	1715	1220	2560	1820
70	587	440	1150	860	1716	1280
100	528	410	1037	800	1547	1190

Table 6. Dose Transmission Factor (DTF) Required to Reduce Initial Radiation Doses to Below Selected Levels*

Overpressure psi	Yield											
	40 KT				300 KT				1 MT			
	DTF		1/DTF		DTF		1/DTF		DTF		1/DTF	
	50 Rads	5 Rads	50 Rads	5 Rads	50 Rads	5 Rads	50 Rads	5 Rads	50 Rads	5 Rads	50 Rads	5 Rads
5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
10	.089	.0089	11	110	1.0	.6	1.0	1.6	1.0	1.0	1.0	1.0
15	.018	.0018	55	550	.66	.066	1.5	15	1.0	1.0	1.0	1.0
20	.0069	.00069	145	1,450	.16	.016	6.3	63	1.0	.22	1.0	4.5
30	.0023	.00023	435	4,350	.030	.0030	33	330	.22	.022	4.5	45
70	.00037	.000037	2,700	27,000	.0018	.00018	550	5,500	.0052	.00052	190	1,900
100	.00012	.000012			.00098	.000098	1,020	10,200	.0023	.00023	435	4,350

*Based on triple point burst heights

Table 7. Initial Radiation Dose Components* from 300 KT TN Weapon Detonated at 100 m and at Triple Point Burst Heights

	Overpressure (psi)					
	10	15	20	30	70	100
100 Meter Burst Height						
Slant Range (m)	2,147	1,698	1,480	1,209	843	701
Neutron Dose	25	400	1,500	9,000	100,000	250,000
Secondary-Gamma Dose	70	600	1,700	7,000	45,000	100,000
Fission-Product-Gamma Dose	150	1,500	4,100	14,000	55,000	92,000
Total Dose	245	2,500	7,300	30,000	200,000	442,000
Triple Point Burst Height						
Slant Range (m)	2,884	2,362	2,064	1,715	1,150	1,037
Neutron Dose	<10	11	60	430	12,000	24,000
Secondary-Gamma Dose	<10	40	150	670	7,800	13,000
Fission-Product-Gamma Dose	<10	25	100	560	8,400	14,000
Total Dose		76	310	1,660	28,200	51,000

*Doses are in rads

Table 8. Fission-Product Gamma Ray Exposure During the First 60 Seconds from a Typical TN Weapon at a 100-M Burst Height

Slant Range (m)	Shock Arrival (sec)	Percent Before Shock	Percent After Shock
	100 KT		
538	0.3678	13.8	86.2
740	0.8187	20.4	79.6
1030	1.822	36.2	63.8
1446	4.055	63.1	36.9
2097	11.02	95.7	4.3
	300 KT		
771	0.5488	13.7	86.3
1060	1.221	20.5	79.5
1472	2.718	38.6	61.4
2065	6.049	69.8	30.2
2995	16.44	98.8	1.2
	1 MT		
1146	0.8187	11.1	88.9
1576	1.822	18.3	81.7
2190	4.055	38.2	61.8
3075	9.024	75.3	24.7
4458	24.53	99.8	0.2

It is observed that the fractions of the fission-product exposure occurring before and after the shock front have little dependence upon the yield, although the time of the shock front arrival at a given overpressure range increases by approximately a factor of 2 between 100 KT and 1 MT. Except at low overpressure ranges (< 20 psi) most of the exposure occurs after the shock front arrival. Thus structural damage may alter the amount of protection against this component. Further work must be performed to determine the sensitivity of the results to other conditions.

VI. FREE-FIELD ENVIRONMENT

In Section V, the slant ranges to be considered for the three weapon yields of interest between overpressure levels of 5 and 30 psi, varied from 880 m (40 KT, 30 psi) to 6900 m (1 MT, 5 psi). In identifying a free-field environment, it was decided to present normalized descriptions of neutrons, air-secondary gamma rays, and fission-product gamma rays at a slant range of 1200 m.

A. Neutrons

The description of the neutron field at the point of interest, 1200 m slant range, is taken from the infinite medium calculations of Straker(1) assuming a typical, intermediate yield, TN weapon. The energy and polar angular distributions (about the receiver-source direction) are given in Table 9 with the intensity normalized to a unit dose. The neutrons in the energy range from 0 to 4.14×10^{-7} MeV can be considered as thermal neutrons. Table 10 contains the dose factors and the neutron fluence (integrated over angle) at 1200 m.

B. Secondary Gammas

For the description of the secondary gamma rays, Straker's calculations at 1200 m are again used and are reproduced in Table 11; again the intensity is normalized to unit dose. Table 12 gives the solid angles and angular intervals associated with the discrete angles given in Tables 9 and 11. Table 10 also gives the dose factors and the gamma-ray fluence (integrated over angle) at 1200 m.

C. Fission-Product Gammas

Table 13 gives the energy and polar angular distribution (about the receiver-source direction) of the fission-product gamma rays for the triple point burst height. Effects of cloud rise are included.

Table 9. Relative Energy and Angle Distribution of $4\pi R^2$ Neutron Fluence 1200 m from a Point TN Source in Infinite Air

4 PI R**2 FLUENCE AT 1200.0 METERS — TYPICAL THERMONUCLEAR SOURCE

(NEUTRONS/GROUP/ANGLE BIN/INCIDENT DOSE)

ENERGY GROUP (MEV)	ANGLE 2 MU=-0.9894	ANGLE 3 MU=-0.9446	ANGLE 4 MU=-0.8656	ANGLE 5 MU=-0.7550	ANGLE 6 MU=-0.6179	ANGLE 7 MU=-0.4580	ANGLE 8 MU=-0.2816	ANGLE 9 MU=-0.0950
1.22E 01---1.50E 01	-3.970E 02	2.416E 01	1.743E 03	3.299E 03	3.383E 03	4.825E 03	9.865E 03	2.244E 04
1.00E 01---1.22E 01	3.526E 03	8.502E 03	1.366E 04	1.834E 04	2.285E 04	2.918E 04	4.000E 04	5.599E 04
8.19E 00---1.00E 01	5.173E 03	1.250E 04	2.039E 04	2.836E 04	3.728E 04	4.995E 04	6.981E 04	9.764E 04
~~6.36E 00---8.19E 00~~	~~1.587E 04~~	~~3.674E 04~~	~~5.809E 04~~	~~8.234E 04~~	~~1.135E 05~~	~~1.555E 05~~	~~2.095E 05~~	~~2.730E 05~~
4.97E 00---6.36E 00	3.577E 04	8.293E 04	1.312E 05	1.842E 05	2.468E 05	3.209E 05	4.047E 05	4.944E 05
4.07E 00---4.97E 00	5.036E 04	1.177E 05	1.863E 05	2.561E 05	3.271E 05	3.995E 05	4.745E 05	5.545E 05
3.01E 00---4.07E 00	7.471E 04	1.717E 05	2.641E 05	3.508E 05	4.322E 05	5.099E 05	5.871E 05	6.672E 05
2.46E 00---3.01E 00	6.245E 04	1.443E 05	2.242E 05	3.021E 05	3.799E 05	4.614E 05	5.526E 05	6.601E 05
2.35E 00---2.46E 00	1.792E 04	4.209E 04	6.739E 04	9.442E 04	1.242E 05	1.577E 05	1.962E 05	2.412E 05
1.83E 00---2.35E 00	1.283E 05	2.996E 05	4.740E 05	6.533E 05	8.410E 05	1.040E 06	1.255E 06	1.489E 06
1.11E 00---1.83E 00	3.402E 05	7.912E 05	1.243E 06	1.693E 06	2.146E 06	2.599E 06	3.049E 06	3.488E 06
5.50E-01---1.11E 00	8.103E 05	1.885E 06	2.963E 06	4.038E 06	5.112E 06	6.178E 06	7.225E 06	8.231E 06
1.11E-01---5.50E-01	2.135E 06	4.950E 06	7.724E 06	1.042E 07	1.299E 07	1.538E 07	1.752E 07	1.932E 07
3.35E-03---1.11E-01	4.158E 06	9.606E 06	1.488E 07	1.986E 07	2.443E 07	2.845E 07	3.175E 07	3.418E 07
5.83E-04---3.35E-03	1.307E 06	4.157E 06	6.423E 06	8.541E 06	1.045E 07	1.210E 07	1.341E 07	1.432E 07
1.01E-04---5.83E-04	1.803E 06	4.158E 06	6.422E 06	8.534E 06	1.044E 07	1.206E 07	1.335E 07	1.423E 07
2.90E-05---1.01E-04	1.264E 06	2.913E 06	4.493E 06	5.973E 06	7.299E 06	8.430E 06	9.322E 06	9.928E 06
1.07E-05---2.90E-05	9.983E 05	2.302E 06	3.553E 06	4.718E 06	5.765E 06	6.657E 06	7.361E 06	7.838E 06
3.06E-06---1.07E-05	1.194E 06	2.752E 06	4.247E 06	5.639E 06	6.888E 06	7.952E 06	8.788E 06	9.354E 06
1.12E-06---3.06E-06	8.386E 05	1.979E 06	3.054E 06	4.054E 06	4.951E 06	5.713E 06	6.312E 06	6.715E 06
4.14E-07---1.12E-06	7.263E 05	1.674E 06	2.583E 06	3.428E 06	4.185E 06	4.828E 06	5.332E 06	5.670E 06
0.0 ---4.14E-07	6.510E 05	1.500E 06	2.312E 06	3.064E 06	3.735E 06	4.302E 06	4.741E 06	5.032E 06

ENERGY GROUP (MEV)	ANGLE 10 MU= 0.0950	ANGLE 11 MU= 0.2816	ANGLE 12 MU= 0.4580	ANGLE 13 MU= 0.6179	ANGLE 14 MU= 0.7550	ANGLE 15 MU= 0.8656	ANGLE 16 MU= 0.9446	ANGLE 17 MU= 0.9894
1.22E 01---1.50E 01	3.993E 04	5.747E 04	7.770E 04	1.121E 05	1.837E 05	3.070E 05	4.570E 05	6.175E 05
1.00E 01---1.22E 01	7.455E 04	5.256E 04	1.126E 05	1.478E 05	2.181E 05	3.239E 05	4.656E 05	5.671E 05
8.19E 00---1.00E 01	1.303E 05	1.649E 05	2.067E 05	2.749E 05	3.962E 05	5.813E 05	7.811E 05	9.204E 05
6.36E 00---8.19E 00	3.427E 05	4.219E 05	5.269E 05	6.862E 05	9.224E 05	1.214E 06	1.437E 06	1.389E 06
4.97E 00---6.36E 00	5.893E 05	6.972E 05	8.341E 05	1.016E 06	1.238E 06	1.451E 06	1.519E 06	1.252E 06
4.07E 00---4.97E 00	6.441E 05	7.496E 05	8.773E 05	1.027E 06	1.181E 06	1.286E 06	1.232E 06	8.681E 05
3.01E 00---4.07E 00	7.544E 05	8.505E 05	9.524E 05	1.047E 06	1.106E 06	1.082E 06	9.074E 05	5.152E 05
2.46E 00---3.01E 00	7.908E 05	9.504E 05	1.142E 06	1.360E 06	1.583E 06	1.753E 06	1.744E 06	1.401E 06
2.35E 00---2.46E 00	2.947E 05	3.594E 05	4.389E 05	5.359E 05	6.475E 05	7.561E 05	8.112E 05	7.556E 05
1.83E 00---2.35E 00	1.740E 06	2.003E 06	2.259E 06	2.475E 06	2.591E 06	2.519E 06	2.126E 06	1.271E 06
1.11E 00---1.83E 00	3.900E 06	4.256E 06	4.515E 06	4.613E 06	4.459E 06	3.943E 06	2.955E 06	1.446E 06
5.50E-01---1.11E 00	9.156E 06	9.934E 06	1.047E 07	1.060E 07	1.015E 07	8.888E 06	6.538E 06	3.178E 06
1.11E-01---5.50E-01	2.065E 07	2.137E 07	2.131E 07	2.026E 07	1.812E 07	1.472E 07	1.011E 07	4.545E 06
3.35E-03---1.11E-01	3.555E 07	3.565E 07	3.442E 07	3.164E 07	2.730E 07	2.147E 07	1.435E 07	6.341E 06
5.83E-04---3.35E-03	1.476E 07	1.467E 07	1.401E 07	1.275E 07	1.090E 07	8.502E 06	5.650E 06	2.487E 06
1.01E-04---5.83E-04	1.465E 07	1.454E 07	1.386E 07	1.259E 07	1.075E 07	8.371E 06	5.557E 06	2.444E 06
2.90E-05---1.01E-04	1.021E 07	1.012E 07	9.633E 06	8.742E 06	7.452E 06	5.799E 06	3.847E 06	1.691E 06
1.07E-05---2.90E-05	8.055E 06	7.984E 06	7.600E 06	6.896E 06	5.877E 06	4.572E 06	3.033E 06	1.333E 06
3.06E-06---1.07E-05	9.610E 06	9.519E 06	9.058E 06	8.215E 06	6.998E 06	5.443E 06	3.609E 06	1.587E 06
1.12E-06---3.06E-06	6.895E 06	6.827E 06	6.493E 06	5.886E 06	5.012E 06	3.896E 06	2.583E 06	1.135E 06
4.14E-07---1.12E-06	5.820E 06	5.760E 06	5.475E 06	4.961E 06	4.223E 06	3.282E 06	2.175E 06	9.560E 05
0.0 ---4.14E-07	5.154E 06	5.089E 06	4.828E 06	4.366E 06	3.710E 06	2.880E 06	1.907E 06	8.375E 05

Table 10. Dose Factors and $4\pi R^2$ Fluence at a Range of 1200 m for a Typical Thermonuclear Weapon

Neutron			Gamma Rays		
Upper Energy (MeV)	Dose Factors*	$4\pi R^2$ Fluence (Neutrons/Group/Incident Dose)	Upper Energy (MeV)	Dose Factors†	$4\pi R^2$ Fluence (Gamma Rays/Group/Incident Dose)
15.0	5.46(−9)	1.898+6	10.0	2.42(−9)	1.498+7
12.2	5.13	2.204+6	8.0	2.07	3.627+7
10.0	4.84	3.777+6	6.5	1.76	1.698+8
8.18	4.62	7.885+6	5.0	1.59	6.959+7
6.36	4.44	1.050+7	4.0	1.27	8.166+7
4.97	4.13	1.023+7	3.0	1.08	4.633+7
4.07	4.01	1.027+7	2.5	8.75(−10)	5.203+7
3.01	3.39	1.351+7	2.0	7.35	4.045+7
2.46	3.15	5.540+6	1.66	6.44	4.760+7
2.35	3.09	2.316+7	1.33	5.30	5.781+7
1.83	2.64	4.544+7	1.00	4.45	4.524+7
1.11	1.97	1.054+8	.80	3.50	6.215+7
5.50(−1)‡	1.12	2.215+8	.60	2.56	1.350+8
1.11(−1)	2.30(−10)	3.741+8	.40	1.77	9.493+7
3.35(−3)	0	1.549+8	.3	1.22	1.722+8
5.83(−4)	0	1.538+8	.2	6.60(−11)	5.488+8
1.01(−4)	0	1.071+8	.1	3.90	8.107+8
2.90(−5)	0	8.454+7	.05	8.37	1.325+8
1.07(−5)	0	1.009+8			
3.06(−6)	0	7.236+7			
1.12(−6)	0	6.108+7			
4.14(−7)	0	5.411+7			

*Units are rads tissue/neutron/cm^2
†Units are rads tissue/photon/cm^2
‡Reads 5.50×10^{-1}

Table 11. Relative Energy and Angle Distribution of $4\pi R^2$ Secondary Gamma Fluence 1200 m from a Point TN Source in Infinite Air

4 PI R**2 FLUENCE AT 1200.0 METERS — TYPICAL THERMONUCLEAR SOURCE

(GAMMAS/GROUP/ANGLE BIN/INCIDENT DOSE)

ENERGY GROUP (MEV)	ANGLE 2 MU=-0.9894	ANGLE 3 MU=-0.9446	ANGLE 4 MU=-0.8656	ANGLE 5 MU=-0.7550	ANGLE 6 MU=-0.6179	ANGLE 7 MU=-0.4580	ANGLE 8 MU=-0.2816	ANGLE 9 MU=-0.0950
8.00E 00---1.00E 01	3.072E 03	1.606E 04	4.193E 04	6.944E 04	8.374E 04	8.509E 04	9.393E 04	1.303E 05
6.50E 00---8.00E 00	-5.686E 03	1.923E 04	1.054E 05	1.814E 05	2.018E 05	1.705E 05	1.591E 05	2.491E 05
5.00E 00---6.50E 00	5.848E 04	3.085E 05	7.997E 05	1.297E 06	1.538E 06	1.535E 06	1.674E 06	2.340F 06
4.00E 00---5.00E 00	-9.176E 04	3.754E 03	2.433E 05	6.297E 05	5.854E 05	1.433E 05	1.495E 05	4.529E 05
3.00E 00---4.00E 00	-6.227E 04	2.427E 04	4.042E 05	6.747E 05	6.698E 05	3.277E 05	4.121E 05	8.246E 05
2.50E 00---3.00E 00	-3.974E 03	3.155E 04	1.602E 05	2.522E 05	2.520E 05	1.950E 05	2.315E 05	4.534E 05
2.00E 00---2.50E 00	4.485E 04	9.735E 04	1.342E 05	1.605E 05	2.046E 05	3.064E 05	4.746E 05	6.550E 05
1.66E 00---2.00E 00	7.169E 04	9.128E 04	3.316E 04	5.669E 03	7.897E 04	2.760E 05	4.753E 05	5.181E 05
1.33E 00---1.66E 00	1.060E 05	1.140E 05	1.407E 04	-2.798E 04	9.495E 04	4.073E 05	6.494E 05	6.069E 05
1.00E 00---1.33E 00	8.112E 04	7.651E 04	-6.597E 03	-1.182E 04	1.253E 05	4.100E 05	5.541E 05	5.092E 05
8.00E-01---1.00E 00	-8.096E 03	6.265E 03	7.111E 04	1.509E 05	2.104E 05	2.058E 05	2.177E 05	5.010E 05
6.00E-01---8.00E-01	-4.887E 04	2.868E 03	1.968E 05	3.559E 05	3.348E 05	3.042E 05	6.144E 05	1.834E 06
4.00E-01---6.00E-01	3.856E 05	8.701E 05	1.340E 06	1.936E 06	2.941E 06	4.694E 06	7.356E 06	1.068E 07
3.00E-01---4.00E-01	2.457E 05	6.607E 05	1.356E 06	2.543E 06	4.295E 06	6.364E 06	8.246E 06	9.463E 06
2.00E-01---3.00E-01	2.191E 06	5.055E 06	7.760E 06	1.011E 07	1.193E 07	1.319E 07	1.402E 07	1.463E 07
1.00E-01---2.00E-01	5.606E 06	1.298E 07	2.019E 07	2.710E 07	3.357E 07	3.943E 07	4.451E 07	4.858E 07
5.00E-02---1.00E-01	8.815E 06	2.036E 07	3.156E 07	4.215E 07	5.191E 07	6.055E 07	6.778E 07	7.326E 07
2.00E-02---5.00E-02	1.641E 06	3.775E 06	5.806E 06	7.669E 06	9.309E 06	1.067E 07	1.170E 07	1.235E 07

ENERGY GROUP (MEV)	ANGLE 10 MU= 0.0950	ANGLE 11 MU= 0.2816	ANGLE 12 MU= 0.4580	ANGLE 13 MU= 0.6179	ANGLE 14 MU= 0.7550	ANGLE 15 MU= 0.8656	ANGLE 16 MU= 0.9446	ANGLE 17 MU= 0.9894
8.00E 00---1.00E 01	1.969E 05	2.779E 05	3.632E 05	4.951E 05	8.214E 05	1.666E 06	3.591E 06	7.047E 06
6.50E 00---8.00E 00	4.466E 05	6.623E 05	6.183E 05	1.023E 06	1.714E 06	3.743E 06	8.503E 06	1.828E 07
5.00E 00---6.50E 00	3.530E 06	4.836E 06	5.955E 06	7.507E 06	1.163E 07	2.200E 07	4.204E 07	6.277E 07
4.00E 00---5.00E 00	1.241E 06	1.899E 06	1.967E 06	1.996E 06	3.860E 06	9.795E 06	1.984E 07	2.687E 07
3.00E 00---4.00E 00	1.647E 06	2.291E 06	2.420E 06	2.973E 06	6.066E 06	1.354E 07	2.372E 07	2.574E 07
2.50E 00---3.00E 00	7.640E 05	9.794F 05	1.165E 06	1.930E 06	4.244E 06	8.555E 06	1.334F 07	1.378E 07
2.00E 00---2.50E 00	7.792E 05	9.168E 05	1.442E 06	3.025E 06	6.244E 06	1.079E 07	1.446E C7	1.229E 07
1.66E 00---2.00E 00	4.313E 05	5.352E 05	1.337E 06	3.226E 06	6.095E 06	9.083E 06	1.047E 07	7.727E 06
1.33E 00---1.66E 00	4.554E 05	8.026E 05	2.311E 06	5.112E 06	8.447E 06	1.086E 07	1.076E 07	6.888E 06
1.00E 00---1.33F 00	7.006E 05	1.902E 06	4.612E 06	8.372E 06	1.167E 07	1.272E 07	1.057E 07	5.518E 06
8.00E-01---1.00E 00	1.391E 06	3.090E 06	5.410E 06	7.666E 06	8.904E 06	8.410E 06	6.174E 06	2.846E 06
6.00E-01---8.00E-01	4.112E 06	6.832E 06	9.207E 06	1.041E 07	1.018E 07	8.683E 06	6.214E 06	2.928E 06
4.00E-01---6.00E-01	1.397E 07	1.634E 07	1.719E 07	1.652E 07	1.481E 07	1.242E 07	9.140E 06	4.434E 06
3.00E-01---4.00E-01	9.857F 06	9.787E 06	9.547E 06	9.272E 06	8.661E 06	7.294E 06	5.057E 06	2.252E 06
2.00E-01---3.00E-01	1.511E 07	1.536E 07	1.516E 07	1.431E 07	1.271E 07	1.033E 07	7.147E 06	3.244E 06
1.00E-01---2.00E-01	5.138E 07	5.261E 07	5.188E 07	4.884E 07	4.317E 07	3.474E 07	2.368E 07	1.059E 07
5.00E-02---1.00E-01	7.660E 07	7.728E 07	7.521E 07	6.970E 07	6.065E 07	4.807E 07	3.235E 07	1.435E 07
2.00E-02---5.00E-02	1.259E 07	1.237E 07	1.169E 07	1.053E 07	8.927E 06	6.914E 06	4.571E 06	2.006E 06

Table 12. Solid Angle Values for Angles Listed in Tables 9 and 11

Angle Index	Cosine of Angle |Mu|	Boundaries of |Mu|	Solid Angle (Steradians)
1	1.000		0.0
2, 17	0.9894	1.0–0.97284	0.170601
3, 16	0.9446	0.97284–0.91058	0.391153
4, 15	0.8656	0.91058–0.81542	0.597895
5, 14	0.7550	0.81542–0.6908	0.783060
6, 13	0.6179	0.6908–0.5412	0.939939
7, 12	0.4580	0.5412–0.3720	1.062838
8, 11	0.2816	0.3720–0.1894	1.147334
9, 10	0.0950	0.1894–0.0	1.190348

Table 13. Fission-Product Gamma-Ray Fluence as a Function of Energy and Polar Angle with Respect to the Source-Detector Axis 45° Above the Horizon

Relative Gamma-Ray Fluence* Energy (MeV)

Polar Angle (degrees)	.01–.07	.07–.12	.12–.21	.21–.3	.3–.4	.4–.6	.6–.9	.9–1.2	1.2–1.6	1.6–2.0	2.0–2.5	2.5–3	3–3.5	3.5–4	4–5	5–6
0.0–13.4	1.35–04	1.09–04	5.13–05	5.13–05	5.71–05	7.02–05	3.98–05	2.13–05	1.60–05	1.60–05	4.13–06	4.13–06	8.41–07	8.41–07	1.49–07	1.49–07
13.4–24.4	5.83–04	4.65–04	2.26–04	2.26–04	2.51–04	3.08–04	1.74–04	9.77–05	7.88–05	7.88–05	2.55–05	2.55–05	1.46–05	1.46–05	4.06–06	4.06–06
24.4–35.3	9.30–04	7.63–04	3.75–04	3.75–04	4.17–04	5.15–04	2.95–04	1.82–04	1.70–04	1.70–04	6.69–05	6.69–05	7.50–05	7.50–05	2.30–05	2.30–05
35.3–46.3	1.19–03	9.85–04	4.91–04	4.91–04	5.44–04	6.62–04	3.54–04	2.10–04	1.86–04	1.86–04	7.63–05	7.63–05	8.04–05	8.04–05	2.46–05	2.46–05
46.3–57.2	6.79–04	5.32–04	2.48–04	2.48–04	2.74–04	3.36–04	1.83–04	1.20–04	1.19–04	1.19–04	4.50–05	4.50–05	2.64–05	2.64–05	7.25–06	7.25–06
57.2–68.1	7.54–04	5.91–04	2.68–04	2.68–04	2.87–04	3.56–04	1.79–04	9.46–05	7.07–05	7.07–05	1.75–05	1.75–05	3.00–06	3.00–06	5.21–07	5.21–07
68.1–79.0	8.23–04	6.44–04	2.87–04	2.87–04	3.17–04	3.73–04	1.67–04	7.40–05	3.72–05	3.72–05	3.44–06	3.44–06	5.77–08	5.77–08		
79.0–90.	8.36–04	6.47–04	2.91–04	2.91–04	3.22–04	3.66–04	1.31–04	4.94–05	1.22–05	1.22–05	2.49–07	2.49–07				
90.0–100.9	7.78–04	5.99–04	2.64–04	2.64–04	2.93–04	3.20–04	7.94–05	2.76–05	2.64–06	2.64–06						
100.9–111.8	7.48–04	5.56–04	2.43–04	2.43–04	2.71–04	2.85–04	4.51–05	1.53–05	4.90–07	4.90–07						
111.8–122.8	6.44–04	4.69–04	2.02–04	2.02–04	2.25–04	2.32–04	2.33–05	7.76–06								
122.8–133.7	6.20–04	4.54–04	1.71–04	1.71–04	1.89–04	1.92–04	9.37–06	3.12–06								
133.7–144.6	5.06–04	3.89–04	1.27–04	1.27–04	1.41–04	1.42–04	4.27–06	1.42–06								
144.6–155.6																
155.6–166.6																
166.6–180.																

*Photons/cm^2 (not per MeV nor per steradian)

VII. APPLICATION CONSIDERATIONS

Application of the free-field environment to determine the initial radiation environment inside structures is beyond the scope of this report and requires penetration data for the recommended free-field distributions. An outline of an approach that may be taken will be discussed however.

The standard environments given in Section VI should be used as a source term for the determinations of dose transmission factors for various shield configurations. (The determination of these configurations is a full study in itself.) That is, the energy-angular distribution of the environment should be used with an arbitrary normalization such that the ratio of the interior dose to the exterior dose determines the transmission factor for the shield. Angular information about the interior dose should be maintained as a percentage of dose in angular intervals. At this step the absolute intensity of the data given in Section VI is not important but only the relative energy angular variations should be utilized. Note that a rotation of coordinates is required before the data in Tables 9-13 (angles measured about receiver-source direction) can be used as a source term for penetration calculations. The rotation to a coordinate system perpendicular to the shield must include the effect of the 45° source elevation as well as the effect of the "halo" source distribution.

As an example of a method that might be used in determining the dose interior to a shielded structure, one could determine the overpressure which the building could withstand, then determine from the data in Figs. 10-12, the free-field radiation dose in rads that would result. Dose transmission factors including geometric attenuation for each of the four quadrants of the building could be determined as well as the transmission factors for the roof. (As used here, a zero thickness shield corresponds to a transmission factor of 1.) The interior dose could then be taken as the exterior dose times the dose transmission factor for the roof plus the exterior dose times the transmission factor for the worst quadrant (assumed preferred source direction) or the average of the dose transmission factors for the four quadrants could be used. An alternate scheme for treating the transmission factors for the various quadrants may be desirable but this required additional study. Due to the use of a 45° angle between the ground and the source direction an approximately equal dose is incident on the roof as on a quadrant of the building, so the transmitted dose should be equally weighted.

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