VERIFICATION OF SHIELDING CALCULATION ON THE DIII-D FACILITY AT LA JOLLA, CA

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SUMMARY

Shielding calculations were performed for the DIII-D facility at La Jolla to independently assess the biological dose from radiation emitted during operation. These calculations for both the fully shielded and bare configurations are in essential agreement with those done by General Atomics. In addition to the basic test problems run by General Atomics, a bare configuration with additional air outside the facility area was calculated. The addition of air to the bare configuration caused the dose at 100 meters from the DIII-D center-line to increase by fifty five percent. The inclusion of the various elemental constituents in the soil composition may change the calculated dose, but will not change the shielding factor nor invalidate the overall conclusion of this report. The overall conclusion is that General Atomics and LLNL results are in general agreement.

INTRODUCTION

The DIII-D facility at La Jolla was originally designed to study proton plasmas. The replacement of hydrogen with deuterium as the plasma material adds a radiation source that was not considered in the original facility design.

The burning of deuterium gives rise to a 2.5 MeV neutron and triton with about equal probability. The 2.5 MeV neutrons produced from the D + D -> N + He_3 create gamma rays from both capture and inelastic scattering. The neutron capture and absorption reactions induce a very low level of residual radioactivity in facility components. The 14 MeV neutrons produced from the D+T-> N + He_4 were not considered in this study, because it was not a part of the agreed verification program.

This report deals with the biological dose as a function of distance from the center-line of the DIII-D. The biological dose was calculated at several distances from the facility and at various heights above the ground level. In this report the primary interest is the spatial point 100 meters radially from the center-line of DIII-D and 1.7 meters above the ground which corresponds to the site boundary closest to the facility.

TRANSPORT METHOD

The TART[1] Neutron and Photon Monte Carlo transport code was used to perform the LLNL calculations. The atomic and nuclear data used in the transport were derived from the ENDL[2] data libraries. The General Atomics calculation were performed with the MCNP[3] code and using data from the ENDF/B-V[4] library. These Monte Carlo codes have been extensively used and verified in the past. They use different methods for treating the cross sections, and have derived their data from different evaluated libraries.

The dose response functions for neutrons and photons that were used in the calculations are given in Figures 1 and 2. They were derived from the ANSI-77[5] standard. The photon flux to dose conversion factors were extrapolated from 10.0 keV to 100 eV in order to obtain a value at the least photon energy of interest.

RESULTS

The three problems that were considered are;

1.) Bare, (as it was before any additional shielding was installed) with air and soil extending 150 meters beyond the DIII-D center-line in the horizontal, and to 80 meters above the soil in the vertical direction. A vacuum (particle leakage region) is beyond 150 meters in the horizontal direction and 80 meters in the vertical direction.

2.) Fully shielded including additional B-Poly outside the concrete wall and additional steel outside the B-Poly shield that is between the borated water roof and the existing concrete wall and the same 150 by 80 meters of air and soil as in 1.) above.

3.) Bare as in 1.), but 450 meters of air added in the horizontal and vertical directions.

The gamma ray energy produced per source neutron is given in Table I for the three problems that were studied. The isotopic composition for each material is given in Table II. The same material numbers were used in each problem, and if the energy produced is zero, it means the material was not present in the calculation . The gamma ray energy production within the facility was not significantly affected by the addition of either air or shielding material. The DIII-D materials accounted for about 92 percent of the gamma energy produced.

Tables III and IV give the calculated dose for neutrons and gamma rays for two of the three configurations that were studied. The data presented in Table III is also plotted in Figures 3 thru 5, and the contents of Table IV are presented in Figures 6 thru 8. At a height of 1.7 meters and a distance of 100 meters (site boundary) from the DIII-D center-line the dose with the shield in place is 303 times less than the unshielded (bare) design.

Additionally at the site boundary, in the unshielded configuration the neutrons contribute 99 percent of the dose, whereas in the fully shielded case the neutrons contributed only 23 percent of the total dose. The shielding material (B-Poly) reduces both the number of neutrons escaping and their energy. This energy reduction diminishes their biological effectiveness (see Fig.1).

The low atomic number elements in the shielding material are not as effective for gamma rays as they are for neutrons. The average energy of the gamma rays produced is 2.32 MeV in the fully shielded configuration and 2.4 MeV in the unshielded configuration.

The average energy of a photon entering the vacuum outside the problem is 1.8 MeV for the unshielded and 1.9 MeV with the full shield in place. The stainless steel added to the exterior of the B-Poly (in the fully shielded problem) hardens the gamma ray leakage spectrum by removing the low energy component.

Table V and Figures 9 thru 11 give the results of adding additional air and soil in the radial direction and air in the vertical direction. Comparing the calculations of the bare unshielded configuration and the unshielded with additional air shows that the additional air and soil increase the total dose by 55 percent. The soil used in these calculations did not have the various minor elemental constituents that are normally found in local soils. The inclusion of the trace elements could make a minor change in the absolute value of the dose. This omission is not expected to affect either the calculated results or the conclusions.

CONCLUSIONS

The calculations at General Atomics and LLNL are essentially in agreement.

REFERENCES

1. E. F. Plechaty and J. R. Kimlinger, "Tartnp: A coupled Neutron-Photon Monte Carlo transport code ," July,1976; UCRL 50400, Vol. 14.

2. R. J. Howerton, et al, "Omega: A Cray 1 Executive Code for LLNL Nuclear Data Libraries," August,1983; UCRL 50400 Vol. 25.

3. J. F. Briesmeister, Editor, "MCNP-A General Monte Carlo Code for Neutron and Photon Transport," September,1986; La-7396-M,Rev. 2.

4. "ENDF/B Summary Documentation," compiled by R. Kinsey,BNL-NCS-17541 (ENDF-201),3rd ed. (ENDF/B-V), Brookhaven National Laboratory (1979).

5. Data taken from appendix H, pages 563 and 564 of reference 3.

TABLE I

GAMMA RAY ENERGY IN MEV. PER SOURCE NEUTRON FOR EACH MATERIAL CONFIGURATION

MATERIAL NO.	MATERIAL COMPOSITION	BARE	FULL SHIELD	BARE+ ADDITIONAL AIR
1.	air	1.29E-02	4.03E-03	4.59E-02
2.	vacuum vessel	2.87E+00	2.87E+00	2.87E+00
3.	pf coils	1.04E+00	1.03E+00	1.04E+00
4.	tfe coils	2.75E+00	2.76E+00	2.73E+00
5.	concrete	3.65E-01	4.28E-01	3.62E-01
6.	borated water	0.	4.46E-02	0.
7.	b-poly shield	0.	2.90E-02	0.
8.	stainless steel	1.10E-01	1.24E-01	1.09E-01
9.	soil	4.96E-02	2.69E-05	1.02E-01
TOTAL		7.20E+00	7.29E+00	7.25E+00

BARE means air to 150. meters radially and 80. meters vertically.

ADDITIONAL AIR means 450. meters of air and soil were added in the radial direction, and 550. meters of air was added vertically.

TABLE II

MATERIAL SPECIFICATIONS

MATERIAL NO.	DENSITY G/CC	RELATIVE ATOM FRACTION
		AIR
1	1.228E-03	3.9638E-05 7014 1.1054E-05 8016 8.1E-07 1001 & 8.3501E-09 6012 1.7158E-07 18000
		VACUUM VESSEL
2	3.97627	2.0073E-02 8016 4.0147E-02 1001 2.1132E-02 28000 & 8.408E-03 24000 1.9072E-03 42000 1.092E-03 26000 & 3.014E-04 13027 7.920E-04 41093 1.8096E-04 14000 & 1.7248E-04 27059 1.6984E-04 22000 9.252E-05 25055 & 8.372E-05 6012
		PF COILS
3	7.42901	6.74475E-02 29000 1.6728E-02 1001 8.3639E-03 8016
		TFE COILS
4	9.1433	8.54335E-02 29000 3.3456E-03 1001 1.6728E-03 8016
		CONCRETE
5	2.33801	4.3855E-02 8016 7.7678E-03 1001 1.5805E-02 14000 & 2.9155E-03 20000 2.3869E-03 13027 1.0475E-03 11023 & 6.9321E-04 19000 3.1276E-04 26000 1.4869E-04 12000 & 5.6349E-05 16032
		WATER, 0.5% BORON
6	1.00577	6.6922E-02 1001 3.3462E-02 8016 2.2266E-04 5011 & 5.5665E-05 5010
		B-POLY
7	.870059	7.1894E-02 1001 3.5252E-02 6012 1.4541E-03 8016 & 3.8743E-04 5011 9.6858E-05 5010
		STAINLESS STEEL
8	7.92000	.055434 26000 .016526 24000 .008946 28000 & .003829 25055 .001493 42000
		SOIL
9	1.5	1. 14000 2. 8016

TABLE III

DIIID Unshielded Configuration

Gamma Dose in Millirem from 10**14 neutrons

Radial Distance from DIIID axis of symmetry in meters

Height\	15.00		20.00		40.00		70.00		100.00		150.00	
(M)	mr	%dev.	mr	%dev.	mr	%dev.	mr	%dev.	mr	%dev.	mr	%dev.
1.7	4.65e-02	6.7	3.02e-02	20.0	4.98e-03	10.3	2.82e-03	15.0	1.24e-03	21.4	2.02e-04	30.1
4.4	2.35e-01	2.1	8.11e-02	3.8	1.02e-02	6.9	2.97e-03	9.1	1.28e-03	9.9	4.47e-04	14.8
6.8	2.60e-01	4.6	1.35e-01	4.2	1.41e-02	8.4	4.00e-03	12.5	1.49e-03	27.2	4.94e-04	21.3
8.7	2.12e-01	3.0	1.35e-01	3.1	2.24e-02	6.4	3.85e-03	9.9	1.86e-03	13.7	4.88e-04	20.0
15.0	1.17e-01	2.4	9.27e-02	2.0	3.01e-02	2.2	6.66e-03	4.1	2.45e-03	5.7	6.08e-04	5.6
25.0	4.62e-02	3.4	4.63e-02	3.8	2.69e-02	2.5	9.93e-03	3.0	3.88e-03	7.4	9.06e-04	6.7
55.0	1.39e-02	4.0	1.38e-02	3.7	1.10e-02	2.0	6.77e-03	1.6	3.78e-03	1.9	1.45e-03	2.5

Neutron Dose in Millirem from 10**14 neutrons

Radial Distance from DIIID axis of symmetry in meters

Height\	15.00		20.00		40.00		70.00		100.00		150.00	
(M)	mr	%dev.	mr	%dev.	mr	%dev.	mr	%dev.	mr	%dev.	mr	%dev.
1.7	2.53e+00	13.4	2.40e+00	16.4	8.58e-01	6.3	3.84e-01	6.3	1.51e-01	6.9	3.50e-02	15.9
4.4	1.87e+01	1.2	6.86e+00	1.9	1.09e+00	4.1	3.77e-01	4.2	1.84e-01	7.0	3.62e-02	9 7
6.8	2.04e+01	1.9	1.12e+01	2.4	1.44e+00	5.4	4.07e-01	6.7	2.04e-01	8.3	4.13e-02	13.8
8.7	1.66e+01	1.3	1.12e+01	2.1	1.79e+00	3.1	5.11e-01	9.2	2.04e-01	13.6	7.49e-02	44 9
15.0	9.12e+00	1.4	7.30e+00	0.9	2.56e+00	1.7	6.03e-01	1.7	2.22e-01	2.9	4.77e-02	4.6
25.0	3.88e+00	2.2	3.68e+00	1.8	2.06e+00	1.4	7.65e-01	1.9	2.75e-01	2.6	5.56e-02	4.1
55.0	1.18e+00	2.6	1.09e+00	2.0	8.89e-01	2.8	4.97e-01	1.7	2.55e-01	1.5	6.87e-02	1.6

Total Dose in Millirem from 10**14 neutrons

Radial Distance from DIIID axis of symmetry in meters

Height\	15.00		20.00		40.00		70.00		100.00		150.00	
(M)	mr	%dev.	mr	%dev.	mr	%dev.	mr	%dev.	mr	%dev.	mr	%dev
1.7	2.57e+00	13.1	2.43e+00	16.2	8.63e-01	6.2	3.86e-01	6.3	1.52e-01	6.8	3.52e-02	15.8
4.4	1.89e+01	1.2	6.94e+00	1.9	1.10e+00	4.0	3.80e-01	4.2	1.85e-01	6.9	3.66e-02	9 6
6.8	2.06e+01	1.9	1.13e+01	2.3	1.46e+00	5.4	4.11e-01	6.7	2.05e-01	8.3	4.18e-02	13.6
8.7	1.68e+01	1.3	1.13e+01	2.1	1.81e+00	3.0	5.14e-01	9.1	2.06e-01	13.5	7.54e-02	44 6
15.0	9.24e+00	1.4	7.40e+00	0.9	2.59e+00	1.7	6.09e-01	1.7	2.24e-01	2.9	4.84e-02	4 5
25.0	3.93e+00	2.2	3.73e+00	1.8	2.09e+00	1.4	7.75e-01	1.9	2.78e-01	2.5	5.65e-02	4 0
55.0	1.19e+00	2.5	1.11e+00	2.0	9.00e-01	2.8	5.04e-01	1.7	2.59e-01	1.5	7.02e-02	1.6

TABLE IV

DIIID Fully Shielded Configuration

Gamma Dose in Millirem from 1014 neutrons**

Height\	Radial Distance from DIIID axis of symmetry in meters: 15.00		20.00		40.00		70.00		100.00		150.00	
(M)	mr	%dev.	mr	%dev.	mr	%dev.	mr	%dev.	mr	%dev.	mr	%dev.
1.7	4.34e-02	1.1	1.87e-02	1.5	3.33e-03	2.1	8.90e-04	2.2	3.85e-04	2.6	1.27e-04	3.5
4.4	1.10e-01	1.7	3.92e-02	2.2	4.18e-03	2.6	9.81e-04	2.8	4.06e-04	3.0	1.30e-04	4.1
6.8	7.53e-02	3.2	5.22e-02	3.3	5.72e-03	4.8	1.24e-03	4.9	4.66e-04	6.0	1.40e-04	3.7
8.7	3.67e-02	2.8	4.06e-02	2.7	7.82e-03	4.1	1.30e-03	4.1	5.15e-04	4.1	1.59e-04	6.7
15.0	2.89e-02	1.9	1.93e-02	1.7	8.94e-03	2.3	2.21e-03	2.8	7.56e-04	3.4	1.97e-04	3.6
25.0	1.61e-02	2.8	1.29e-02	2.2	5.28e-03	2.1	2.65e-03	2.9	1.08e-03	3.2	3.10e-04	4.1
55.0	5.26e-03	2.6	4.66e-03	2.3	2.87e-03	1.6	1.47e-03	1.6	8.69e-04	1.9	3.89e-04	2.2

Neutron Dose in Millirem from 1014 neutrons**

Height\	Radial Distance from DIIID axis of symmetry in meters: 15.00		20.00		40.00		70.00		100.00		150.00	
(M)	mr	%dev.	mr	%dev.	mr	%dev.	mr	%dev.	mr	%dev.	mr	%dev.
1.7	1.98e-02	4.6	7.76e-03	5.3	1.21e-03	6.7	3.66e-04	9.1	1.16e-04	13.4	4.93e-05	35.1
4.4	1.61e-02	4.5	7.63e-03	4.7	1.21e-03	6.6	3.47e-04	7.3	1.22e-04	10.5	2.56e-05	15.6
6.8	1.05e-02	15.1	6.09e-03	5.6	1.19e-03	8.4	3.12e-04	10.2	1.25e-04	14.3	3.44e-05	20.3
8.7	5.54e-03	9.0	4.89e-03	6.5	1.30e-03	6.2	3.87e-04	8.2	1.27e-04	10.6	3.36e-05	13.6
15.0	3.04e-03	9.7	2.42e-03	5.9	1.11e-03	4.5	3.69e-04	7.7	1.64e-04	6.9	3.84e-05	8.2
25.0	1.70e-03	13.4	1.77e-03	9.0	8.18e-04	6.1	3.43e-04	5.5	1.75e-04	6.7	4.56e-05	17.3
55.0	6.15e-04	9.6	5.44e-04	6.5	3.78e-04	5.3	2.05e-04	4.2	1.10e-04	4.7	3.86e-05	5.4

Total Dose in Millirem from 1014 neutrons**

Height\	Radial Distance from DIIID axis of symmetry in meters: 15.00		20.00		40.00		70.00		100.00		150.00	
(M)	mr	%dev.	mr	%dev.	mr	%dev.	mr	%dev.	mr	%dev.	mr	%dev.
1.7	6.32e-02	1.6	2.64e-02	1.9	4.54e-03	2.4	1.26e-03	3.1	5.01e-04	3.7	1.76e-04	10.1
4.4	1.26e-01	1.6	4.68e-02	2.0	5.39e-03	2.5	1.33e-03	2.8	5.28e-04	3.4	1.55e-04	4.3
6.8	8.58e-02	3.4	5.83e-02	3.1	6.91e-03	4.2	1.55e-03	4.5	6.13e-04	5.6	1.75e-04	5.0
8.7	4.22e-02	2.7	4.55e-02	2.5	9.11e-03	3.6	1.68e-03	3.7	6.42e-04	3.9	1.93e-04	6.0
15.0	3.19e-02	2.0	2.17e-02	1.6	1.01e-02	2.1	2.57e-03	2.6	9.20e-04	3.0	2.35e-04	3.3
25.0	1.79e-02	2.9	1.47e-02	2.2	6.09e-03	2.0	2.99e-03	2.7	1.26e-03	2.9	3.56e-04	4.2
55.0	5.88e-03	2.5	5.20e-03	2.2	3.25e-03	1.5	1.67e-03	1.5	9.79e-04	1.7	4.28e-04	2.0

TABLE V

DIIID existing configuration with additional air.

Gamma Dose in Millirem from 10**14 neutrons

Height\	Radial Distance from DIIID axis of symmetry in meters											
	15.00		20.00		40.00		70.00		100.00		150.00	
(M)	mr	%dev.	mr	%dev.	mr	%dev.	mr	%dev.	mr	%dev.	mr	%dev.
1.7	4.94e-02	4.5	2.17e-02	6.6	7.21e-03	7.4	3.51e-03	11.4	1.87e-03	11.4	9.22e-04	14.2
4.4	2.33e-01	1.6	8.17e-02	2.1	9.68e-03	6.1	4.36e-03	9.6	2.04e-03	7.8	1.07e-03	14.1
6.8	2.67e-01	2.3	1.42e-01	3.5	1.54e-02	5.9	4.12e-03	9.4	2.24e-03	14.1	8.17e-04	12.0
8.7	2.12e-01	2.2	1.39e-01	1.8	2.26e-02	4.4	5.30e-03	7.7	2.44e-03	16.7	1.10e-03	10.8
15.0	1.15e-01	1.8	9.19e-02	1.3	3.16e-02	1.8	7.64e-03	2.5	3.04e-03	4.5	1.09e-03	6.3
25.0	4.75e-02	2.5	4.58e-02	2.3	2.68e-02	1.5	1.03e-02	2.0	4.35e-03	2.6	1.41e-03	3.4
55.0	1.52e-02	3.2	1.41e-02	2.5	1.20e-02	1.7	7.83e-03	1.2	4.57e-03	1.2	2.03e-03	1.7

Neutron Dose in Millirem from 10**14 neutrons

Height\	Radial Distance from DIIID axis of symmetry in meters											
	15.00		20.00		40.00		70.00		100.00		150.00	
(M)	mr	%dev.	mr	%dev.	mr	%dev.	mr	%dev.	mr	%dev.	mr	%dev.
1.7	2.15e+00	4.6	2.02e+00	3.8	1.00e+00	7.2	4.68e-01	5.5	2.34e-01	4.1	9.59e-02	6.4
4.4	1.86e+01	0.7	6.81e+00	1.3	1.07e+00	2.6	4.32e-01	2.9	2.25e-01	3.5	9.57e-02	4.1
6.8	2.03e+01	1.2	1.13e+01	1.6	1.40e+00	3.3	4.80e-01	4.1	2.55e-01	5.3	1.02e-01	7.0
8.7	1.69e+01	1.0	1.09e+01	1.2	1.89e+00	3.2	4.97e-01	3.2	2.50e-01	3.2	1.00e-01	5.2
15.0	9.11e+00	1.0	7.39e+00	0.8	2.57e+00	1.0	6.54e-01	1.4	2.77e-01	1.9	1.09e-01	3.0
25.0	3.85e+00	1.4	3.76e+00	1.5	2.18e+00	1.8	8.35e-01	1.7	3.42e-01	2.4	1.17e-01	2.2
55.0	1.29e+00	1.5	1.22e+00	1.3	9.97e-01	1.1	5.93e-01	0.8	3.40e-01	1.0	1.43e-01	1.4

Total Dose in Millirem from 10**14 neutrons

Height\	Radial Distance from DIIID axis of symmetry in meters											
	15.00		20.00		40.00		70.00		100.00		150.00	
(M)	mr	%dev.	mr	%dev.	mr	%dev.	mr	%dev.	mr	%dev.	mr	%dev.
1.7	2.20e+00	4.5	2.04e+00	3.8	1.01e+00	7.1	4.72e-01	5.5	2.36e-01	4.0	9.68e-02	6.4
4.4	1.88e+01	0.7	6.89e+00	1.3	1.08e+00	2.6	4.36e-01	2.9	2.27e-01	3.5	9.68e-02	4.1
6.8	2.05e+01	1.2	1.15e+01	1.5	1.42e+00	3.3	4.84e-01	4.1	2.57e-01	5.2	1.02e-01	7.0
8.7	1.71e+01	1.0	1.11e+01	1.2	1.91e+00	3.2	5.02e-01	3.2	2.52e-01	3.1	1.01e-01	5.1
15.0	9.22e+00	0.9	7.48e+00	0.8	2.60e+00	1.0	6.62e-01	1.4	2.80e-01	1.9	1.10e-01	2.9
25.0	3.90e+00	1.4	3.80e+00	1.4	2.21e+00	1.8	8.46e-01	1.7	3.47e-01	2.3	1.19e-01	2.2
55.0	1.30e+00	1.5	1.23e+00	1.2	1.01e+00	1.1	6.01e-01	0.8	3.44e-01	1.0	1.45e-01	1.4

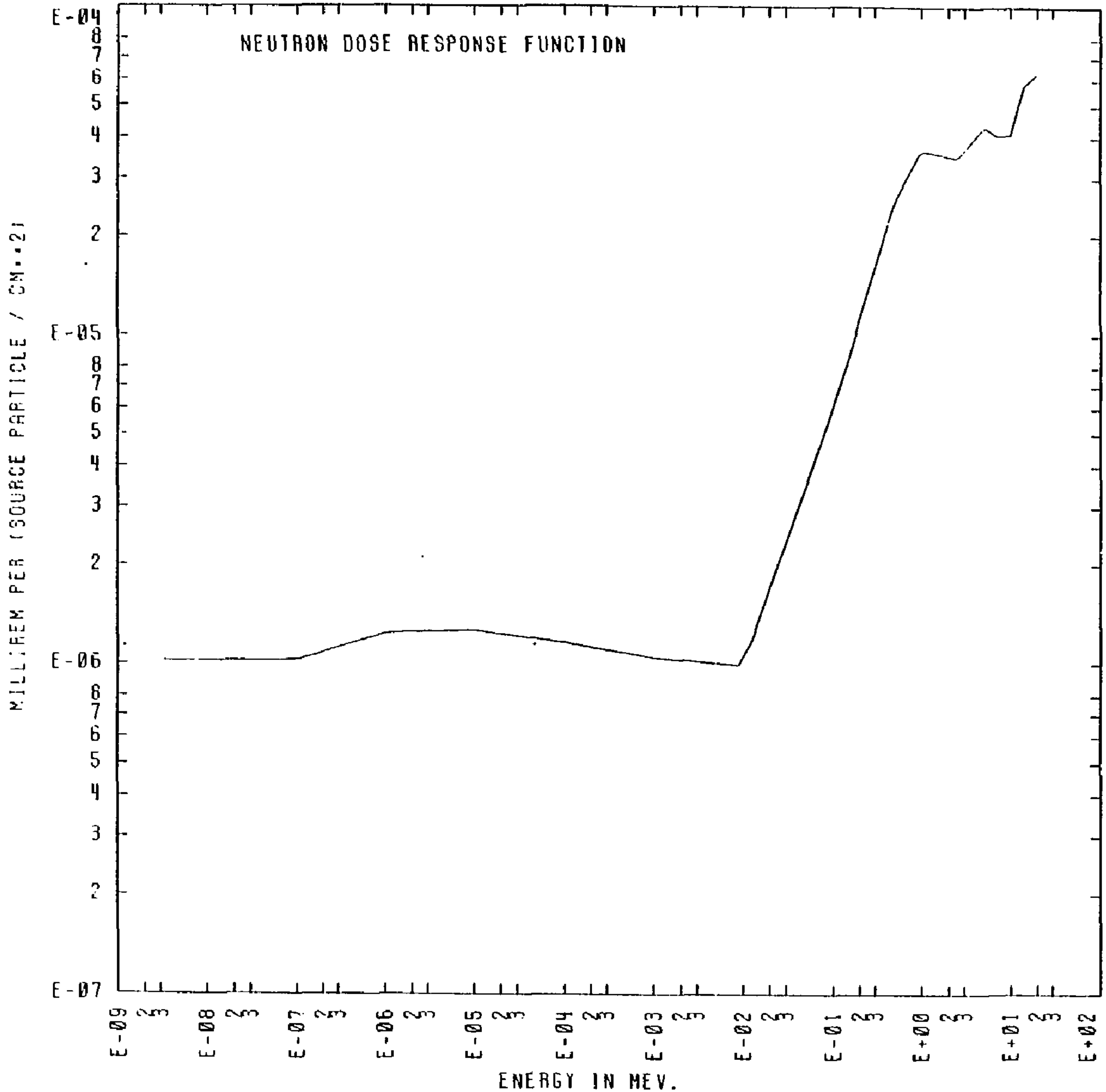

NEUTRON DOSE RESPONSE FUNCTION
MILLIREM PER (SOURCE PARTICLE / CM**2)
E-04
E-05
E-06
E-07
E-09
E-08
E-07
E-06
E-05
E-04
E-03
E-02
E-01
E+00
E+01
E+02
ENERGY IN MEV.

FIGURE 1

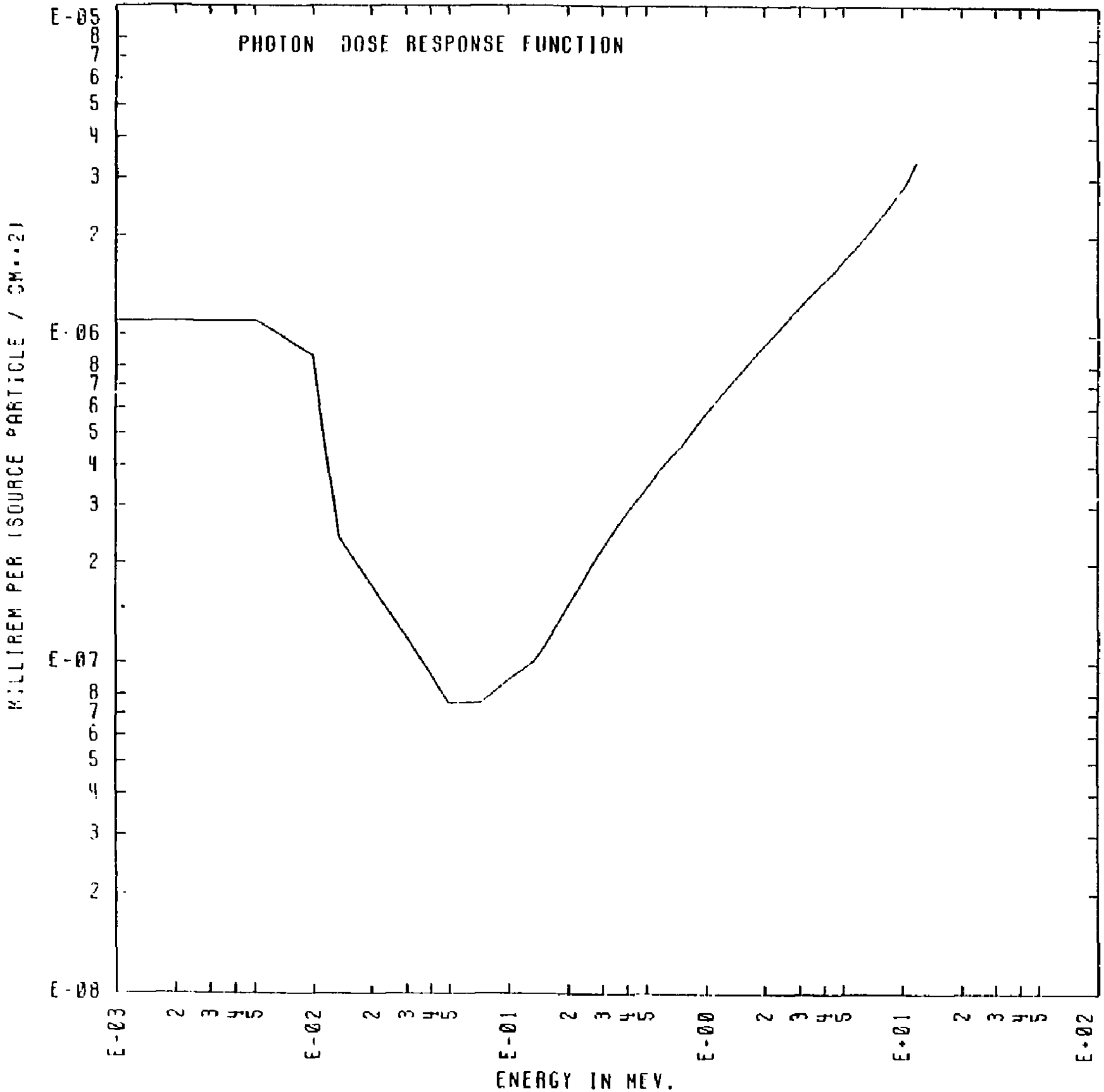
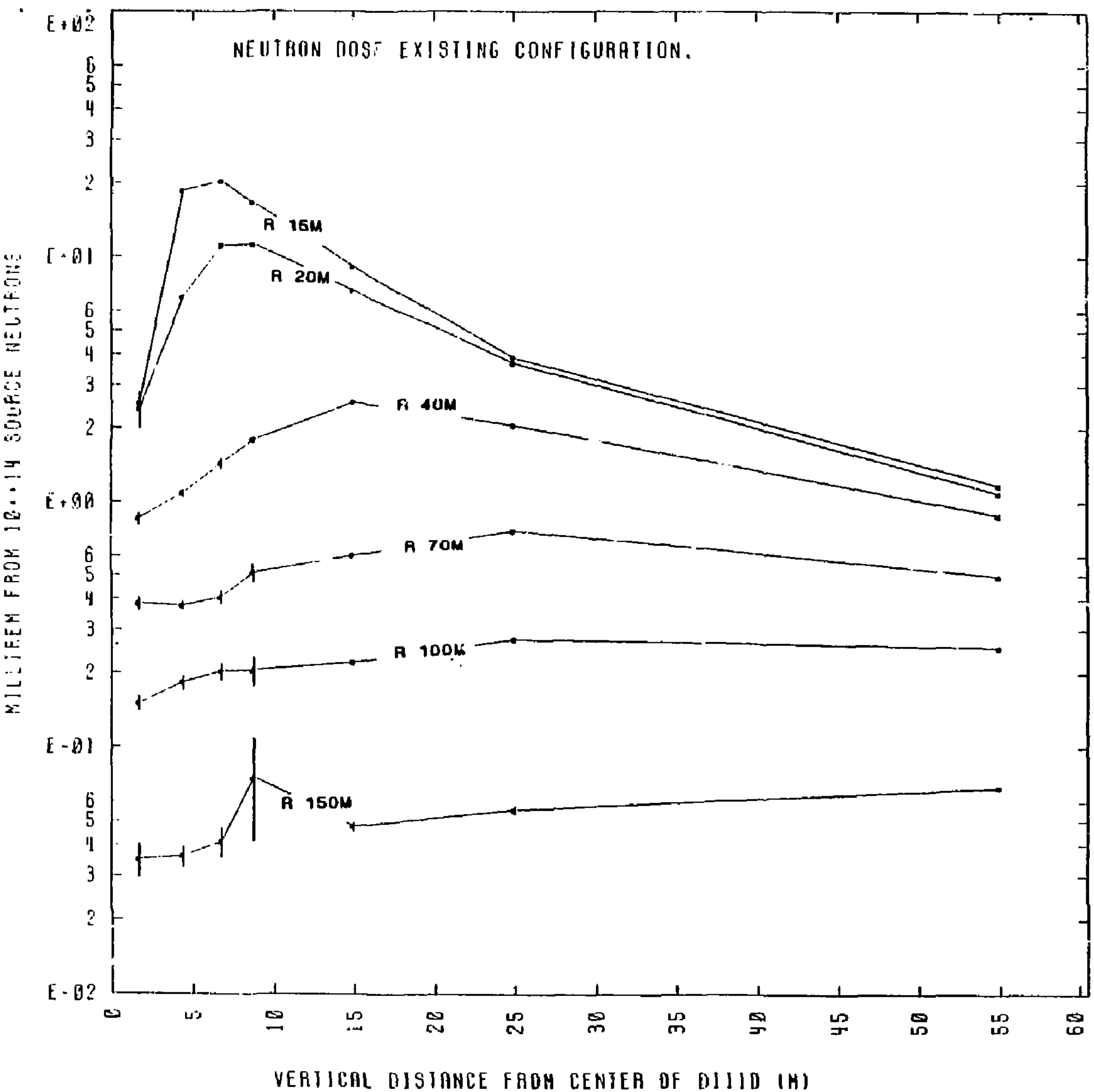
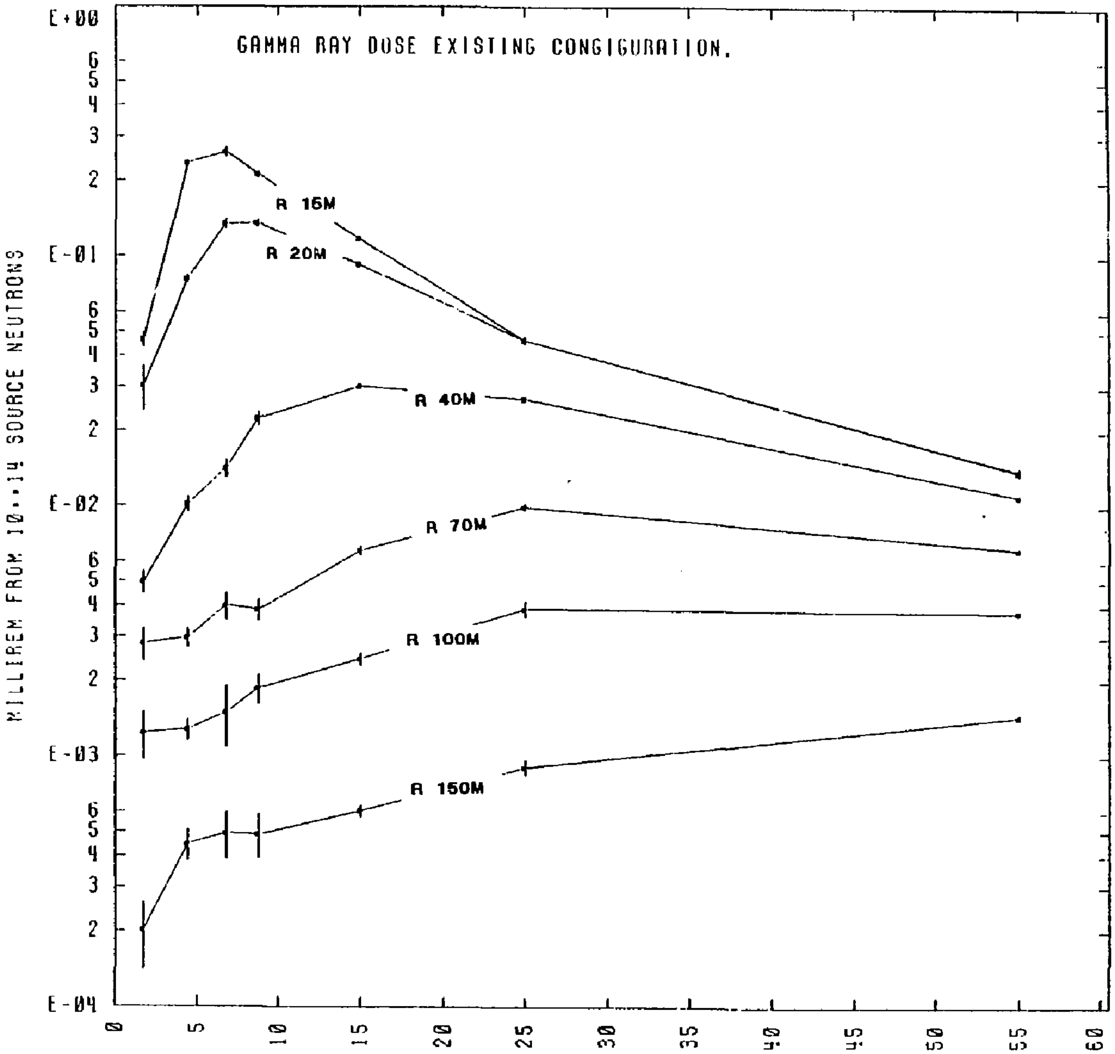

PHOTON DOSE RESPONSE FUNCTION
MILLIREM PER (SOURCE PARTICLE / CM**2)
ENERGY IN MEV.
E-05
E-06
E-07
E-08
E-03
E-02
E-01
E-00
E+01
E+02

FIGURE 2



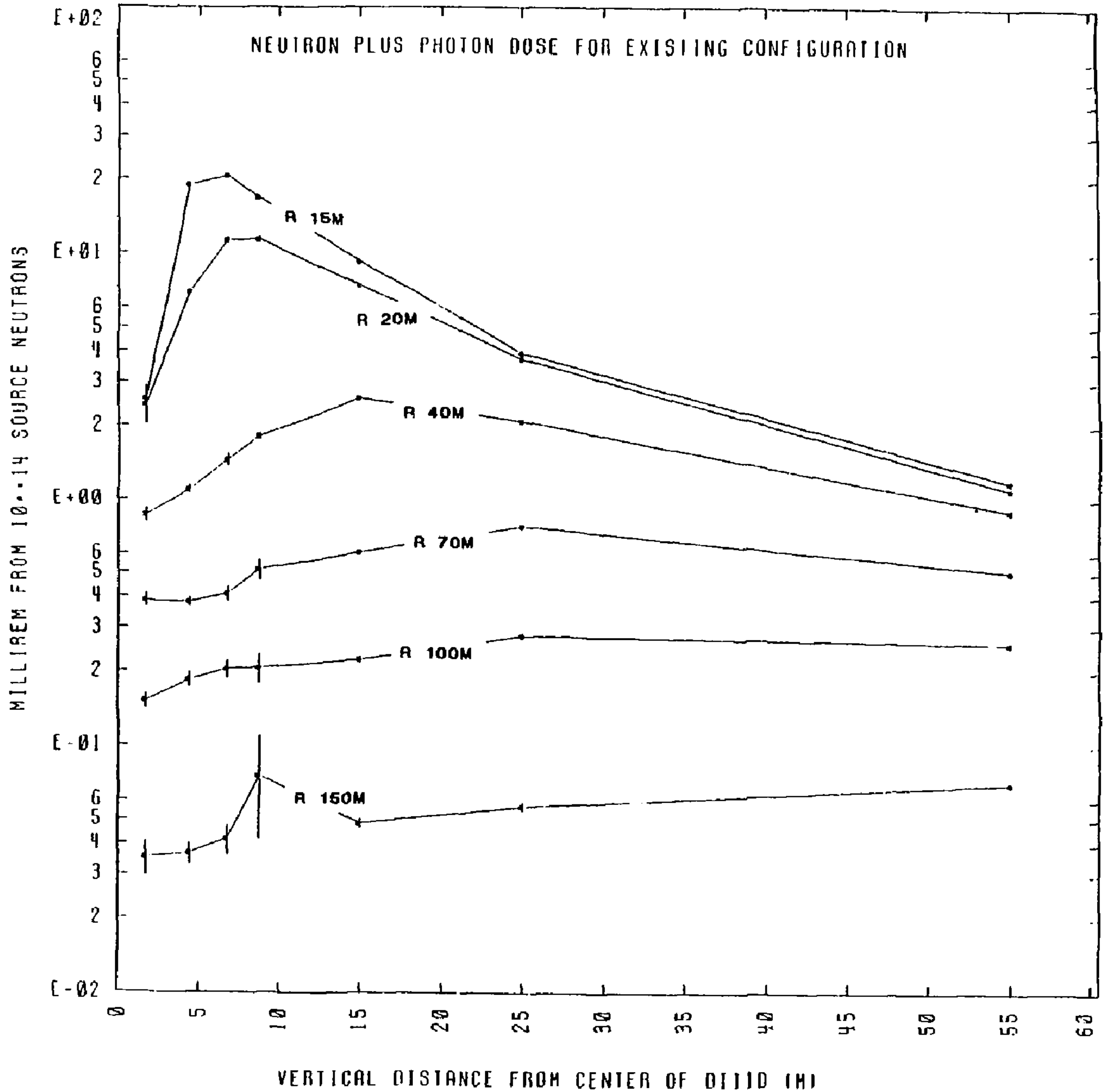
NEUTRON DOSE

FIGURE 3



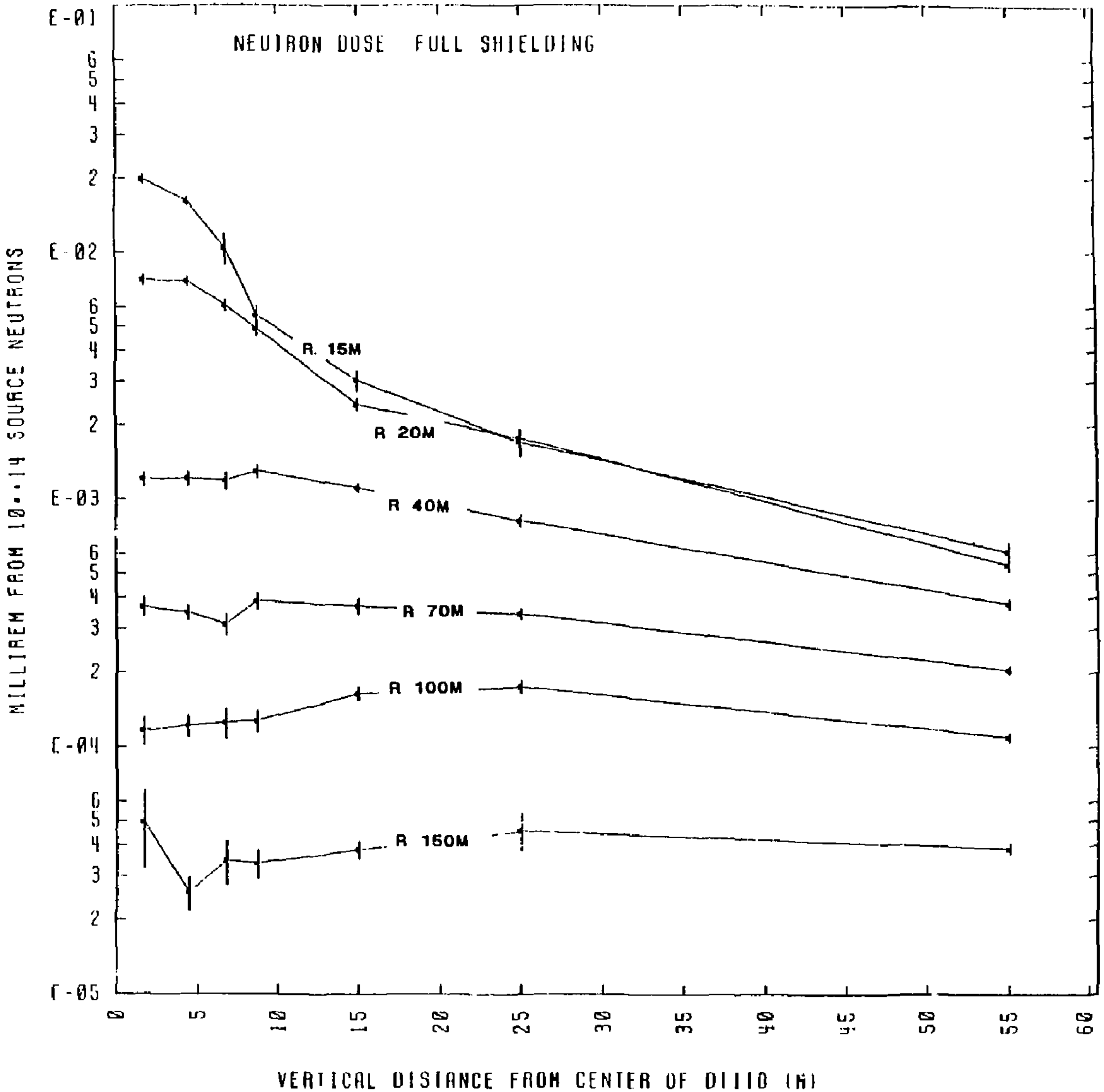
VERTICAL DISTANCE FROM CENTER OF DIIID (M)
PHOTON DOSE

FIGURE 4



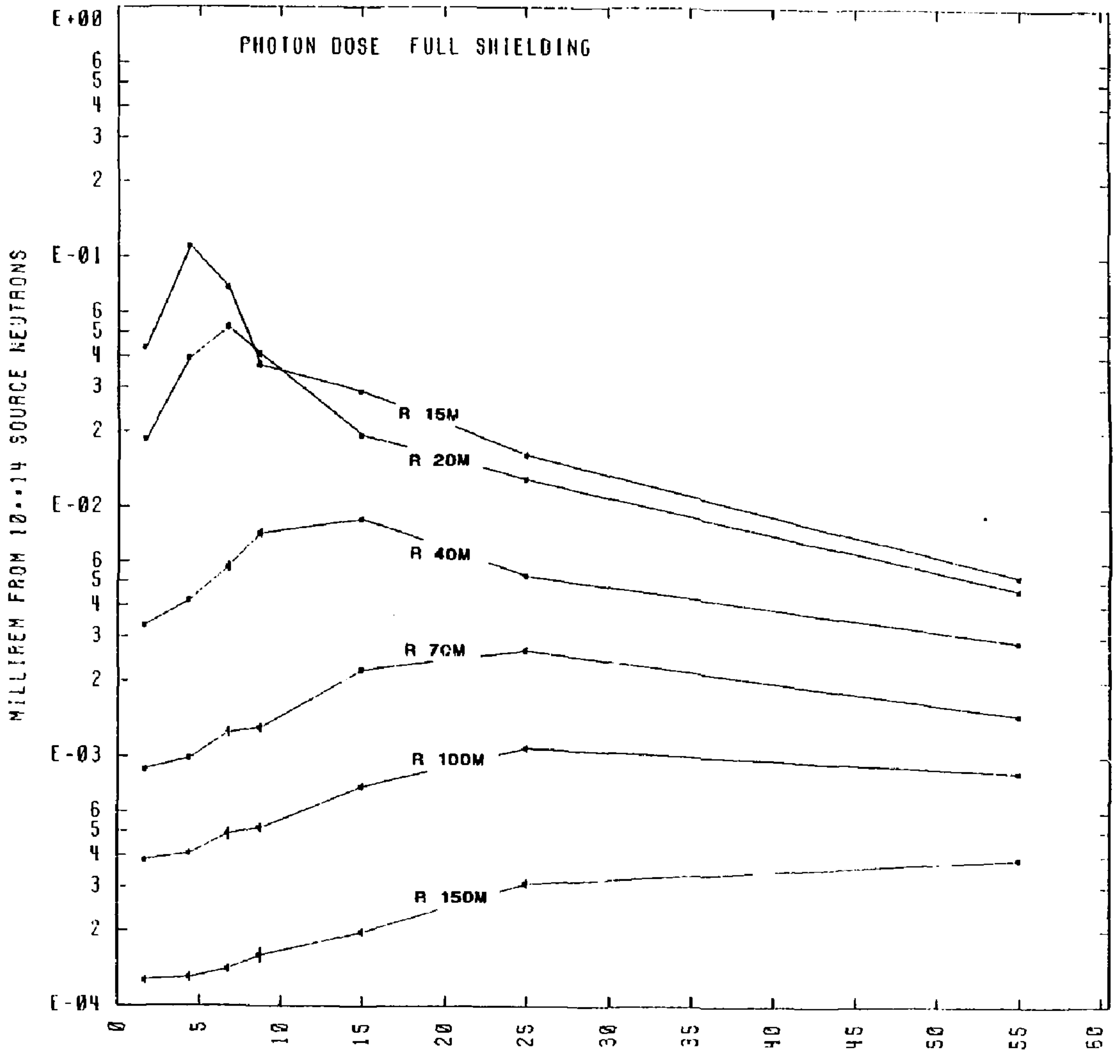
TOTAL DOSE

FIGURE 5



NEUTRON DOSE

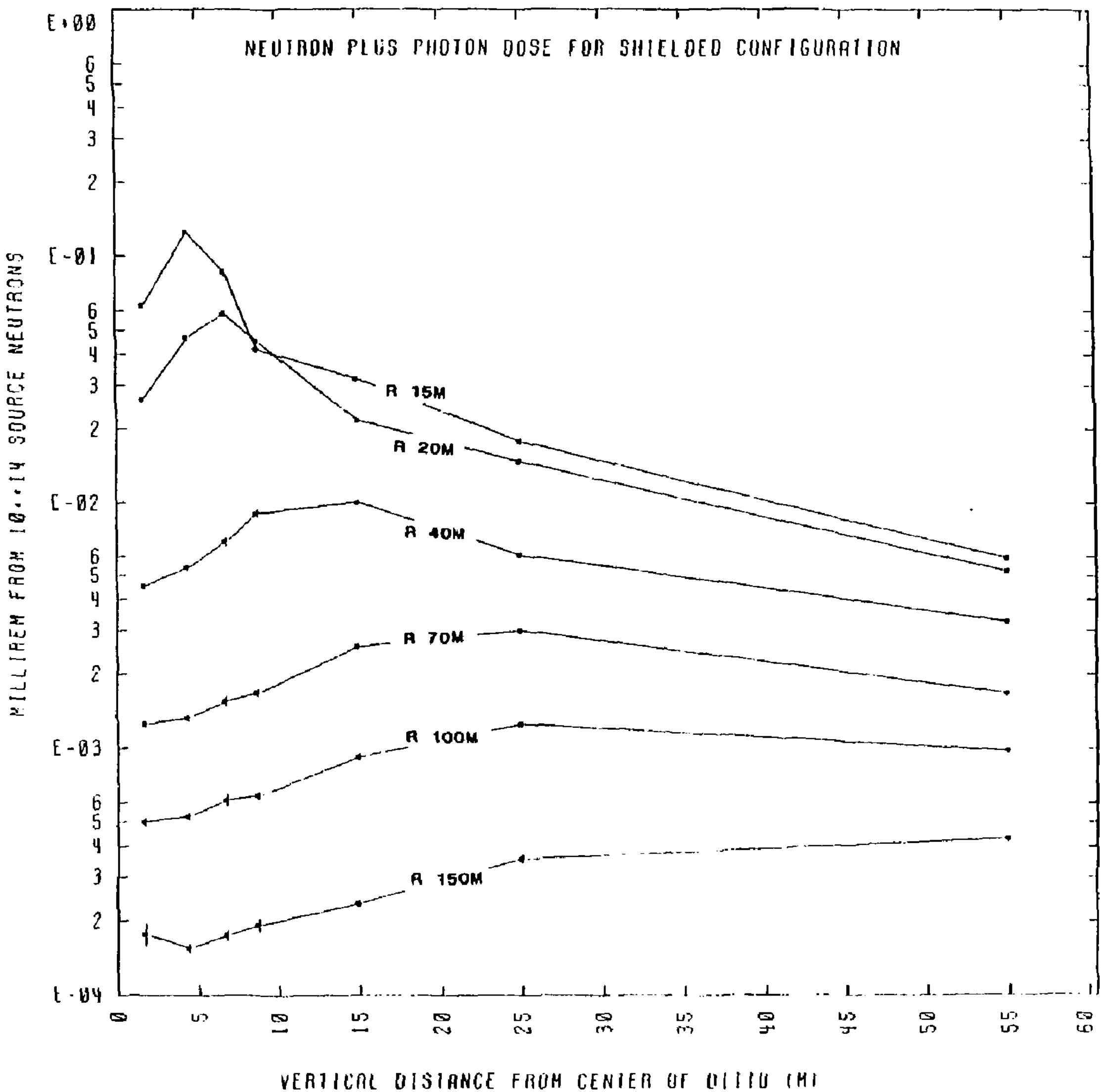
FIGURE 6



VERTICAL DISTANCE FROM CENTER OF DIIID (M)

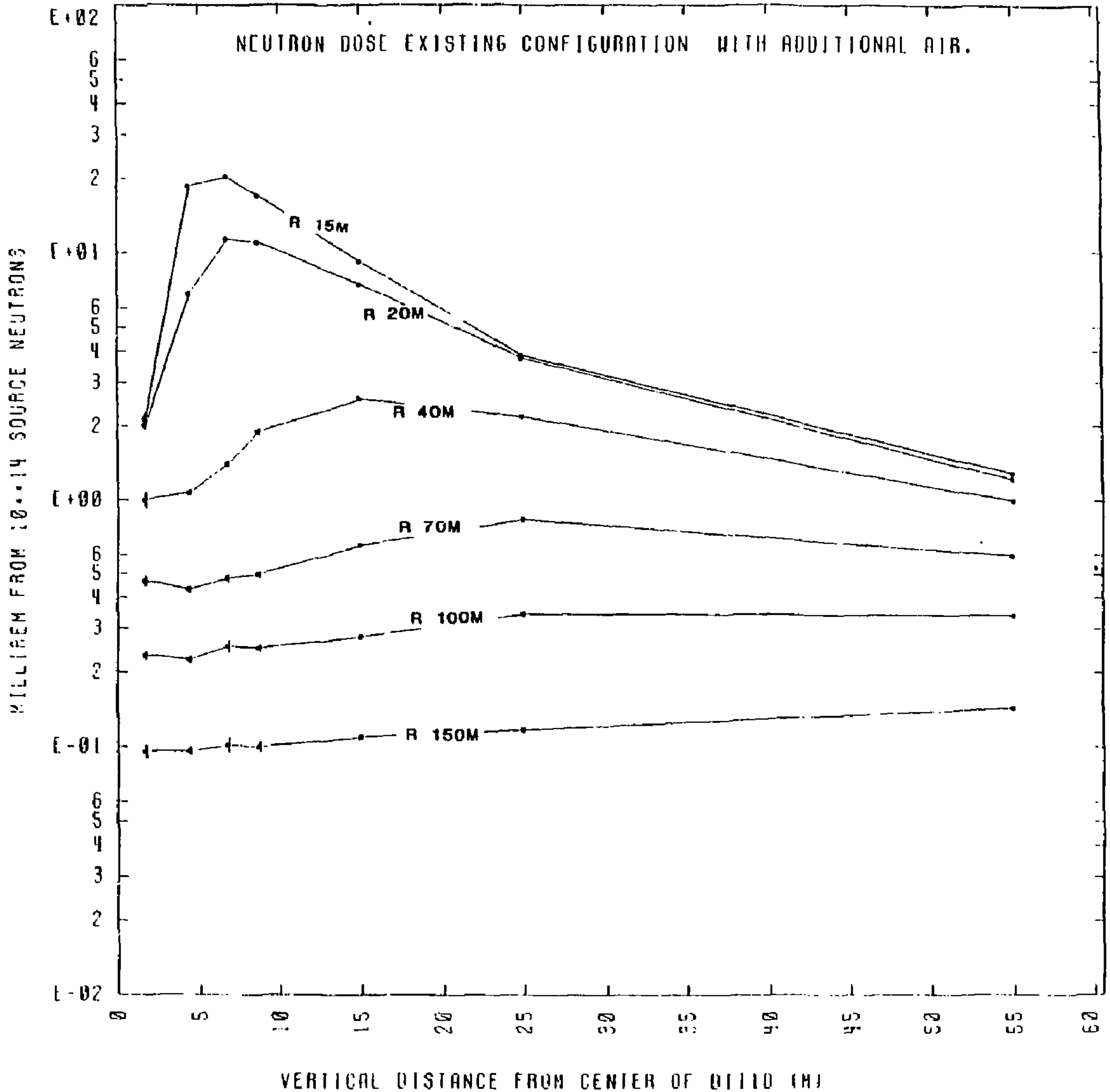
PHOTON DOSE

FIGURE 7



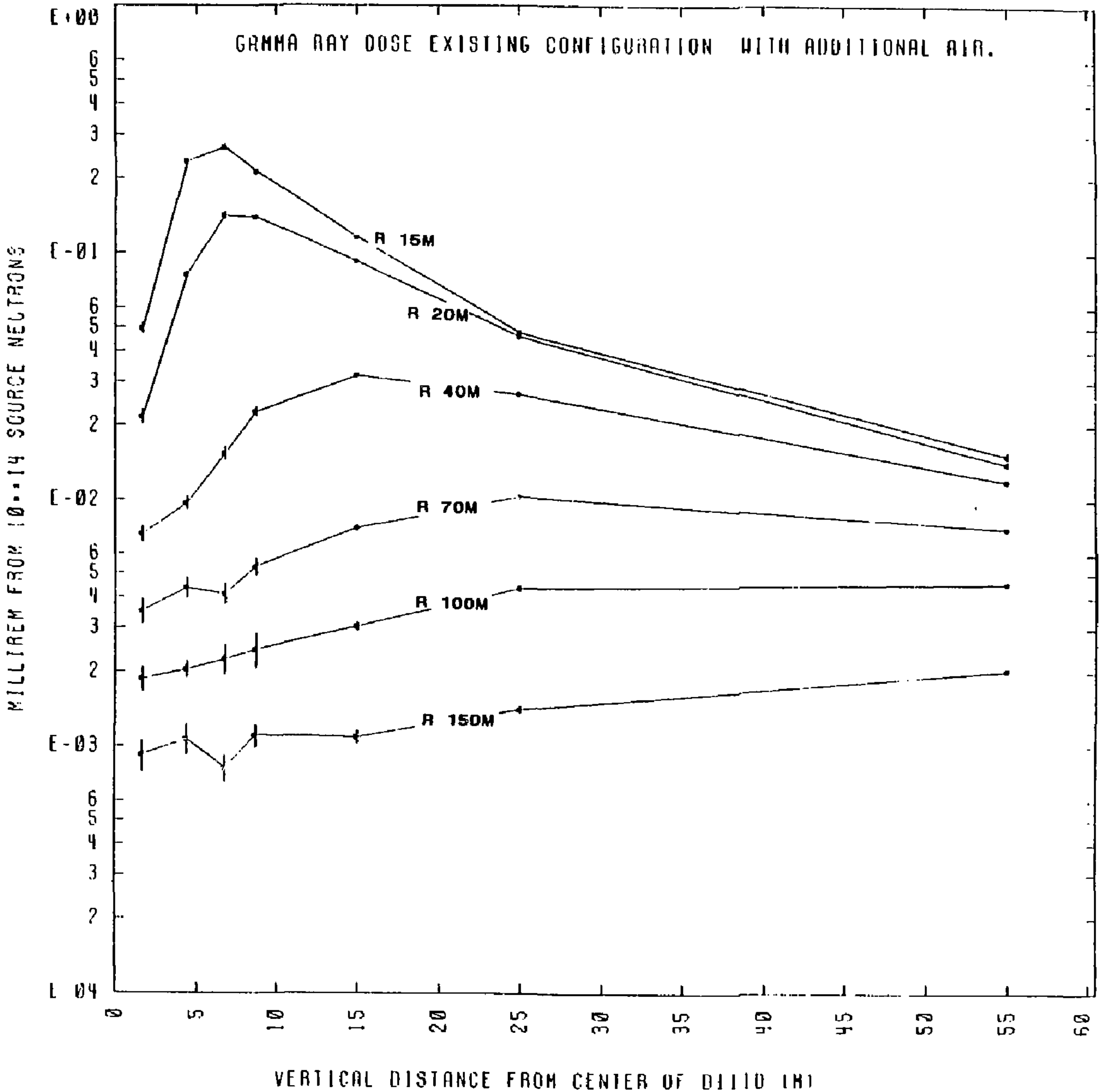
TOTAL DOSE

FIGURE 8

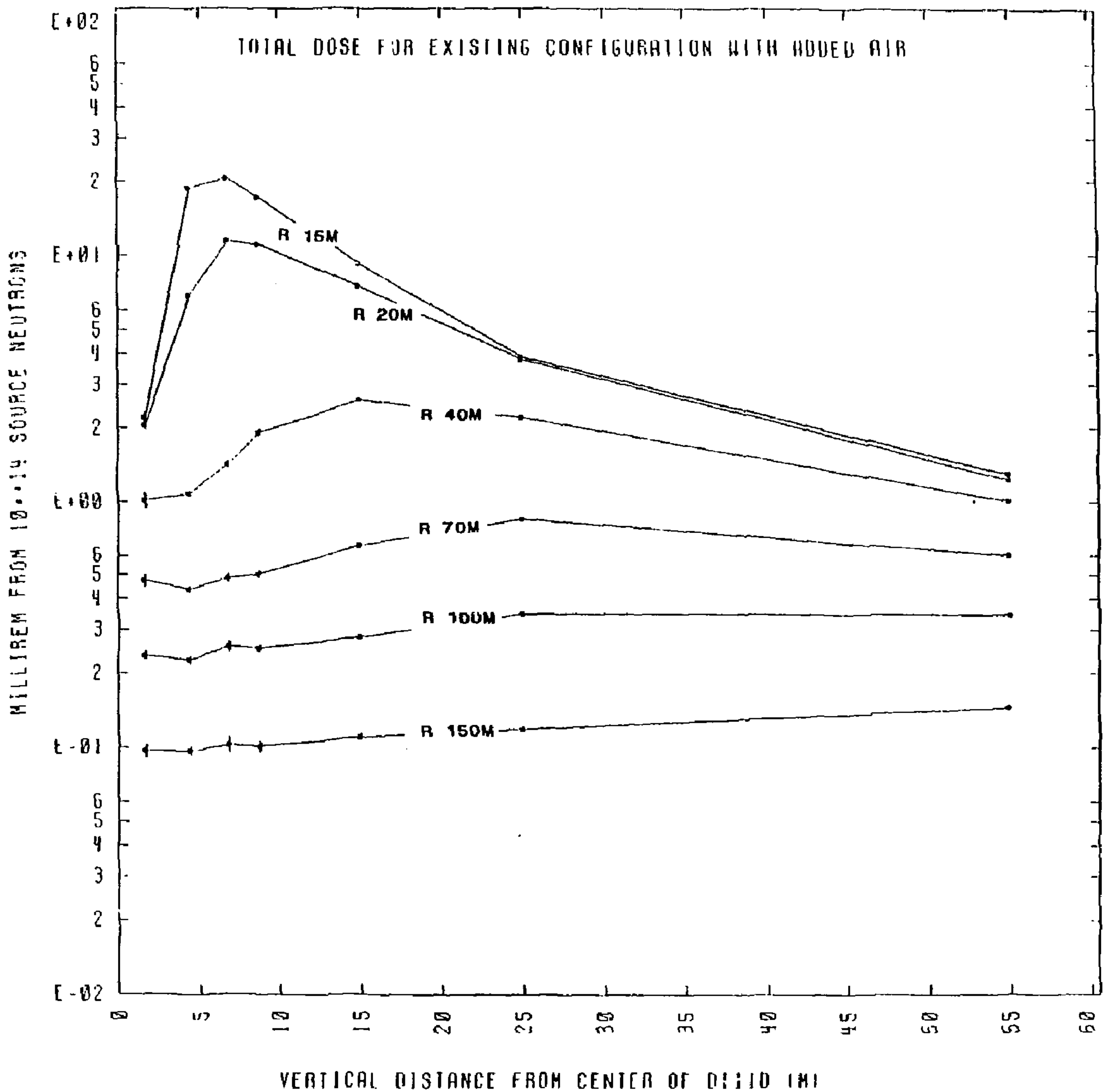


NEUTRON DOSE

FIGURE 9



PHOTON DOSE
FIGURE 10



TOTAL DOSE

FIGURE 11