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LID TANK SHIELDING FACILITY

MEASUREMENTS BEHIND THE

ML-1 MOCKUP

A. D. MacKellar
L. Jung
D. R. Mathews
F. J. Muckenthaler
J. M. Miller
N. K. Sowards

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Neutron Physics Division

Lid Tank Shielding Facility Measurements Behind the ML-1 Mockup

A. D. MacKellar
L. Jung
D. R. Mathews*
F. J. Muckenthaler
J. M. Miller
N. K. Sowards*

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*Aerojet-General Nucleonics, San Ramon, California.

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Abstract

At the request of Aerojet-General Nucleonics an experimental evaluation of the shield design for the ML-1 mobile reactor was made at the Lid Tank Shielding Facility of the Oak Ridge National Laboratory. Thermal-neutron fluxes, fast-neutron dose rates, and gamma-ray dose rates were measured behind slab mockups of the basic shield design and a number of possible variations. The designs embodied various combinations of lead, Hevimet, stainless steel, boral, water, and aqueous solutions of ammonium pentaborate at two concentrations. The after-shutdown decay characteristics of the basic design were determined, and data was obtained from a fairly accurate mockup of the stainless steel plenum and gas duct typical of the top and bottom regions of the ML-1 shield. Analysis of results and application to the final shield design were performed by Aerojet-General, and are not reported here.

LID TANK SHIELDING FACILITY MEASUREMENTS BEHIND THE ML-1 MOCKUP

A. D. MacKellar, F. J. Muckenthaler, Lincoln Jung,
J. M. Miller, D. R. Mathews,[1] and N. K. Sowards[1]

INTRODUCTION

The ML-1 reactor[2] of Aerojet-General Nucleonics, a high-temperature, gas-cooled, transportable power reactor, utilizes an integral radiation shield consisting primarily of metal and borated water. At the request of Aerojet-General, a series of experiments has been completed at the Lid Tank Shielding Facility (LTSF) for the purpose of evaluating the characteristics of the original ML-1 shield design as well as several possible variations. Data obtained behind slab mockups in the steel configuration tank of the LTSF included thermal-neutron fluxes, fast neutron dose rates, and gamma-ray dose rates. Data were also obtained using a mockup of the stainless steel plenum and gas duct typical of the top and bottom regions of the ML-1 shield. The postshutdown decay characteristics of the shield, important because of the requirement that the reactor be mobile 24 hours after shutdown, have been observed.

Analysis of these results and application to the ML-1 shield design were performed by Aerojet-General Nucleonics, and are not reported herein.

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1. Aerojet-General Nucleonics, San Ramon, California.

2. The ML-1 Design Report, IDO-28550, Aerojet-General Nucleonics, San Ramon, California, May 16, 1960.

EXPERIMENTAL PROCEDURE

A complete list of the configurations tested is given in Table 1. Mockups were placed in the steel configuration tank of the LTSF as close to the source plate as possible. A "probe distance," defined as the distance from the source plate assembly to the rear of the slab configuration plus the thickness of the front wall of the thin-walled aluminum tank within which measurements were made, was measured for each experiment. The probe distance was used to compute the unavoidable air gap within the experimental configuration, as well as in extrapolation of data to zero water thickness. The air gap in the shield mockup was equal to the probe distance less the distance from the source plate assembly to the rear face of the aluminum window of the configuration tank plus the thicknesses of the components of the mockup.

Thermal-neutron fluxes were measured with U^{235} fission chambers and BF_3 counters, and were normalized to gold foil measurements. Fast-neutron dose rates were measured with Hurst-type dosimeters, and gamma-ray dose rates with either an anthracene crystal scintillation counter or a 50-cc graphite ionization chamber. All data were normalized to a per-watt basis by dividing by 5.22 watts, the nominal source plate power.

EXPERIMENTAL RESULTS

Configuration I-0 was the first to be tested, and represents the types and thicknesses of materials proposed in the original ML-1 reference design except that it contained tap water instead of water mixed with ammonium pentaborate (APB). Configuration I-8 was identical, except that a 7.5 wt % solution of APB in water was substituted for the plain

Table 1. Description of Configurations

Configuration Number	Components in Order of Location in Front of Tank	Probe Distance (cm)	Per Cent Boron
I-0	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 3-3/4 in. lead, 1/8 in. stainless steel 5-in. stainless steel tank containing 1/8 in. stainless steel, 5 in. dry APB, 1/8 in. stainless steel 1/8 in. boral 25-in. aluminum tank containing 1/8 in. aluminum, 25 in. water, 1/8 in. aluminum	43.67	0.0
I-8	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 3-3/4 in. lead, 1/8 in. stainless steel 5-in. stainless steel tank containing 1/8 in. stainless steel, 5 in. dry APB, 1/8 in. stainless steel 1/8 in. boral 25-in. aluminum tank containing 1/8 in. aluminum, 25 in. 7.5%* APB, 1/8 in. aluminum	43.67	1.52
II-8	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 3-3/4 in. lead, 1/8 in. stainless steel, 1/8 in. boral 5-in. stainless steel tank containing 1/8 in. stainless steel, 5 in. 7.5% APB, 1/8 in. stainless steel 25-in. aluminum tank containing 1/8 in. aluminum, 25 in. 7.5% APB, 1/8 in. aluminum	43.20	1.52

*7.5% means 7.5% APB by weight in water.

Table 1 (continued)

Configuration Number	Components in Order of Location in Front of Tank	Probe Distance (cm)	Per Cent Boron
III-8-(1/2)	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 3-1/4 in. lead	42.32	1.52
	5-in. stainless steel tank containing 1/8 in. stainless steel, 5 in. 7.5% APB, 1/8 in. stainless steel		
	1/2 in. lead, 1/8 in. stainless steel, 1/8 in. boral		
	25-in. aluminum tank containing 1/8 in. aluminum, 25 in. 7.5% APB, 1/8 in. aluminum		
III-8-1	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 2-3/4 in. lead	42.42	1.52
	5-in. stainless steel tank containing 1/8 in. stainless steel, 5 in. 7.5% APB, 1/8 in. stainless steel		
	1 in. lead, 1/8 in. stainless steel, 1/8 in. boral		
	25-in. aluminum tank containing 1/8 in. aluminum, 25 in. 7.5% APB, 1/8 in. aluminum		
III-8-2	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 1-3/4 in. lead	42.42	1.52
	5-in. stainless steel tank containing 1/8 in. stainless steel, 5 in. 7.5% APB, 1/8 in. stainless steel		
	2 in. lead, 1/8 in. stainless steel, 1/8 in. boral		
	25-in. aluminum tank containing 1/8 in. aluminum, 25 in. 7.5% APB, 1/8 in. aluminum		

Table 1 (continued)

Configuration Number	Components in Order of Location in Front of Tank	Probe Distance (cm)	Per Cent Boron
IIIA-8-1	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 2-3/4 in. lead, 1/2 in. boral, 1/2 in. air 5-in. stainless steel tank containing 1/8 in. stainless steel, 5 in. 7.5% APB, 1/8 in. stainless steel 1 in. lead, 1/8 in. stainless steel, 1/8 in. boral 25-in. aluminum tank containing 1/8 in. aluminum, 25 in. 7.5% APB, 1/8 in. aluminum	44.37	1.52
IIIC-8-1	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 2-3/4 in. lead, 1/8 in. boral, 7/8 in. air 5-in. stainless steel tank containing 1/8 in. stainless steel, 5 in. 7.5% APB, 1/8 in. stainless steel 1 in. lead, 1/8 in. stainless steel, 1/8 in. boral 25-in. aluminum tank containing 1/8 in. aluminum, 25 in. 7.5% APB, 1/8 in. aluminum	44.31	1.52
IIID-8-1	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 2-3/4 in. lead, 1/8 in. boral, 1/4 in. air 5-in. stainless steel tank containing 1/8 in. stainless steel, 5 in. 7.5% APB, 1/8 in. stainless steel 1/4 in. boral, 1 in. lead, 1/8 in. stainless steel, 1/8 in. boral 25-in. aluminum tank containing 1/8 in. aluminum, 25 in. 7.5% APB, 1/8 in. aluminum	44.02	1.52

Table 1 (continued)

Configuration Number	Components in Order of Location in Front of Tank	Probe Distance (cm)	Per Cent Boron
IIIE-8-1	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 2-3/4 in. lead, 1/2 in. boral, 3/4 in. air	43.68	1.52
	5-in. stainless steel tank containing 1/8 in. stainless steel, 5 in. 7.5% APB, 1/8 in. stainless steel		
	1 in. lead		
	25-in. aluminum tank containing 1/8 in. aluminum, 25 in. 7.5% APB, 1/8 in. aluminum		
IV-8-0	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 3-3/4 in. lead, 1/8 in. stainless steel, 1/2 in. boral	29.88	1.52
	31-in. aluminum tank containing 1/8 in. aluminum, 31 in. 7.5% APB, 1/8 in. aluminum		
IV-8-(1/2)-5	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 3-1/4 in. lead, 1/8 in. stainless steel, 1/2 in. boral	35.75	1.52
	31-in. aluminum tank containing 1/8 in. aluminum, 5 in. 7.5% APB, 1/2 in. lead, 25-1/2 in. 7.5% APB, 1/8 in. aluminum		
IV-8-(1/2)-10	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 3-1/4 in. lead, 1/8 in. stainless steel, 1/2 in. boral	48.45	1.52
	31-in. aluminum tank containing 1/8 in. aluminum, 10 in. 7.5% APB, 1/2 in. lead, 20-1/2 in. 7.5% APB, 1/8 in. aluminum		

Table 1 (continued)

Configuration Number	Components in Order of Location in Front of Tank	Probe Distance (cm)	Per Cent Boron
IV-8-(1/2)-18	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 3-1/4 in. lead, 1/8 in. stainless steel, 1/2 in. boral 31-in. aluminum tank containing 1/8 in. aluminum, 18 in. 7.5% APB, 1/2 in. lead, 12-1/2 in. 7.5% APB, 1/8 in. aluminum	61.13	1.52
IV-8-1-5	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 2-3/4 in. lead, 1/8 in. stainless steel, 1/2 in. boral 31-in. aluminum tank containing 1/8 in. aluminum, 5 in. 7.5% APB, 1 in. lead, 25 in. 7.5% APB, 1/8 in. aluminum	43.97	1.52
IV-8-1-10	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 2-3/4 in. lead, 1/8 in. stainless steel, 1/2 in. boral 31-in. aluminum tank containing 1/8 in. aluminum, 10 in. 7.5% APB, 1 in. lead, 20 in. 7.5% APB, 1/8 in. aluminum	56.89	1.52
IV-8-1-18	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 2-3/4 in. lead, 1/8 in. stainless steel, 1/2 in. boral 31-in. aluminum tank containing 1/8 in. aluminum, 18 in. 7.5% APB, 1 in. lead, 12 in. 7.5% APB, 1/8 in. aluminum	77.04	1.52
IVA-8-(1-1/2)-5	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 2-3/4 in. lead, 1/8 in. stainless steel, 1/2 in. boral	45.68	1.52

Table 1 (continued)

Configuration Number	Components in Order of Location in Front of Tank	Probe Distance (cm)	Per Cent Boron
IVA-8-(1-1/2)-5 (continued)	31-in. aluminum tank containing 1/8 in. aluminum, 5 in. 7.5% APB, 1-1/2 in. lead, 24-1/2 in. 7.5% APB, 1/8 in. aluminum		
IV-8-2-(2-1/2)	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 1-3/4 in. lead, 1/8 in. stainless steel, 1/2 in. boral	37.24	1.52
	31-in. aluminum tank containing 1/8 in. aluminum, 2-1/2 in. 7.5% APB, 2 in. lead, 26-1/2 in. 7.5% APB, 1/8 in. aluminum		
IV-8-2-5	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 1-3/4 in. lead, 1/8 in. stainless steel, 1/2 in. boral	42.72	1.52
	31-in. aluminum tank containing 1/8 in. aluminum, 5 in. 7.5% APB, 2 in. lead, 24 in. 7.5% APB, 1/8 in. aluminum		
IV-8-2-10	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 1-3/4 in. lead, 1/8 in. stainless steel, 1/2 in. boral	56.42	1.52
	31-in. aluminum tank containing 1/8 in. aluminum, 10 in. 7.5% APB, 2 in. lead, 19 in. 7.5% APB, 1/8 in. aluminum		
IVB-8-2-(2-1/2)	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 1-3/4 in. lead, 1/8 in. stainless steel, 1/2 in. boral	38.62	1.52
	31-in. aluminum tank containing 1/8 in. aluminum, 2-1/2 in. 7.5% APB, 1/2 in. boral, 2 in. lead, 26 in. 7.5% APB, 1/8 in. aluminum		

Table 1 (continued)

Configuration Number	Components in Order of Location in Front of Tank	Probe Distance (cm)	Per Cent Boron
IVC-8-(3-1/2)-(2-1/2)	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 1-3/4 in. lead, 1/8 in. stainless steel, 1/2 in. boral 31-in. aluminum tank containing 1/8 in. aluminum, 2-1/2 in. 7.5% APB, 3-1/2 in. lead, 25 in. 7.5% APB, 1/8 in. aluminum	42.42	1.52
IVC-8-(3-1/2)-5	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 1-3/4 in. lead, 1/8 in. stainless steel, 1/2 in. boral 31-in. aluminum tank containing 1/8 in. aluminum, 5 in. 7.5% APB, 1/2 in. boral, 3-1/2 in. lead, 22 in. 7.5% APB, 1/8 in. aluminum	47.91	1.52
IVD-8-(3-1/2)-5A	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 1-3/4 in. lead, 1/8 in. stainless steel, 1/2 in. boral 31-in. aluminum tank containing 1/8 in. aluminum, 2-1/2 in. 7.5% APB, 1/2 in. boral, 2 in. lead, 2-1/2 in. 7.5% APB, 1-1/2 in. lead, 22 in. 7.5% APB, 1/8 in. aluminum	47.88	1.52
IVE-8-5-5	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 1-3/4 in. lead, 1/8 in. stainless steel, 1/2 in. boral 31-in. aluminum tank containing 1/8 in. aluminum, 5 in. 7.5% APB, 1/2 in. boral, 5 in. lead, 20-1/2 in. 7.5% APB, 1/8 in. aluminum	52.42	1.52

Table 1 (continued)

Configuration Number	Components in Order of Location in Front of Tank	Probe Distance (cm)	Per Cent Boron
IV-15-1-0	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 2-3/4 in. lead, 1/8 in. stainless steel, 1/2 in. boral 31-in. aluminum tank containing 1/8 in. aluminum, 1 in. lead, 30 in. 15% APB, 1/8 in. aluminum	31.10	3.12
IV-15-1-(2-1/2)	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 2-3/4 in. lead, 1/8 in. stainless steel, 1/2 in. boral 31-in. aluminum tank containing 1/8 in. aluminum, 2-1/2 in. 15% APB, 1 in. lead, 27-1/2 in. 15% APB, 1/8 in. aluminum	36.69	3.12
IV-15-1-5	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 2-3/4 in. lead, 1/8 in. stainless steel, 1/2 in. boral 31-in. aluminum tank containing 1/8 in. aluminum, 5 in. 15% APB, 1 in. lead, 25 in. 15% APB, 1/8 in. aluminum	43.57	3.12
IV-15-1-10	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 2-3/4 in. lead, 1/8 in. stainless steel, 1/2 in. boral 31-in. aluminum tank containing 1/8 in. aluminum, 10 in. 15% APB, 1 in. lead, 20 in. 15% APB, 1/8 in. aluminum	55.72	3.12
IV-15-1-18	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 2-3/4 in. lead, 1/8 in. stainless steel, 1/2 in. boral	76.61	3.12

Table 1 (continued)

Configuration Number	Components in Order of Location in Front of Tank	Probe Distance (cm)	Per Cent Boron
IV-15-1-18 (continued)	31-in. aluminum tank containing 1/8 in. aluminum, 18 in. 15% APB, 1 in. lead, 12 in. 15% APB, 1/8 in. aluminum		
IV-15-1-(2-1/2)A	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 2-3/4 in. lead, 1/8 in. stainless steel, 1/2 in. boral	40.17	3.12
	31-in. aluminum tank containing 1/8 in. aluminum, 2-1/2 in. 15% APB, 1/2 in. boral, 1 in. lead, 1/4 in. boral, 26-3/4 in. 15% APB, 1/8 in. aluminum		
IV-15-0A	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. type-347 stainless steel, 1/8 in. boral, 2-3/4 in. lead, 1/8 in. stainless steel, 1/2 in. boral	32.36	3.12
	31-in. aluminum tank containing 1/8 in. aluminum, 1 in. lead, 1/4 in. boral, 29-3/4 in. 15% APB, 1/8 in. aluminum		
V	Iron duct in 7.5% APB		1.52
VI	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/8 in. stainless steel, 1/4 in. Lucite, 1/4 in. stainless steel, 2 in. lead, 1/8 in. boral, 1/4 in. aluminum	48.20	1.73
	56-in. aluminum tank containing 1/8 in. aluminum, 3 in. 7.5% APB, 1/4 in. aluminum, 1/8 in. boral, 2 in. lead, 1/8 in. boral, 1/4 in. aluminum, 2 in. polyethylene, 48-1/4 in. 7.5% APB, 1/8 in. aluminum		
VI-A	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/8 in. stainless steel, 1/4 in. Lucite, 1/4 in. stainless steel, 2 in. lead, 1/8 in. boral, 1/4 in. aluminum	43.27	1.67
	56-in. aluminum tank containing 1/8 in. aluminum, 3 in. 7.5% APB, 1/4 in. aluminum, 1/8 in. boral, 2 in. lead, 1/8 in. boral, 1/4 in. aluminum, 50-1/4 in. 7.5% APB, 1/8 in. aluminum		

Table 1 (continued)

Configuration Number	Components in Order of Location in Front of Tank	Probe Distance (cm)	Per Cent Boron
IV-8-1/2	2 in. lead, 1/4 in. aluminum, 2 in. Hevimet, 1/4 in. aluminum, 1/4 in. Lucite, 1/4 in. stainless steel, 1/8 in. boral, 3-1/4 in. lead, 1/8 in. stainless steel, 1/2 in. boral 31-in. aluminum tank containing 1/8 in. aluminum, 1/2 in. lead, 30-1/2 in. air, 1/8 in. aluminum		1.56

water. Figure 1 shows the thermal-neutron flux, as a function of distance, behind each of these configurations. The addition of boron to the water decreased the thermal flux by a factor varying from 10 to nearly 100. As shown in Fig. 2, however, the fast-neutron dose rate was reduced only about 10% by the addition of boron. Figure 3 compares the gamma-ray dose rates, showing roughly a factor-of-2 decrease with boron addition.

Configuration II-8, a variation on I-8 in which a 7.5 wt % solution of APB was substituted for the dry APB and the 1/8-in. boral plate placed before rather than behind the APB tank, showed roughly a 60% reduction in thermal-neutron flux relative to the I-8 results; a 50% reduction in fast-neutron dose rate; but little change in gamma-ray dose rate other than a slight flattening of the curve.

The after-shutdown decay of gamma radiation from configuration I-0 is displayed in Fig. 4, where gamma-ray dose rate is plotted as a function of time after shutdown.

The preferred distribution of a fixed total thickness of lead around the 5-in. tank of 7.5 wt % APB was investigated with configurations III-8-1/2, III-8-1, and III-8-2. In the first, 3-1/4 in. of lead preceded the APB tank, with 1/2 in. of lead behind. In the second the division was 2-3/4 in.-- 1 in., and in the third only 1-3/4 in. of lead was in front, with 2 in. of lead behind. (It will be noted that these thicknesses are keyed by the last number in the configuration designation.) From Fig. 5 it is clear that the lead shielded most effectively against gamma rays when placed behind the tank, the dose rate for 2 in. of lead behind the tank being about a factor of 3 lower than the rate with 1/2 in. of lead behind the tank. Since the relative placement of the lead should not

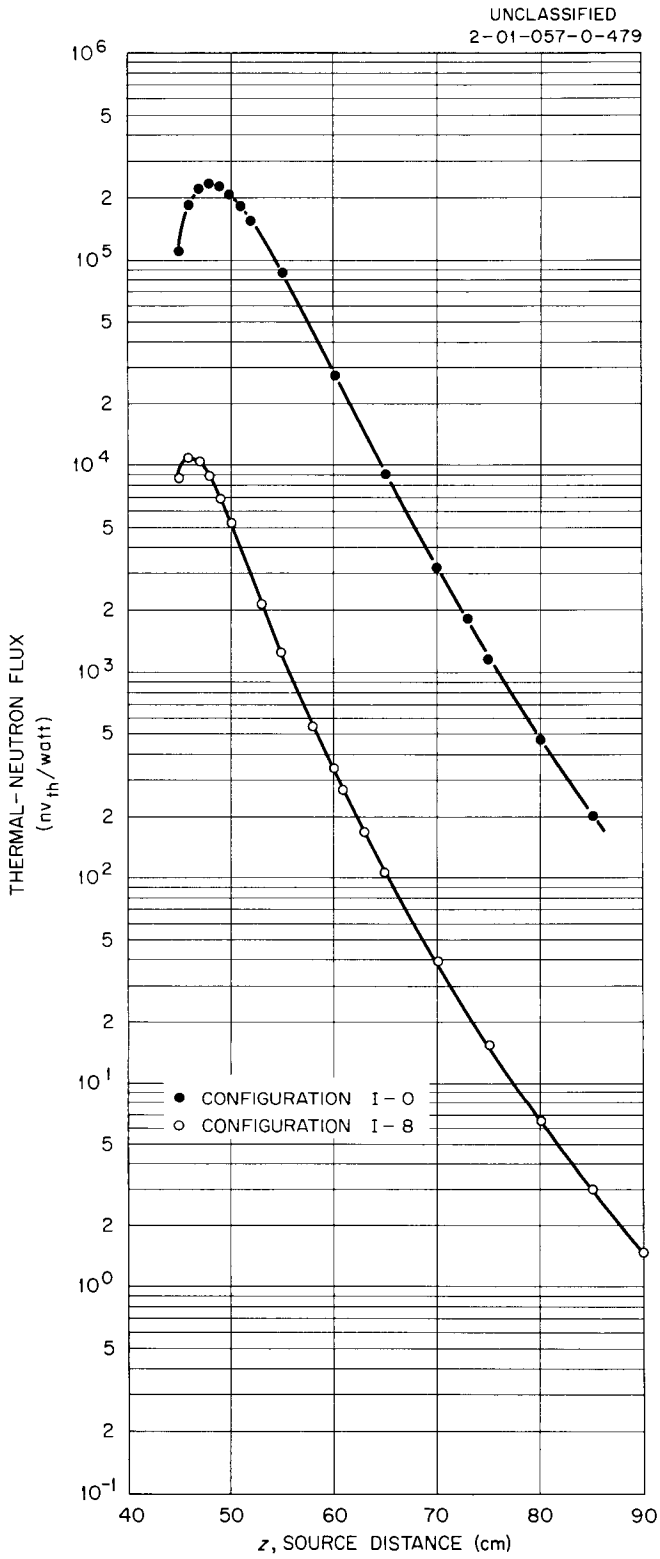

Fig. 1. Thermal-Neutron Flux as a Function of Distance from Source, Measured Behind Configurations I-0 and I-8.

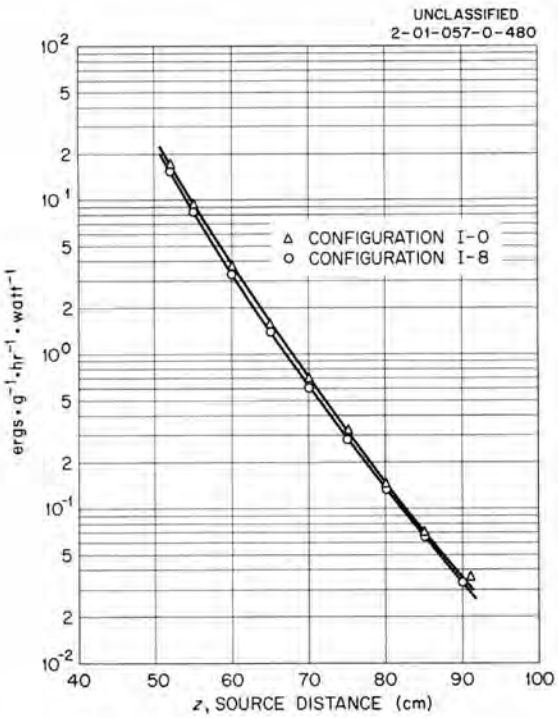

Fig. 2. Fast-Neutron Dose Rate as a Function of Distance from Source, Measured Behind Configurations I-0 and I-8.

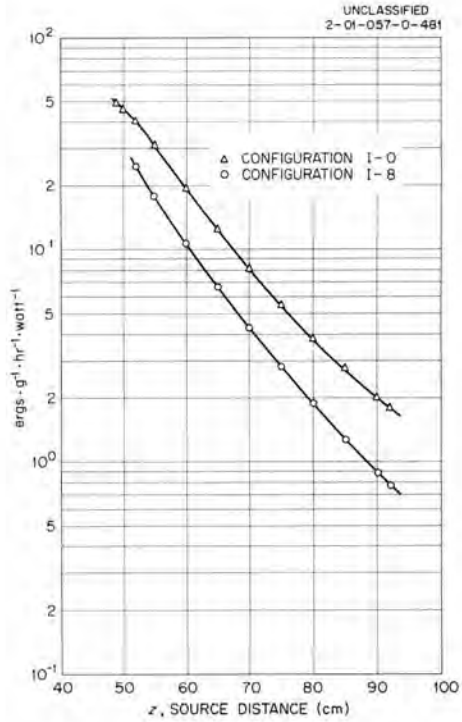

Fig. 3. Gamma-Ray Dose Rate as a Function of Distance from Source, Measured Behind Configurations I-0 and I-8.

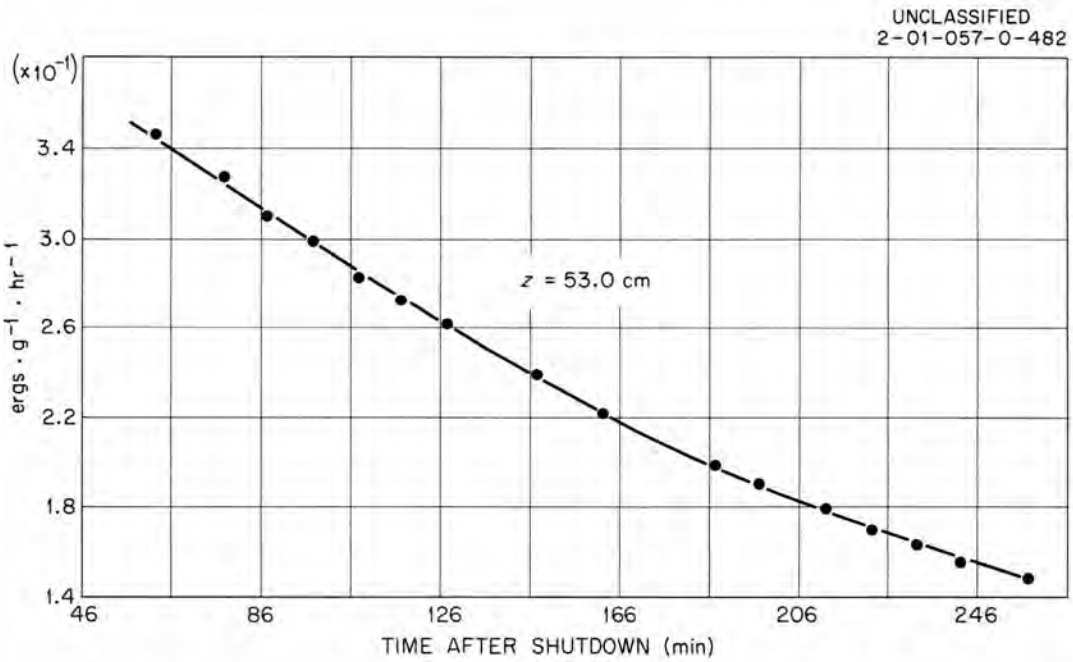

Fig. 4. Gamma-Ray Dose Rate Behind Configuration I-0 as a Function of Time After Power Shutdown.

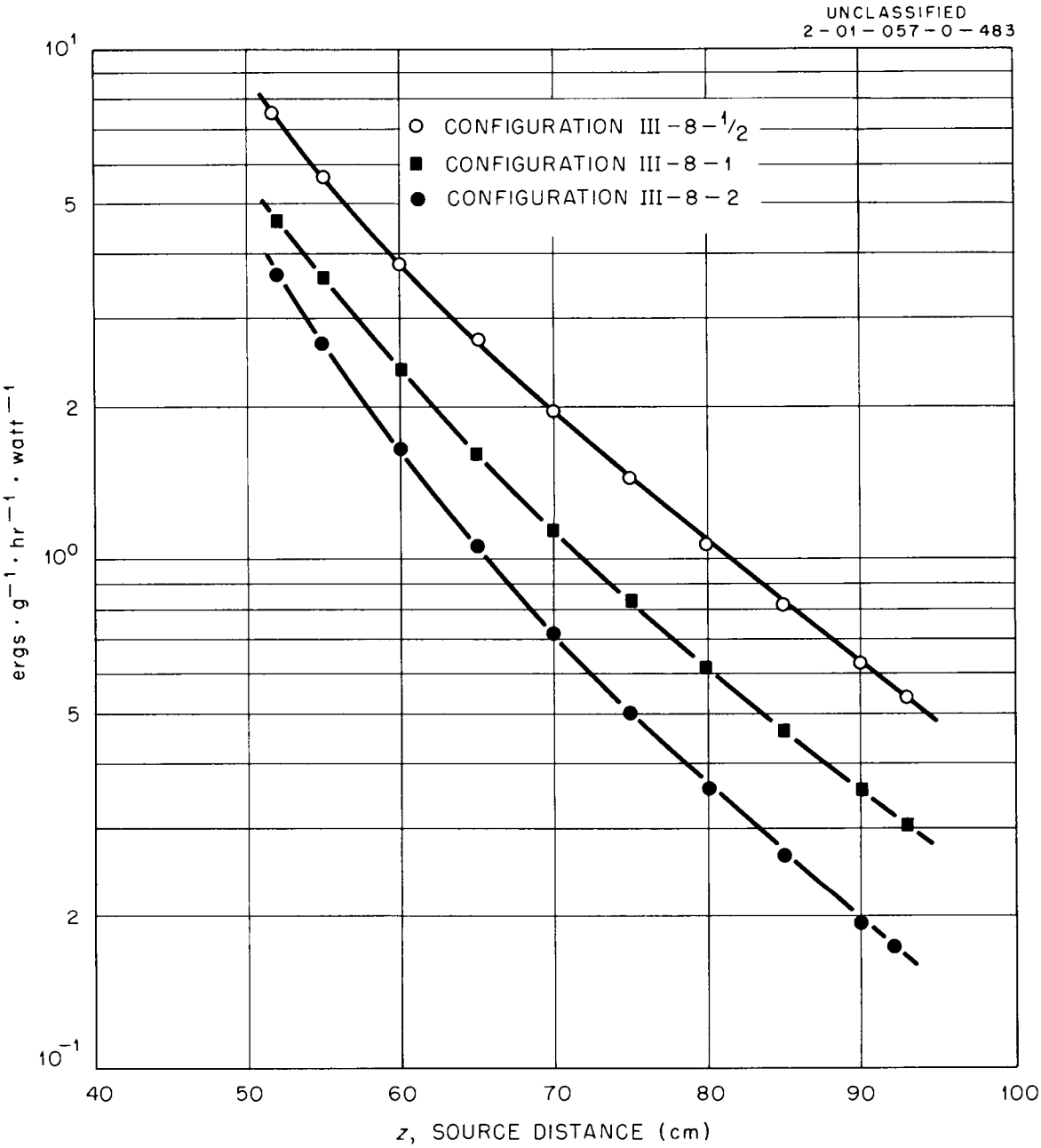

Fig. 5. Gamma-Ray Dose Rate as a Function of Distance from Source, Measured Behind Configurations III-8-(1/2), III-8-1, and III-8-2.

change the dose rate unless the gamma rays originate within the tank, a significant contribution to the gamma-ray dose rate must come from neutron captures in the stainless steel walls of the APB tank.

The relative importance of the stainless steel and lead within the shield in producing capture gamma rays was investigated through gamma-ray dose rate measurements with 5 configurations. Curves 1, 2, and 3 of Fig. 6 show the effect of boral placement immediately preceding the stainless steel tank of 7.5 wt % of APB. Curve 1, configuration III-8-1, shows the gamma-ray dose rate with no boral preceding the tank. Curve 3, configuration IIIC-8-1, displays the result of the addition of 1/8 in. of boral before the tank, a decrease in dose rate of from 25 to 30%. An increase in boral thickness to 1/2 in., curve 2, configuration IIIA-8-1, produced an additional decrease in dose rate of about 7-1/2%. Curve 4 of Fig. 6 is from configuration IIID-8-1, identical with IIIC-8-1 except that 1/4 in. of boral was added following the APB tank. The difference from curve 3, about 8%, resulted from the absorption by the boral of neutrons which could have caused capture gamma ray production in following thicknesses of stainless steel and lead. Curve 5 is from configuration IIIE-8-1, similar to IIIA-8-1 except that the 1/8 in. of stainless steel and 1/8 in. of boral following the APB tank were removed, and is identical with curve 2.

The configuration-IV series of gamma-ray dose rate measurements examined the effect of a fixed thickness of lead behind varied thicknesses of APB solution of two concentrations. In Fig. 7 are compared the gamma-ray dose rates behind configurations having first no lead, then 1/2 in. of lead behind 5, 10, and 18 in. of 7.5 wt % APB solution. (Again the arrangements are suggested by the configuration numbers.) Placing the

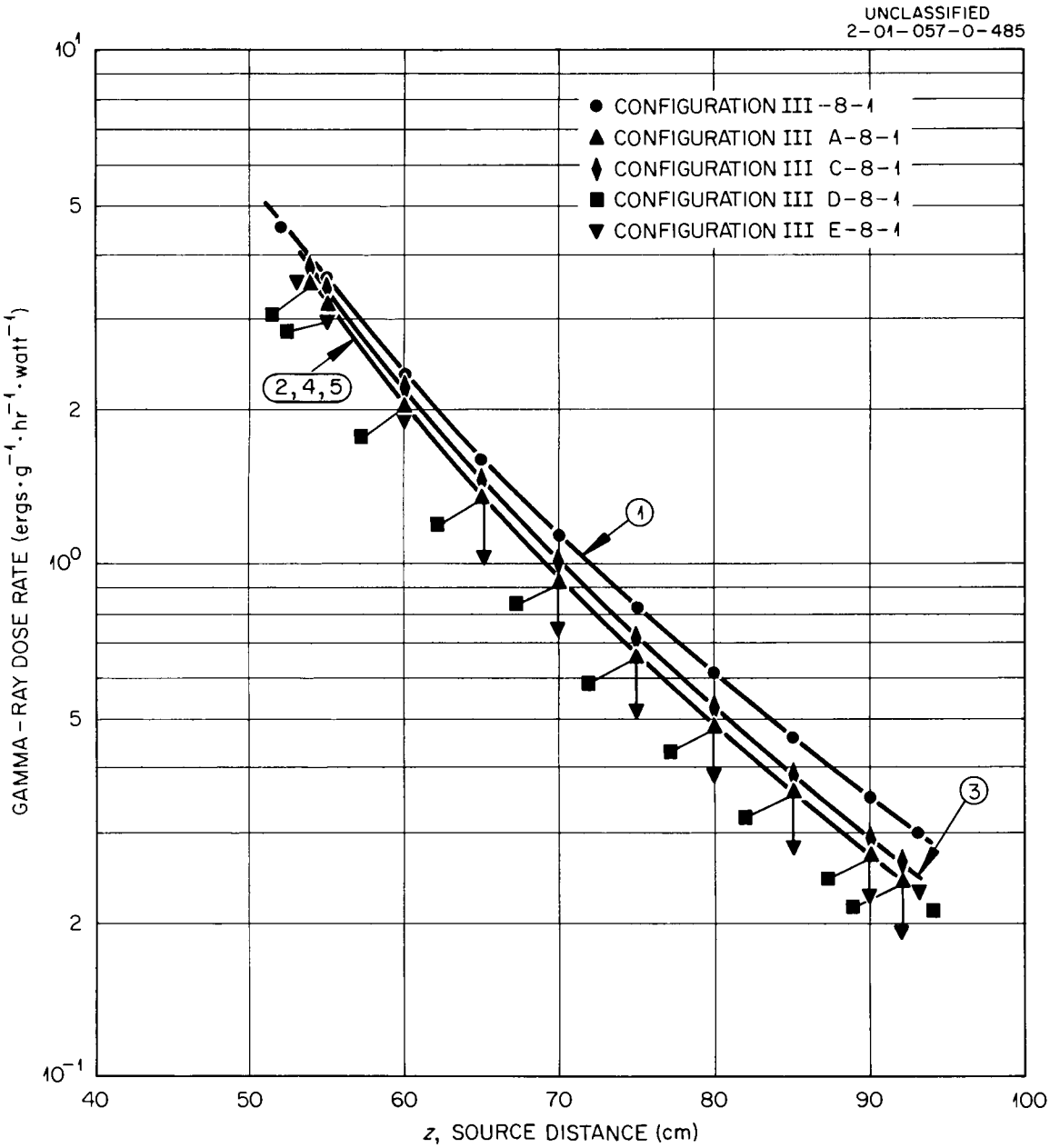

Fig. 6. Gamma-Ray Dose Rate as a Function of Source Distance; Configurations III-8-1, IIIA-8-1, IIIC-8-1, and IIIE-8-1.

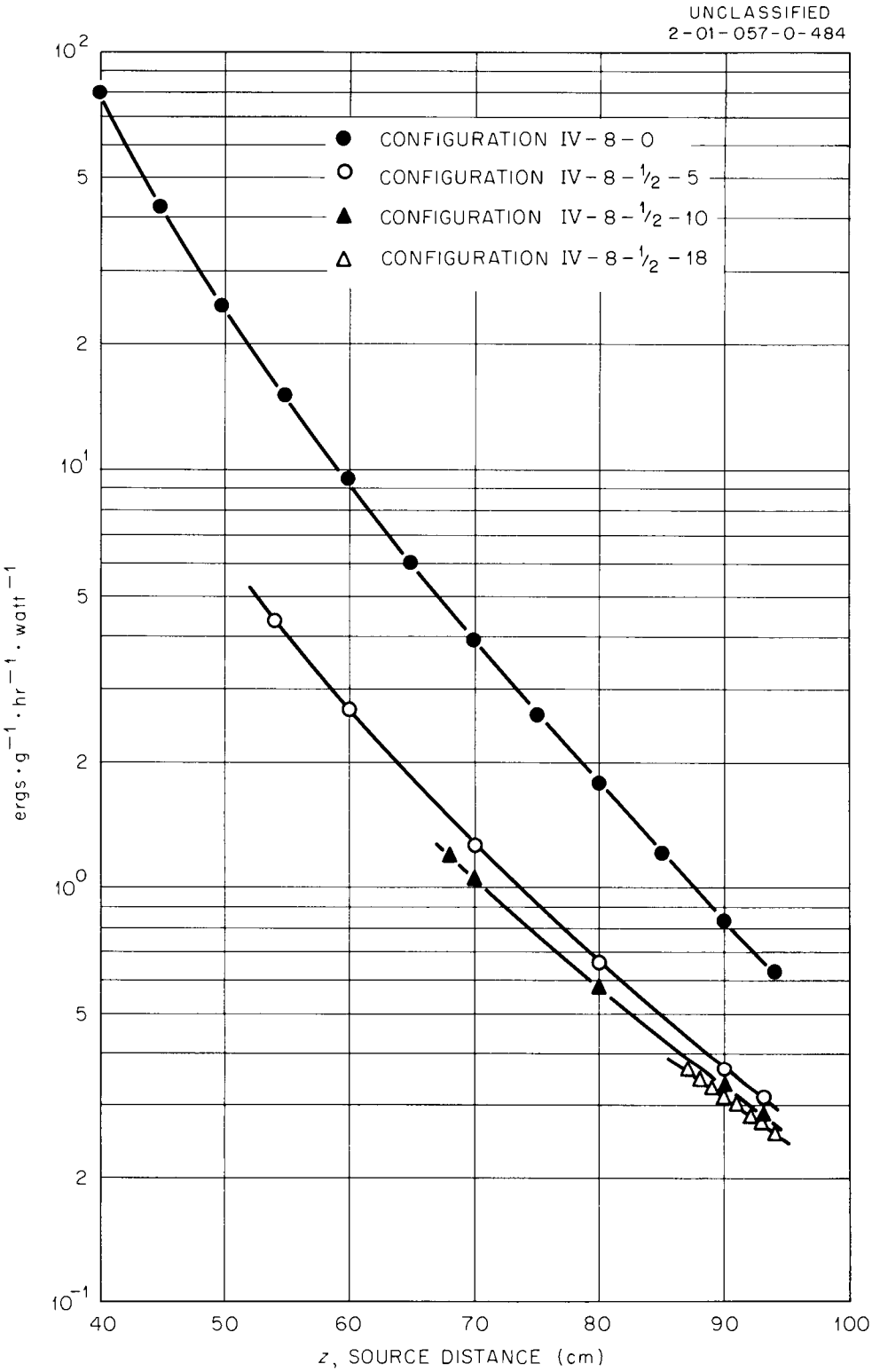

Fig. 7. Gamma-Ray Dose Rate as a Function of Distance from Source, Measured Behind Configurations IV-8-0, IV-8-(1/2)-5, IV-8-(1/2)-10, and IV-8-(1/2)-18.

1/2 in. of lead behind 5 in. of APB produced over a 50% reduction in dose rate compared to the configuration without lead. Increasing the APB slab thickness to 10 in. decreased the dose rate 10% below that of the 5-in. slab at 90 cm. An 18-in.-thick slab gave dose rates 17% below those of the 5-in. thickness.

Parallel effects were observed for similar configurations in which the lead thickness was increased to 1 in. These results are shown in Fig. 8. The increase in lead thickness resulted in a general lowering of the dose rate curves about 30%, but the variation with APB solution thickness was essentially similar to the results with 1/2 in. of lead.

Figure 9 shows gamma-ray dose rates obtained with 2 in. of lead behind 2-1/2, 5, and 10 in. of 7.5 wt % APB, as well as a single curve obtained with 1-1/2 in. of lead behind 5 in. of APB. The 1-1/2 in. and 2 in. lead results are within 4% of each other, but comparison of the 1-1/2-in. data with the 1-in. data from the previous figure shows a 35% difference in dose rate at 80 cm from the source. This suggests that the major advantage is gained in going from 1 to 1-1/2 in., with little additional gain in adding another 1/2 in.

When the concentration of the APB solution was increased to 15 wt %, the over-all effect was to decrease the gamma-ray dose rate by about 28%; the decrease caused by placement of a 1-in.-thick slab of lead behind successively greater thicknesses of APB followed the same pattern as data from the 7.5 wt % solutions. These curves are shown in Fig. 10.

Figures 11 through 15 show the effects of variations of lead thickness behind given thicknesses of 7.5 wt % APB solutions. In the identifying configuration numbers, the last two figures represent the lead

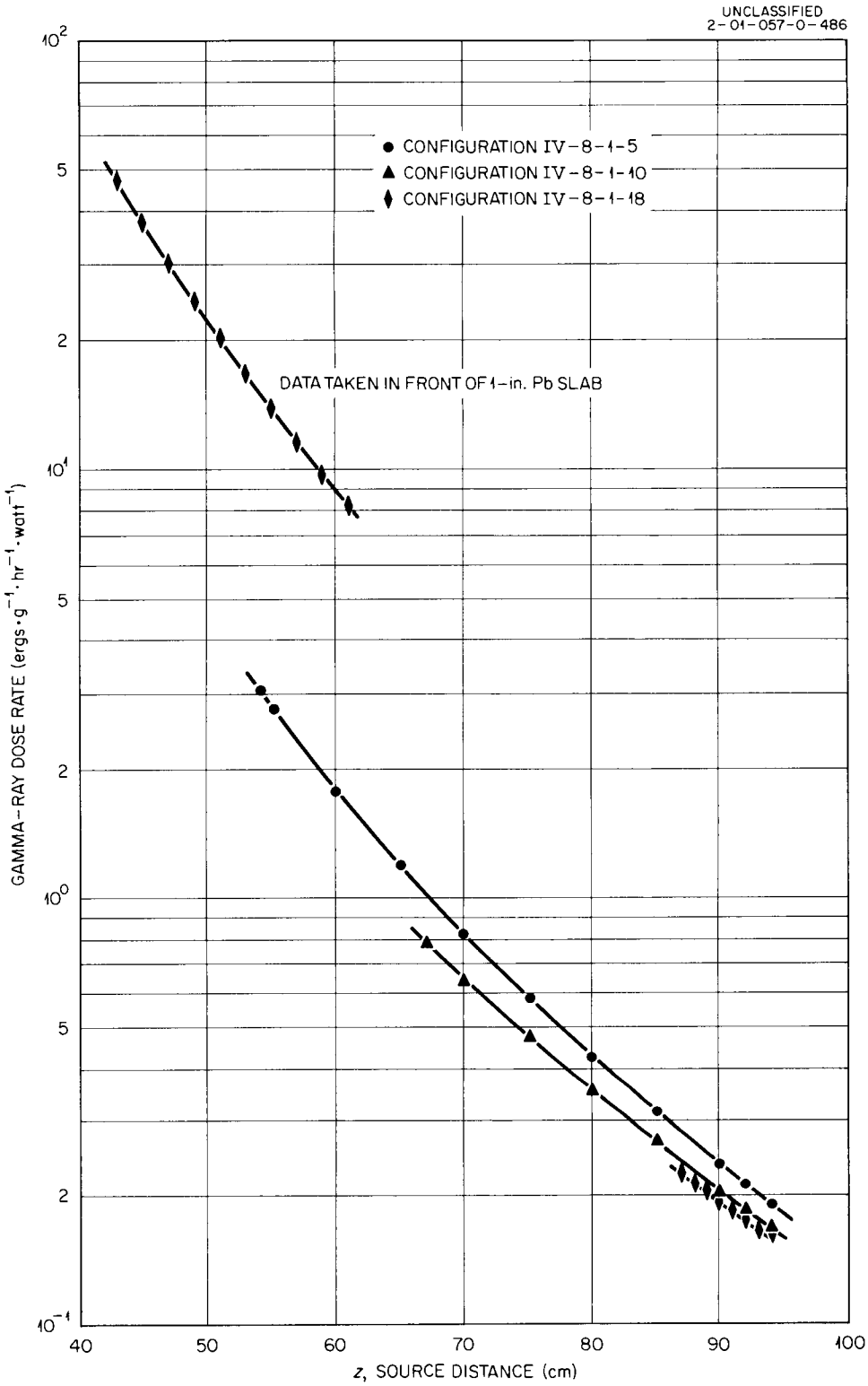

Fig. 8. Gamma-Ray Dose Rate as a Function of Source Distance; Configurations IV-8-1-5, IV-8-1-10, and IV-8-1-18.

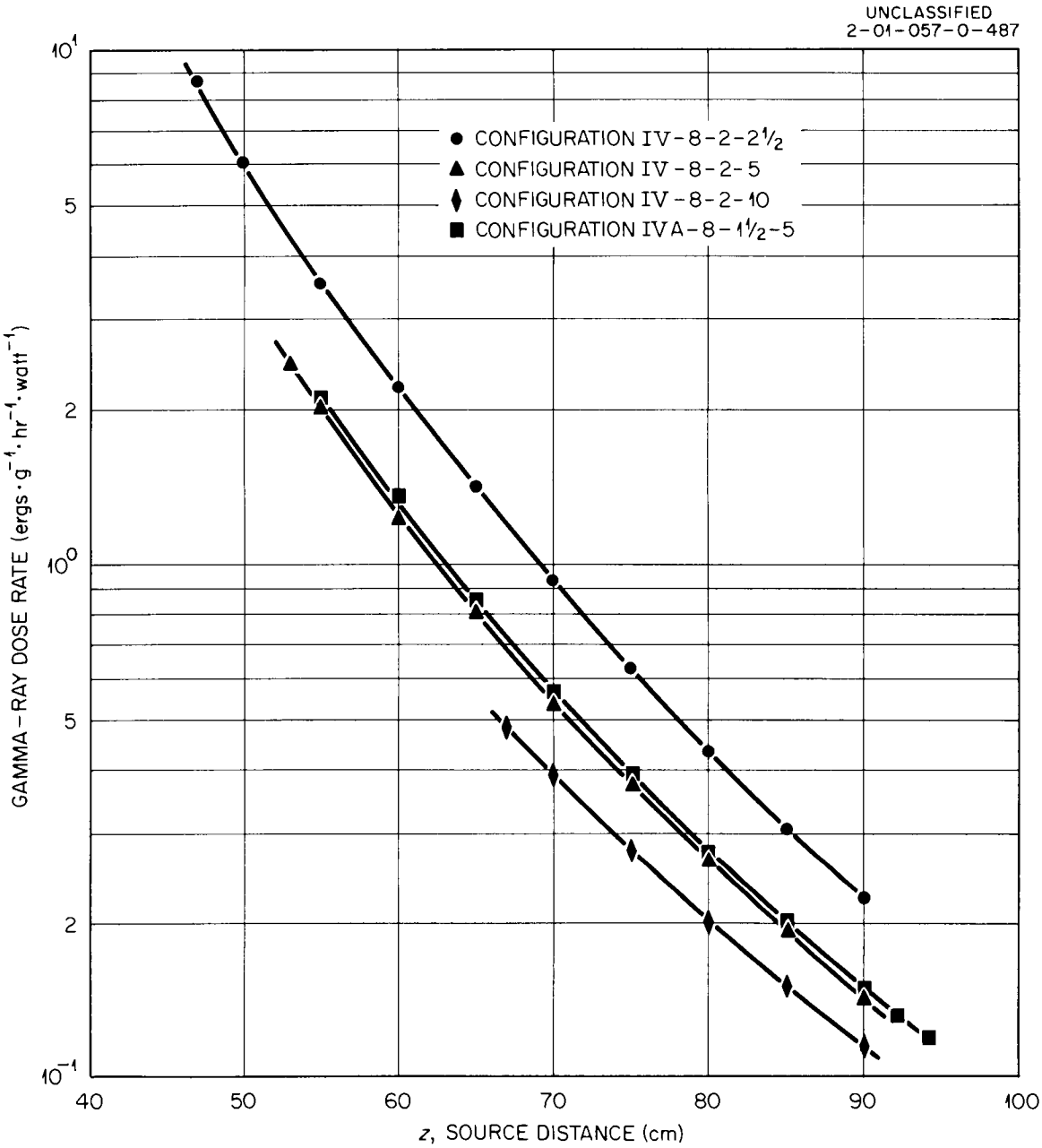

Fig. 9. Gamma-Ray Dose Rate as a Function of Source Distance; Configurations IV-8-2-2-1/2, IV-8-2-5, IV-8-2-10, and IVA-8-1-1/2-5.

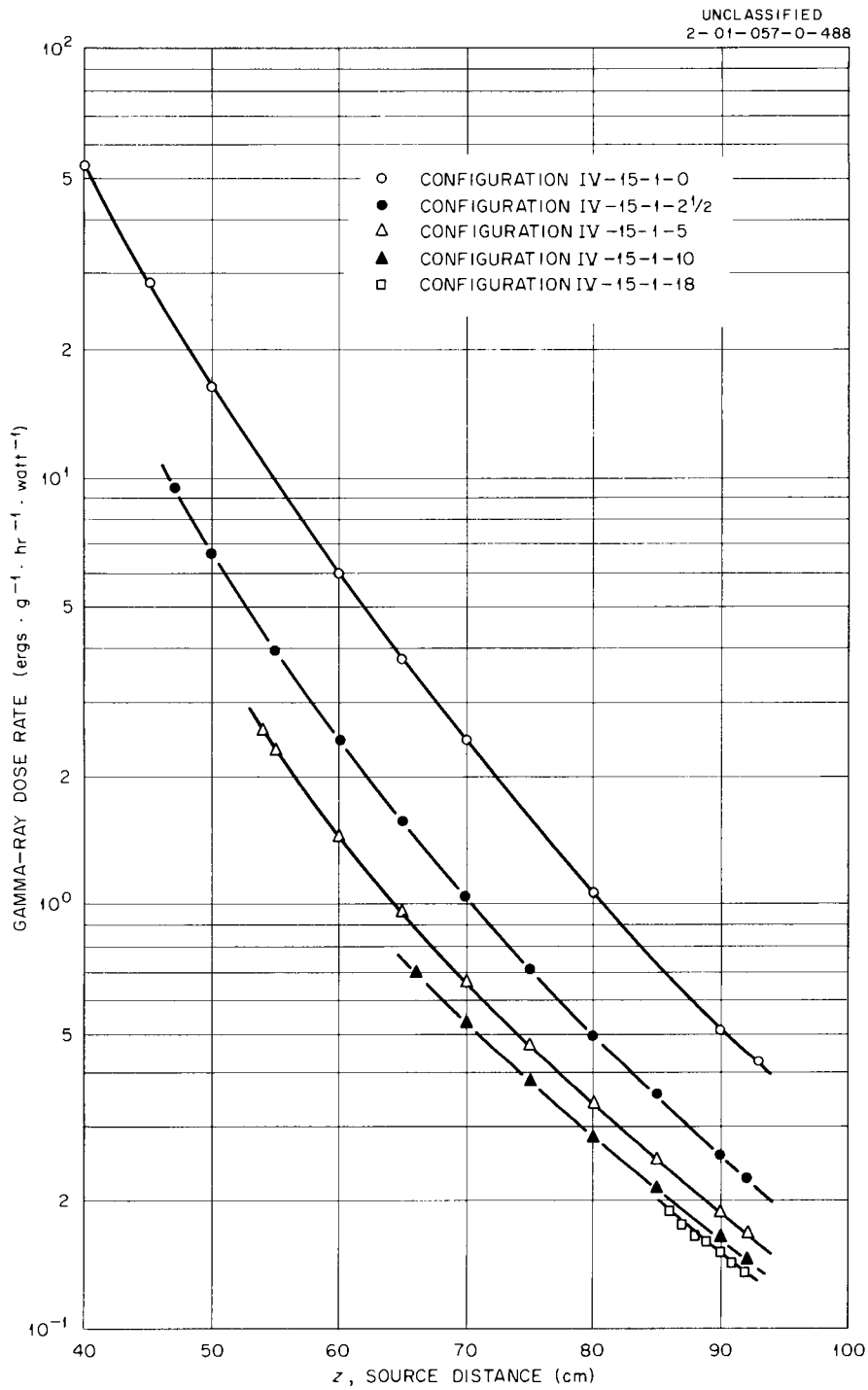

Fig. 10. Gamma-Ray Dose Rate as a Function of Source Distance; Configurations IV-15-1-0, IV-15-1-2-1/2, IV-15-1-5, IV-15-1-10, and IV-15-1-18.

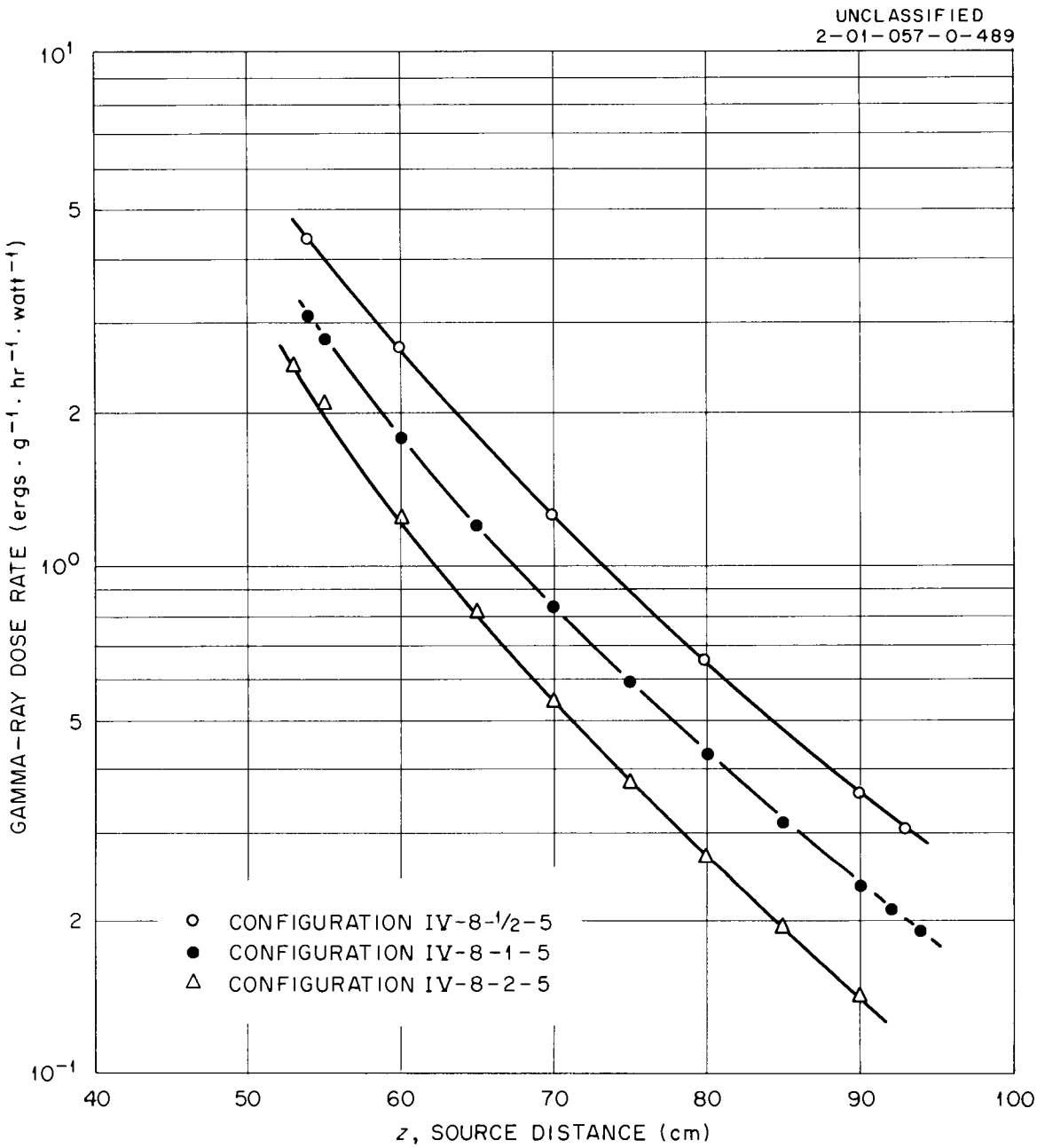

Fig. 11. Gamma-Ray Dose Rate as a Function of Source Distance; Configurations IV-8-1/2-5, IV-8-1-5, and IV-8-2-5.

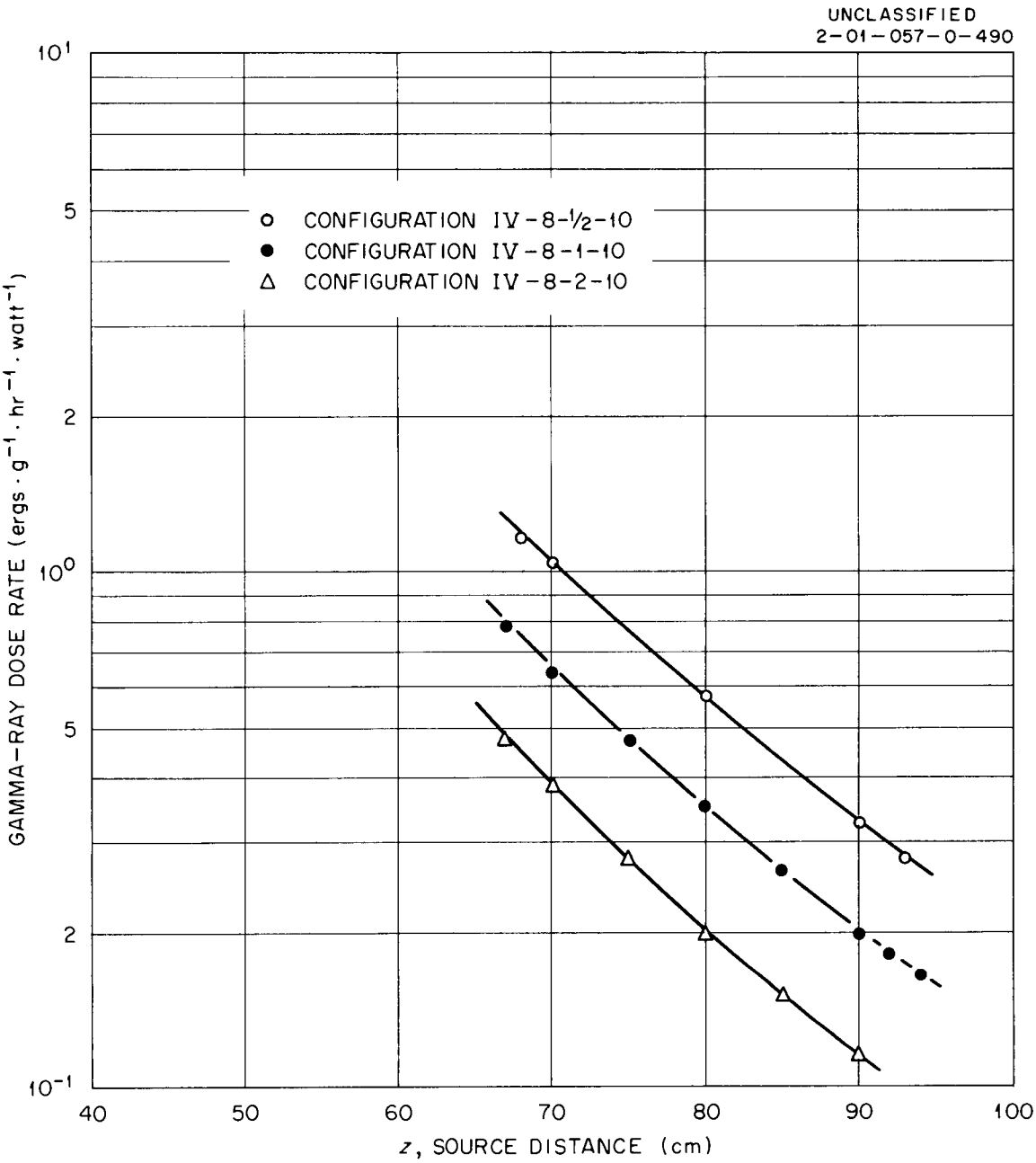

Fig. 12. Gamma-Ray Dose Rate as a Function of Source Distance; Configurations IV-8-1/2-10, IV-8-1-10, and IV-8-2-10.

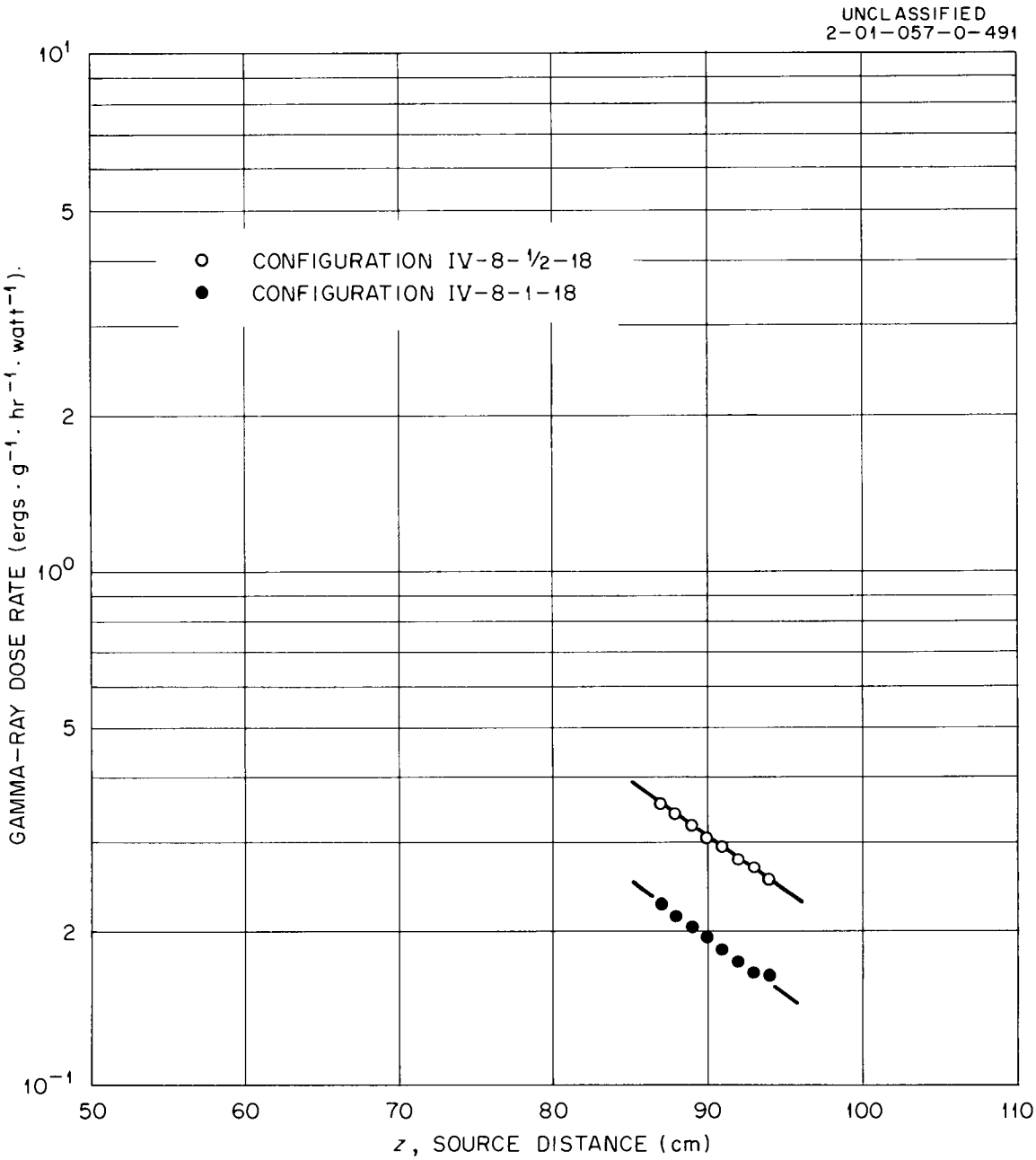

Fig. 13. Gamma-Ray Dose Rate as a Function of Source Distance; Configurations IV-8-1/2-18, and IV-8-1-18.

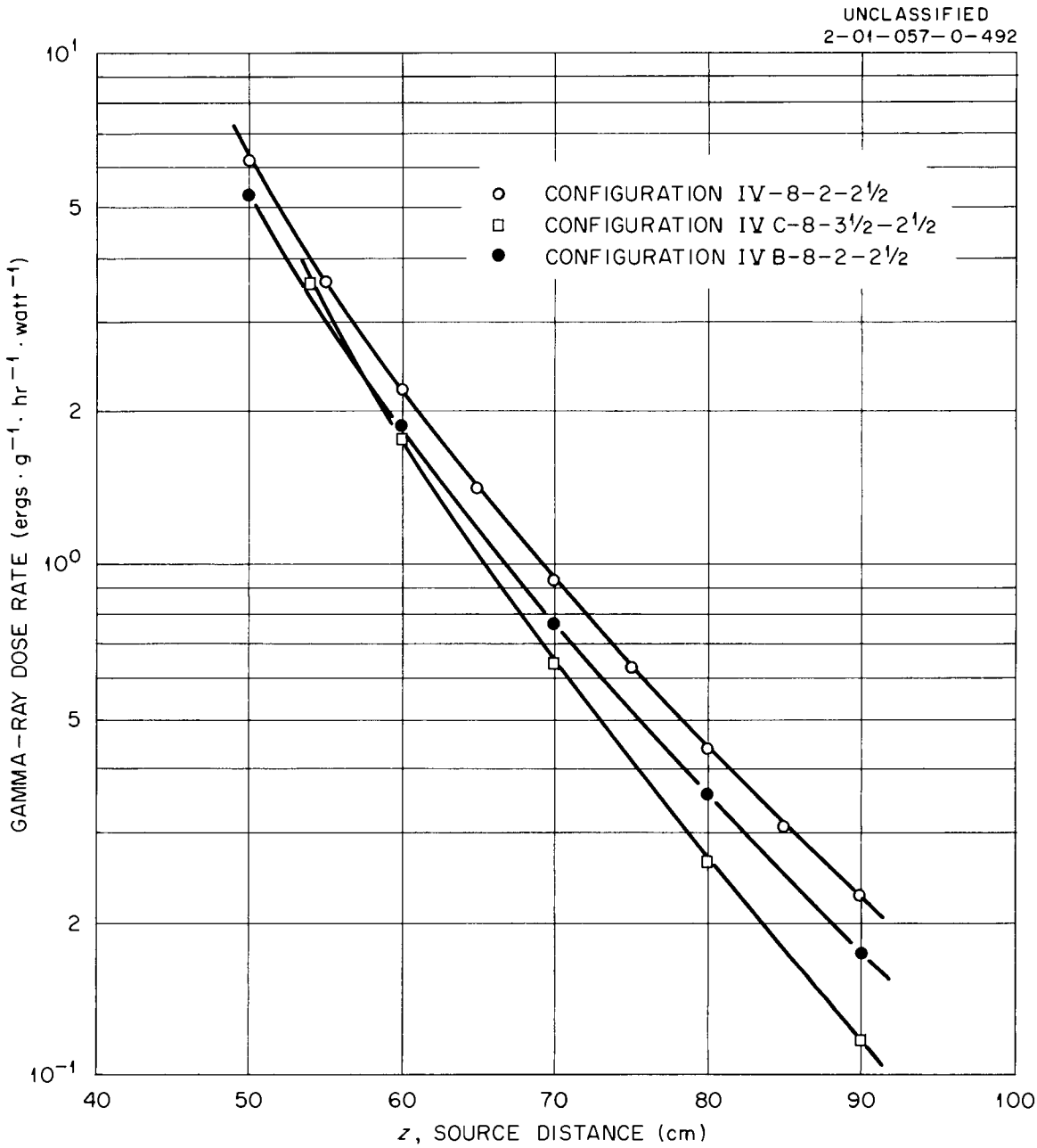

Fig. 14. Gamma-Ray Dose Rate as a Function of Source Distance; Configurations IV-8-2-2-1/2, IVC-8-3-1/2-2-1/2, and IVB-8-2-2-1/2.

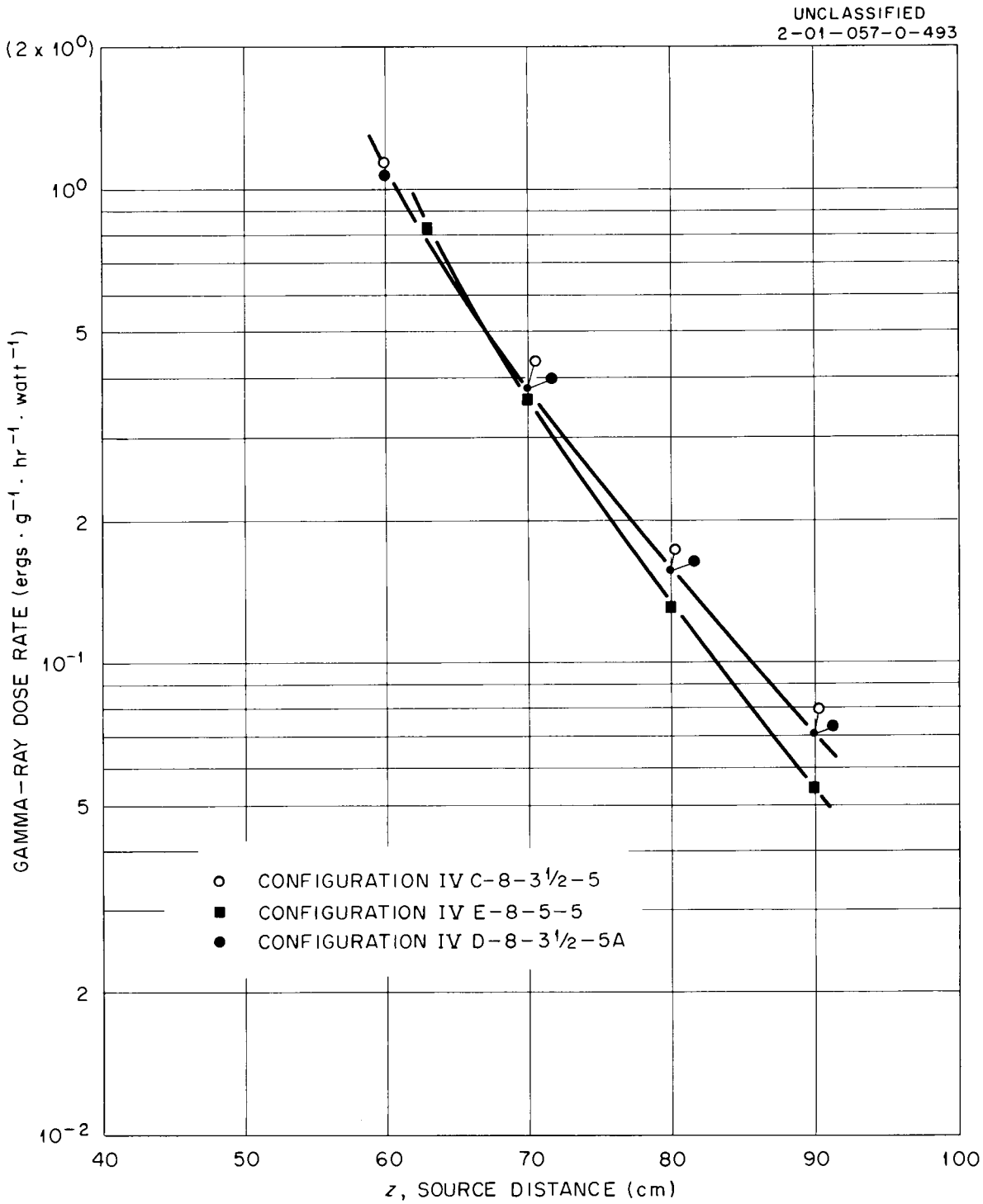

Fig. 15. Gamma-Ray Dose Rate as a Function of Source Distance; Configurations IVC-8-3-1/2-5, IVE-8-5-5, and IVD-8-3-1/2-5A.

thickness and APB thickness respectively; i.e., configuration IV-8-1/2-5 describes 1/2 in. of lead behind 5 in. of APB solution. These curves all demonstrate that increasing the lead thickness while keeping all other quantities fixed results in a decrease in gamma-ray dose rate.

Figure 16 displays the result of introducing a 2-1/2 in. slab of 15 wt % APB and a 1/2-in. plate of boral before the 1-in. lead slab of configuration IV-15-0A. The decrease in gamma-ray dose rate is presumably due to the decrease in neutron captures in the lead.

A measurement of the gamma-ray dose rate behind configuration I-0 as a function of time after shutdown has been previously noted. Further information concerning the decay characteristics of the gamma radiation after shutdown was obtained from a pair of traverses made in air behind configuration IV-8-1/2, which differs from I-0 principally by the removal of the 5-in. APB slab of I-0. A z-traverse, normal to the source plate and on the source plate center line, is shown in Fig. 17. A y-traverse, run horizontally and parallel to the source plate at a distance of 53 cm from the source, is shown in Fig. 18. The figure captions give the specific times after shutdown for each traverse.

Configuration V consisted of the stainless steel mockup of the ML-1 plenum and gas duct, in a 7.5 wt % solution of APB. The mockup is shown in Fig. 19. A system of rectangular axes was established, in which z is along the centerline axis, normal to the source plate, y horizontal, parallel to the source plate and positive to the right as one faces the source plate, and x vertical, parallel to the source plate and positive upwards. Thermal-neutron flux, fast-neutron dose rate, and gamma-ray dose rate traverses were run on each of these axes, and the data is plotted in Figs. 20 through 29.

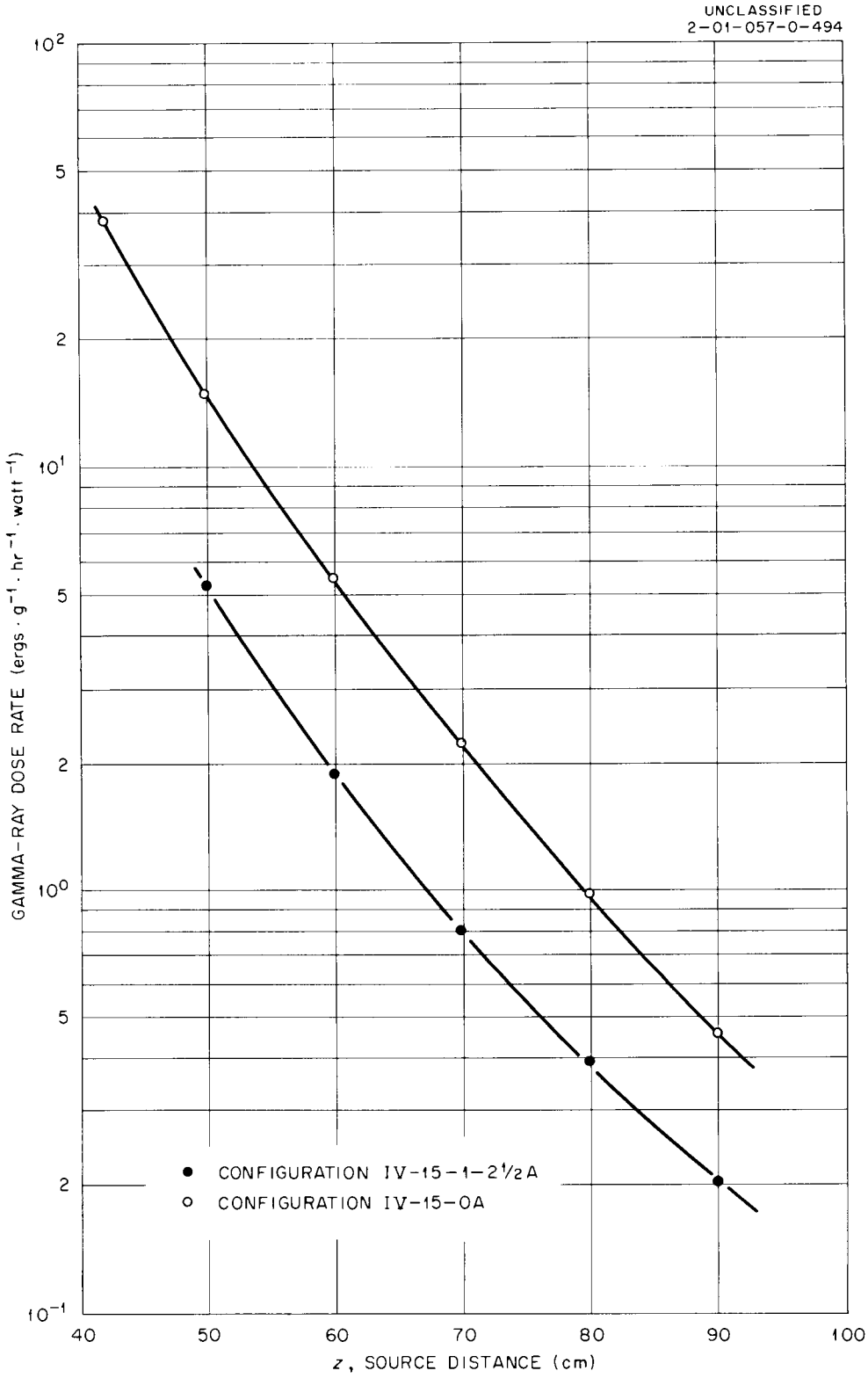

Fig. 16. Gamma-Ray Dose Rate as a Function of Source Distance; Configurations IV-15-1-2-1/2A and IV-15-0A.

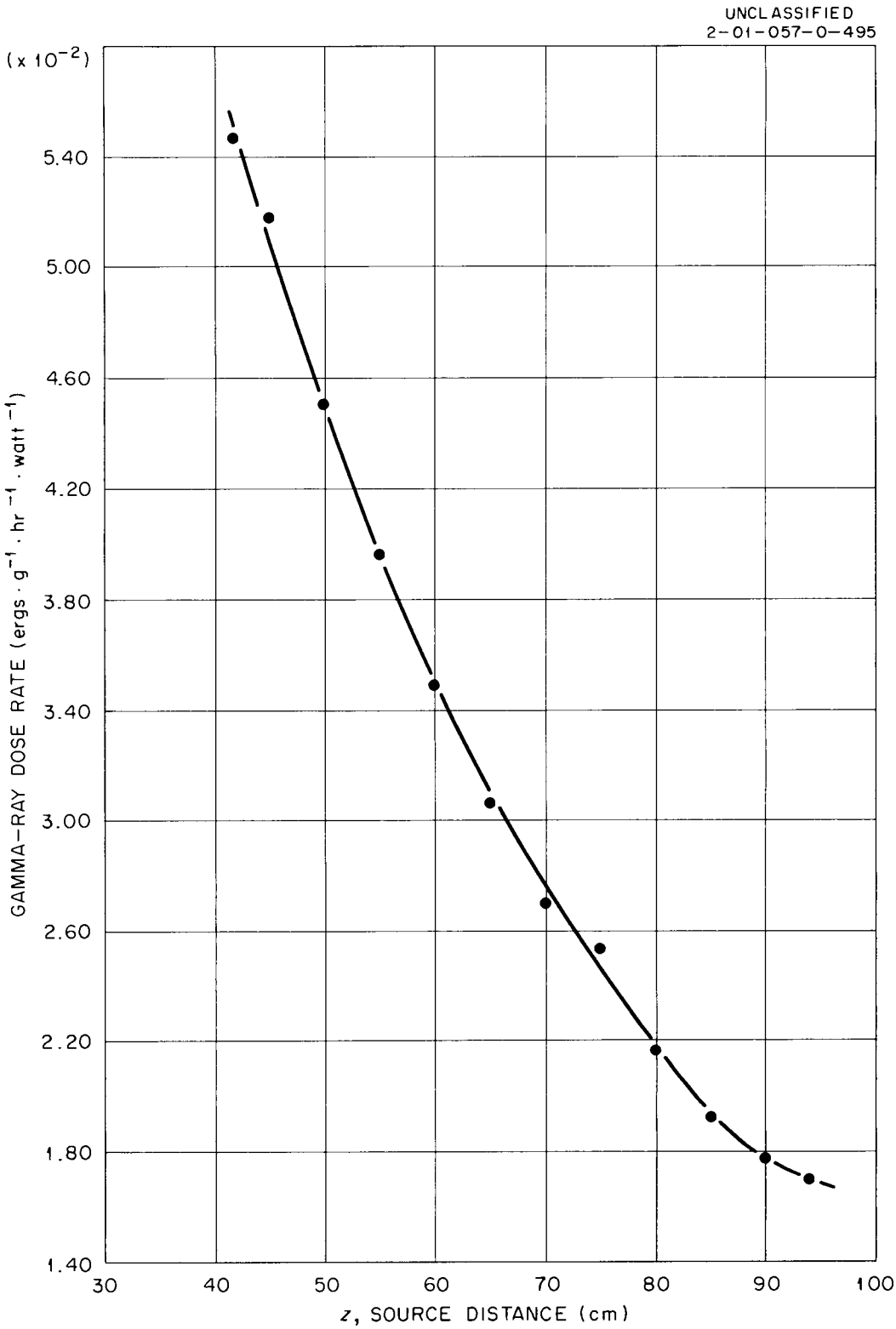

Fig. 17. Gamma-Ray Dose Rate as a Function of Source Distance; z Traverse, 4 hr 45 min After Shutdown, Configuration IV-8-1/2.

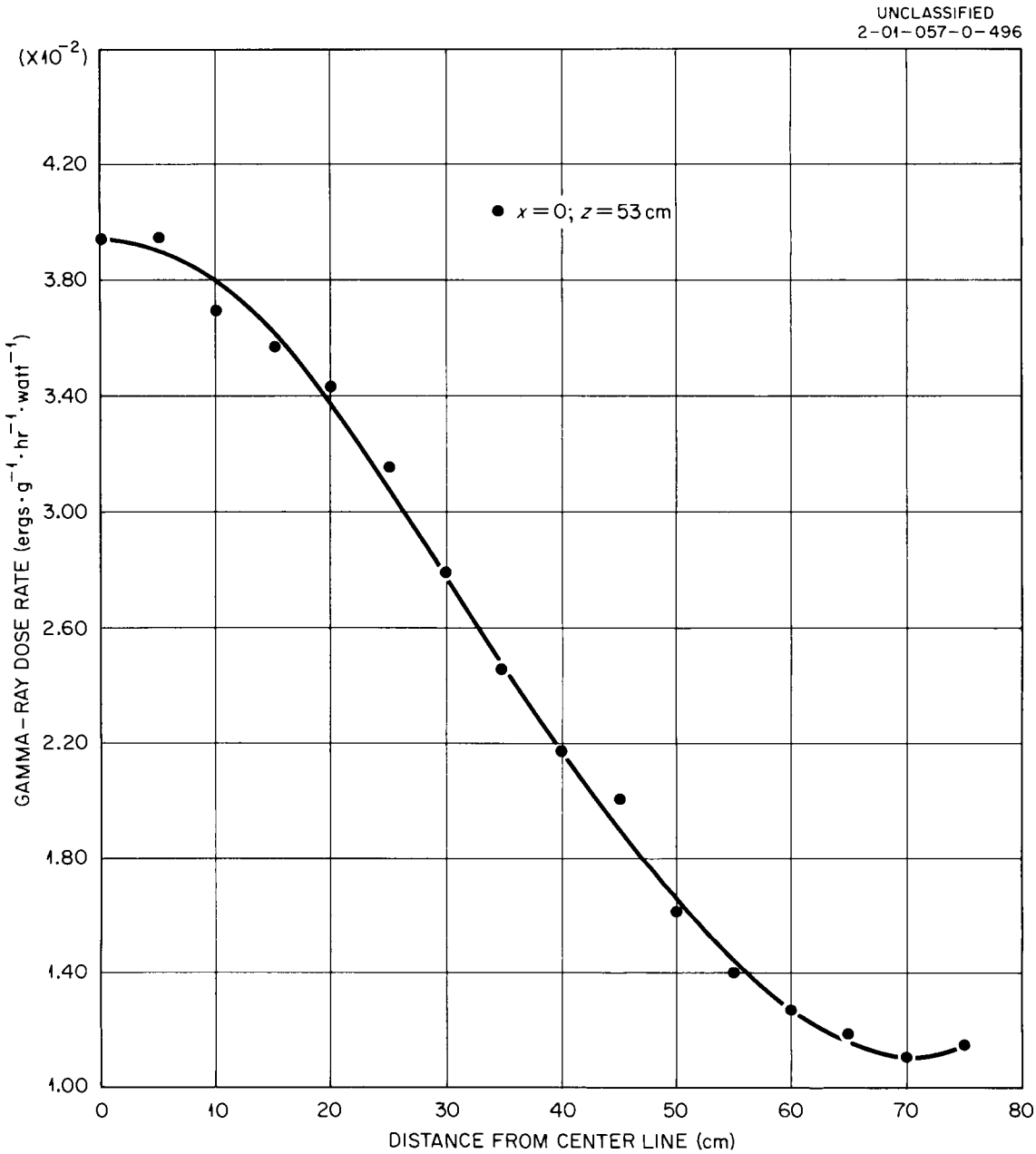

Fig. 18. Gamma-Ray Dose Rate as a Function of Distance from Center Line; y Traverse, 5 hr 56 min to 6 hr 18 min After Shutdown, Configuration IV-8-1/2.

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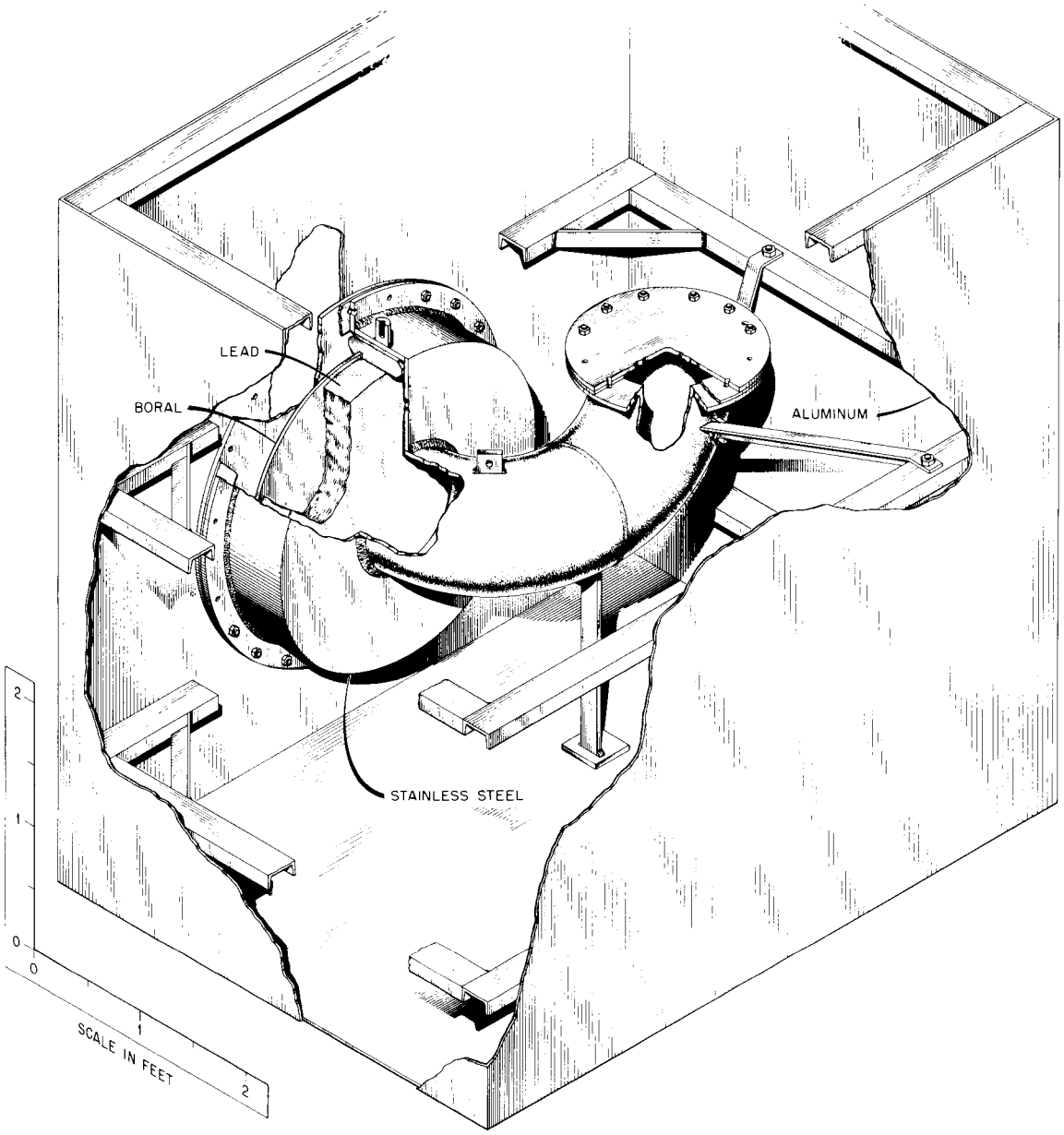

Fig. 19. Plenum and Duct Mockup, ML-1 Reactor Shield.

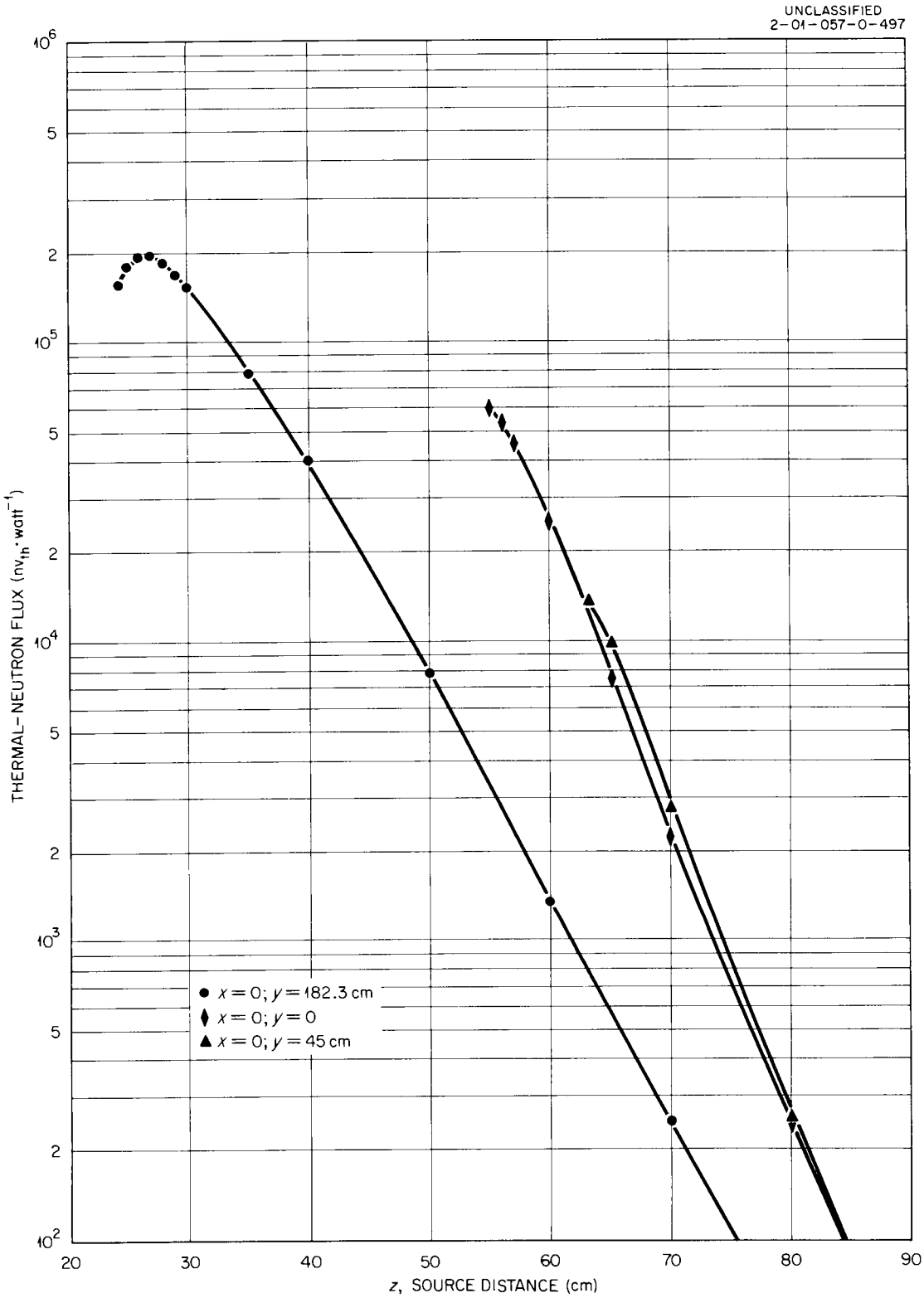

Fig. 20. Thermal-Neutron Flux as a Function of Distance from Source Plate (a-Traverse), Configuration V.

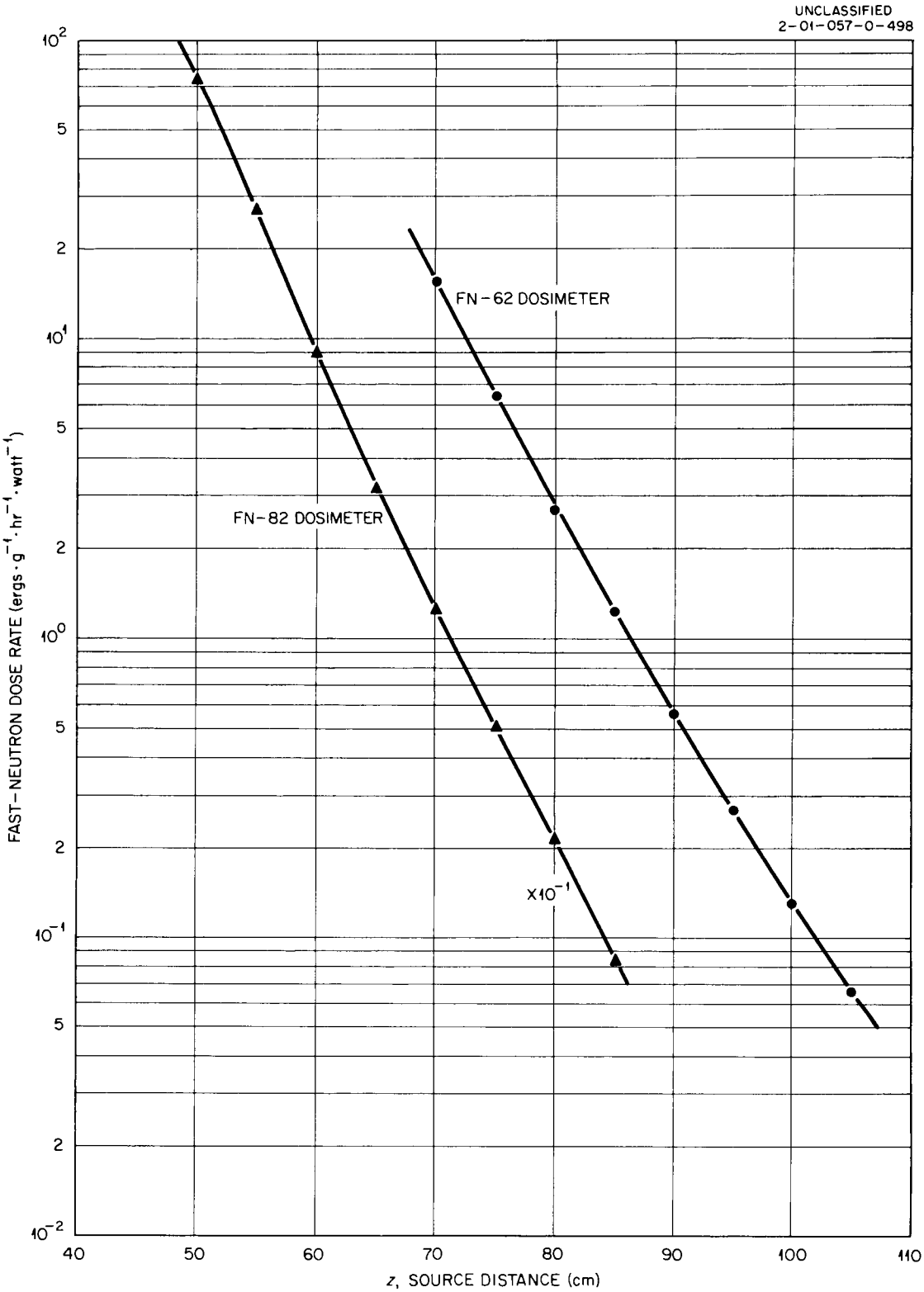

Fig. 21. Fast-Neutron Dose Rate as a Function of Distance from Source Plate (a-Traverse), Configuration V.

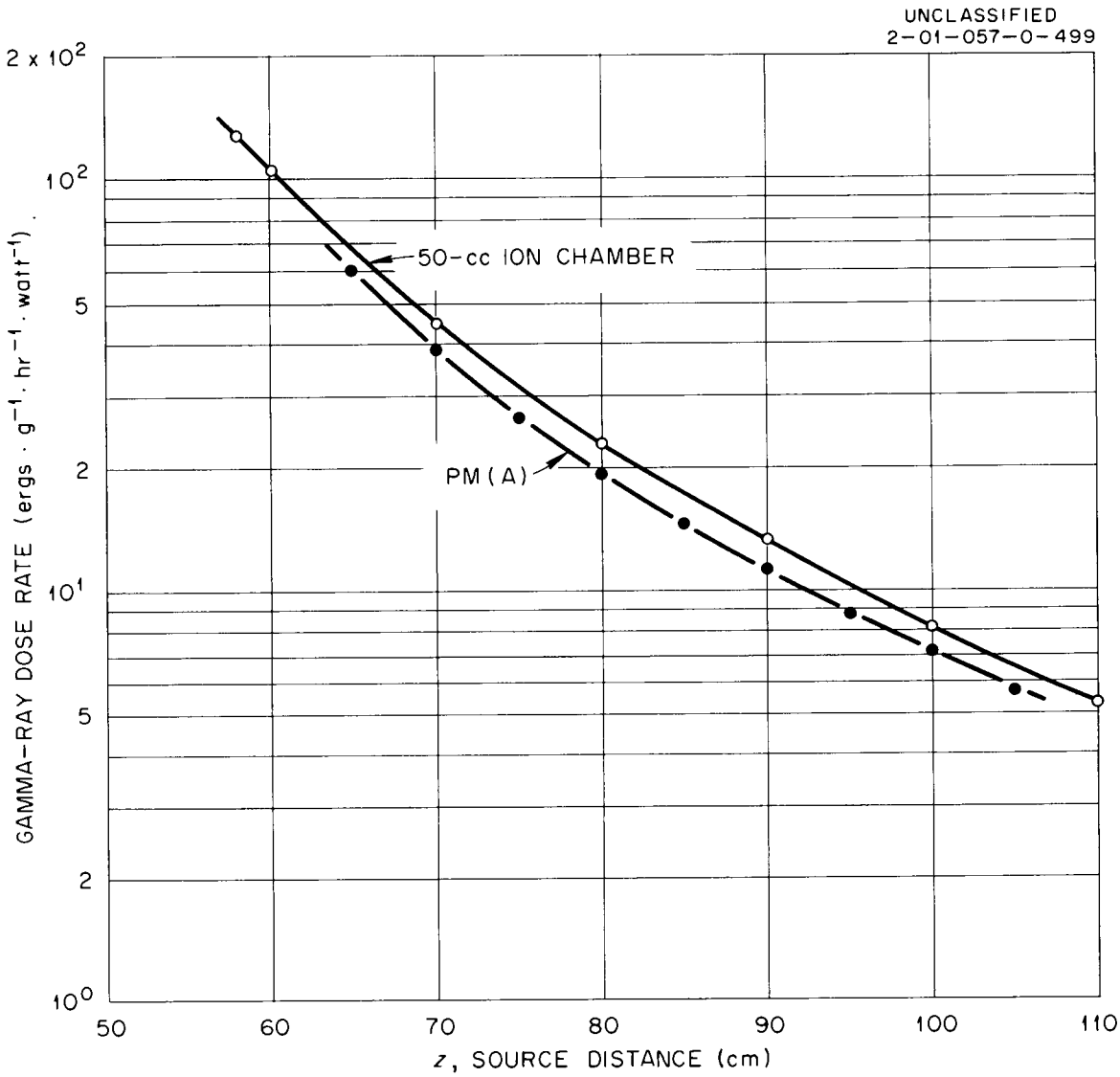

Fig. 22. Gamma-Ray Dose Rate as a Function of Distance from Source Plate (a-Traverse), Configuration V.

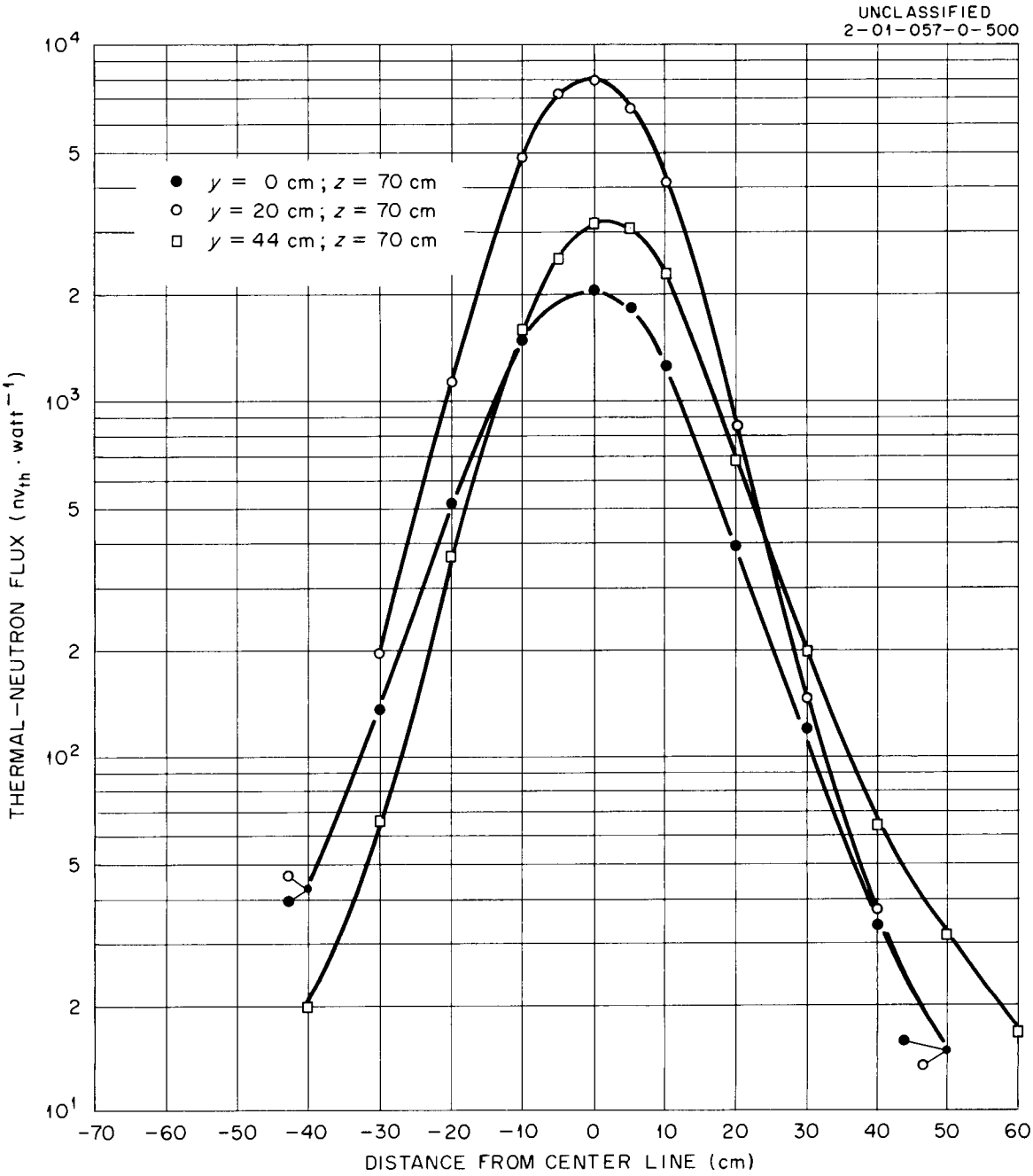

Fig. 23. Thermal-Neutron Flux as a Function of Distance from Center Line (x-Traverse), Configuration V.

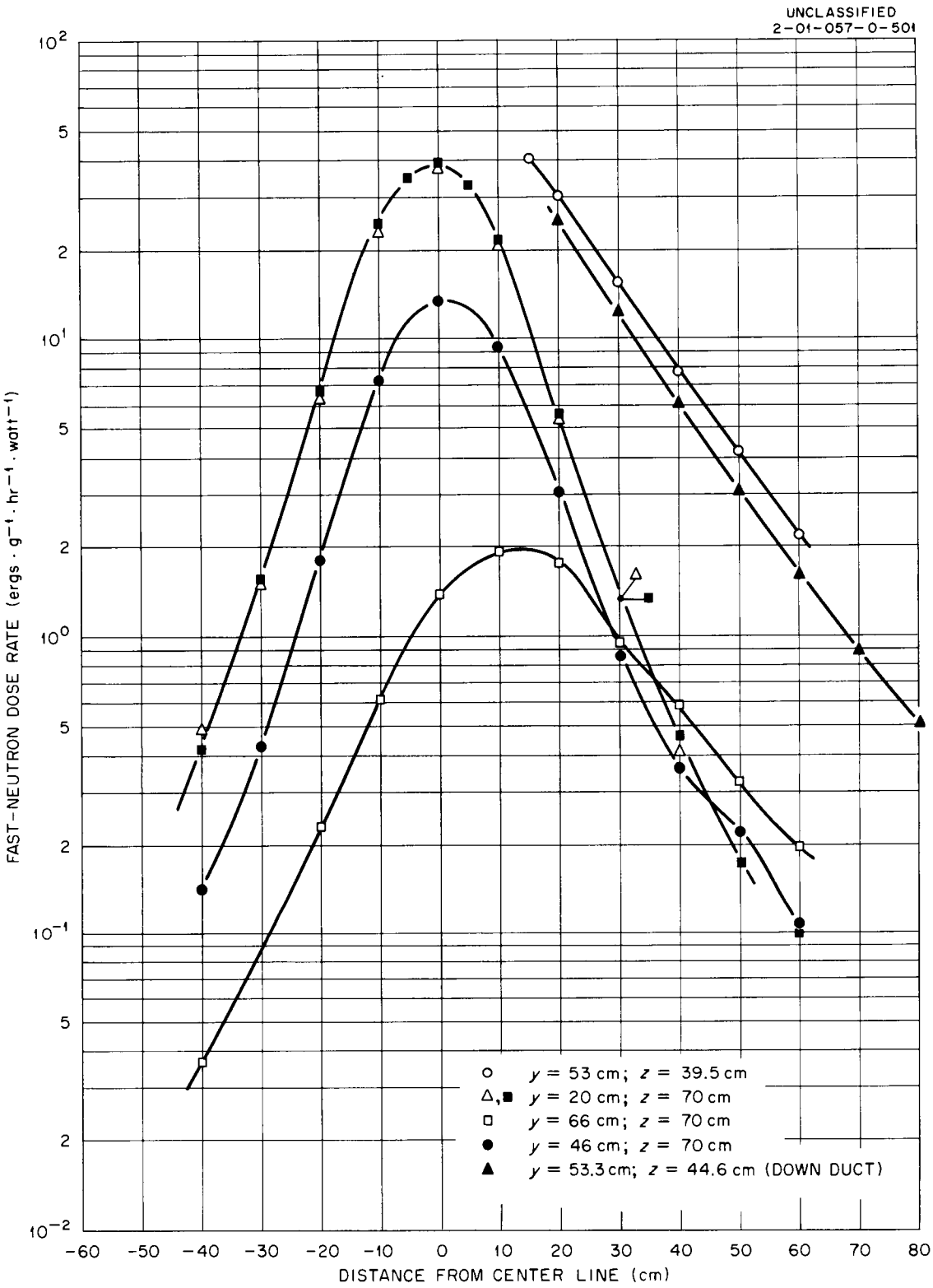

Fig. 24. Fast-Neutron Dose Rate as a Function of Distance from Center Line (x-Traverse), Configuration V.

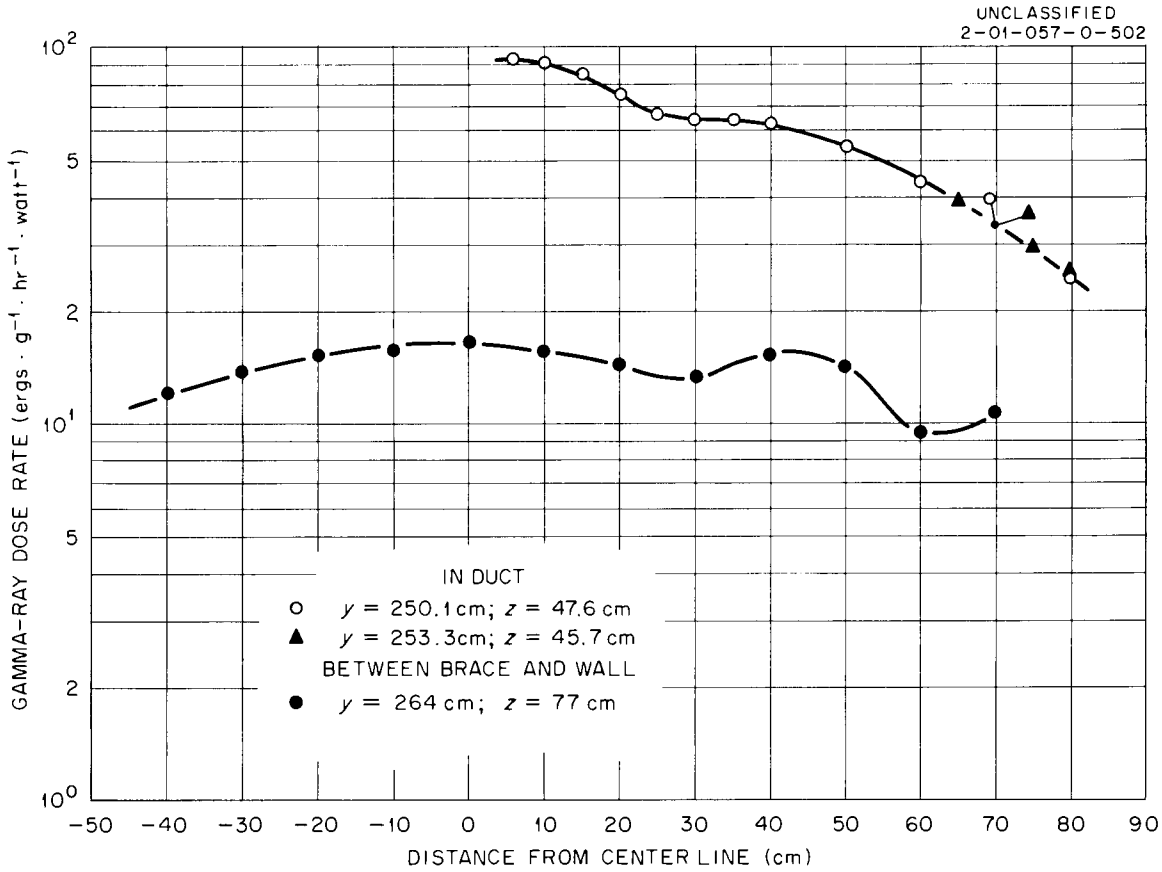

Fig. 25. Gamma-Ray Dose Rate as a Function of Distance from Center Line (x-Traverse), Configuration V.

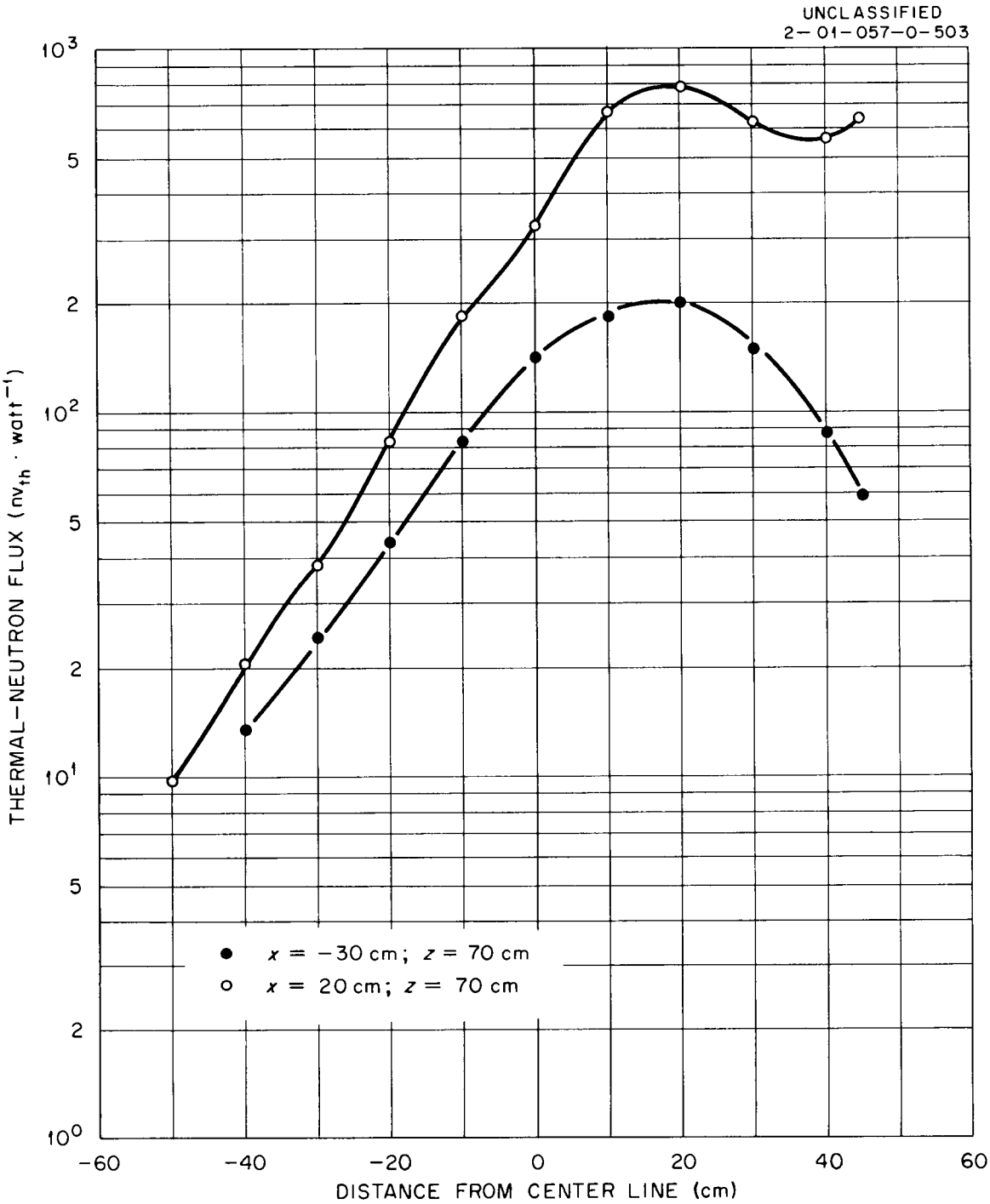

Fig. 26. Thermal-Neutron Flux as a Function of Distance from Center Line (y-Traverse), for x = -30 cm and 20 cm, Configuration V.

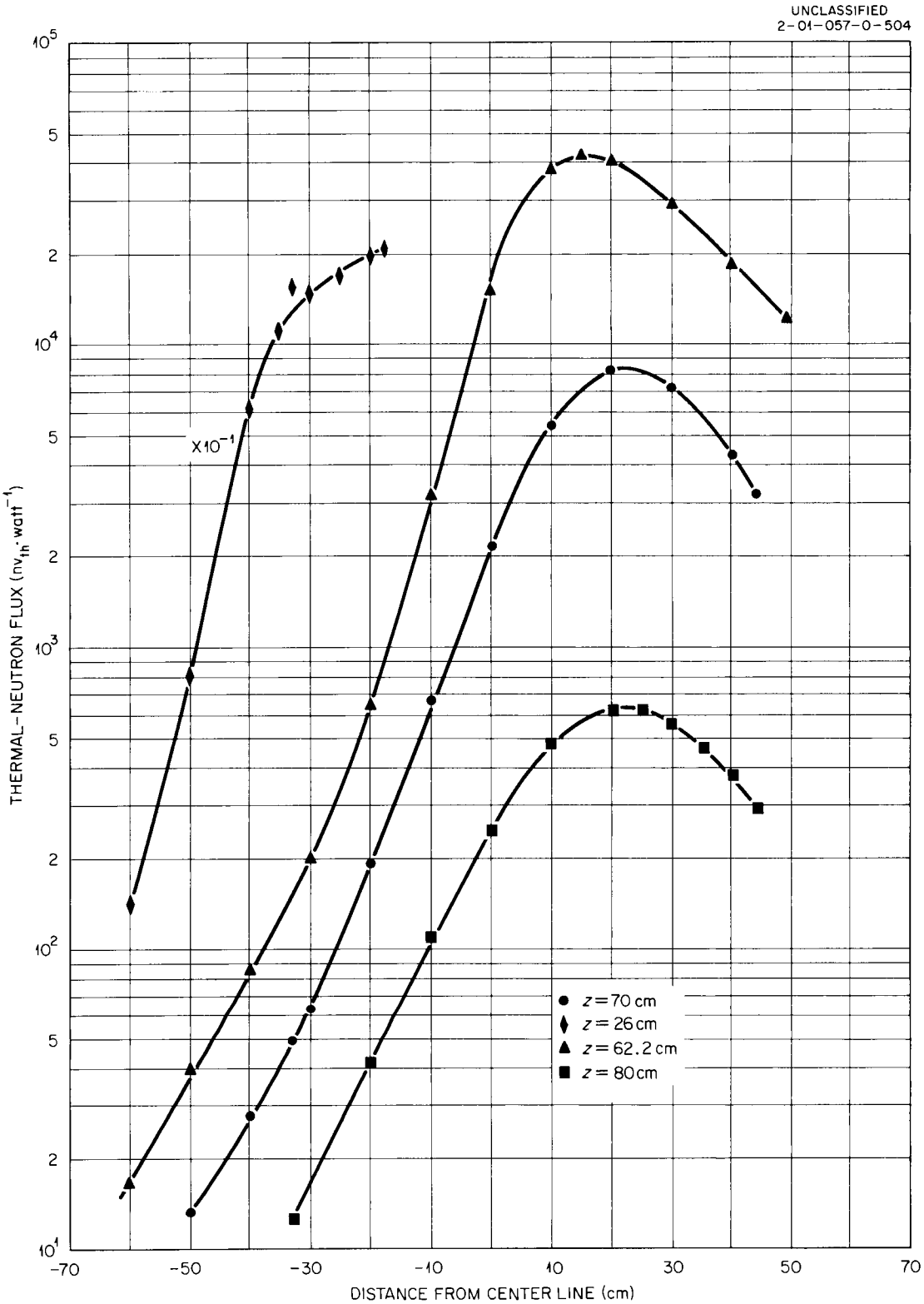

Fig. 27. Thermal-Neutron Flux as a Function of Distance from Center Line (y-Traverse) for Various Values of z, Configuration V.

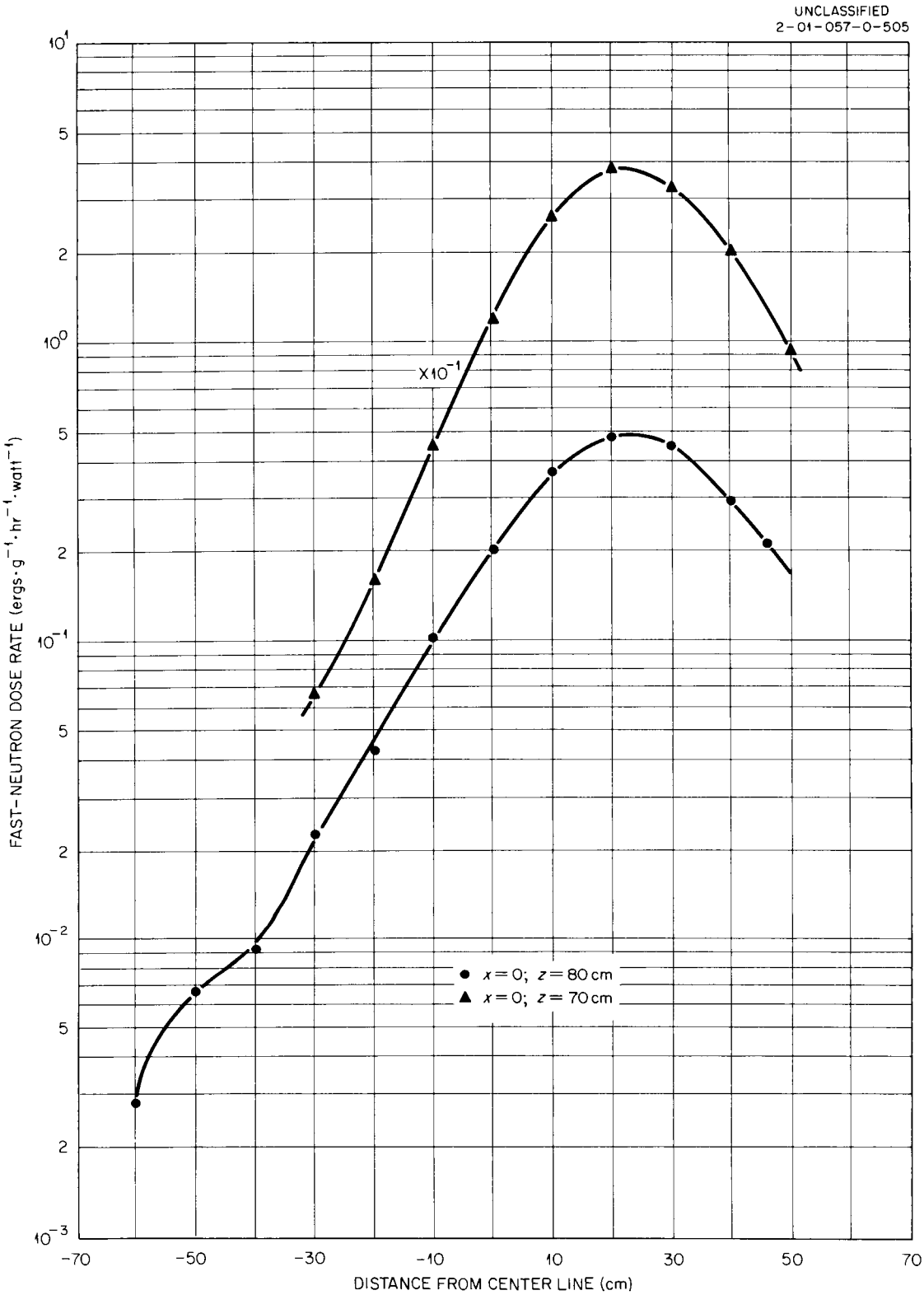

Fig. 28. Fast-Neutron Dose Rate as a Function of Distance from Center Line (y-Traverse), Configuration V.

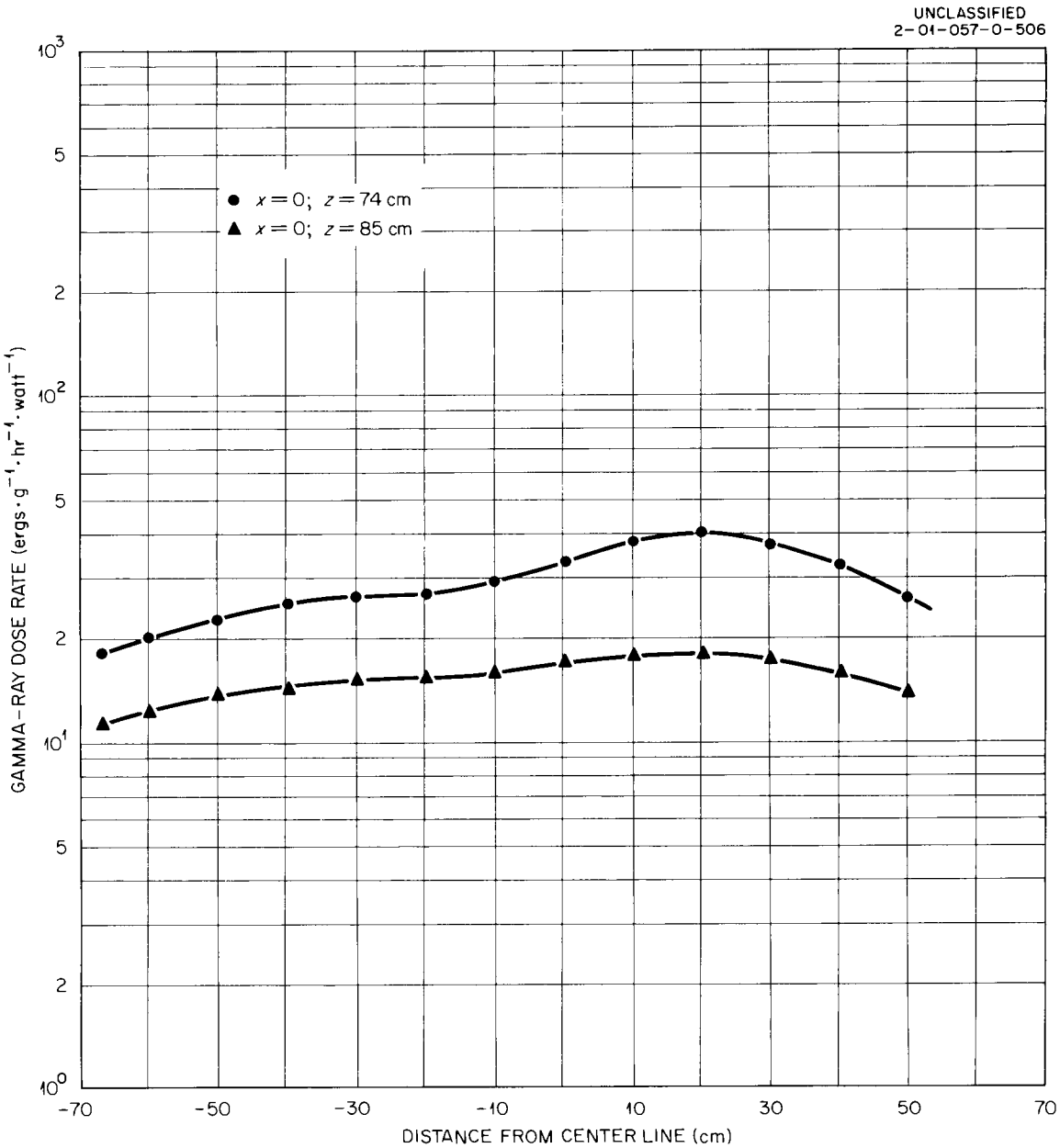

Fig. 29. Gamma-Ray Dose Rate as a Function of Distance from Center Line (y-Traverse), Configuration V.

The investigation was concluded with measurements upon a pair of configurations, VI and VIA, somewhat more complex than the original reference design. Data from these configurations is presented in Figs. 30, 31, and 32. Thermal-neutron flux data from the two configurations is essentially identical. However, the gamma-ray dose rate from configuration VI-A, which differed from configuration VI only in that the 2 in. of polyethylene was removed, was approximately 30% lower than the rate for configuration VI, implying a significant contribution from neutron captures in polyethylene to the dose rate behind VI.

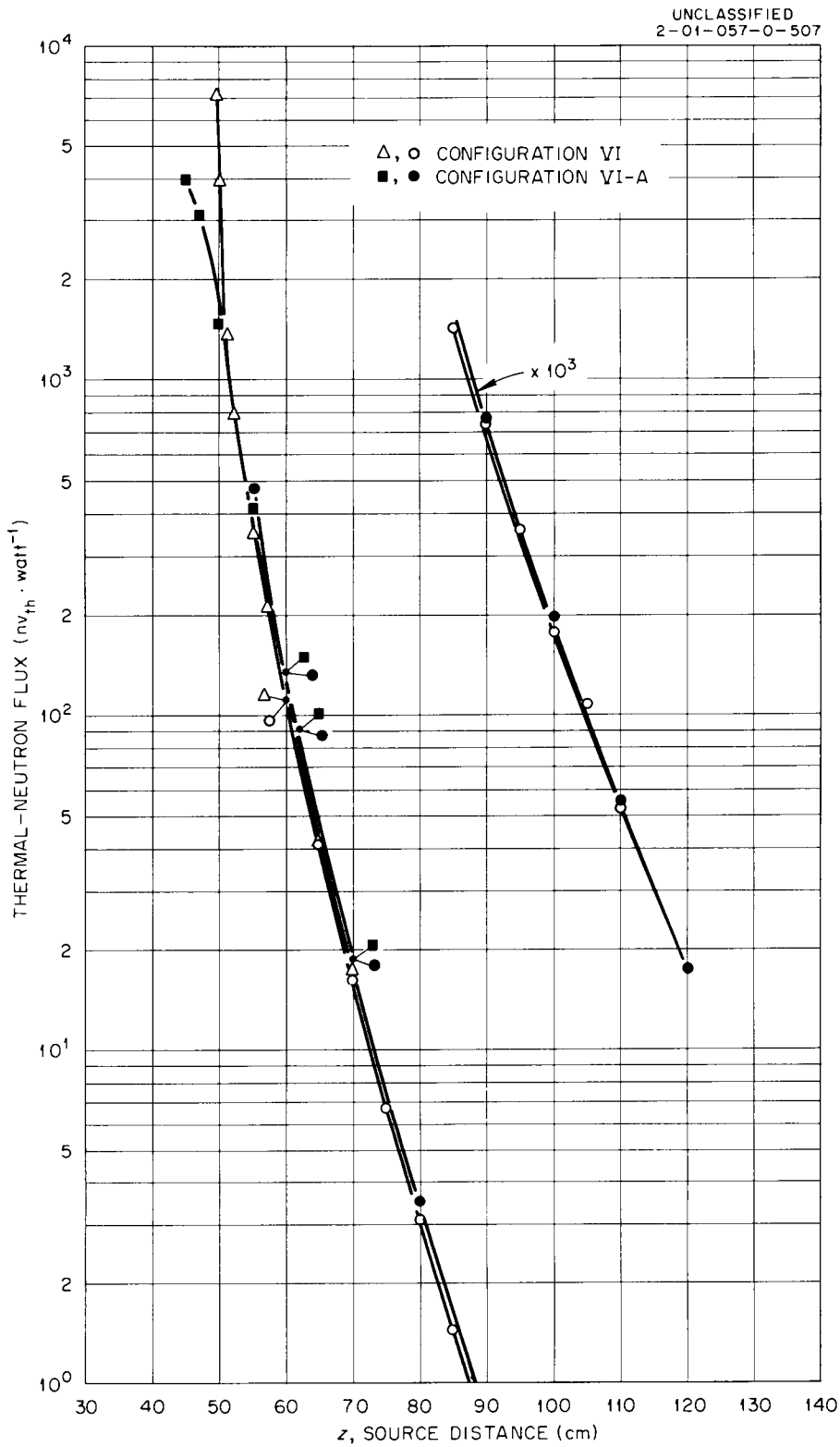

Fig. 30. Thermal-Neutron Flux as a Function of Source Distance; Configurations VI and VI-A.

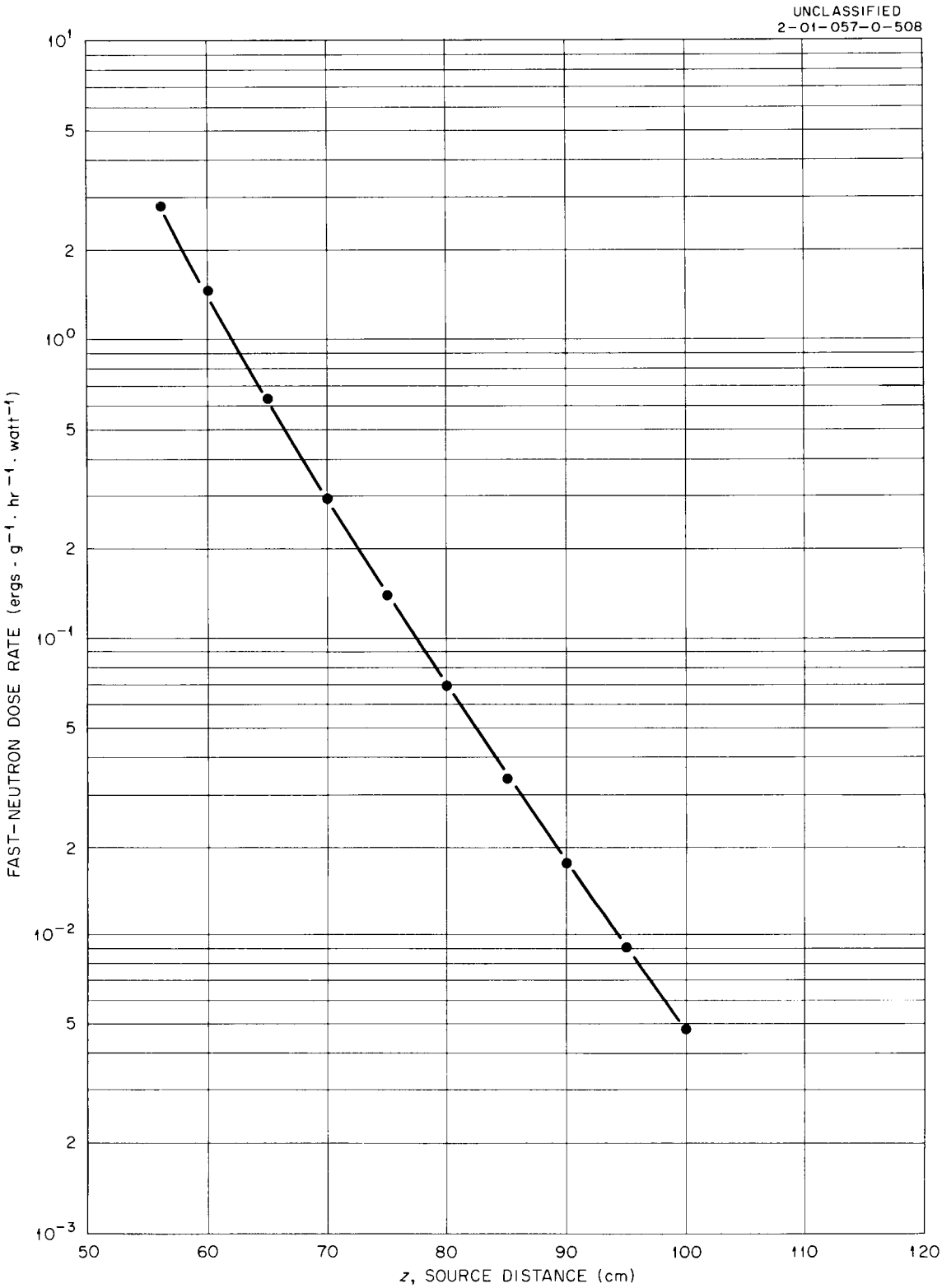

Fig. 31. Fast-Neutron Dose Rate as a Function of Source Distance; Configuration VI.

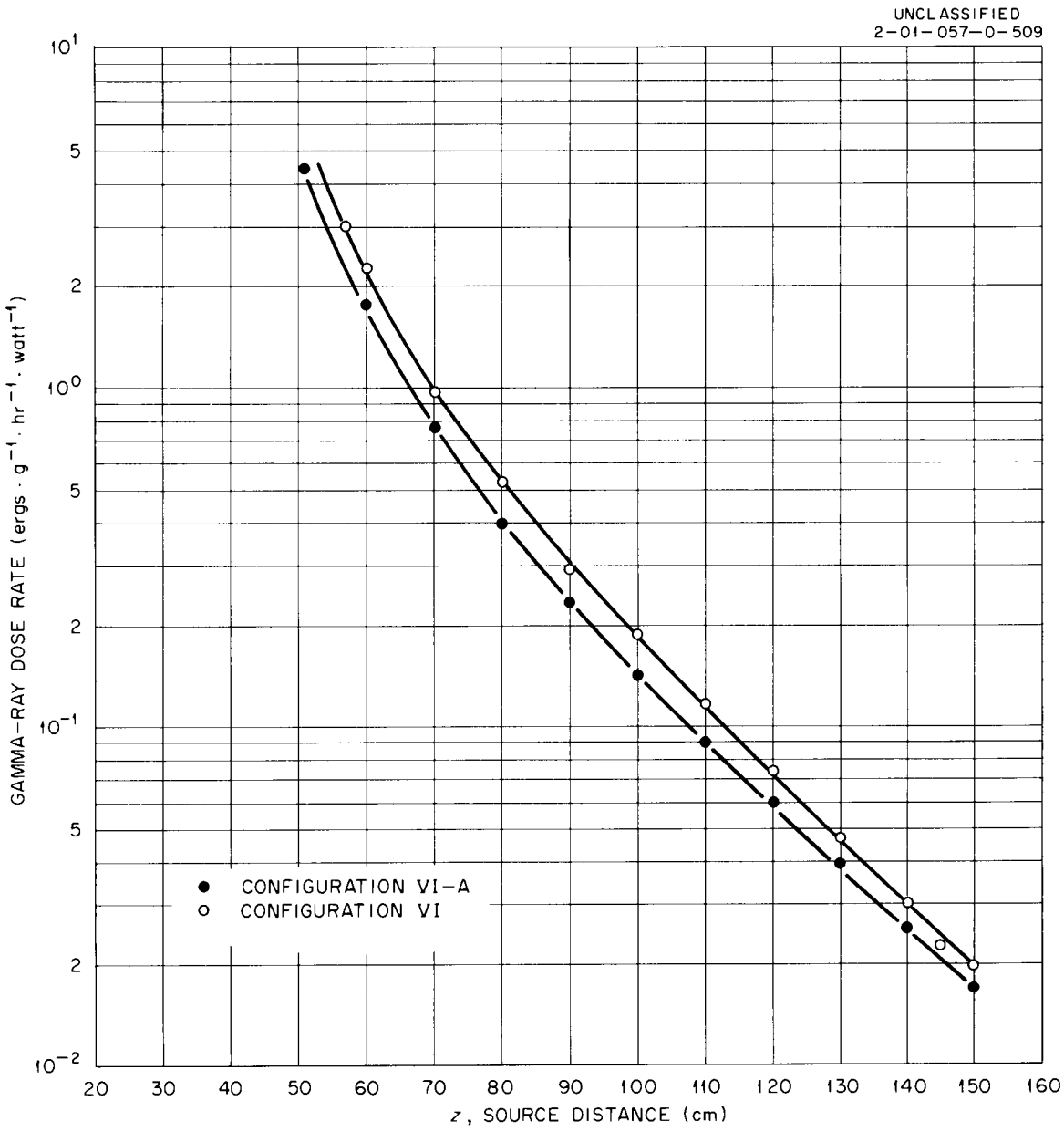

Fig. 32. Gamma-Ray Dose Rate as a Function of Source Distance; Configurations VI and VI-A.

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