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FAST-NEUTRON AND GAMMA SPECTRUM AND DOSE IN BERYLLIUM OXIDE

by

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CORRECTION OF REPORT BMI-1493

In the upper right corner of the figures, add the following:

Figure 13 (page 19) - Fission Plate Power 19.5 watts

Figure 14a (page 20) - Fission Plate Power 19.5 watts

Figure 14b (page 20) - Fission Plate Power 19.5 watts

Figure 14c (page 21) - Fission Plate Power 19.5 watts

Figure 14d (page 21) - Fission Plate Power 19.5 watts

Figure 15a (page 22) - Fission Plate Power 21.65 watts

Figure 15b (page 22) - Fission Plate Power 21.5 watts

Figure 15c (page 23) - Fission Plate Power 21.9 watts

Figure 15d (page 23) - Fission Plate Power 21.9 watts

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FAST-NEUTRON AND GAMMA SPECTRUM AND DOSE IN BERYLLIUM OXIDE

Raymond W. Klingensmith, Richard G. Jung, William A. Lindgren, Harold M. Epstein, and Joel W. Chastain, Jr.

Neutron and gamma penetrations through and behind BeO were measured in the Battelle-GE-ANPD Lid-Tank Shielding Facility. The BeO was in the form of slabs 35 in. square and 4 or 9 in. thick. To prevent short circuiting of radiation around the slabs they were mounted in 48-in.-square iron frames. One of the slabs contained a 7/8-in.-diameter instrument hole. This instrumented slab was placed at desired locations within a 21-in. array of slabs to permit measurements through an effectively solid medium.

Neutron-spectra measurements by threshold foil techniques indicated practically no change in the fast-neutron spectrum above 2.5 Mev in 13 in. of BeO. Thus, beryllium appears to lie in the transition region between the very light elements such as water which harden a fission spectrum and the heavier elements which soften it. The ratio of fast-neutron flux below 2.5 Mev to the flux above it increases rapidly with distance through the BeO. Present spectral information indicates that the flux peaks in the region of 1-1/2 to 2-1/2 Mev. In this energy range the scattering cross section of beryllium goes through a minimum.

Fast-neutron dose measurements with Hurst dosimeters through 21 in. of BeO were compared with those calculated by the NDA moments method. The experimental results were within 30 per cent of those calculated by GE-ANPD based on the moments calculations.

The removal cross section for BeO was determined from fast-neutron dose rates measured in the water behind the slabs to be 2.02 barns.

Gamma dose rates were measured through and behind the BeO slabs with a 3/4-in.-diameter carbon chamber. The gamma dose rate decreased with a relaxation length of about 11 cm near the source. The relaxation length increases with distance through BeO indicating spectrum hardening.

Gamma spectra were measured at 4-in. intervals behind BeO slabs from 0 to 21 in. thick with a collimated 8 by 8-in. sodium iodide crystal. The 6.8- and 3.41-Mev beryllium capture gammas become dominant as the distance through the BeO increases.

Thermal flux was measured through and behind the BeO with both a 3/4-in.-diameter fission chamber and 1/4 by 1/4-in. by 1-mil-thick gold foils. Thermal-flux distributions for these tests were calculated by GE-ANPD with the 6-2 multilevel diffusion code. The calculations differ by about a factor of 2 from the experiment at large penetration distances through BeO.

INTRODUCTION

As part of the GE-ANPD shielding program being conducted at Battelle a series of tests was run to determine the shielding properties of BeO. The material was in the form of slabs 35 in. square and either 4 or 9 in. thick. To prevent short circuiting of radiation around the slabs they were mounted in 48-in.-square steel frames. The slabs could be combined to give configurations which were 4, 8, 9, 12, 13, 17, or 21 in. thick. Measurements were made behind these various configurations. One of the 4-in.-thick slabs contained a 7/8-in.-diameter by 27-in.-long vertical instrument hole. This instrumented slab was placed at desired locations within the 21-in. configuration to permit measurements through an effectively solid medium.

The tests were conducted at the Battelle Lid-Tank Shielding Facility which consists of a 28-in.-diameter highly enriched uranium plate 0.020 in. thick placed in one wall of a water pool 15 by 15 by 12 ft deep. The pool and fission plate are located at the end of the thermal column of the Battelle Research Reactor.[1,2] About 30 w is generated in the fission plate at steady-state 2-megawatt reactor operation. The fission-plate power can be reduced by a factor of 8.5 without reduction of reactor power by means of a borated polyethylene curtain positioned between the plate and the thermal column. This curtain replaces the previous lithium-magnesium curtain which reduced the plate power by a factor of 2.3.[1]

INSTRUMENTATION

The Facility is equipped to measure fast-neutron dose rate, gamma dose rate, thermal-neutron flux, gamma energy spectra, and integrated fast-neutron spectra. A detailed description of the instrumentation is reported elsewhere[1,2], and only a brief summary will be given here.

For measurements of fast-neutron dose rate Hurst-type fast-neutron dosimeters are used. One 2-in.-diameter Reuter-Stokes, Inc., RSN-2 dosimeter, two 3/4-in.-diameter Reuter-Stokes, Inc., modified RSN-3 dosimeters, two 3/4-in.-diameter ORNL Q-1329 D dosimeters, and one 1-in.-diameter GE-ANPD dosimeter were used in the BeO tests. Due to thermal-neutron sensitivity it was necessary to place a 0.020-in.-thick cadmium sheath around each dosimeter.

Carbon-wall ionization chambers filled with CO_2 to 10 psig are used to measure gamma dose rate. Measurements over an extended range of dose rate are accomplished by using three chambers of different sensitivity. Dose rates in the range of 0.5 to 30 rad per hr are measured with a 500-cm^3 chamber; dose rates in the range of 25 to 1000 rad per hr are measured with a 10-cm^3 chamber; dose rates in the range of 100 to 2000 rad per hr are measured with a 9-cm^3 chamber. The 9-cm^3 chamber is 3/4 in. in diameter and was used for measurements within the instrumented slab.

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(1) References at end.

Thermal-neutron-flux distributions are measured with gold foils and fission chambers. The chambers, made by GE-ANPD, are 3/4 in. in diameter by 7-3/4 in. long and have an active length of 3 in. For absolute flux determinations, the output of the fission chamber is normalized to flux as determined by gold-foil activation. A Maxwellian-averaged gold cross section is used in the flux determination.

Measurements of gamma-ray energy spectra from 0.2 to 10 Mev are made with an 8 by 8-in. NaI crystal.[3,4]

Threshold foil techniques patterned after the techniques of Trice[5], are used to measure integrated fast-neutron fluxes.

DESCRIPTION OF EXPERIMENT

Measurements of fast-neutron dose rate, gamma dose rate, and thermal-neutron flux were made along the water center line behind 4-, 9-, 13-, 17-, and 21-in.-thick configurations of BeO. The results are shown in Figures 1, 2, and 3. Experimental data points are given in the Appendix. From the fast-neutron dose rates measured in the water behind these configurations, the removal cross section for BeO was determined to be 2.02 barns.

Measurements of fast-neutron dose rate, gamma dose rate, and thermal-neutron flux were made along the center line through the 21-in. configuration. The results are shown in Figures 4, 5, and 6. The fast-neutron dose rate through the 21-in. configuration was compared with the NDA moments method calculation[6]. The experimental results are within 30 per cent of those calculated by GE-ANPD based on the moments calculations. A relaxation length of about 5.3 cm for the fast-neutron dose rate through BeO was calculated from the slope of the curve in Figure 4. The relaxation length of the gamma dose rate was calculated from Figure 5 to be about 11 cm near the fission plate. As shown by the change in shape, the relaxation length increases with penetration into the BeO indicating a hardening of the spectrum. This is verified by gamma-energy-spectrum measurements. Thermal-flux distributions for these tests were calculated by GE-ANPD with the G-2 multilevel diffusion code. The calculations agree well near the source but differ by about a factor of 2 from the experimental data at large penetration distances through BeO.

Measurements of fast-neutron dose rate, gamma dose rate, and thermal-neutron flux were made in a vertical plane at various positions within the 21-in. configuration. These results are shown in Figures 7, 8, and 9.

Integral fast-neutron spectra were measured through the 21-in. configuration by means of threshold foils. Data points obtained are shown in Figures 10 and 11. There is very little change in the shape of the spectrum with penetration through BeO for neutrons above 2.4 Mev. This fact is emphasized by the Watt's spectrum drawn through the data points and normalized to the 8.1-Mev point. To measure the integral fast-neutron spectrum above 1.4 Mev, depleted uranium-238 foils were used. The results are compared with the corresponding phosphorus (2.4-Mev threshold) data in Figure 12.

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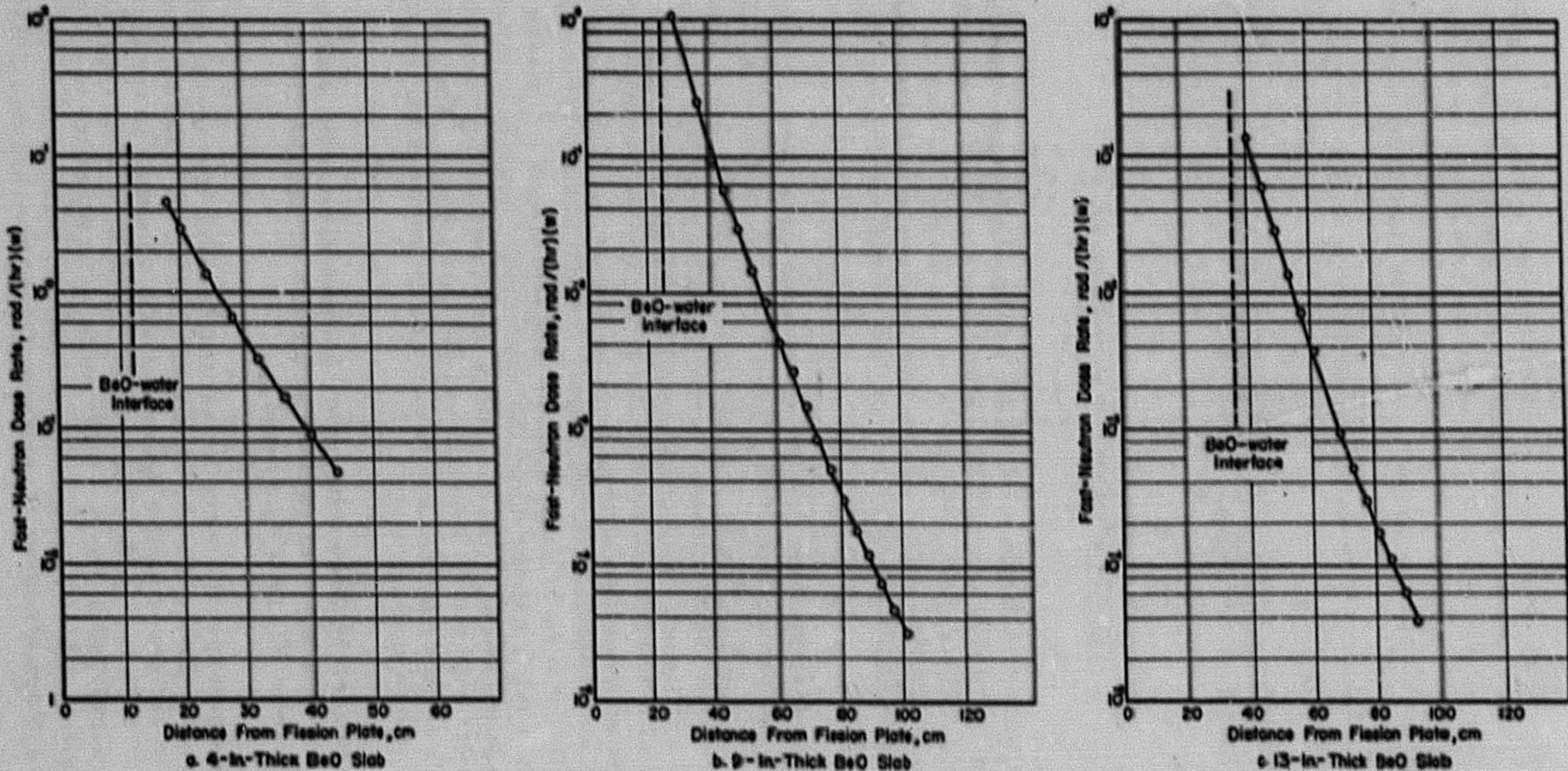

FIGURE 1. FAST-NEUTRON DOSE RATE MEASURED ALONG THE CENTER LINE BEHIND THE BeO SLABS

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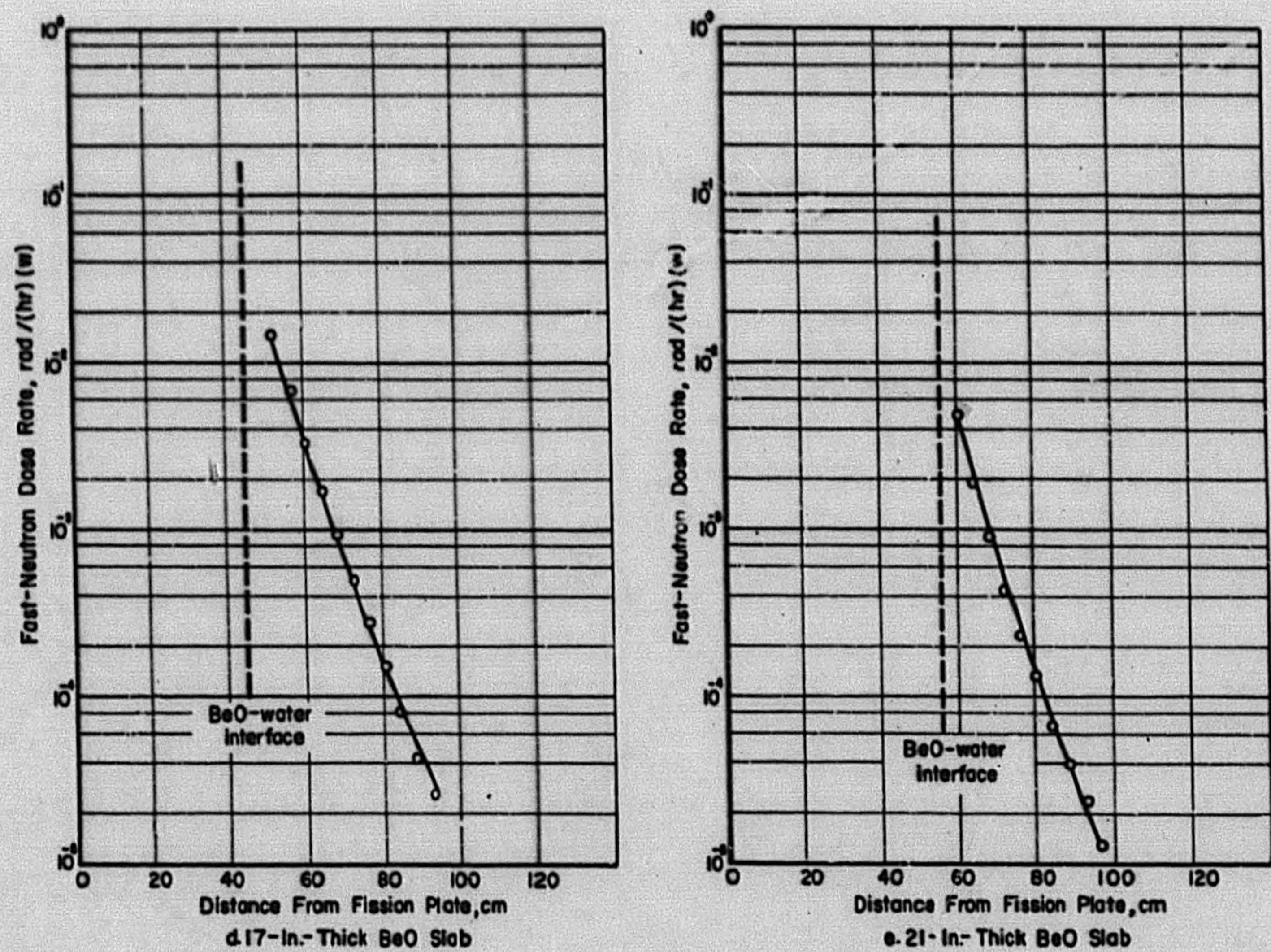

FIGURE 1. (CONTINUED)

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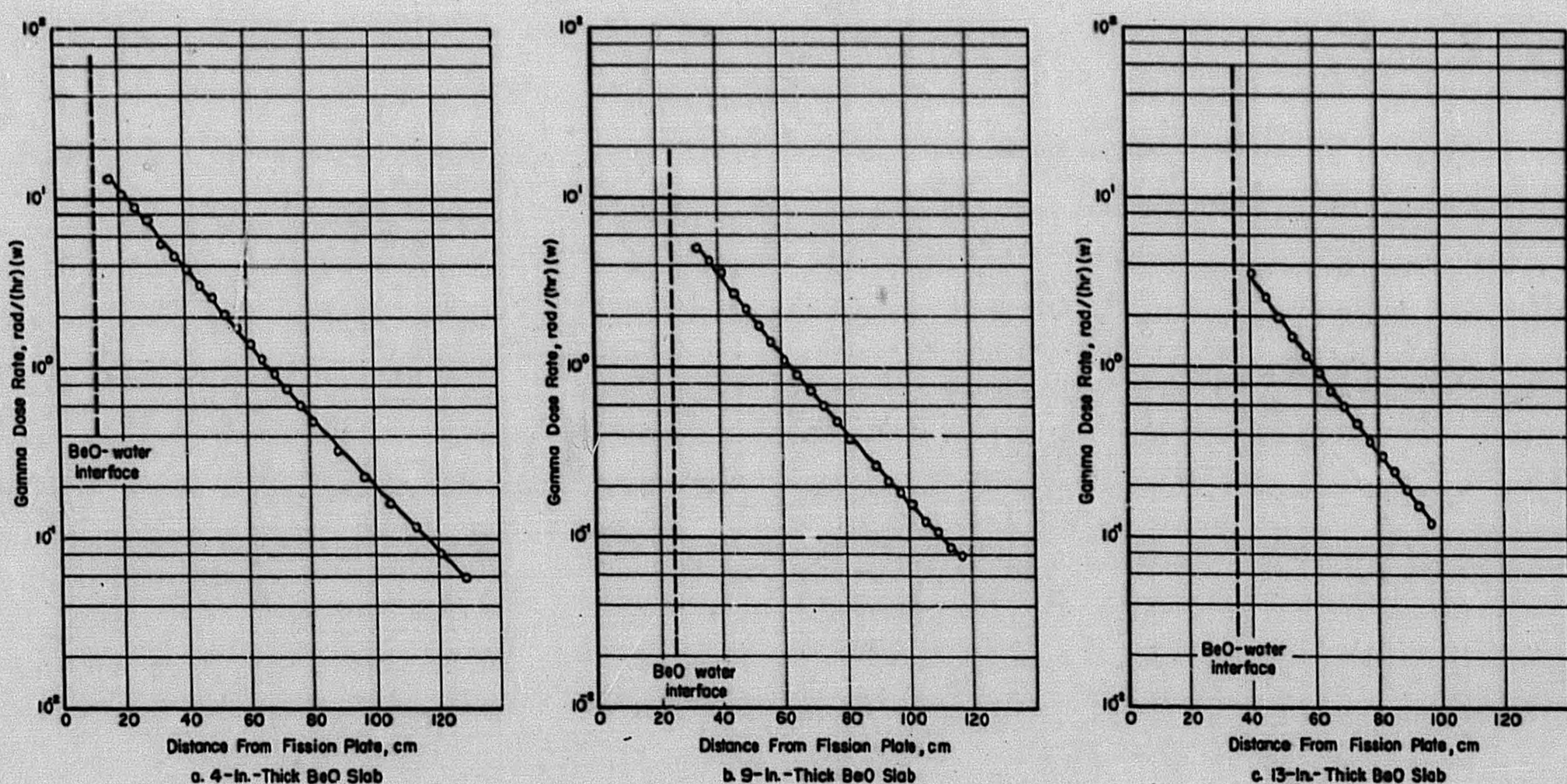

FIGURE 2. GAMMA DOSE RATE MEASURED ALONG THE CENTER LINE BEHIND THE BeO SLABS

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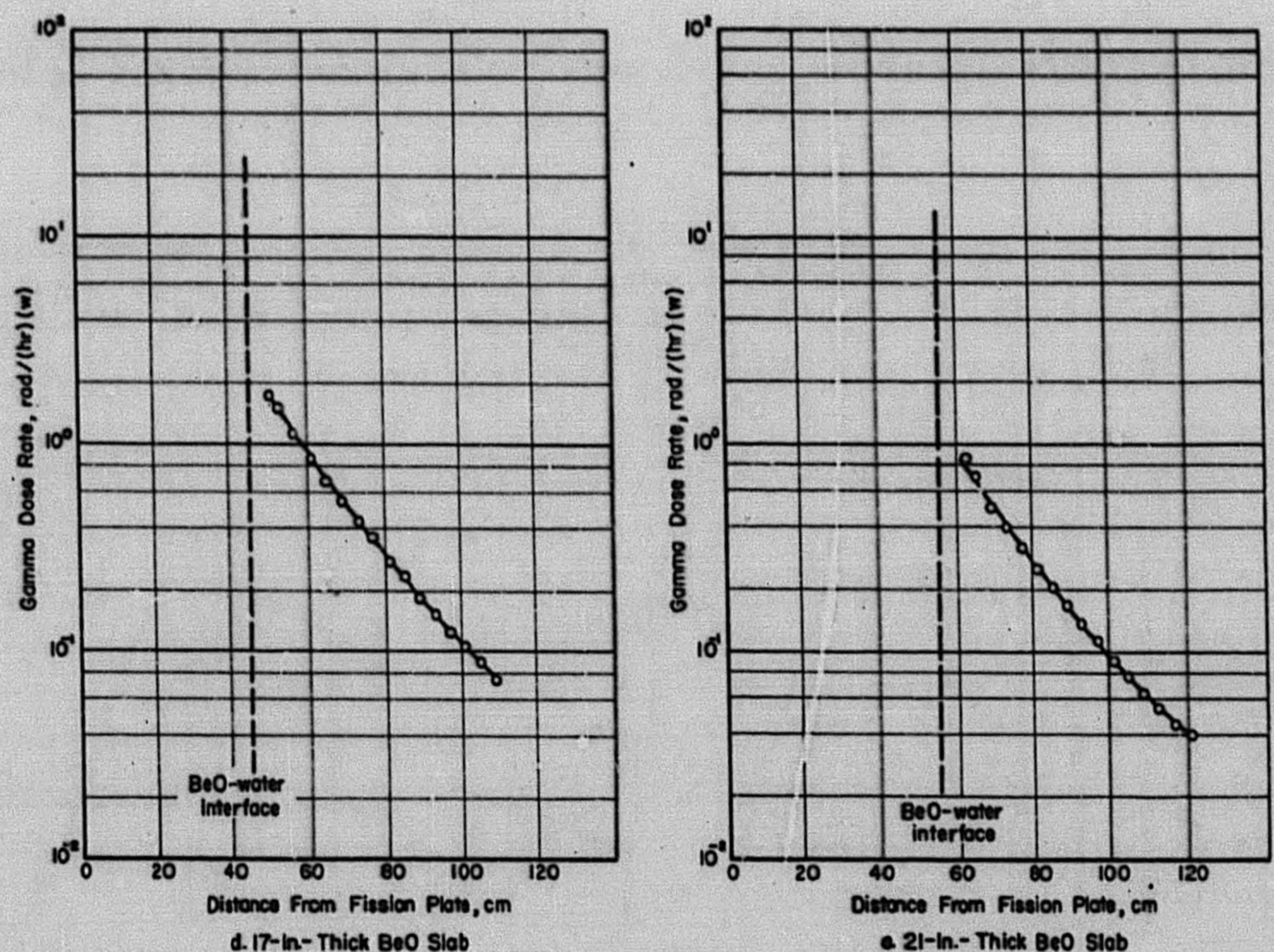

FIGURE 2. (CONTINUED)

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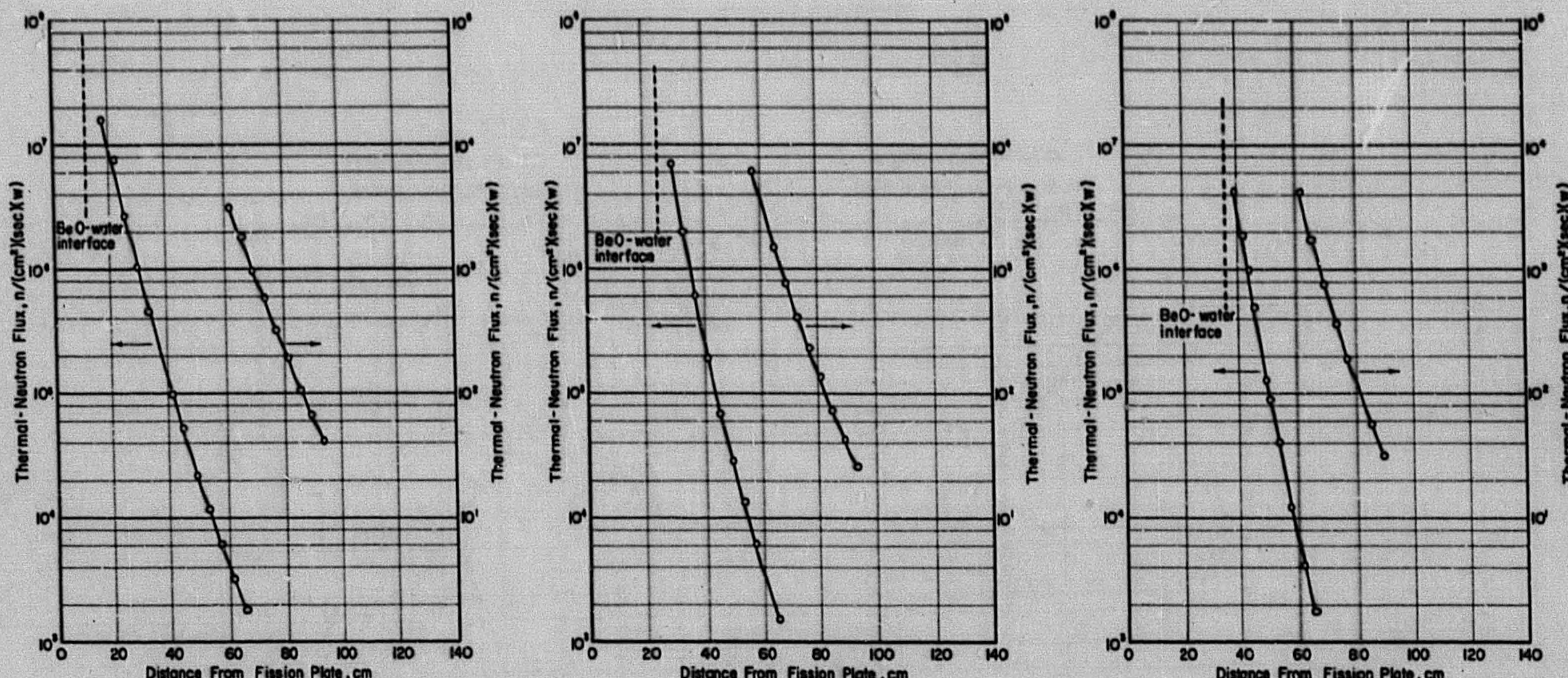

a. 4-Inch-Thick BeO Slab

b. 9-Inch-Thick BeO Slab

c. 13-Inch-Thick BeO Slab

FIGURE 3. THERMAL-NEUTRON FLUX MEASURED ALONG THE CENTER LINE BEHIND THE BeO SLABS

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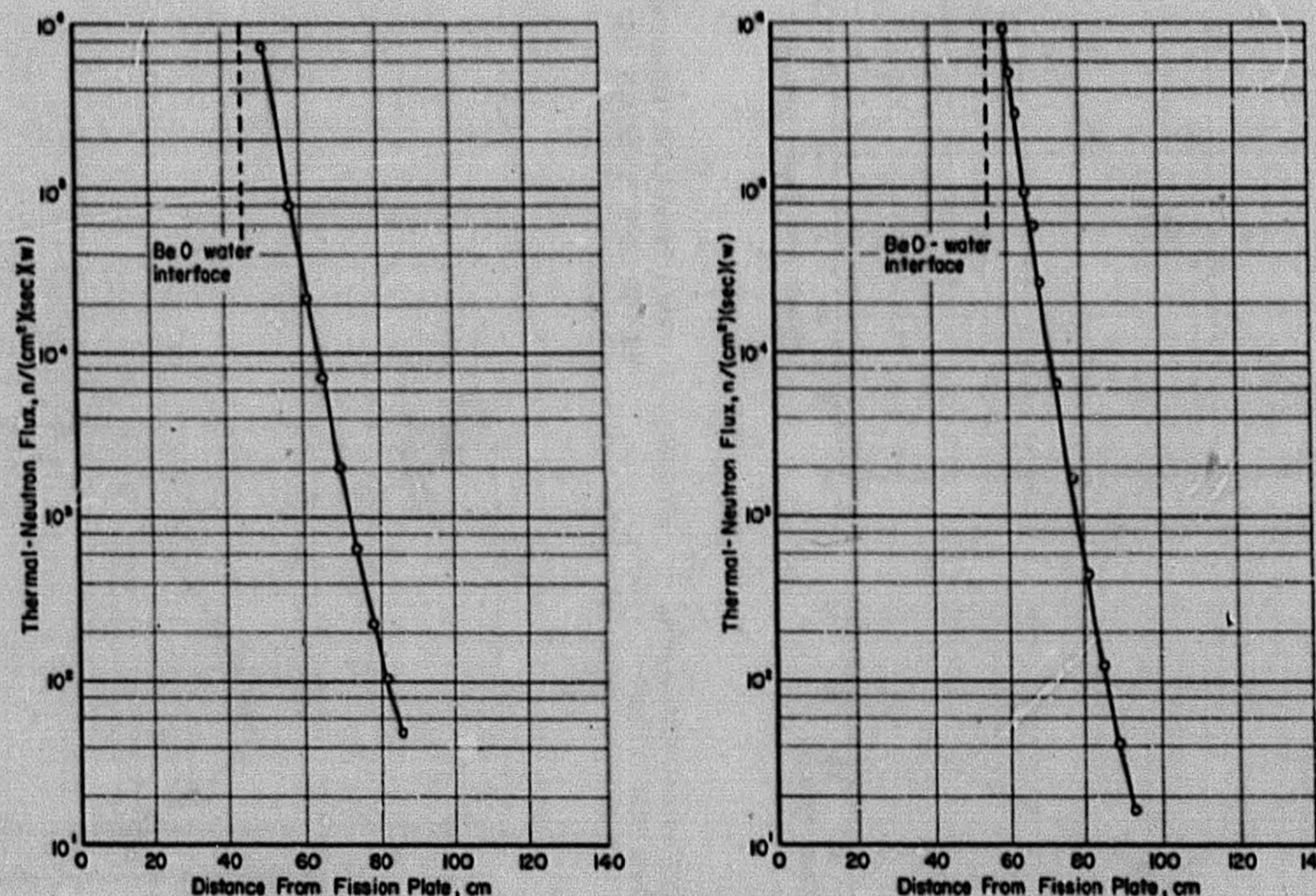

d. 17-Inch-Thick BeO Slab

e. 21-Inch-Thick BeO Slab

FIGURE 3. (CONTINUED)

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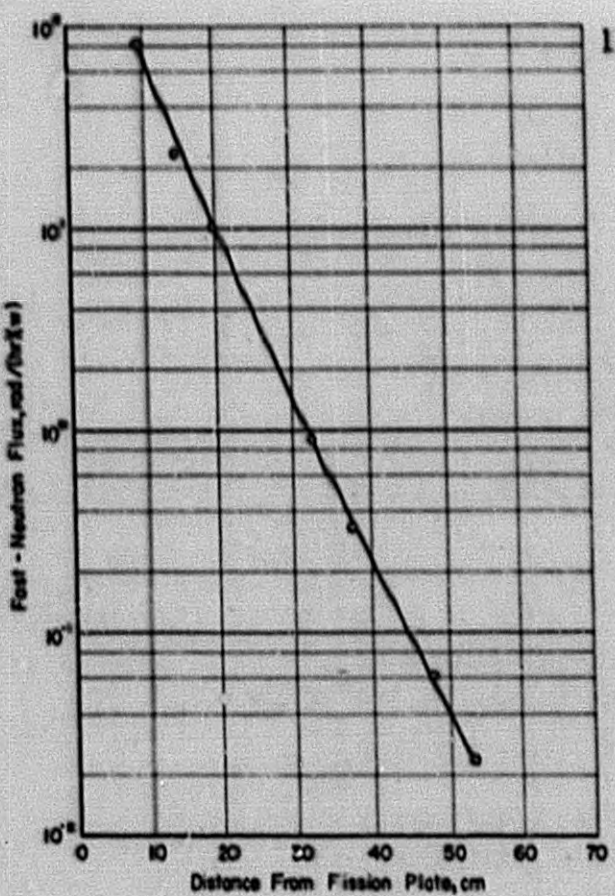

FIGURE 4. FAST-NEUTRON DOSE RATE MEASURED ALONG THE CENTER LINE THROUGH THE 21-IN.-THICK BeO SLAB

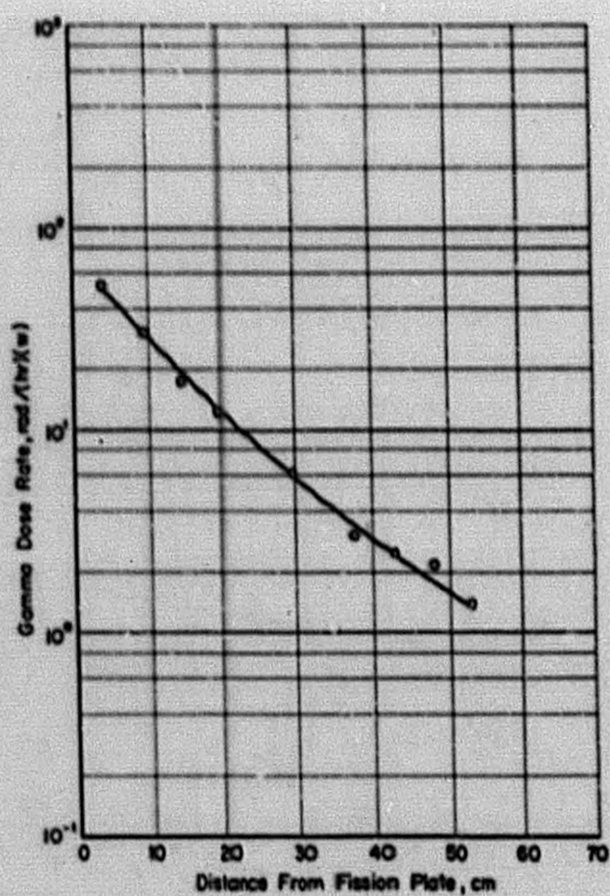

FIGURE 5. GAMMA DOSE RATE MEASURED ALONG THE CENTER LINE THROUGH THE 21-IN.-THICK BeO SLAB

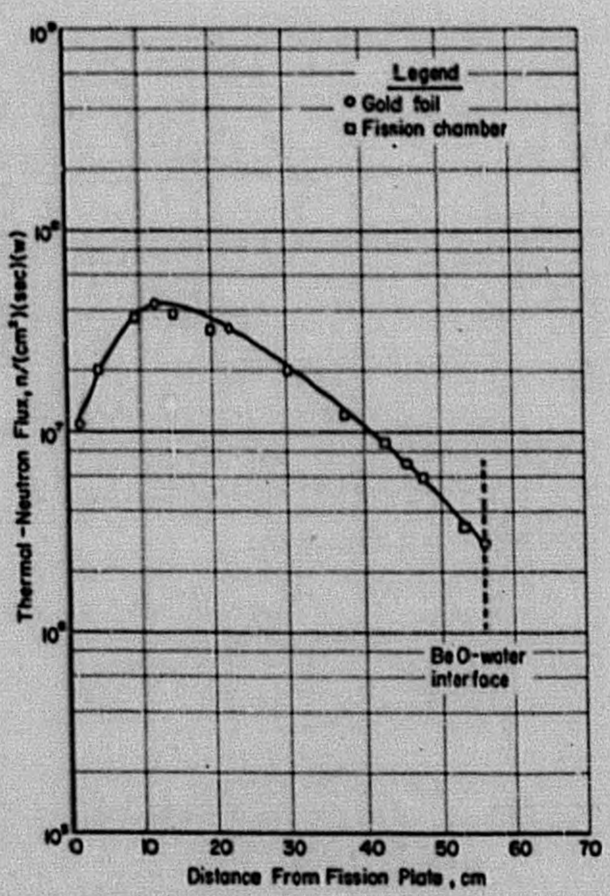

FIGURE 6. THERMAL-NEUTRON FLUX PER WATT MEASURED ALONG THE CENTER LINE THROUGH THE 21-IN. THICK BeO SLAB

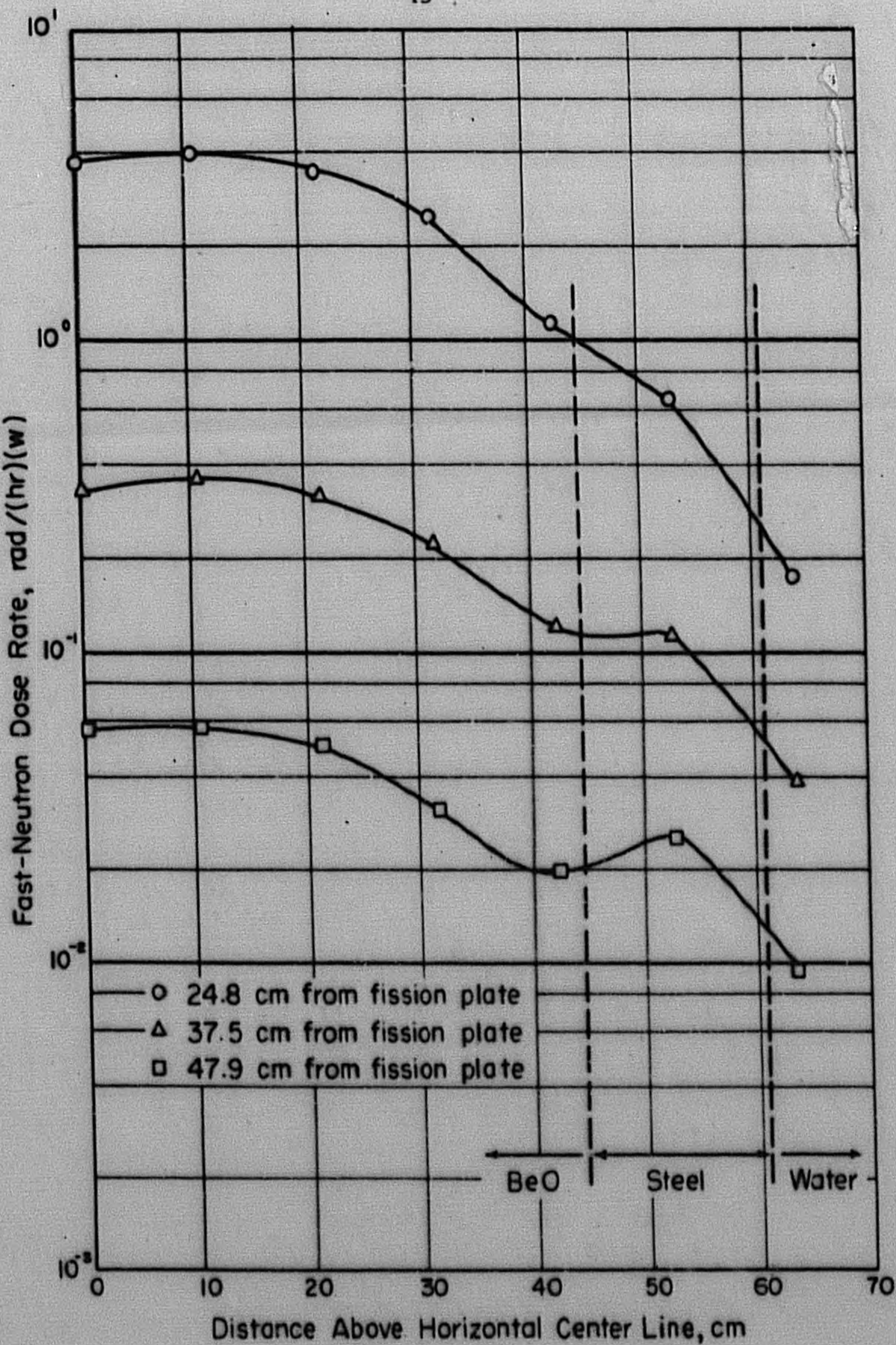

FIGURE 7. FAST-NEUTRON DOSE RATE MEASURED IN A VERTICAL PLANE WITHIN THE 21-IN.-THICK BeO SLAB

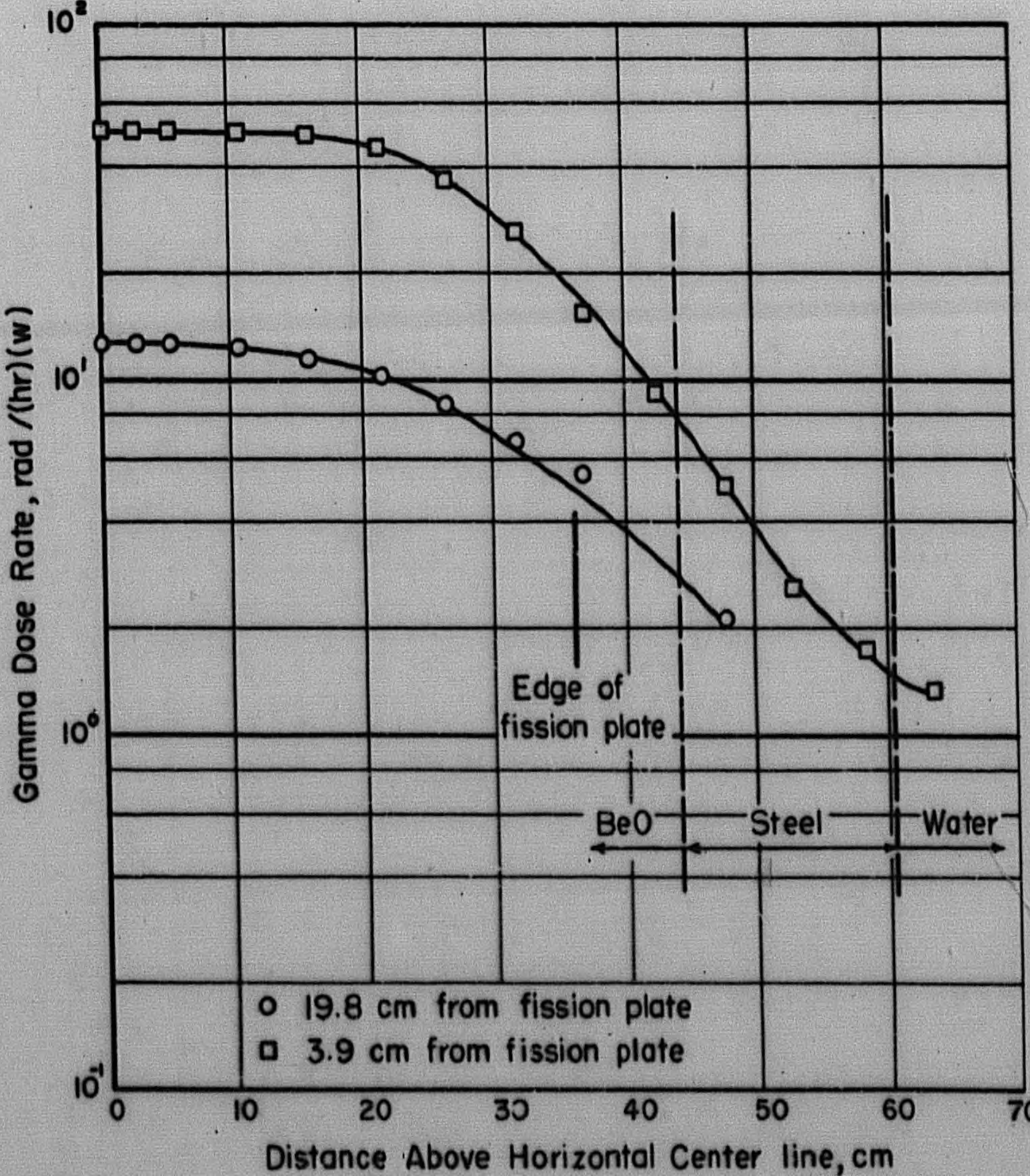

FIGURE 8. GAMMA DOSE RATE MEASURED IN A VERTICAL PLANE WITHIN THE 21-IN.-THICK BeO SLAB

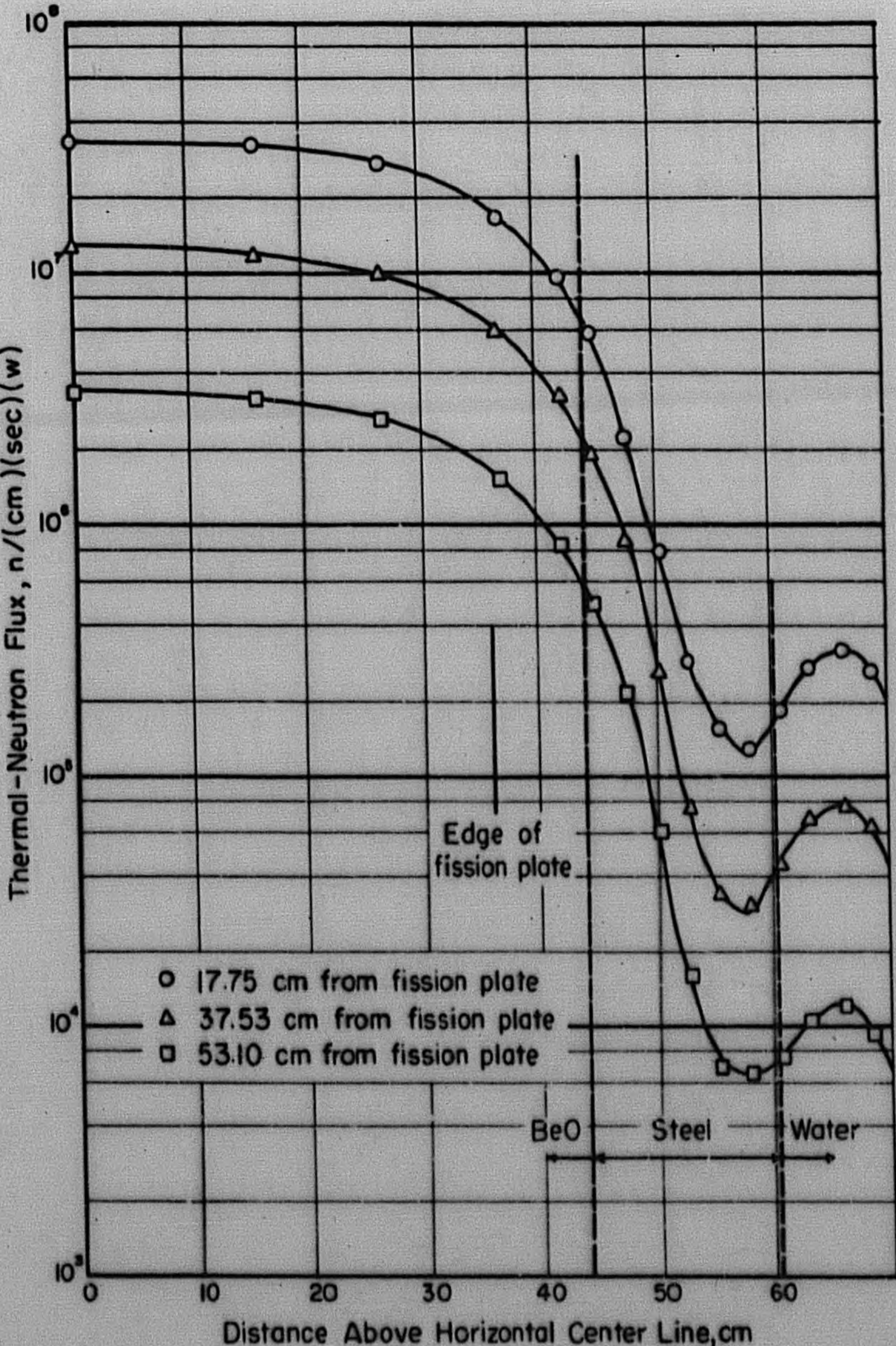

FIGURE 9. THERMAL-NEUTRON FLUX MEASURED IN A VERTICAL PLANE WITHIN THE 21-IN.-THICK BeO SLAB

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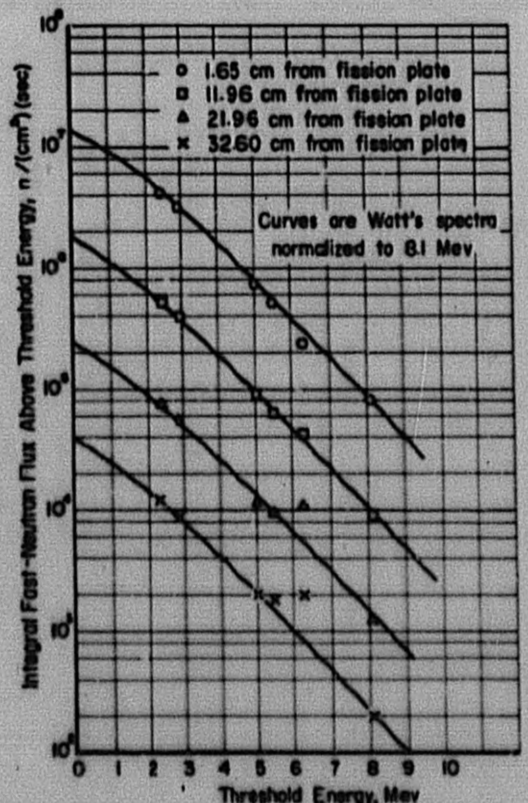

FIGURE 10. INTEGRAL FAST-NEUTRON FLUX VERSUS THRESHOLD ENERGY THROUGH THE 21-IN. BeO SLAB

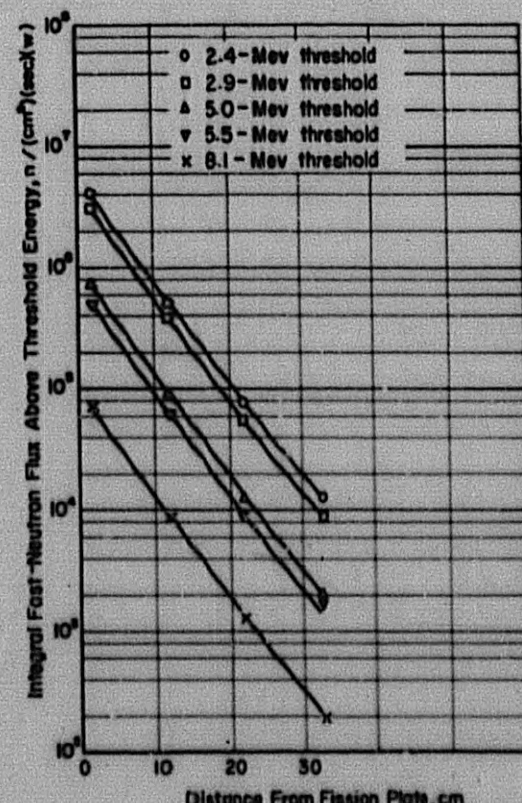

FIGURE 11. INTEGRAL FAST-NEUTRON FLUX VERSUS DISTANCE FROM FISSION PLATE THROUGH THE 21-IN. BeO SLAB

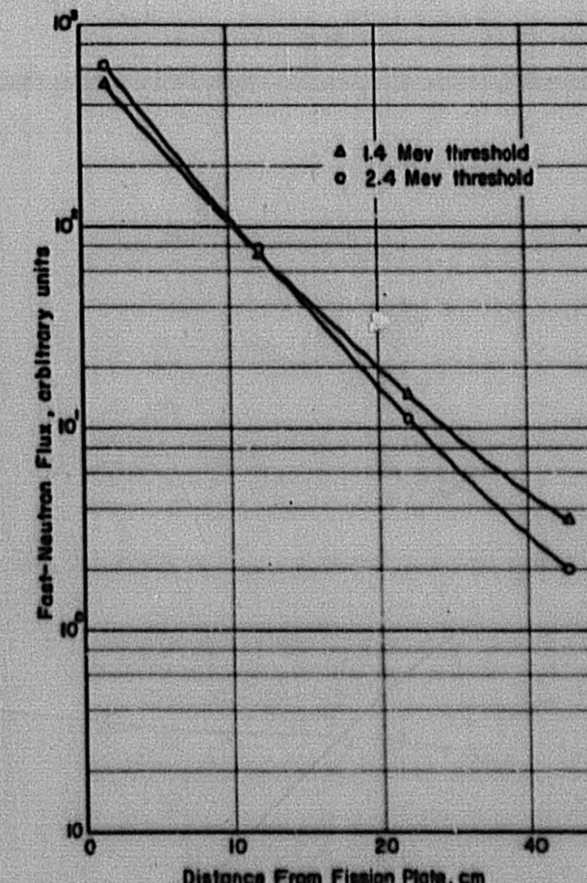

FIGURE 12. COMPARISON OF INTEGRAL FAST-NEUTRON FLUX ABOVE 1.4 MEV TO INTEGRAL FAST-NEUTRON FLUX ABOVE 2.4 MEV THROUGH THE 21-IN. BeO SLAB

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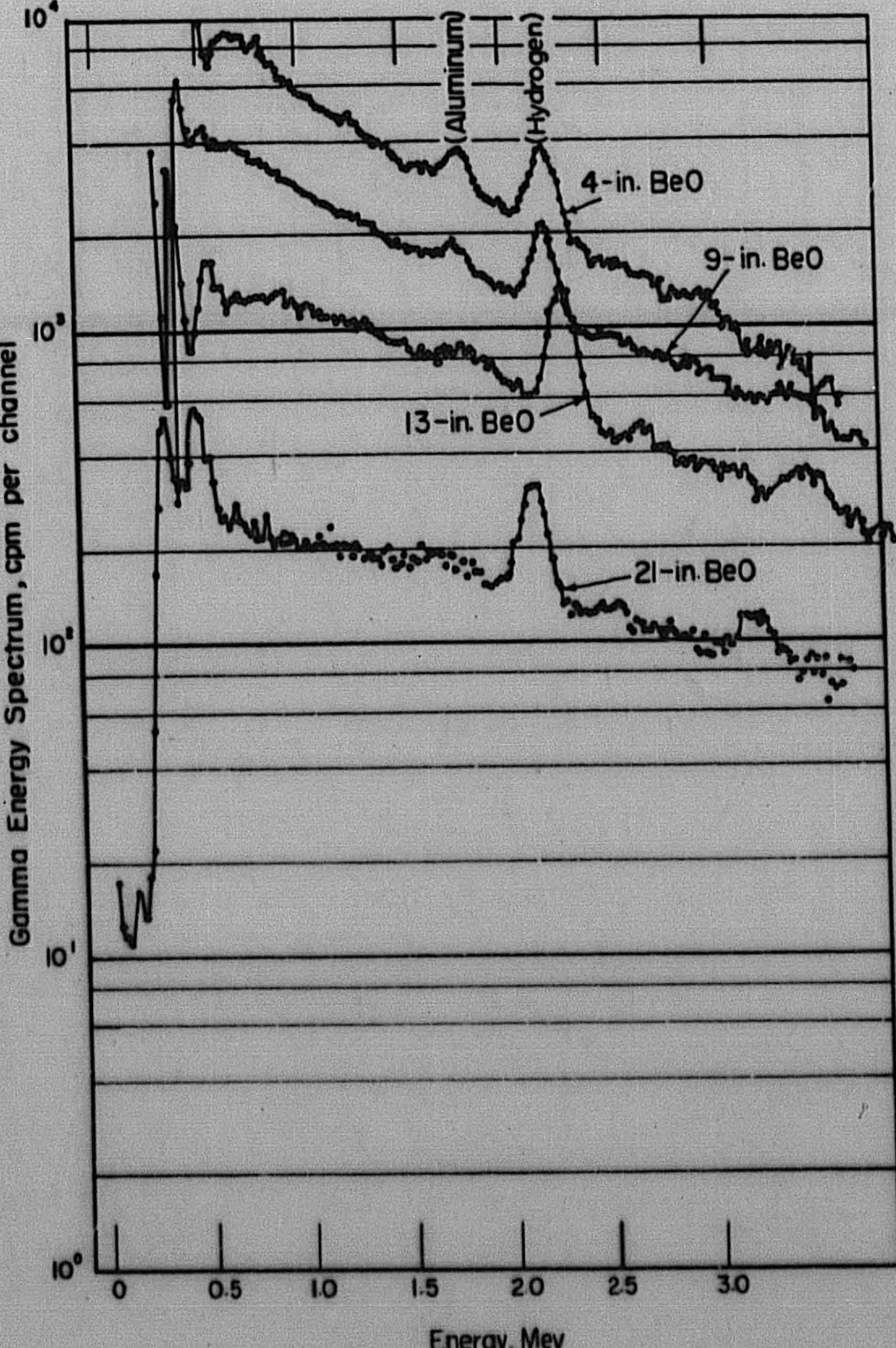
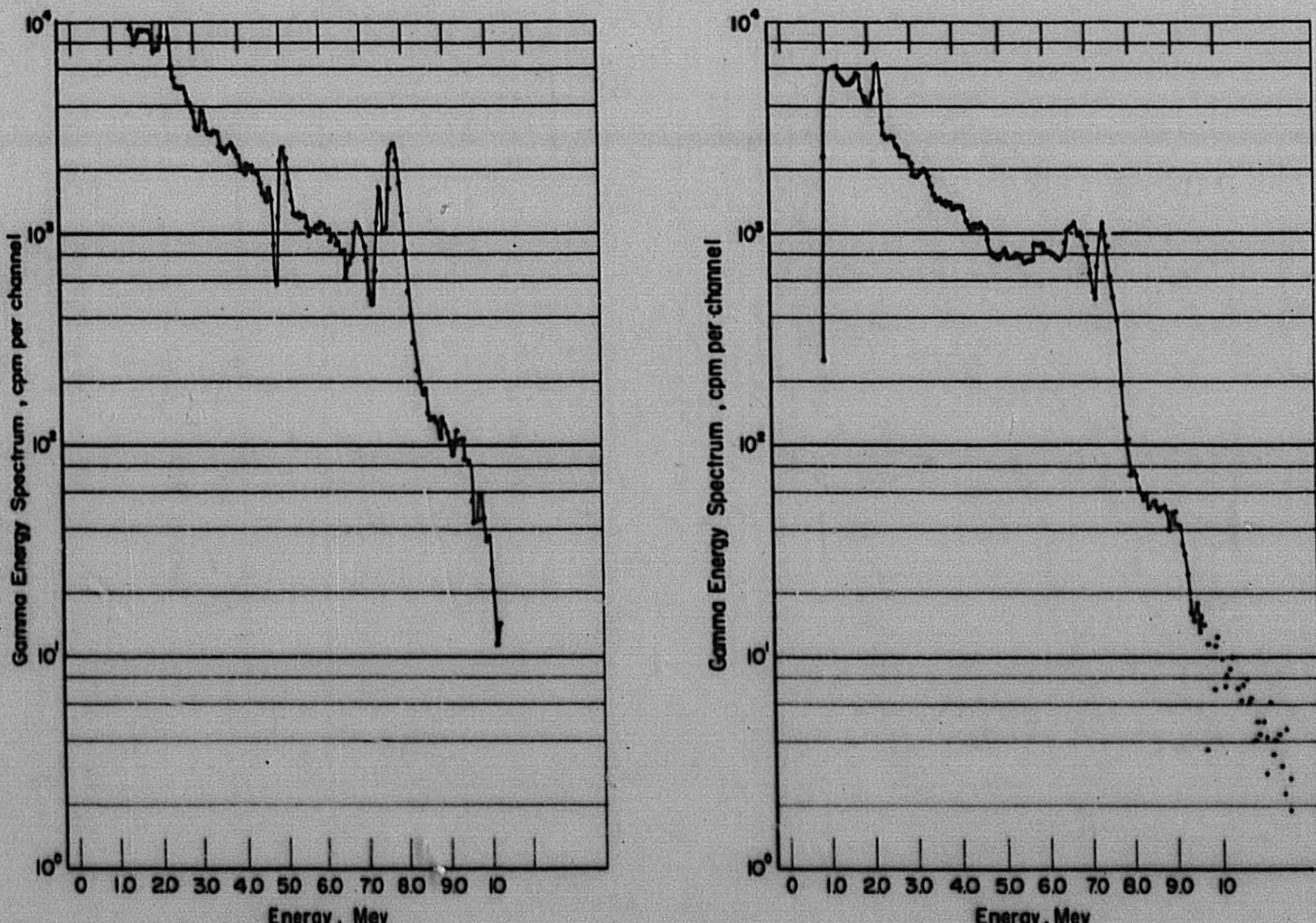


FIGURE 13. LOW-ENERGY GAMMA SPECTRA MEASURED BEHIND THE BeO SLABS USING AN 8 BY 8-IN. NaI CRYSTAL AT 0 DEG WITH THE HORIZONTAL CENTER LINE



a. 4-Inch-Thick BeO Slab

b. 9-Inch-Thick BeO Slab

FIGURE 14. HIGH-ENERGY GAMMA SPECTRA MEASURED BEHIND THE BeO SLABS USING AN 8 BY 8-IN. NaI CRYSTAL AT 0 DEG WITH THE HORIZONTAL CENTER LINE

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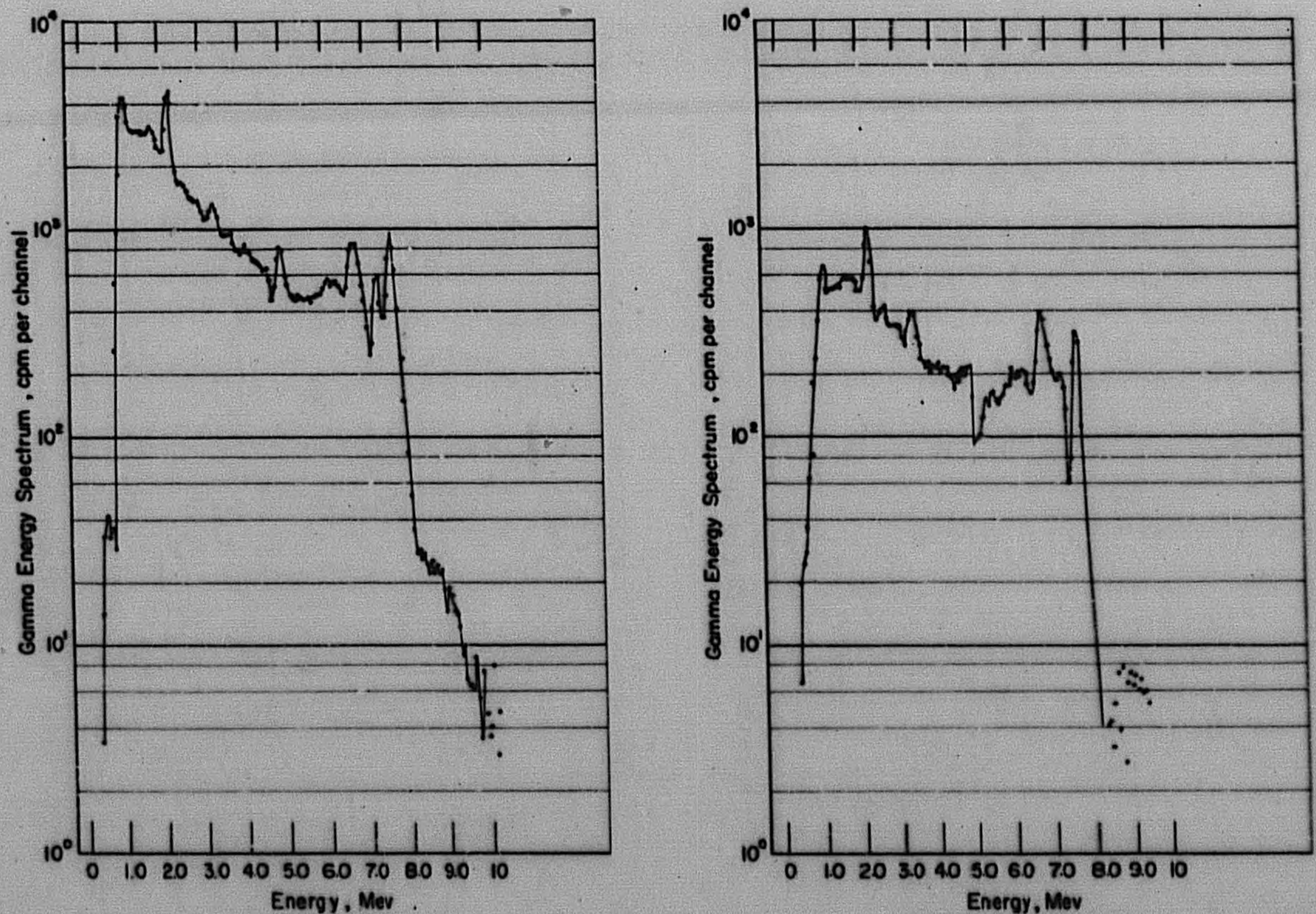

c. 13-Inch-Thick BeO Slab

d. 21-Inch-Thick BeO Slab

FIGURE 14. (CONTINUED)

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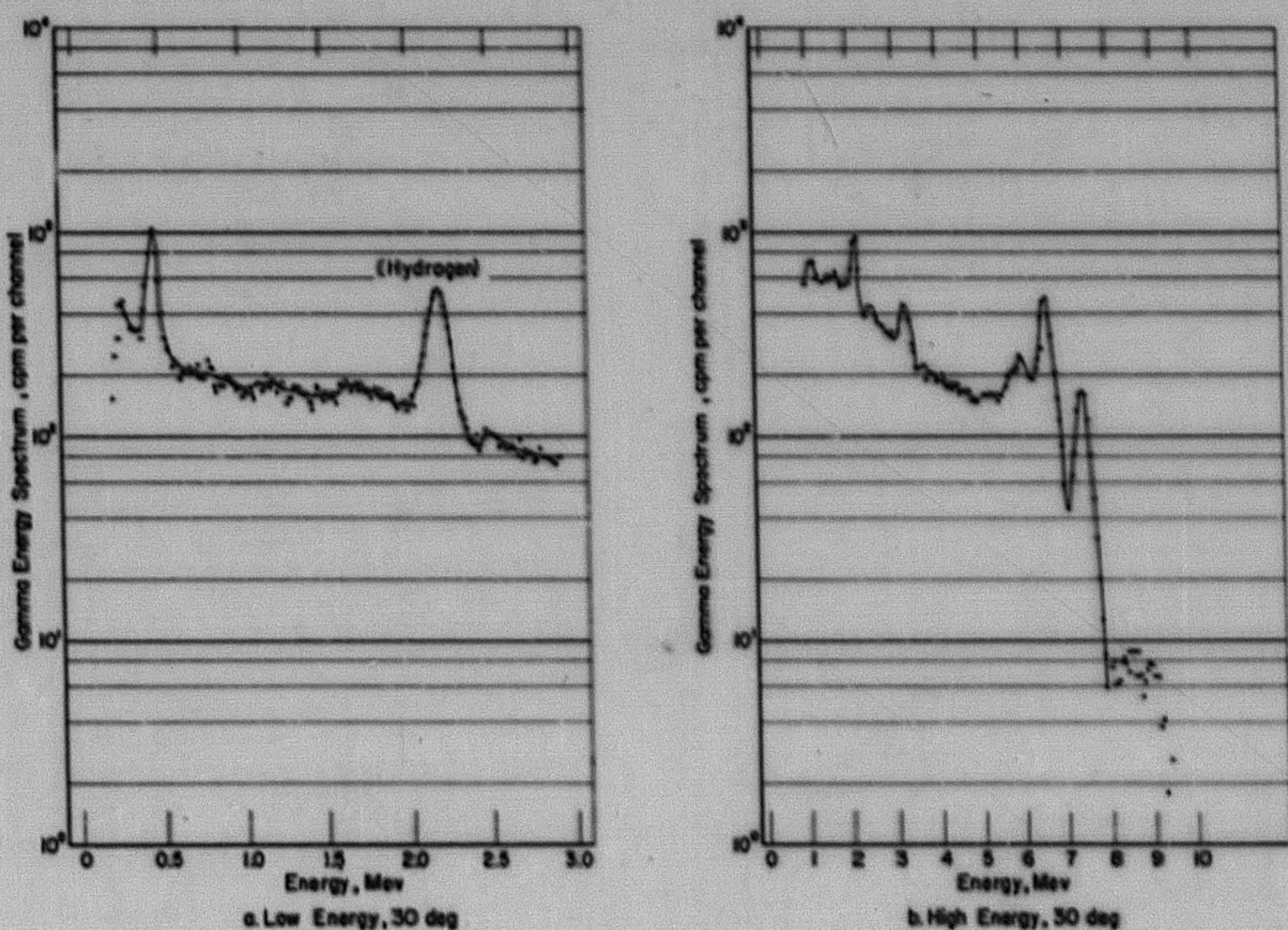

FIGURE 15. HIGH- AND LOW-ENERGY GAMMA SPECTRA MEASURED BEHIND THE 21-IN.-THICK BeO SLAB USING AN 8 BY 8-IN. NaI CRYSTAL AT 30 AND 45 DEG WITH THE HORIZONTAL CENTER LINE

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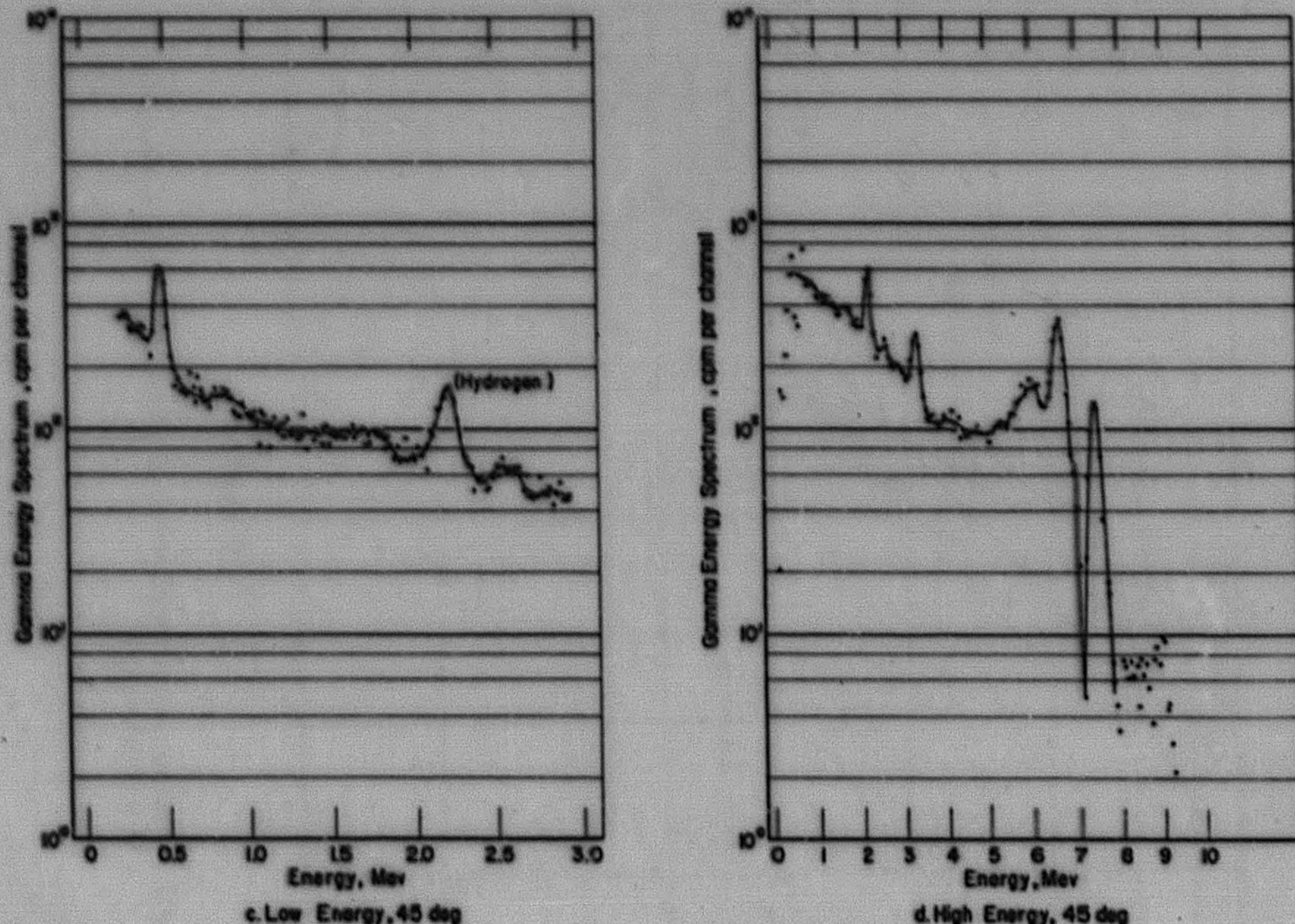

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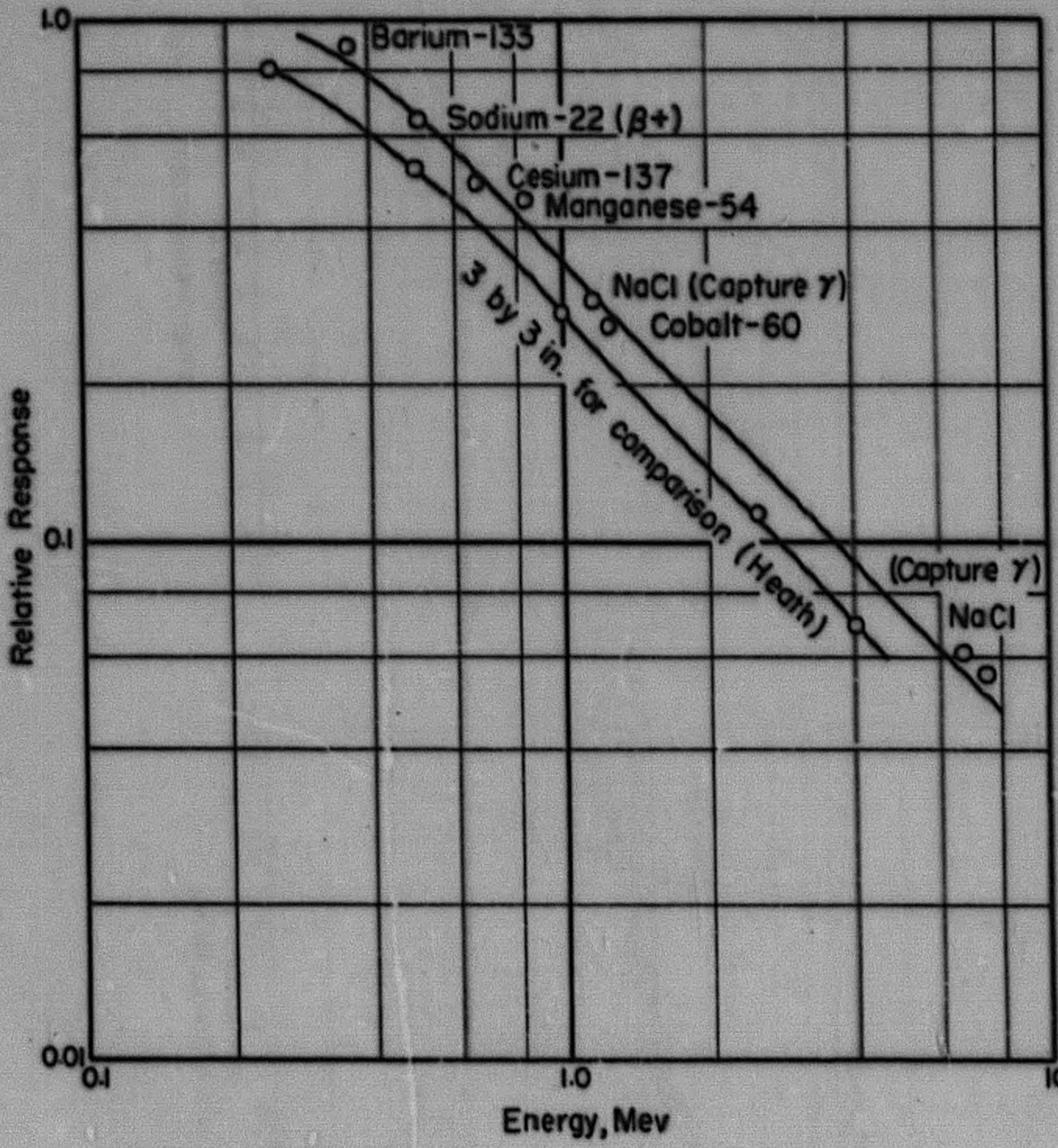

FIGURE 16. EXPERIMENTAL PHOTOPEAK EFFICIENCY FOR 8 BY 8-IN. NAI (Tl) CRYSTAL

The curve indicates that the neutrons above 1.4 Mev are attenuated with a relaxation length of 5.1 cm. A relaxation length of 5.3 cm for fast-neutron dose rate due to neutrons above 0.3 Mev has been determined. It is thus concluded that there is a build-up of neutrons in the 1.0 to 2.0-Mev range and is attributed to the minimum in the beryllium cross section in this energy range.

Gamma energy spectra behind 4, 9, 13, 17, and 21 in. of BeO were measured using an 8 by 8-in. NaI crystal.[3,4] The beam was collimated by a 5/8-in.-diameter by 5-ft-long watertight collimator which could be positioned at angles of 0, 30, and 45 deg with the horizontal center line. The crystal was placed in a watertight lead cask with 10-in.-thick walls. Figures 13, 14, and 15 show the results of the spectra measurements. The 6.8 and the 3.41-Mev beryllium capture gammas became prominent as the thickness of BeO increased. The 2.2-Mev hydrogen capture gamma from the water could also be seen. Hardening of the spectrum with penetration into the BeO is evident. The angular dependence of the spectrum shape is only slight. No unscrambling or efficiency correction has been done on these spectra. The change of efficiency with incident gamma energy is shown in Figure 16.

REFERENCES

(1) Morgan, W. R., Epstein, H. M., Anno, J. N., and Chastain, J. W., "Shielding-Research Area at Battelle", BMI-1291 (Sept. 18, 1958).

(2) Klingensmith, R. W., Epstein, H. M., and Chastain, J. W., "Shielding Studies on Salt Slabs", BMI-1384 (October 7, 1959). Confidential.

(3) Weiss, W. L., "Calibration of an 8 In. x 8 In. Sodium Iodide (Tl) Crystal", XDC-60-3-212 (March 24, 1960).

(4) Brooks, E. H., and Weiss, W. L., "Resolution of Total Absorption NaI (Tl) Crystals", paper presented at the Total Absorption Gamma-Ray Spectrometry Symposium, Gatlinburg, Tennessee (May 10, 1960).

(5) Trice, J. B., "A Series of Thermal, Epithermal, and Fast Neutron Measurements in the MTR", CF-55-10-140 (October, 1955).

(6) Goldstein, H., and Krumbein, A. D., "Moments Method Calculation of the Penetration of Neutrons From a Point Fission Source Through Be and BeO", NDA Memo 2124-1 (May 27, 1960).

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APPENDIX

TABLES OF EXPERIMENTAL DATA

TABLE A-1. FAST-NEUTRON DOSE RATE MEASURED ALONG THE CENTER LINE BEHIND THE BeO SLABS

Dose rate is rad/(hr)(w); distance is cm from fission plate

4-In. BeO		9-In. BeO		13-In. BeO		17-In. BeO		21-In. BeO	
Distance	Dose	Distance	Dose	Distance	Dose	Distance	Dose	Distance	Dose
17.78	4.56	28.14	1.09	39.57	1.35×10^{-1}	51.98	1.44×10^{-2}	60.07	4.82×10^{-3}
20.00	2.92	36.22	2.41×10^{-1}	44.24	5.9×10^{-2}	56.03	6.67×10^{-3}	64.06	1.90×10^{-3}
24.00	1.35	40.28	9.00×10^{-2}	48.29	2.8×10^{-2}	60.04	3.29×10^{-3}	68.11	8.98×10^{-4}
28.02	6.48×10^{-1}	44.29	5.50×10^{-2}	52.22	1.3×10^{-2}	64.04	1.70×10^{-3}	72.11	4.37×10^{-4}
32.00	3.25×10^{-1}	48.26	2.80×10^{-2}	56.38	6.9×10^{-3}	68.07	9.15×10^{-4}	76.11	2.34×10^{-4}
36.01	1.68×10^{-1}	52.51	1.40×10^{-2}	60.35	3.6×10^{-3}	72.02	4.86×10^{-4}	80.13	1.31×10^{-4}
40.00	8.82×10^{-2}	56.98	8.09×10^{-3}	68.97	9.05×10^{-4}	76.04	2.72×10^{-4}	84.14	6.63×10^{-5}
44.04	4.75×10^{-2}	60.97	4.17×10^{-3}	73.00	5.09×10^{-4}	80.08	1.51×10^{-4}	88.98	3.94×10^{-5}
44.97	4.19×10^{-2}	64.96	2.53×10^{-3}	77.00	2.91×10^{-4}	84.09	8.19×10^{-5}	93.06	2.36×10^{-5}
49.90	2.39×10^{-2}	68.95	1.39×10^{-3}	80.98	1.72×10^{-4}	88.95	4.30×10^{-5}	96.95	1.25 x 10[illegible]
52.96	1.30×10^{-2}	72.97	8.07×10^{-4}	84.98	1.04×10^{-4}	93.00	2.62×10^{-5}		
56.97	7.56×10^{-3}	77.00	4.82×10^{-4}	89.00	6.05×10^{-5}				
61.00	4.37×10^{-3}	80.98	2.88×10^{-4}	93.00	3.75×10^{-5}				
64.96	2.81×10^{-3}	85.00	1.71×10^{-4}						
69.00	1.59×10^{-3}	89.00	1.13×10^{-4}						
72.58	9.57×10^{-4}	92.98	7.01×10^{-5}						
77.00	5.74×10^{-4}	96.96	4.42×10^{-5}						
80.59	3.52×10^{-4}	101.02	3.03×10^{-5}						
85.00	2.17×10^{-4}								
88.97	1.32×10^{-4}								
92.95	8.50×10^{-5}								
97.01	5.25×10^{-5}								

TABLE A-2. GAMMA DOSE RATE MEASURED ALONG THE CENTER LINE BEHIND THE BeO SLABS

Dose rate is in rad/(hr)(w); distance is cm from fission plate

4-in. BeO		9-in. BeO		13-in. BeO		17-in. BeO		21-in. BeO	
Distance	Dose	Distance	Dose	Distance	Dose	Distance	Dose	Distance	Dose
17.18	13.1	33.17	5.01	41.19	3.55	51.23	1.77	62.66	8.53×10^{-1}
21.20	10.5	37.20	4.30	45.21	2.58	53.12	1.52	65.25	7.03×10^{-1}
25.17	8.88	41.20	3.61	49.13	1.96	57.21	1.15	69.28	4.96×10^{-1}
29.16	7.43	45.22	2.77	53.24	1.51	61.24	8.65×10^{-1}	73.29	4.00×10^{-1}
33.19	5.38	49.23	2.21	57.21	1.17	65.25	6.78×10^{-1}	77.28	3.15×10^{-1}
37.25	4.57	53.14	1.77	61.23	9.21×10^{-1}	69.30	5.40×10^{-1}	81.39	2.52×10^{-1}
41.23	3.84	57.23	1.41	65.26	7.20×10^{-1}	73.28	4.32×10^{-1}	85.30	2.06×10^{-1}
45.18	3.07	61.11	1.12	69.25	5.67×10^{-1}	77.30	3.63×10^{-1}	89.32	1.67×10^{-1}
49.23	2.63	65.29	9.13×10^{-1}	73.27	4.67×10^{-1}	81.26	2.77×10^{-1}	93.32	1.38×10^{-1}
53.21	2.09	69.31	7.26×10^{-1}	77.24	[illegible].03 x 10^{-1}	85.27	2.33×10^{-1}	97.33	1.15×10^{-1}
57.13	1.76	73.27	5.90×10^{-1}	81.29	3.06×10^{-1}	89.30	1.85×10^{-1}	101.34	9.13×10^{-2}
61.24	1.40	77.30	4.77×10^{-1}	85.30	2.45×10^{-1}	93.28	1.55×10^{-1}	105.35	7.66×10^{-2}
65.29	1.40	81.29	3.15×10^{-1}	89.35	1.90×10^{-1}	97.32	1.27×10^{-1}	109.36	6.27×10^{-2}
69.27	9.95×10^{-1}	89.30	2.63×10^{-1}	93.34	1.53×10^{-1}	101.34	1.09×10^{-1}	113.37	5.40×10^{-2}
73.30	7.61×10^{-1}	93.36	2.11×10^{-1}	97.35	1.22×10^{-1}	105.34	9.17×10^{-2}	117.38	4.52×10^{-2}
77.30	6.14×10^{-1}	97.11	1.63×10^{-1}	105.34	7.14×10^{-2}	109.36	7.48×10^{-2}	121.41	[illegible] x 10^{-2}
81.29	4.93×10^{-1}	101.34	1.57×10^{-1}	113.40	4.08×10^{-2}				
89.33	3.26×10^{-1}	105.35	1.25×10^{-1}	12[illegible].37	1.36×10^{-2}				
97.34	2.31×10^{-1}	109.34	1.08×10^{-1}						
105.38	1.62×10^{-1}	113.35	8.71×10^{-2}						
113.37	1.18×10^{-1}	117.39	7.84×10^{-2}						
121.42	8.26×10^{-2}								
129.29	5.88×10^{-2}								

TABLE A-3. THERMAL-NEUTRON FLUX MEASURED ALONG THE CENTER LINE BEHIND THE BeO SLABS

Flux is n/(cm^2)(sec)(w); distance is cm from fission plate

4-in. BeO		9-in. BeO		13-in. BeO		17-in. BeO		21-in. BeO	
Distance	Flux	Distance	Flux	Distance	Flux	Distance	Flux	Distance	Flux
17.20	1.59×10^7	29.13	7.01×10^6	38.87	4.30×10^6	50.96	7.33×10^5	59.95	9.44×10^5
21.18	7.42×10^6	33.22	2.02×10^6	41.21	1.68×10^6	53.24	3.27×10^5	61.27	5.07×10^5
25.13	2.68×10^6	37.21	6.24×10^5	43.25	9.79×10^5	57.24	1.95×10^4	63.30	2.92×10^5
29.16	1.05×10^6	41.19	1.95×10^5	45.23	4.92×10^5	61.24	2.17×10^4	65.65	9.79×10^4
33.23	4.49×10^5	45.21	6.96×10^4	49.22	1.26×10^5	65.27	7.13×10^3	67.28	6.01×10^4
41.21	9.87×10^5	49.21	2.88×10^4	50.23	9.01×10^4	69.26	2.08×10^3	69.26	2.78×10^4
45.23	5.18×10^4	53.22	1.34×10^4	53.22	4.04×10^4	73.22	6.65×10^2	73.29	6.59×10^3
49.29	2.19×10^4	57.14	6.22×10^3	57.14	1.22×10^4	77.29	2.46×10^2	77.32	1.73×10^3
53.27	1.16×10^4	65.13	1.51×10^3	61.25	4.19×10^3	81.30	1.06×10^2	81.33	4.57×10^2
57.23	6.10×10^3	69.24	7.97×10^2	65.27	1.75×10^3	85.35	5.00×10^1	85.34	1.27×10^2
61.26	3.20×10^3	73.21	4.27×10^2	69.27	7.79×10^2			89.33	4.30×10^1
65.22	1.61×10^3	77.29	2.37×10^2	73.27	3.69×10^2			93.32	1.68×10^1
69.31	9.79×10^2	81.31	1.34×10^2	77.28	1.94×10^2				
73.27	5.81×10^2	85.18	7.40×10^1	--	--				
77.31	3.21×10^2	89.35	4.32×10^1	85.31	5.69×10^1				
81.29	1.90×10^2	93.38	2.59×10^1	89.35	3.20×10^1				
85.29	1.07×10^2								
89.29	6.75×10^1								
93.30	4.10×10^1								

TABLE A-4. FAST-NEUTRON DOSE RATE, GAMMA DOSE RATE, AND THERMAL-NEUTRON FLUX MEASURED ALONG THE CENTER LINE THROUGH THE 21-IN.-THICK BeO SLAB

Fast Neutron		Gamma		Thermal Neutron: Gold-Foil Measurements		Thermal Neutron: Fission-Chamber Measurements	
Distance From Fission Plate, cm	Dose Rate, rad/(hr)(w)	Distance From Fission Plate, cm	Dose Rate, rad/(hr)(w)	Distance From Fission Plate, cm	Flux, n/(cm²)(sec)(w)	Distance From Fission Plate, cm	Flux, n/(cm²)(sec)(w)
9.4	82.4	3.9	52.9	1.75	1.10×10^{7}	4.2	2.07×10^{7}
14.5	23.9	9.4	30.9	12.16	4.31×10^{7}	9.5	3.74×10^{7}
19.8	10.4	14.5	17.8	22.5	3.31×10^{7}	14.6	3.94×10^{7}
32.3	9.10×10^{-1}	19.6	12.4	45.50	7.08×10^{6}	19.8	3.30×10^{7}
37.5	3.30×10^{-1}	29.8	6.2	56.00	2.86×10^{6}	30.1	2.04×10^{7}
47.9	6.20×10^{-2}	37.5	3.1			37.6	1.22×10^{7}
53.1	2.40×10^{-2}	42.8	2.5			42.8	8.97×10^{6}
		47.9	2.2			47.9	5.94×10^{6}
		53.1	1.4			53.1	3.36×10^{6}

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TABLE A-5. FAST-NEUTRON DOSE RATE, GAMMA DOSE RATE, AND THERMAL-NEUTRON FLUX IN A VERTICAL PLANE WITHIN THE 21-IN.-THICK BeO SLAB

Fast Neutron

Vertical Distance From Horizontal Center Line, cm	Dose Rate at Indicated Distance From Fission Plate, rad/(hr)(w): 24.8 Cm	37.5 Cm	47.9 Cm
0.00	3.70	3.31×10^{-1}	5.66×10^{-2}
10.56	3.98	3.60×10^{-1}	5.76×10^{-2}
21.12	3.46	3.16×10^{-1}	5.00×10^{-2}
31.68	2.44	2.22×10^{-1}	3.17×10^{-2}
42.25	1.13	1.21×10^{-1}	1.99×10^{-2}
52.80	6.43×10^{-1}	1.15×10^{-1}	2.51×10^{-2}
63.38	1.73×10^{-1}	3.86×10^{-2}	9.40×10^{-3}
73.92	1.07×10^{-2}	--	4.56×10^{-3}

Gamma

Vertical Distance From Horizontal Center Line, cm	Dose Rate at Indicated Distance From Fission Plate, rad/(hr)(w): 3.9 Cm	19.8 Cm
0.00	50.0	12.8
2.64	50.0	12.8
5.28	50.4	12.8
10.56	49.4	12.4
15.84	48.5	11.6
21.12	44.8	10.3
26.41	36.9	8.6
31.69	26.4	6.8
36.97	15.4	5.45
42.25	9.20	--
47.53	5.11	2.16
52.81	2.62	--
58.09	1.79	--
63.37	1.35	--

Thermal Neutron

Vertical Distance From Horizontal Center Line, cm	Flux at Indicated Distance From Fission Plate, n/(cm²)(sec)(w): 19.75 Cm	37.73 Cm	53.10 Cm
0	3.30×10^{7}	1.28×10^{7}	3.36×10^{6}
15.84	3.23×10^{7}	1.18×10^{7}	3.21×10^{6}
26.41	2.75×10^{7}	1.01×10^{7}	2.63×10^{6}
36.97	1.69×10^{7}	5.94×10^{6}	1.54×10^{6}
42.25	9.74×10^{6}	3.27×10^{6}	8.56×10^{5}
44.89	5.98×10^{6}	1.93×10^{6}	4.86×10^{5}
47.53	2.27×10^{6}	8.81×10^{5}	2.18×10^{5}
50.17	8.05×10^{5}	2.65×10^{5}	6.11×10^{4}
52.81	2.91×10^{5}	7.50×10^{5}	1.61×10^{4}
55.45	1.58×10^{5}	3.46×10^{5}	6.99×10^{3}
58.09	1.30×10^{5}	3.09×10^{5}	5.59×10^{3}
60.73	1.86×10^{5}	4.44×10^{5}	7.62×10^{3}
63.37	2.71×10^{5}	6.64×10^{5}	1.07×10^{4}
66.01	3.19×10^{5}	7.57×10^{5}	1.22×10^{4}
68.65	2.69×10^{5}	6.30×10^{5}	9.52×10^{3}
71.30	1.75×10^{5}	3.94×10^{5}	5.94×10^{3}
73.93	9.73×10^{4}	2.09×10^{4}	3.36×10^{3}

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TABLE A-6. MEASUREMENTS OF FAST-NEUTRON INTEGRAL FLUX THROUGH THE 21 IN.-THICK BeO SLAB

Reaction	Threshold Energy, Mev	Integral Flux, $n/(cm^2)(sec)(w)$, at Indicated Distance from Fission Plate			
		1.65 Cm	11.96 Cm	21.96 Cm	32.60 Cm
P(n,p)	2.4	$(4.17 \pm 0.07) \times 10^6$	$(5.07 \pm 0.20) \times 10^5$	$(7.80 \pm 0.60) \times 10^4$	$(1.33 \pm 0.12) \times 10^4$
S(n,p)	2.9	$(3.16 \pm 0.13) \times 10^6$	$(3.97 \pm 0.10) \times 10^5$	$(5.50 \pm 0.13) \times 10^4$	$(8.80 \pm 0.20) \times 10^3$
Ni(n,p)	2.4	$(4.17 \pm 0.07) \times 10^6$	$(5.13 \pm 0.07) \times 10^5$	$(6.90 \pm 0.10) \times 10^4$	$(1.15 \pm 0.01) \times 10$[illegible]
Ni(n,p)	5.0	$(7.26 \pm 0.07) \times 10^5$	$(8.97 \pm 0.13) \times 10^4$	$(1.20 \pm 0.02) \times 10^4$	$(2.00 \pm 0.02) \times 10^3$
Si(n,p)	5.5	$(5.16 \pm 0.20) \times 10^5$	$(6.37 \pm 0.27) \times 10^4$	$(9.20 \pm 0.77) \times 10^3$	$(1.85 \pm 0.26) \times 10^3$
Mg(n,p)	6.3	$(2.46 \pm 0.05) \times 10^5$	$(4.13 \pm 0.70) \times 10^4$	$(1.19 \pm 0.01) \times 10^4$	$(1.97 \pm 0.17) \times 10^3$
Al(n,α)	8.1	$(7.06 \pm 0.13) \times 10^4$	$(8.87 \pm 0.40) \times 10^3$	$(1.29 \pm 0.07) \times 10^3$	$(1.98 \pm 0.16) \times 10^2$