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GAMMA SPECTRUM MEASUREMENTS

SNAP 8 RADIATION EFFECTS TEST PROGRAM

VOLUME I

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for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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FOREWORD

Gamma-ray spectra resulting from Radiation Effects Reactor fission gamma-rays and thermal neutron capture gamma-rays filtered by water and Lithium Hydride have been obtained.

This work, originally issued as Georgia Nuclear Report ER 7448, was done under subcontract for the Aerojet General Corporation (NASA Contract No. NAS 5-417) in support of the SNAP 8 Radiation Effects on Materials and Components Program. The contract and subcontract were under the technical management of H. O. Slone and A. W. Nice, respectively, of the NASA Lewis Research Center.

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1.0 SUMMARY

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The gamma spectra of the Radiation Effects Reactor was measured with three external shield configurations, i.e., 16 inches of Lithium Hydride, 16 inches of Lithium Hydride plus 8 inches of water, and 8 inches of water. These measurements were made with a collimated single crystal sodium iodide scintillator (4" x 5" diameter). Histogram photon and dose distributions were then computed by means of a 33 x 33 inversion matrix.

These measurements show considerable hardening of the basic reactor spectrum, i.e., the U-235 fission spectrum plus capture gammas from the reactor coolant and structural materials. Data reveals that Lithium Hydride is not unique in shaping the resultant filtered spectra, but instead demonstrates effects similar to those produced by water. The measured dose distribution shows qualitative agreement with the calculated SNAP-8 environment.

Author

2.0 INTRODUCTION

The essentially unperturbed fission gamma-ray spectrum has been measured by several investigators in the past.[1] Unshielded reactor gamma-ray spectra have also been measured, with these spectra differing from the fission spectra by the addition of gamma-rays arising from thermal neutron capture in the reactor coolant and structural materials.[2] When intervening reactor test specimen shielding is used, the fission spectrum becomes modified further. In general, shielding tends to harden the fission spectrum with the degree of hardening being a function of the shield type and thickness.

The GNL Radiation Effects Reactor is a light water moderated unshielded reactor with MTR type fuel elements. External reactor shielding is added at will to obtain the gamma-ray spectra and neutron to gamma flux ratios desired for individual irradiation experiments.

The present Aerojet program involves the determination of radiation damage parameters of selected materials and components. In order to simulate SNAP-8 radiation environment, it has been necessary to utilize a 16-inch thick Lithium Hydride shield with the RER.

Of prime concern was the degree of radiation quality simulation; specifically, a knowledge of resultant gamma-ray spectra obtained by filtering the RER gamma-ray spectrum through the Lithium Hydride shield and the Lithium Hydride shield plus 8 inches of light water. This report discusses experimental procedures, data reduction techniques, and the results of the experiment designed to measure these resulting gamma-ray spectra.

3.0 EXPERIMENTAL PROCEDURE

Spectra were measured with Lithium Hydride, Lithium Hydride plus 8 inches water, and 8 inches water only with a collimated four-inch thick by five-inch diameter sodium iodide single crystal spectrometer located approximately 400 feet from the RER. Air and ground scattering were minimized by collimation. Pulse height distributions were unscrambled by use of a 33 x 33 response matrix extended from the J. H. Hubbell matrix.[3] Matrix inversion was done on the IBM 7090 computer. The inverted response matrix is given in Table 1.

The shield-collimator assembly is shown in Figures 1 and 2. The front face shield thickness was designed so that ninety-nine percent of the total gamma-ray flux impingent on the crystal face must pass through the collimator hole when a 1 cm^2 cross sectional area collimator hole is used. Wall thickness was designed to present approximately 4 tenth value layers to 90^o scattered radiation. The shield-collimator assembly weighed 6000 pounds and was positioned in the center of a test car. After arriving at the RER facility with the experimental apparatus, the collimator was "bore" sighted on the RER core center. Figure 3 shows the RER with and without the Lithium Hydride shield in place. The 8-inch water tank is an integral part of the RER and is easily drained. To minimize the effects of thermal neutrons on the NaI(TL) crystal, the crystal was surrounded by approximately 2 cm of Li_2CO_3 (Figure 1) and a sheet of 0.020 inch cadmium was placed across the shield face.

During the preparation phase of the experiment, it was observed that thermal neutron produced I^{128} activity ($T_{1/2}$ = 25 min.), thereby giving a beta particle interference pulse height spectrum up to about 2 MeV. This problem was eliminated with the above mentioned techniques.

The four-inch thick by five-inch diameter NaI(TL) crystal was used in conjunction with an RCA 8055 photomultiplier tube and a cathode follower type preamplifier. Photo-tube high voltage and preamplifier power was provided by power supplies located on the test car. There was approximately 700 feet of RG-62 coaxial cable between the preamplifier and the A-61 linear amplifier; however, pulse distortion was shown to be negligible. Pulse height data were collected on an RCL Model 20611, 256 channel pulse height analyzer utilizing automatic background subtraction and automatic dead time correction.

The RER was loaded with a "cold" core, and a 15 curie Pu-Be start-up source. It was operated at a power level of 200 watts; the level at which fission gamma-rays and thermal neutron capture gamma-rays were about 90% of the total gamma field. Background was primarily contributed by previously activated reactor structure, and was in general below 2 MeV. Reactor run times were only about 15 minutes, so fission product gamma-ray contributions were small. Several reactor-to-spectrometer distances were tried, and it was found that a distance of 400 feet was adequate to keep down excessive dead times. Background subtraction was performed on the multichannel analyzer with the RER at zero power level.

Since the fast neutron to gamma-ray flux ratio was not known behind the Lithium Hydride and water shielding, the appropriate collimator hole size was not determined until the first reactor run was made. It was found that the fast neutron response of the spectrometer was excessive with the 1 cm^2 collimator hole discussed previously, when minimum reactor shielding (8 inch water) was used. In determining the proper collimator hole size, the criterion was established that the fast neutron response should be less than 5 percent of the total spectrometer response under all reactor shielding conditions. This requirement was verified by obtaining collimator to solid lead plug (Figure 1) total count ratios for several collimator hole sizes with the RER operating at the 200 watt power level. This ratio was obtained with each of the three reactor shielding configurations. Optimum collimator hole size was determined to be 11.4 cm^2, which was used throughout the remainder of the experiment.

Spectrometer calibration and linearity verification was accomplished with the following mono-energetic gamma-rays:

Cs^{137}	- 0.661 MeV
Co^{60}	- 1.17, 1.33 MeV
Hydrogen capture gamma-ray	- 2.23 MeV
Gamma-ray from C^{12} (Pu-Be Source)	- 4.43 MeV
N^{16}	- 6.13 MeV
Fe^{56} capture gamma-ray	- 7.639 MeV

The N^{16} gamma-ray was seen in the primary coolant (water) lines leading to the RER fission product monitoring system located near the reactor control room. The spectrometer was completely remote from the RER for this part of the experiment. Since it was necessary to operate the RER at 1 MW to get adequate N^{16} activity, and thus generate a "hot" reactor core, this calibration point was the final data collected.

The iron capture gamma-ray was seen by placing three 15 curie Pu-Be neutron sources in water near a 40 pound ingot of iron. The 7.639 MeV gamma-ray intensity was low, but sufficient statistical counting accuracy was obtained in 1 hour count times.

The 2.23 MeV hydrogen capture gamma-ray was seen in all of the RER spectra taken. It originates from thermal neutron capture by hydrogen in the RER primary coolant water and in the water shielding. This mono-energetic gamma-ray served an additional important purpose in providing a check on pulse height stability during RER pulse height data accumulation. Figure 4 shows the linearity of spectrometer response with gamma-ray energy.

4.0 RESULTS

Figures 5, 6 and 7 show the pulse height energy spectra, the unscrambled gamma-ray photon energy spectra, and the gamma-ray dose energy spectra for each of the three reactor shielding configurations. The dose energy spectra were obtained by multiplication of photon energy spectra by the roentgen per photon flux dose conversion curve [4] normalized to unity at 0.5 MeV. The noticeable high energy peaks in the pulse height energy spectra are attributed to the following sources:

Ni^{58} capture gamma-ray - 8.99 MeV - reactor structure
Ni^{58} capture gamma-ray single escape - 8.48 MeV
Al^{27} capture gamma-ray - 7.22 MeV - reactor structure
Fe^{56} capture gamma-ray - 7.639 MeV - reactor structure
Al^{27} capture gamma-ray single escape - 7.21 MeV
Fe^{56} capture gamma-ray single escape - 7.13 MeV

The degree of spectral hardening with increasing shield thickness is striking. Data reveals that Lithium Hydride is not unique in shaping the resultant filter spectra, but instead demonstrates effects similar to those produced by water. Figures 8, 9 and 10 present the gamma-ray dose energy spectra in a different form; i.e., the percent of total gamma-ray dose contributed by each MeV interval versus gamma-ray energy for the three reactor shielding configurations. Figure 11 is a similar histogram, obtained from calculations, of the energy distribution of the shielded SNAP-8 reactor. These calculations were furnished by Atomics International. These data are in reasonable agreement with experimental data taken at the RER.

REFERENCES

(1) Gamble, R. L., "Prompt Fission Gamma-Rays from Uranium 235, " Doctoral Thesis, University of Texas, June 1955.

(2) Chapman, G. T., et. al., "Preliminary Report on the Measured Gamma-Ray Spectra from a Stainless Steel Reactor, " ORNL-3360, Annual Progress Report for Period Ending September 1, 1962.

(3) Hubbell, J. H., "Response of a Large Sodium-Iodide Detector to High Energy X-Rays, " The Review of Scientific Instruments, Vol. 29, January 1958.

(4) Hine, G. J. and Brownell, G. L., "Radiation Dosimetry, "Academic Press, 1956, p. 88.

ANALYZER PULSE HEIGHT DISTRIBUTION (MeV)																	True Photon Distribution (MeV)
0.01	0.04	0.09	0.16	0.25	0.36	0.49	0.64	0.81	1.00	1.21	1.44	1.69	1.96	2.25	2.56	2.89	
1000.0	0.0	-5.1	-.9	-2.1	-3.1	-4.4	-7.3	-9.1	-7.5	-5.7	-3.9	-1.9	-0.1	-1.5	-2.0	1.4	0.005
	1000.0	-5.1	-.9	-3.1	-6.4	-12.5	-17.1	-20.9	-16.1	-16.7	-10.3	-9.3	-8.0	-9.7	-3.6	-3.3	0.025
		1010.1	-18.6	-1.2	-9.4	-21.8	-25.4	-29.6	-32.5	-24.4	-16.5	-13.8	-13.9	-9.8	-6.1	-2.9	0.065
			1020.4	-51.8	-27.6	-26.3	-33.3	-34.9	-32.8	-32.0	-21.7	-17.0	-12.4	-10.4	-11.0	-3.1	0.125
				1058.2	-58.5	-46.9	-46.4	-45.3	-41.8	-36.9	-26.9	-19.9	-16.4	-14.8	-12.1	-5.4	0.205
					1106.2	-73.0	-71.7	-63.9	-56.5	-49.6	-42.3	-25.2	-13.9	-20.0	-8.9	-9.5	0.305
						1200.5	-107.8	-105.5	-83.3	-65.2	-55.9	-41.1	-24.3	-12.7	-20.9	-8.2	0.425
							1360.5	-171.4	-143.6	-101.4	-70.2	-60.7	-36.6	-19.3	-17.7	-13.9	0.565
								1574.8	-262.9	-187.5	-114.4	-67.8	-57.9	-46.8	-28.1	-22.7	0.725
									1834.8	-387.9	-217.7	-123.7	-65.3	-61.7	-41.8	-28.1	0.905
										2114.2	-536.1	-243.8	-129.6	-62.2	-64.8	-48.7	1.105
											2392.3	-708.8	-245.8	-119.1	-63.7	-56.7	1.325
												2645.5	-920.2	-238.7	-101.5	-67.6	1.565
													2898.6	-1123.2	-193.7	-88.1	1.825
														3125.0	-1388.9	-126.6	2.105
															3367.0	-1689.6	2.405
																3610.1	2.725
																	3.065
																	3.425
																	3.805
																	4.205
																	4.635
																	5.085
																	5.555
																	6.045
																	6.555
																	7.085
																	7.565
																	8.125
																	8.705
																	9.305
																	9.925
																	10.565

ANALYZER PULSE HEIGHT DISTRIBUTION (MeV) (Continued)																True Photon Distribution (MeV)
3.24	3.61	4.00	4.41	4.84	5.29	5.76	6.25	6.76	7.29	7.84	8.41	9.00	9.61	10.24	10.89	
-0.6	-0.8	3.2	-0.1	0.8	0.2	0.3	0.3	0.2	0.2	0.1	0.1	0.1	0.1	0.0	0.1	0.005
+2.1	-2.8	5.6	-1.3	0.4	3.7	-0.3	1.8	0.1	1.0	0.3	0.6	0.3	0.6	-0.1	0.3	0.025
+0.5	-0.9	0.7	1.3	-1.7	+3.4	-1.6	0.9	-1.1	-0.3	-0.8	4.1	-1.0	3.4	-1.9	1.7	0.065
-5.6	-0.6	2.3	0.0	-2.3	2.2	-3.0	-0.1	-2.4	3.5	-2.2	0.8	3.5	-0.2	1.1	0.2	0.125
-4.0	-6.2	0.3	-2.9	-0.5	0.2	1.2	-1.4	-1.1	-1.7	-1.5	3.1	-2.1	6.9	-2.9	3.0	0.205
-11.1	-2.8	-4.4	-2.8	-2.3	-1.0	0.1	-2.8	2.9	-3.2	-0.1	-2.3	4.0	-3.4	7.1	-2.4	0.305
-10.1	-2.4	-7.0	-6.8	0.1	-3.4	-0.5	1.2	-3.9	-1.9	2.5	-3.1	-0.3	2.1	-0.5	5.4	0.425
-9.1	-9.9	+1.1	-8.9	2.1	-10.6	-0.3	-1.3	1.0	-4.8	-1.5	2.6	-3.4	0.6	2.8	-1.6	0.565
-13.3	+2.9	-19.4	0.6	-11.2	1.9	-5.3	-4.8	8.6	-9.3	1.3	-5.6	5.8	-7.8	2.9	2.6	0.725
-20.9	-7.27	-7.0	-19.9	4.9	-2.9	-12.7	3.2	-11.9	11.8	-11.4	1.9	-6.7	7.8	-7.6	1.3	0.905
-30.7	-16.1	-18.1	-4.4	-6.3	-12.1	-0.5	-13.0	3.3	-4.5	4.6	-8.0	-1.0	-8.8	10.2	-9.3	1.105
-32.3	-45.3	-8.2	-11.4	-22.1	8.1	-8.3	-11.1	-10.7	-2.6	0.0	1.6	-7.4	-1.7	-6.3	7.9	1.325
-38.9	-37.3	-24.2	-21.3	-5.2	-22.4	-7.6	4.7	-22.8	8.3	-20.2	10.6	-5.2	-0.1	-9.4	-2.2	1.565
-76.4	-26.6	-46.9	-9.8	-30.0	-17.2	-1.5	-26.4	6.0	-22.9	4.2	-17.2	9.2	-11.3	1.0	-8.5	1.825
-99.4	-80.6	18.9	-40.6	-21.7	-10.8	-25.5	-9.0	6.7	-28.6	11.9	-25.0	-0.7	-11.6	11.8	-16.8	2.105
-28.9	-94.0	-89.7	53.2	-57.5	-21.5	3.8	-27.0	-15.4	-5.5	-15.9	4.3	-21.8	-1.4	-1.2	1.1	2.405
-2041.1	140.5	-133.8	-58.1	42.3	-30.6	-18.6	-11.4	-20.8	12.0	-36.0	-0.3	-5.9	-17.7	-6.5	2.8	2.725
3846.2	-2405.8	332.2	-221.4	-2.4	33.3	-37.9	-12.1	-8.4	-26.1	14.9	-39.4	1.9	-22.6	-2.1	-15.1	3.065
	3984.0	-2743.1	674.6	-415.7	83.3	-13.3	-16.2	-20.4	-5.2	-5.6	-6.7	-27.6	-7.7	0.1	-23.7	3.425
		4098.4	-3170.1	1069.3	-627.9	212.9	-63.3	-24.5	7.2	-38.2	20.5	-23.1	-8.9	-18.1	6.0	3.805
			4273.5	-3592.8	1436.4	-868.7	365.3	-211.4	82.9	-81.2	30.4	-18.4	14.4	-44.9	8.7	4.205
				4424.8	-3926.5	1864.7	-1215.2	671.7	-452.7	227.5	-170.9	85.2	-122.6	92.3	-85.3	4.635
					4504.5	-4254.3	2148.5	-1411.8	803.7	-558.0	309.4	-217.7	241.6	-197.3	105.5	5.085
						4629.6	-4416.3	2394.9	-1615.7	958.0	-672.4	376.2	-534.1	416.7	-243.5	5.555
							4608.3	-4608.3	2630.2	-1728.8	1017.3	-708.9	812.4	-692.0	386.6	6.045
								4694.8	-4739.1	2677.3	-1739.1	1026.0	-1416.6	1114.4	-679.6	6.555
									4717.0	-4761.0	2689.5	-1747.1	2116.6	-1813.7	1026.7	7.085
										4672.9	-4716.6	2664.4	-3635.0	2943.1	-1796.8	7.565
											4672.9	-4716.6	4551.0	-3635.0	2096.8	8.125
												4672.9	-4716.6	2664.4	-1730.8	8.705
													4672.9	-4716.6	2664.4	9.305
														4672.9	-4716.6	9.925
															4672.9	10.565

TABLE I - INVERTED RESPONSE MATRIX FOR COLLIMATED 4" X 5" DIAMETER NaI (TL) SCINTILLATOR

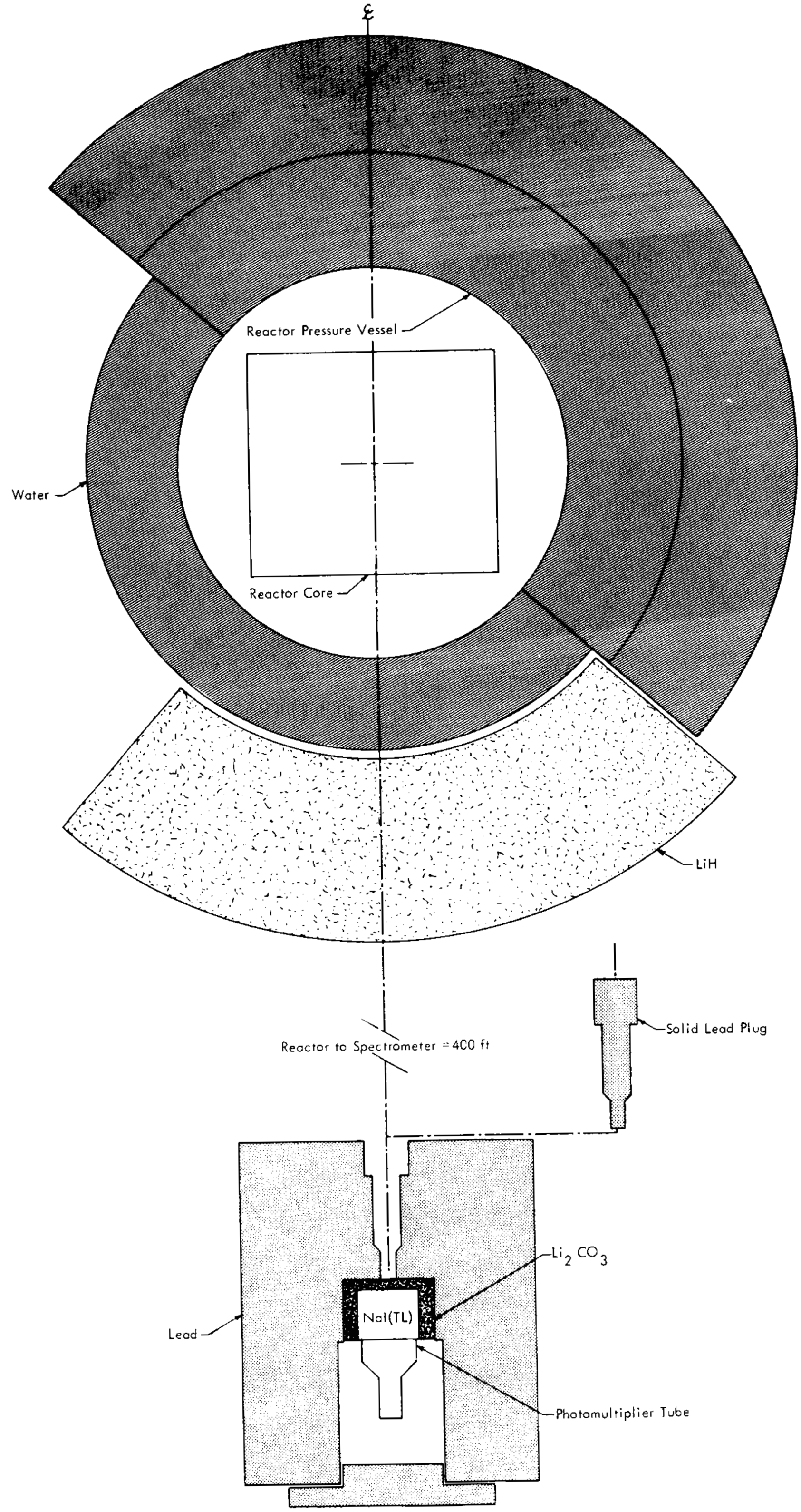
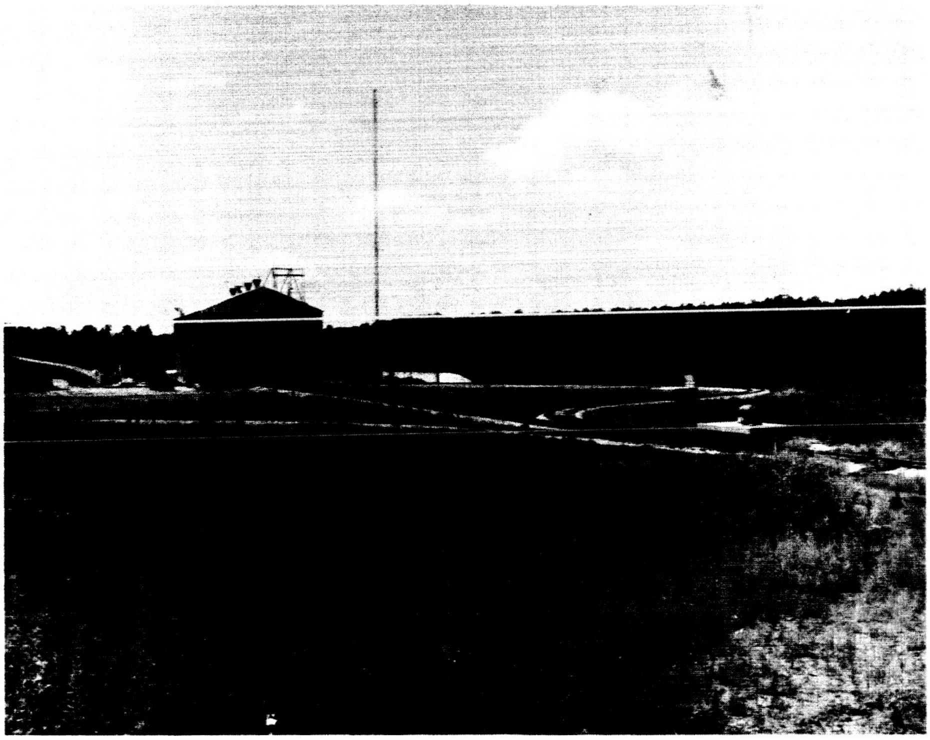


FIGURE 1 - SPECTROMETER ASSEMBLY



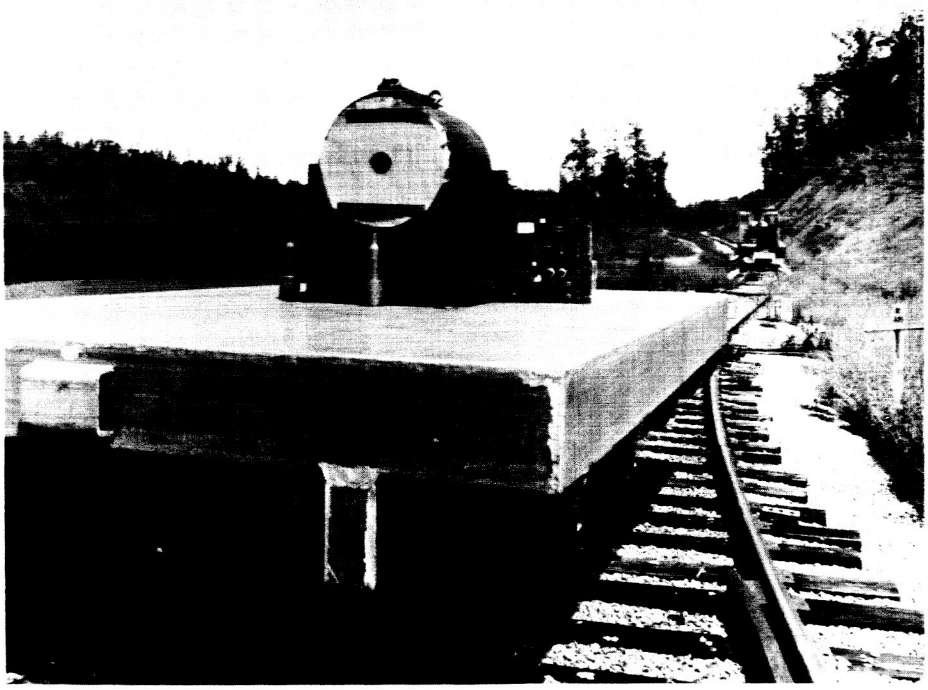


FIGURE 2 - SPECTROMETER ON TEST CAR

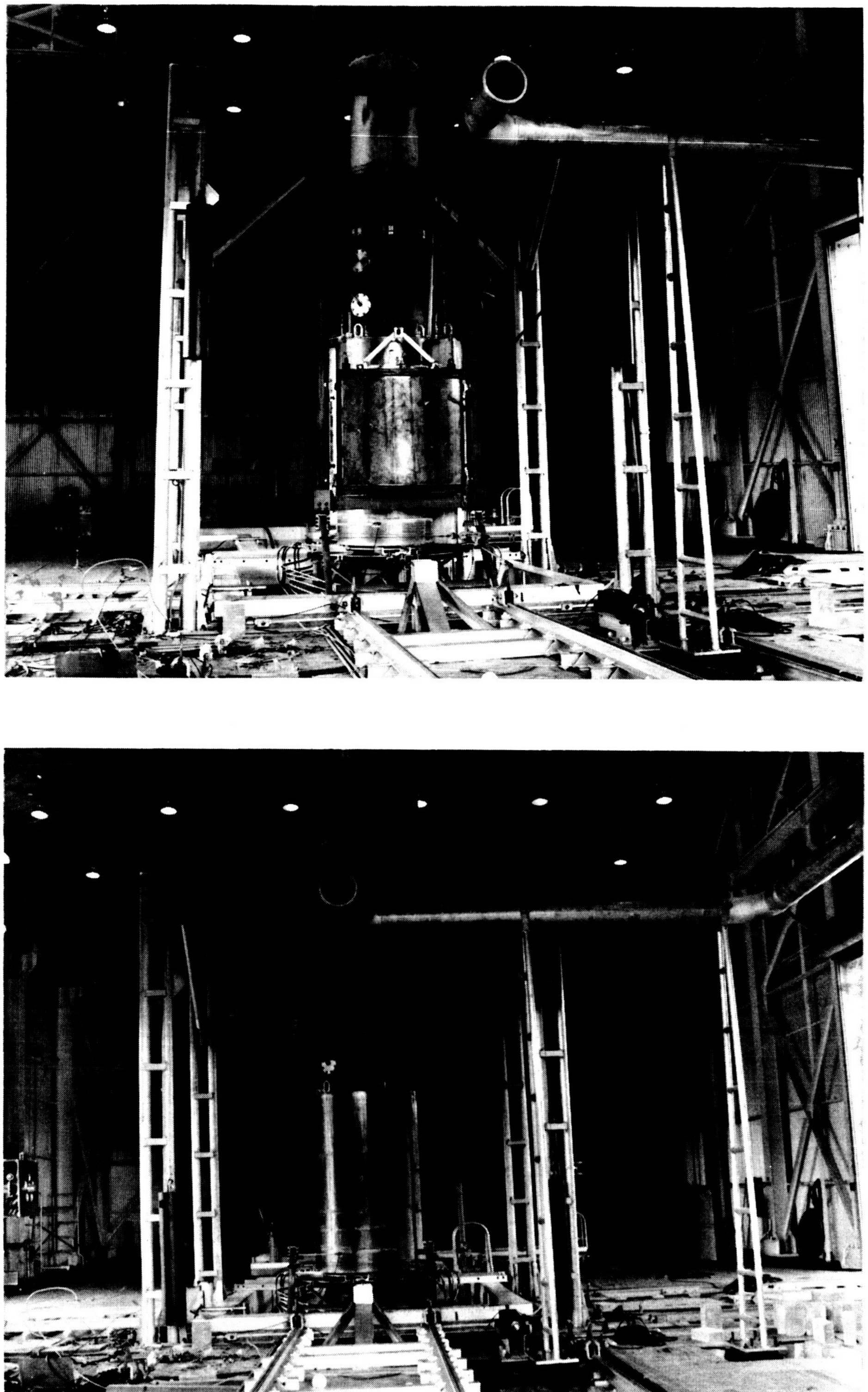


FIGURE 3 - RER WITH AND WITHOUT LITHIUM HYDRIDE SHIELD IN PLACE

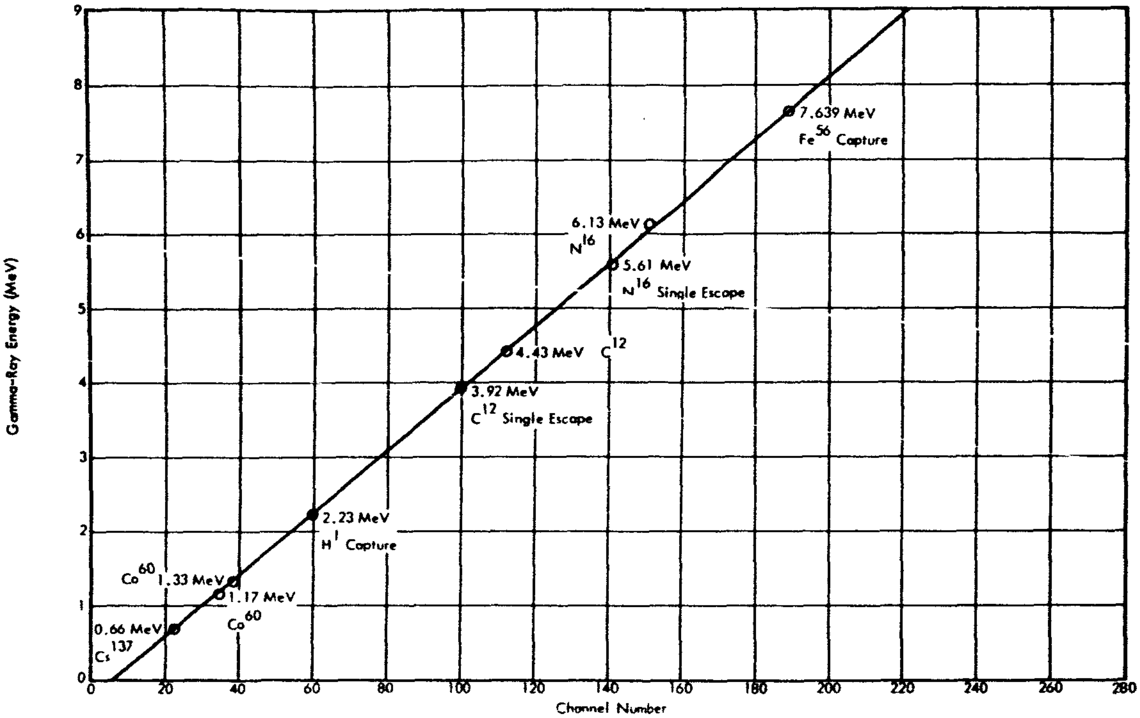


FIGURE 4 - SPECTROMETER LINEARITY

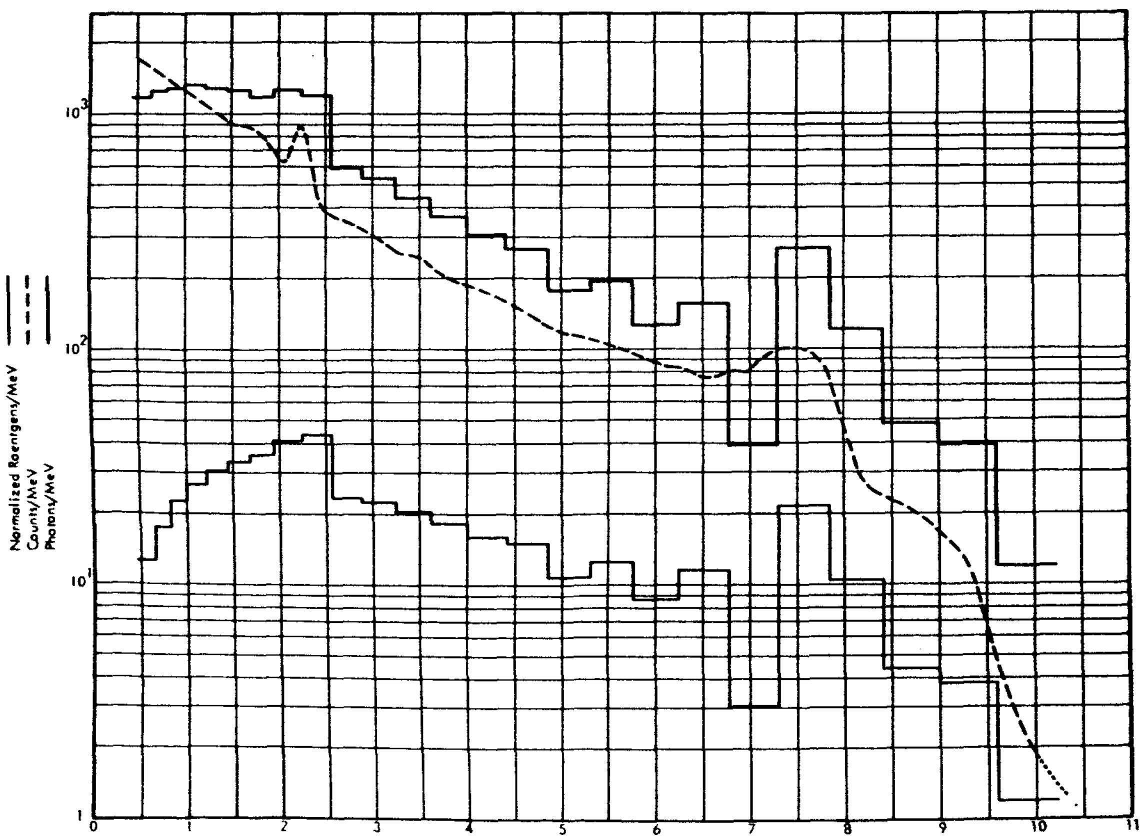


FIGURE 5 - PULSE HEIGHT, PHOTON, AND DOSE SPECTRA (LiH ONLY)

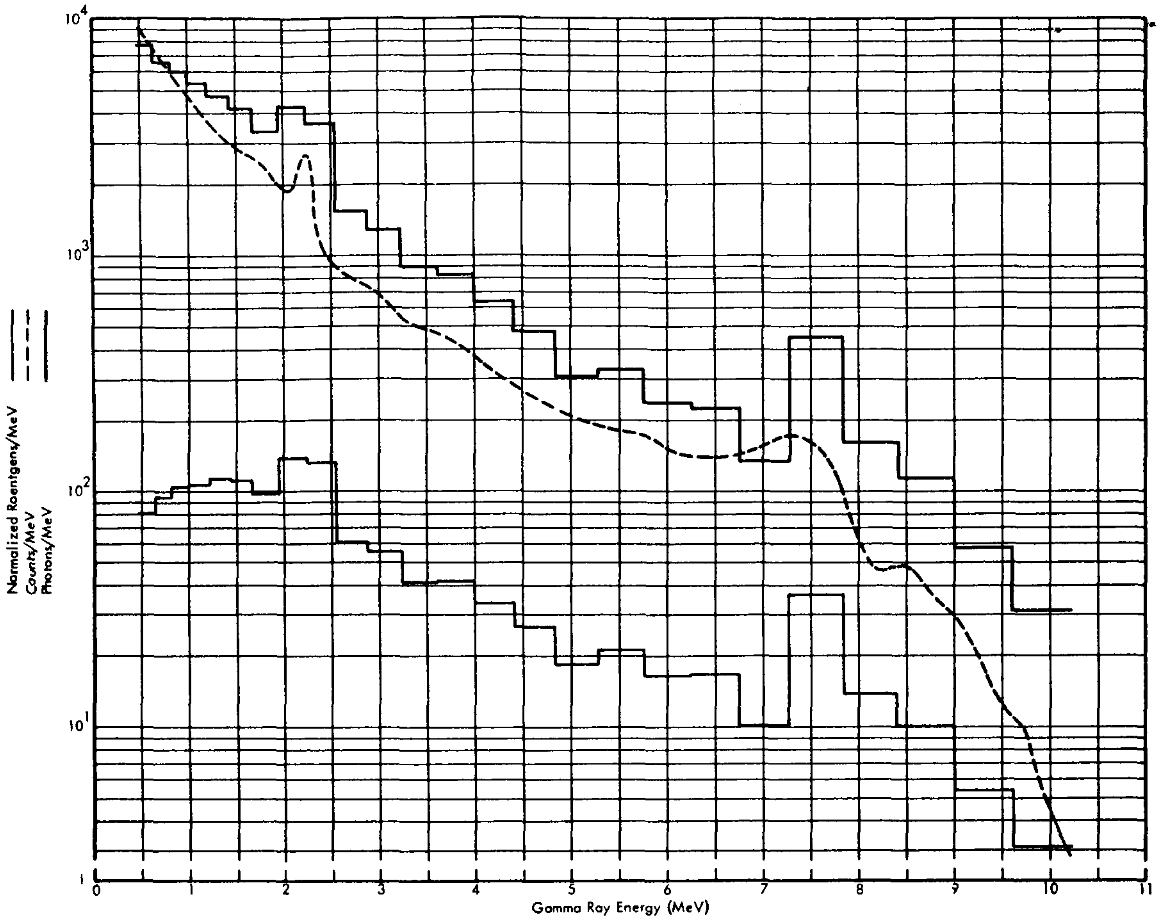


FIGURE 6 PULSE HEIGHT, PHOTON, AND DOSE SPECTRA (8 INCHES WATER ONLY)

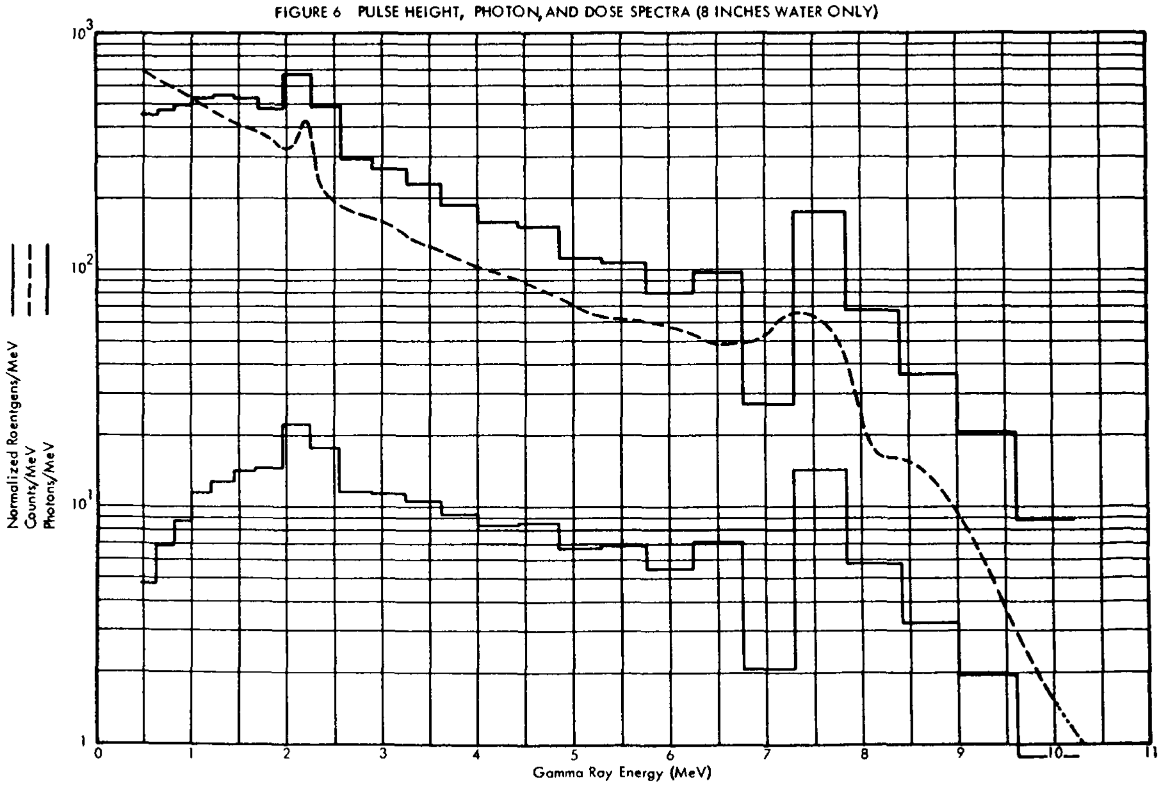


FIGURE 7 PULSE HEIGHT, PHOTON, AND DOSE SPECTRA (LiH PLUS 8 INCHES WATER)

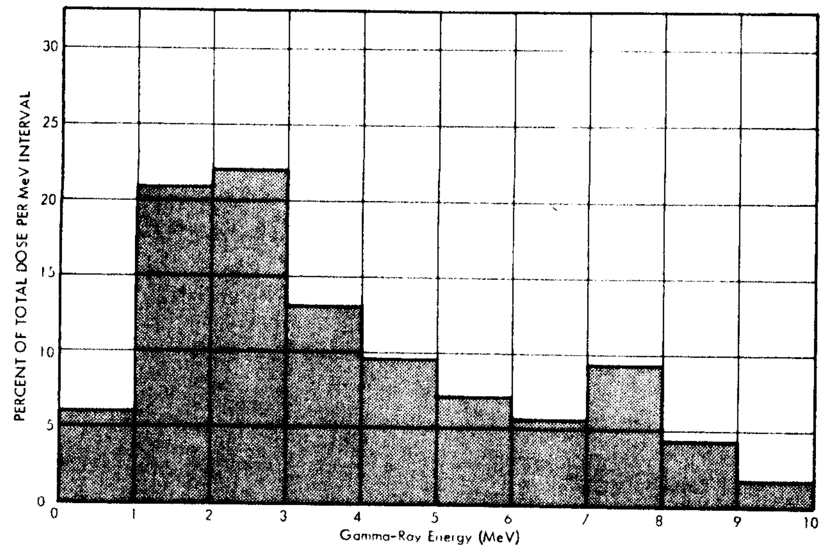


FIGURE 8 PERCENT DOSE DISTRIBUTION - LiH ONLY

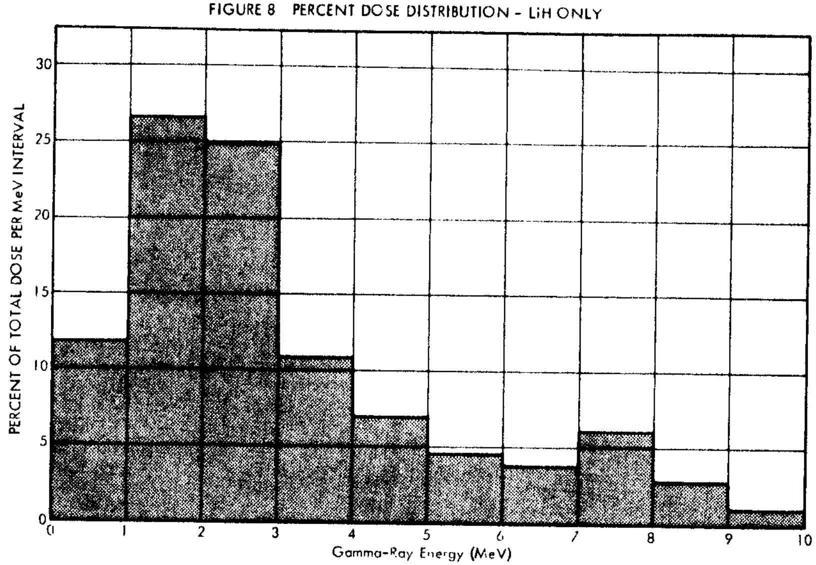


FIGURE 9 PERCENT DOSE DISTRIBUTION - 8 INCHES WATER ONLY

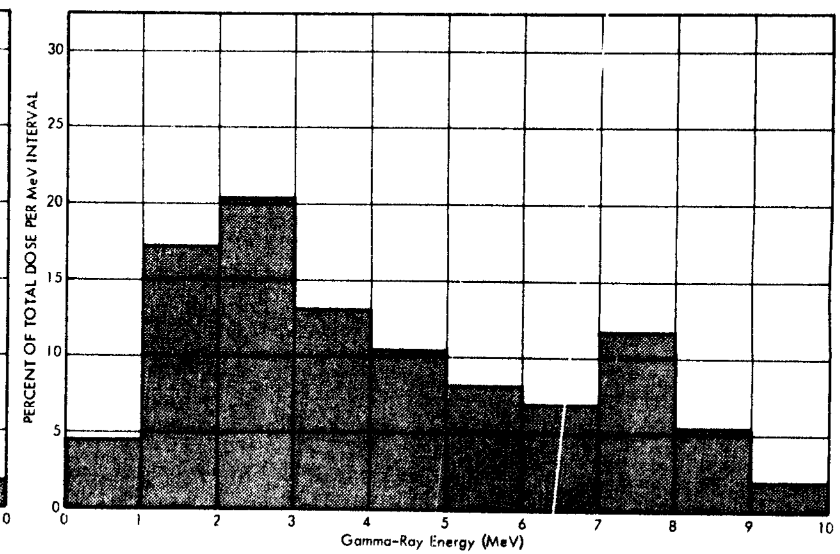


FIGURE 10 PERCENT DOSE DISTRIBUTION - LiH + 8 INCHES WATER

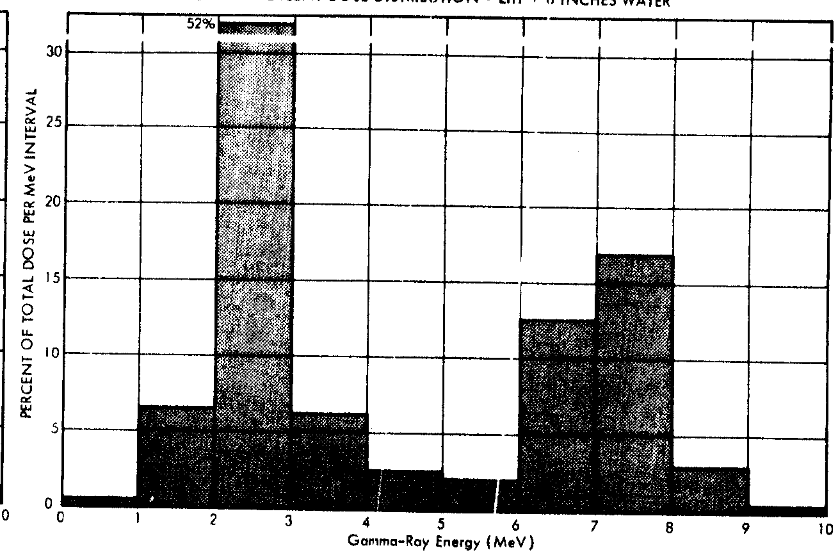


FIGURE 11 PERCENT DOSE DISTRIBUTION - CALCULATED (Al)