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R. A. Wolfe and W. F. Stubbins

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ABSTRACT

Subcritical neutron multiplication experiments were performed with four SNAP-19B (IRHS) heat sources containing plutonium-238 at different array spacings in both air and water. These experiments are a continuation of an established program at Mound Laboratory to evaluate the criticality safety of heat sources containing plutonium-238. Each source contained approximately 1 kg of plutonium-238, the largest quantity of this isotope ever assembled in a controlled experiment. The maximum neutron multiplication of 1.19 was obtained with the four heat sources completely submerged in water in a 1/8-in. (0.3-cm) edge-to-edge planar array.

INTRODUCTION

Mound Laboratory is engaged in the assembly of SNAP (Systems for Nuclear Auxiliary Power) isotopic power heat sources containing large quantities of enriched plutonium-238 isotope. A program has been established at Mound to evaluate experimentally the neutron multiplication and, thus, the criticality safety of plutonium-238 heat sources. This report discusses the experimental results obtained with the largest quantity of plutonium-238 ever assembled in a controlled environment.

A subcritical neutron multiplication experiment was performed with four SNAP-19B (IRHS, Intact Reentry Heat Source) heat sources containing plutonium-238. The neutron multiplication was determined for three different array spacings in both water and air. Also, the effect of water and lead slab reflectors were evaluated.

The results of these experiments provide insight into the criticality behavior of plutonium-238. The experimental data will be used to establish nuclear safety guides for the storage, processing, assembling, and design of heat sources.

RESULTS AND DISCUSSIONS

The four SNAP-19B (IRHS) heat sources were assembled in three planar arrays which had edge-to-edge spacings between heat sources of 3, 3/4, and 1/8 in. (7.6, 1.9, and 0.3 cm). The fuel in the SNAP-19B (IRHS) sources is a "high grade" plutonium dioxide. The isotopic abundance of the "high-grade" plutonium is approximately 80% plutonium-238, 16% plutonium-239, 3% plutonium-240, and 1% plutonium-241. Each source contained approximately 995 g of plutonium-238. The configuration of these SNAP-19B (IRHS) heat sources was significantly different than a previous experiment with three SNAP-19B (Ref.) heat sources.[1,2] The

[1] R. A. Wolfe and D. A. Edling, Subcritical Neutron Multiplication Experiments With SNAP 19C-2 and SNAP-19B Heat Sources Containing Plutonium-238 Isotope, MLM-1416 (DEL-1) (Sept. 29, 1967), 12 pp.

[2] The SNAP-19B heat sources from the earlier study are designated SNAP-19B (Ref.). The SNAP-19B heat sources used in the study reported here were of a modified design and are designated SNAP-19B (IRHS).

fuel was in a cylindrical configuration in the SNAP-19B (IRHS), whereas in the SNAP-19B (Ref.) the fuel was in an annular configuration. A schematic of the experimental arrangements and reflector configurations is shown in Figure 1. Several adjacent laboratory views are shown in Figures 2, 3, and 4. As shown in the photographs, fans were used to maintain the heat sources below a temperature of 150°C. The experimental procedure and data obtained in each array configuration and medium are discussed below:

Neutron Multiplication in Air The experiments performed in air determined the neutron multiplication as a function of the quantity of plutonium-238 for the three planar array spacings. The multiplication was first determined for the array with the largest spacing and, thus, the safest configuration. The recorded neutron count rate of each heat source was measured individually in its array position with the two helium-3 proportional detectors as illustrated in Figure 1. Actual dummy capsules filled with equivalent weights of lead shot were used in the array placement to correct for the neutron scattering and reflection characteristics of the heat source capsules. The heat sources were added one at a time, each to its unique preassigned location, to build the array as the corresponding dummy capsule was removed. The neutron yield was measured with each increment of added source, and a neutron multiplication M was calculated as follows:

$$M = \frac{\text{Recorded Count Rate - Background}}{\text{Accumulative Count Rate - Background}} .$$

The neutron multiplication obtained for each array and each medium is given in Table 1. The neutron multiplication for each array in air is plotted in Figure 5. These results indicate that a small neutron multiplication existed in each array, but the array of the smallest spacing (curve 3) showed the highest multiplication; that is, the array of 1/8-in. (0.3-cm) edge-to-edge spacing showed a maximum multiplication of 1.105. No significant multiplication was observed between the coupling of two sources. This result is as expected since the planar configuration of two sources allows the greatest neutron leakage. This result is observed in Figures 6, 7, and 8, but to a lesser extent due to the contribution of the reflectors.

Neutron Multiplication in Air When Reflected by a Water and a Lead Slab The experimental arrangements for each type of reflector are shown in configurations B, C, D, and E of Figure 1. The neutron multiplication was determined for each array by the same technique as previously described for air. The results are given in Table 1 and plotted in Figures 6 and 7. These results indicate that both the water and the lead slab reflectors slightly increased the neutron multiplication. No significant difference existed in multiplication as a result of the two different types of reflectors. Although it was expected that the lead reflector would result in a higher neutron multiplication than the water slab, that difference in multiplications may possibly have been so small as to be immeasurable. The maximum neutron multiplication was obtained when the 1/8-in. (0.3-cm) array was reflected on four sides by 4-in. (10.2 cm) thick lead slabs as shown in Curve 3D in Figure 6. This increase in multiplication was due to the more efficient reflector configuration.

Neutron Multiplication in Water The purpose of the experiments in water was to determine whether the neutron multiplication would increase as the heat sources were brought closer together, thus changing the water medium properties from less moderation to more reflection. The neutron multiplication was determined for each array by the same technique as previously described for the air medium. The combined results are given in Table 1 and plotted in Figure 8. The increase in multiplication as the array spacing decreased indicates that the arrays containing plutonium-238 exhibited less multiplication in a moderating medium [curve 1, 3-in. (7.6-cm) edge-to-edge spacing] than in a fast medium [curve 3, 1/8-in. (0.3-cm) edge-to-edge spacing]. The maximum multiplication (approximately 1.19) which existed in the closest array spacing [1/8-in. (0.3-cm) edge-to-edge spacing] was 7% greater due to the reflection of the water. In this configuration, the multiplication was expected to be higher than obtained with the slab reflectors since the system was completely reflected. It would be expected that the multiplication would be significantly higher for a plutonium-238 system completely reflected by heavy metal than completely reflected by water, because of the differences that exist in the fission and capture cross sections to the various neutron energy ranges for the different reflectors.

The 3-in. (7.6-cm) spacing between capsules was adequate for effective moderation of the neutrons (curve 1 of Figure 8), and as expected, no neutron multiplication existed.

CONCLUSIONS

The conclusions drawn in this experiment are essentially the same as those conclusions drawn from the previous experiments with seven SNAP-19C-2 and three SNAP-19B (Ref.) heat sources.[1] However, due to the larger quantity of plutonium-238 assembled than in the previous experiments and due to the larger neutron multiplication obtained, the results of the experiments provide additional support for the previously drawn conclusions:

1. The neutron multiplication significantly increased as the edge-to-edge spacing between heat sources decreased in both air and water. These results indicate that only a fast or epithermal critical system is probable with heat sources containing plutonium-238.

2. The neutron multiplication for the 3-in. (7.6-cm) space array was smaller with water than with air, and the multiplication for the 1/8-in. (0.3-cm) space array was significantly larger in water than in air. These

results support the belief that a well-moderated (thermal) critical system of plutonium-238 cannot be assembled. Also, these results reveal the reflection contribution of the water.

3. A small neutron multiplication did exist with the cluster of four SNAP-19B (IRHS) heat sources. The maximum multiplication observed was approximately 1.19. This multiplication was not large enough to extrapolate to the critical size of clusters of heat sources containing plutonium-238.

4. The results of these experiments confirm that no criticality hazard exists with four SNAP-19B (IRHS) heat sources when assembled in any array configuration provided the capsules maintain their integrity.

Table 1

NEUTRON MULTIPLICATION OF FOUR SNAP-19B (IRHS) HEAT SOURCES AT VARIOUS ARRAY SPACINGS AND REFLECTORS

Edge-to-Edge Spacing (in.)	Edge-to-Edge Spacing (cm)	Quantity of Plutonium-238 Isotope (g)	Multiplication for Various Reflectors: Air	Multiplication for Various Reflectors: Two Sides, Lead Slab 4 in. (10.2 cm) Thick	Multiplication for Various Reflectors: Two Sides, Water Slab 5 in. (12.7 cm) Thick	Multiplication for Complete Submersion in Water
3	7.6	994	1.000 ± 0.010	1.000 ± 0.010	1.000 ± 0.010	1.000 ± 0.011
		1994	1.005 ± 0.006	1.003 ± 0.005	1.005 ± 0.006	1.000 ± 0.010
		2986	1.008 ± 0.005	1.005 ± 0.004	1.018 ± 0.004	1.000 ± 0.006
		3981	1.015 ± 0.004	1.015 ± 0.003	1.023 ± 0.004	1.004 ± 0.005
3/4	1.9	994	1.000	1.000	1.000	1.000
		1994	1.002	1.010	1.010	1.016
		2986	1.039	1.044	1.049	1.070
		3981	1.050	1.068	1.075	1.120

Edge-to-Edge Spacing (in.)	Edge-to-Edge Spacing (cm)	Quantity of Plutonium-238 Isotope (g)	Multiplication for Various Array-Reflector Configurations[a]: A	B	C	D	E	F
1/8	0.3	994	1.000	1.000	1.000[b]	1.000[c]	1.000	1.000
		1994	1.004	1.014	1.020[b]	1.030[c]	1.025	1.023
		2986	1.060	1.068	1.070[b]	1.075[c]	1.075	1.110
		3981	1.105	1.125	1.120[b]	1.140[c]	1.130	1.190

[a] See Figure 1.

[b] Reflected on two sides by 6-in. (15.2-cm) thick lead slabs.

[c] Reflected on four sides by 4-in. (10.2-cm) thick lead slabs.

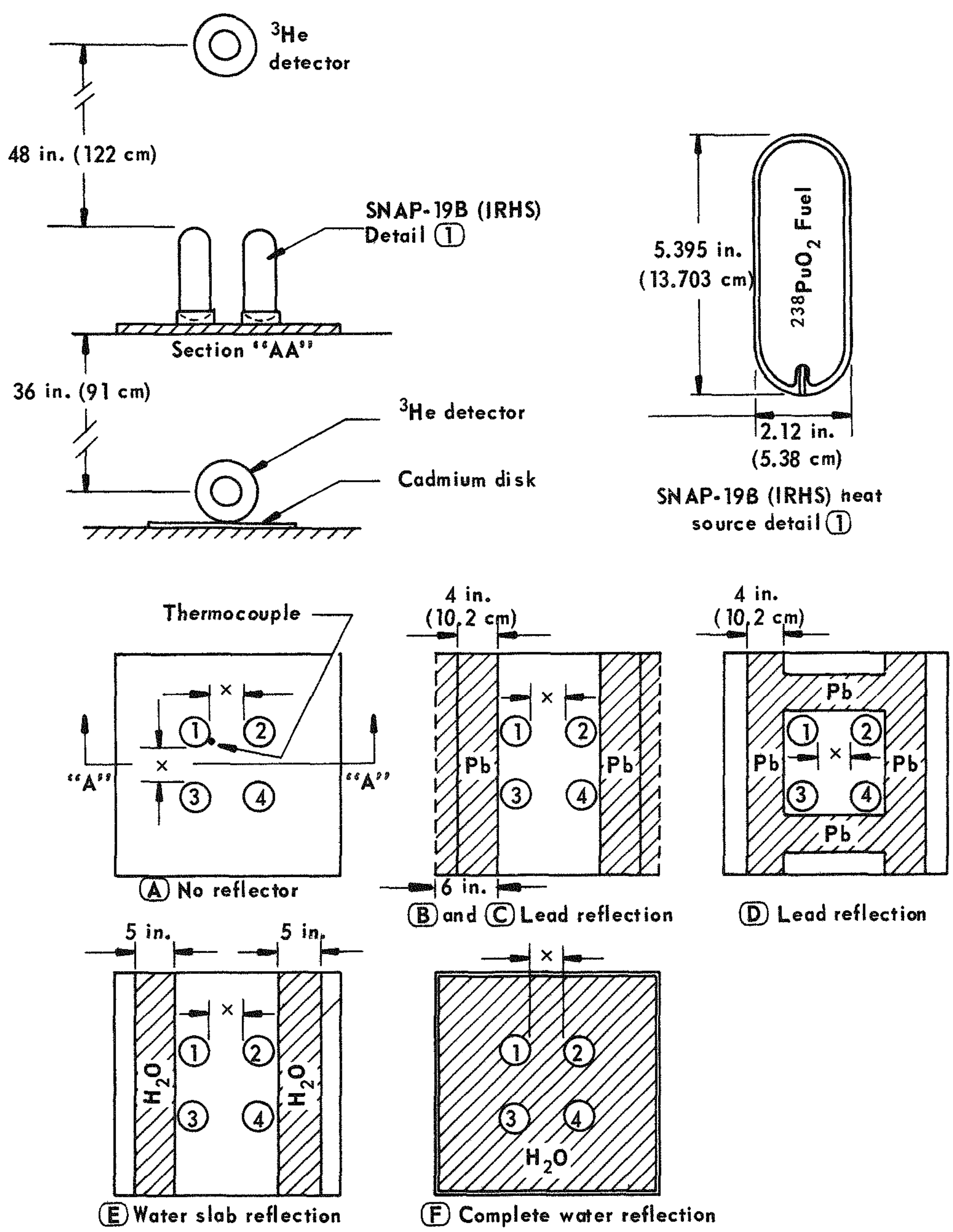

FIGURE 1 - Neutron multiplication experimental arrangement for SNAP-19B (IRHS) heat sources and reflector configurations.

Edge-to-Edge Spacing	(in.)	(cm)
X	3	7.6
X	3/4	1.9
X	1/8	0.3

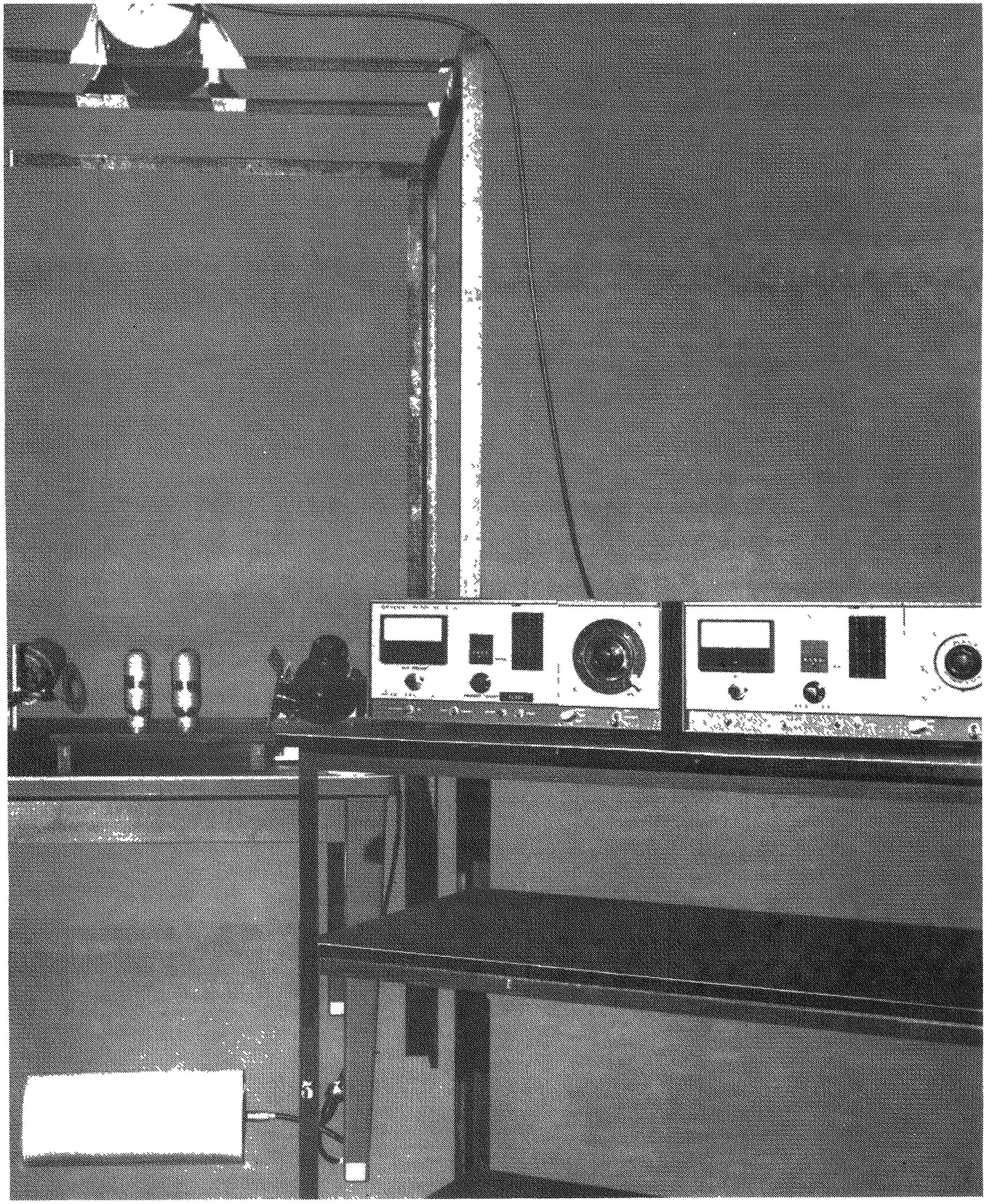

FIGURE 2 - The neutron multiplication experimental arrangement with four SNAP-19B (IRHS) heat sources.

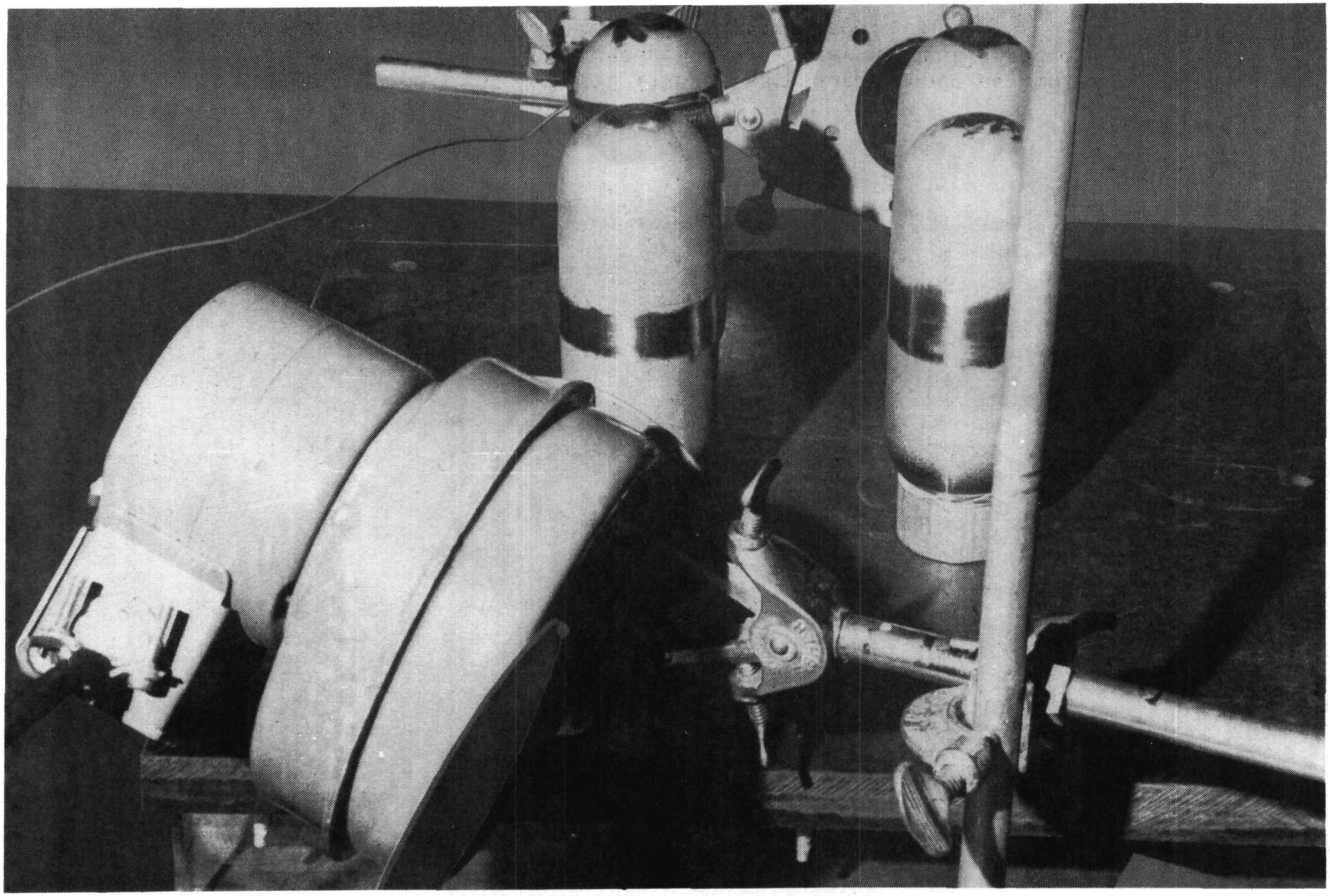

FIGURE 3 - Four SNAP-19B (IRHS) heat sources assembled in a 3-in. (7.6-cm) edge-to-edge planar array with no reflector (Configuration A).

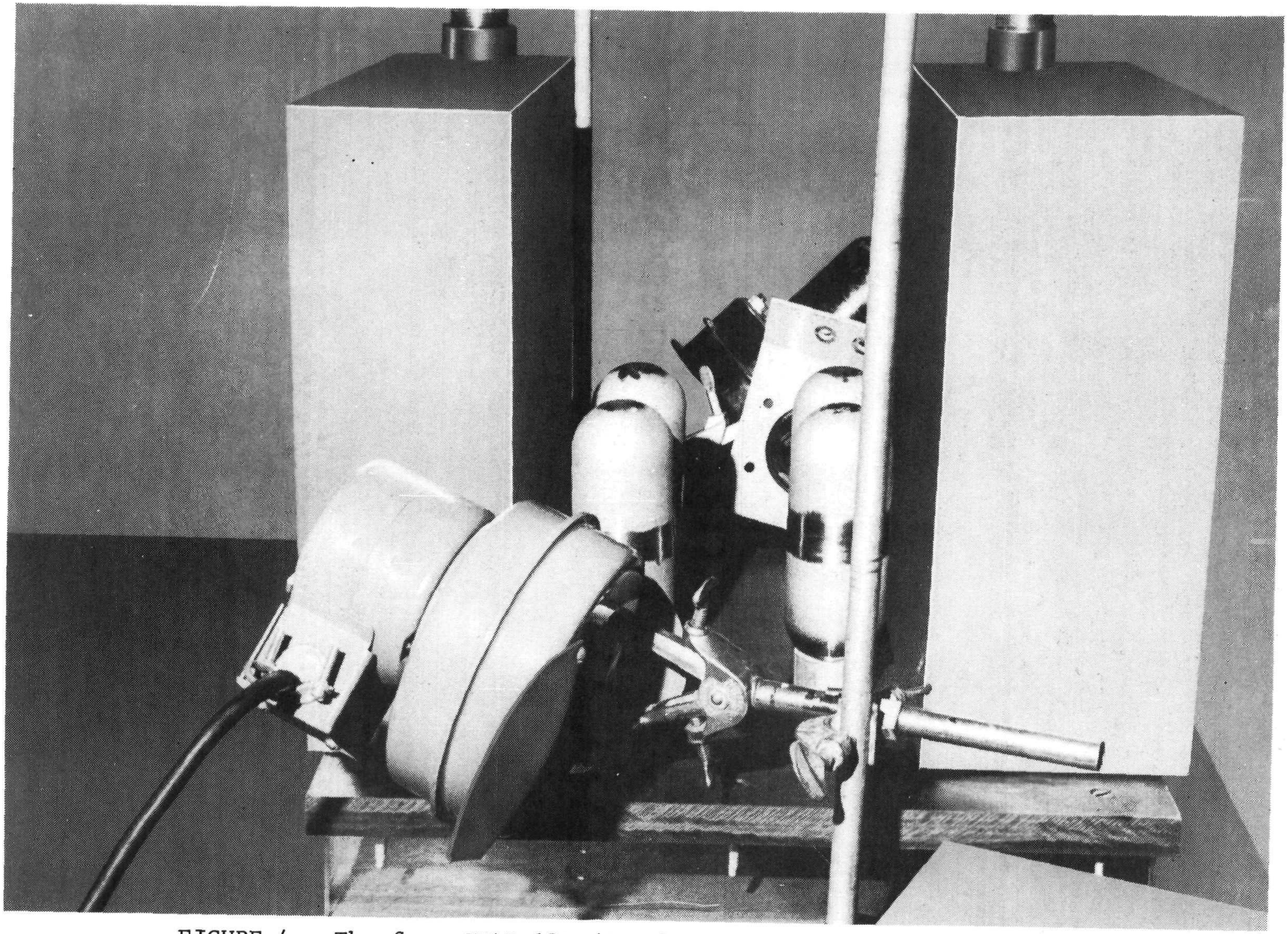

FIGURE 4 - The four SNAP-19B (IRHS) heat sources when assembled in a 3-in. (7.6-cm) edge-to-edge planar array and reflected on two sides by 5-in. (12.7-cm) thick water slabs.

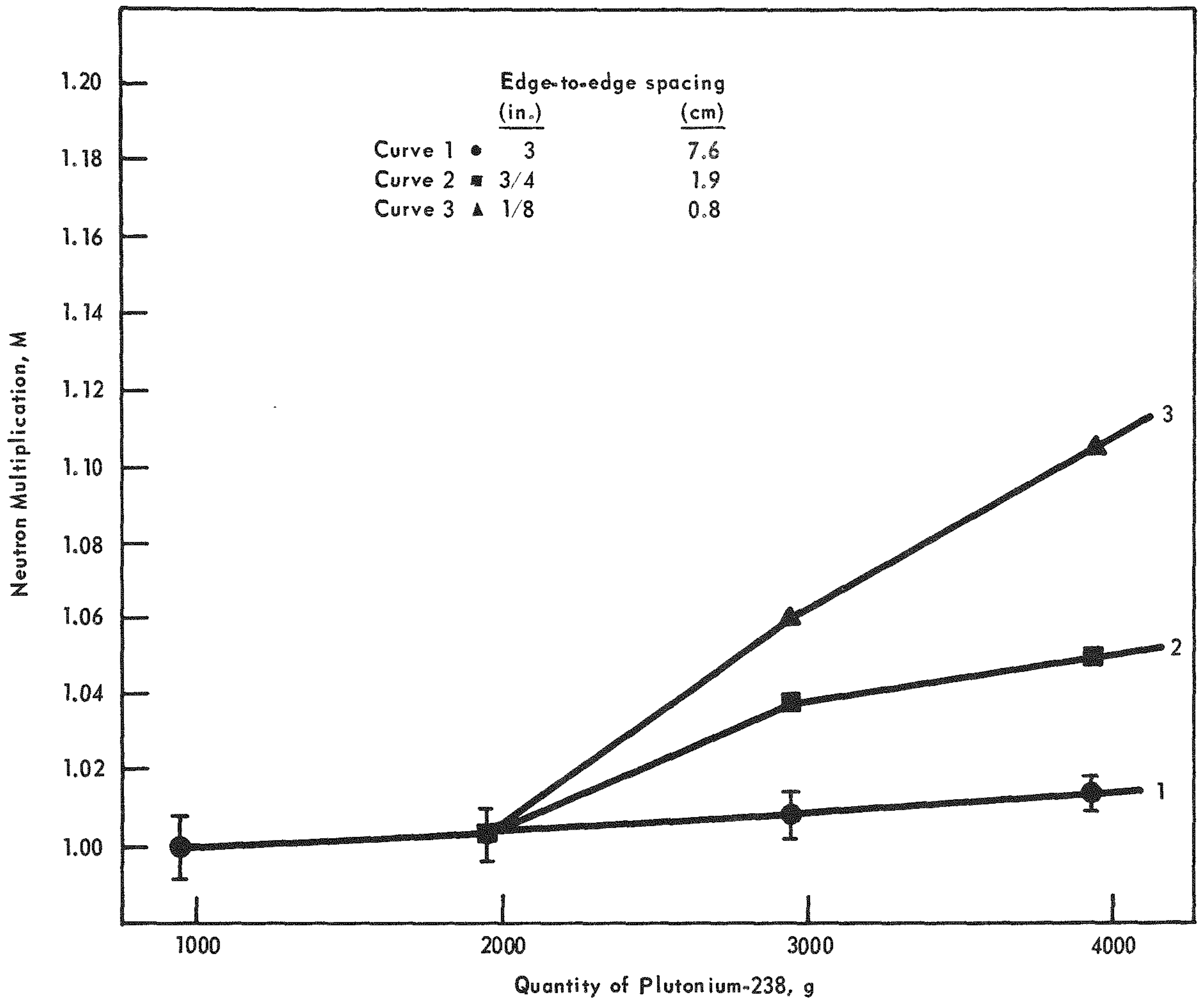

FIGURE 5 - Neutron multiplication of four SNAP-19B heat sources containing plutonium-238 assembled in different planar arrays in air. Each data point represents the average multiplication obtained with two detectors. The error bars represent the approximate statistical error for each point.

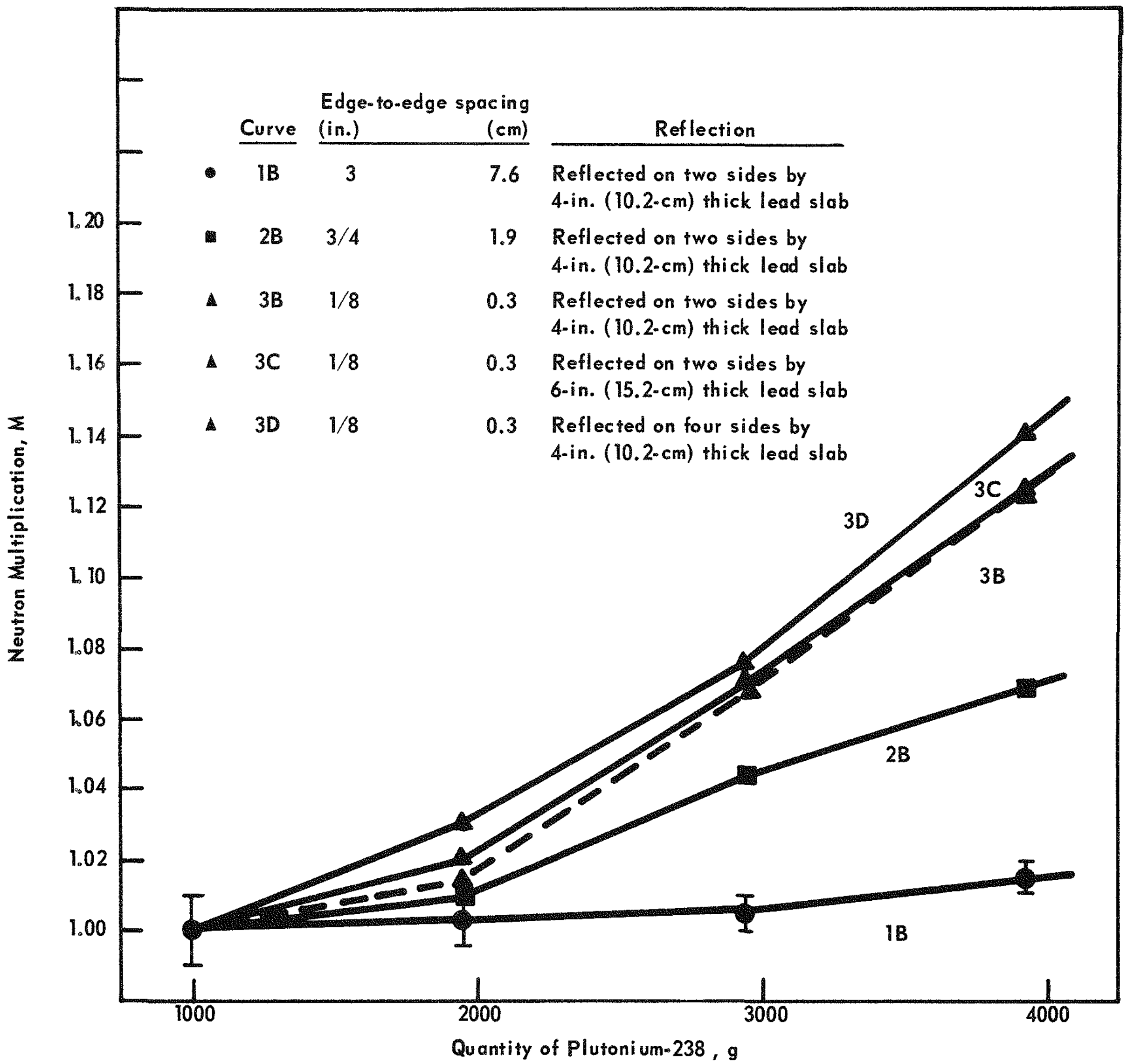

FIGURE 6 - Neutron multiplication of four SNAP-19B (IRHS) heat sources containing plutonium-238 assembled in different planar arrays in air when reflected by lead slabs. Each data point represents the average multiplication obtained with two detectors. The error bars represent the approximate statistical error for each point.

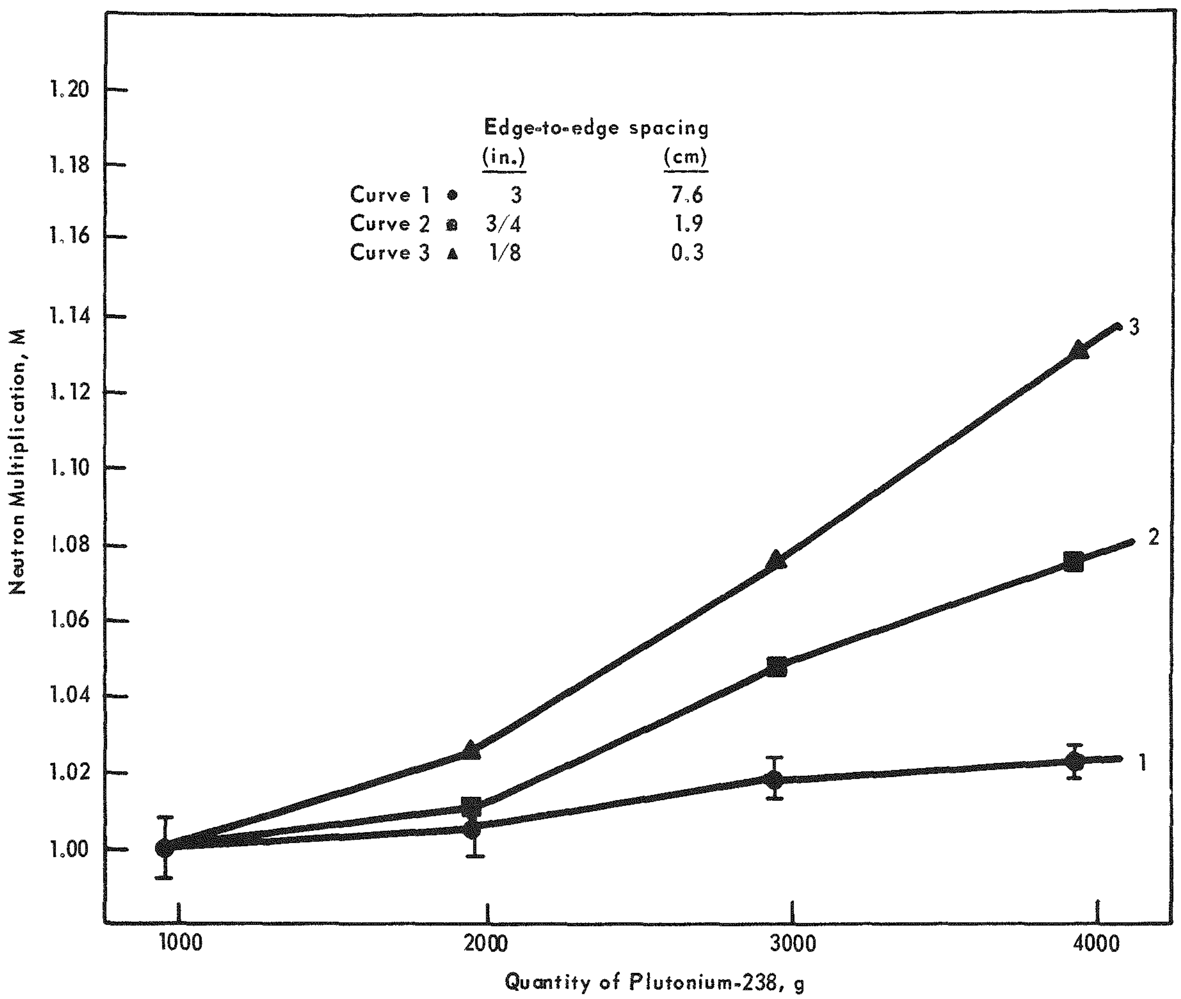

FIGURE 7 - Neutron multiplication of four SNAP-19B heat sources containing plutonium-238 assembled in different planar arrays in air when reflected on two sides by 5 in. (12.7 cm) of water. Each data point represents the average multiplication obtained with two detectors. The error bars represent the approximate statistical error for each point.

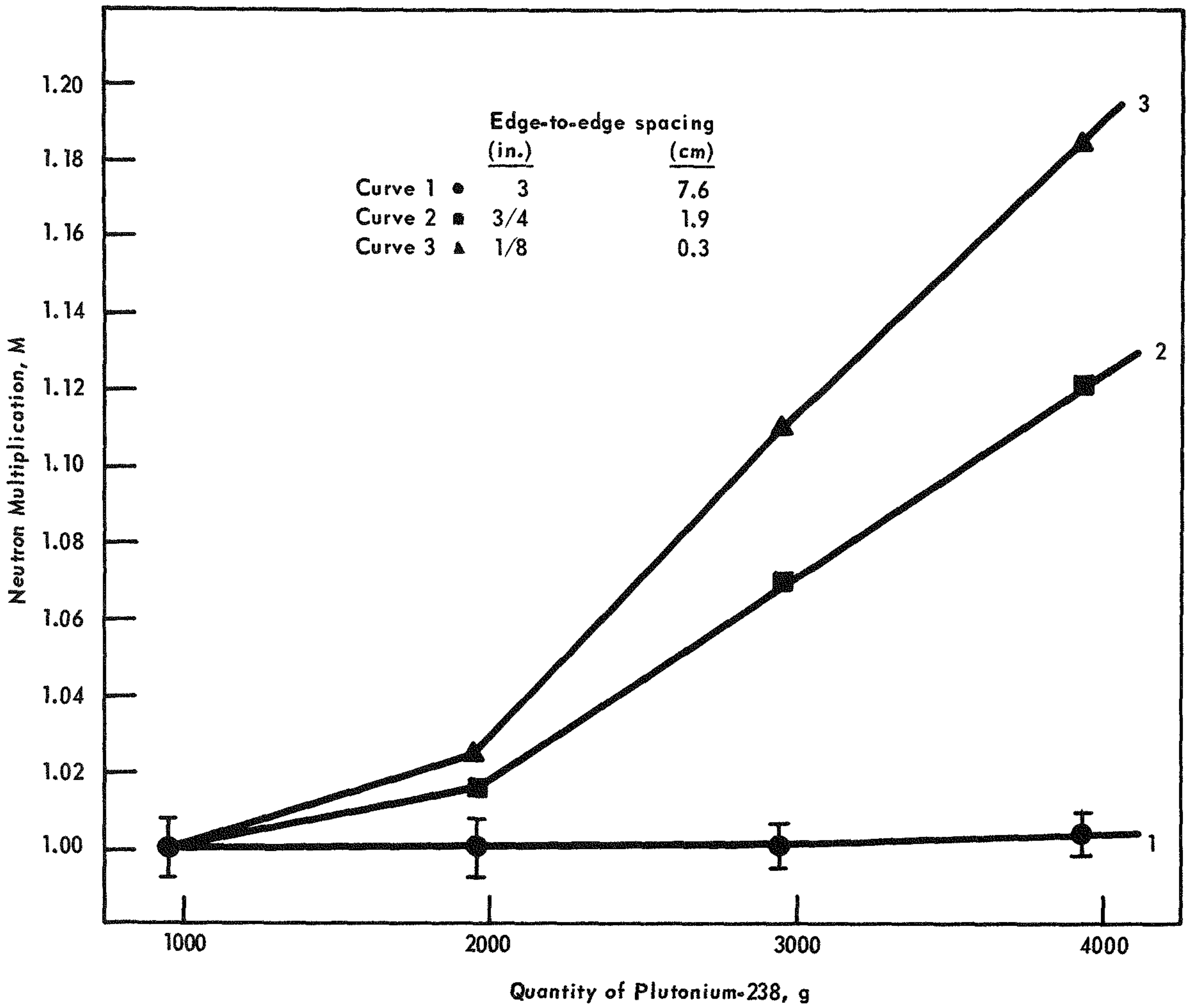

FIGURE 8 - Neutron multiplication of four SNAP-19B heat sources containing plutonium-238 assembled in different planar arrays in a completely reflected water medium. Each data point represents the average multiplication obtained with two detectors. The error bars represent the approximate statistical error for each point.