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FURTHER CRITICAL EXPERIMENTS ON A SMALL REACTOR OF ENRICHED U-235 WITH AL-H_2O MODERATOR AND BERYLLIUM REFLECTOR

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PHYSICS DIVISION

FURTHER CRITICAL EXPERIMENTS ON A SMALL REACTOR OF ENRICHED U-235 WITH AL-H_2O MODERATOR AND BERYLLIUM REFLECTOR

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Further Critical Experiments on a Small Reactor of Enriched U-235 with Al-H_2O Moderator and Be Reflector

Introduction

The experimental facilities and operating procedures which have been used in the conduct of critical experiments to study the characteristics of small enriched reactors have been described in MonP-357. The purpose of the present report is to describe briefly certain improvements that have been made in the experimental facilities and to present the results of further measurements on critical masses and spatial neutron flux distributions in Be reflected reactors having square and thin slab geometries. The critical mass of a reactor having the usual U-Al-H_2O core and no reflector has also been measured, and preliminary experiments to determine the fast neutron flux in these reactors have been carried out.

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Experimental Facilities

With the termination of the experiments dealing with liquid reflectors, and in preparation for a series of experiments on reactors having solid reflectors, it was decided that it would be worthwhile to make certain major changes in the experimental arrangement in the criticality cell in order to provide for greater flexibility and greater convenience in stacking solid reflectors. The entire liquid storage and piping system was removed from the cells and in place of the tank assemblies which had been used for D_2O and H_2O reflectors a low platform framework of cast iron was erected. A $\frac{1}{2}$ inch plate of 2S aluminum was placed over the cast iron framework to serve as a floor on which to build critical assemblies. The center portion of the plate is cut out and flanges are provided to hold a center plate of $\frac{1}{4}$ inch aluminum through which are drilled a rectangular array of holes accurately spaced to position the lower ends of the fuel tubes for Al to H_2O ratios equal to or greater than 0.65. Thus the bottom of the reactor is relatively clean, the core and a considerable portion of the reflector having only the $\frac{1}{4}$ inch perforated aluminum plate immediately under them.

The upper ends of the fuel tubes are held in position by cross bars of aluminum angle which are adjustable to accommodate rectangular cores of various sizes. The mounting plate for the control wire pulleys and the control rod guide plates have been replaced by new plates which are drilled and tapped to provide for the location of control elements at suitable positions in any of the various assemblies that can be constructed on the base support. Plates 1 and 2 show a core of square cross section with Be reflector assembled on the platform. The level of the fuel is at the same height as the top of the reflector in these assemblies, the remaining upper portion of the fuel tubes being empty up to the rubber stoppers. Plate 2 shows the control rod guide plate, which also holds the control rod shock absorber cups, and the mirror which enables the action of the source drive mechanism to be viewed from the control room.

Since our earlier report, MonP-357, was written, practically all of the radiation detection and monitoring instruments have been replaced by improved circuits of more recent design. In particular, we have found that the vibrating reed monitrons, two of which are shown in Plate 1, are a decided improvement over the older designs in stability, sensitivity and response time.

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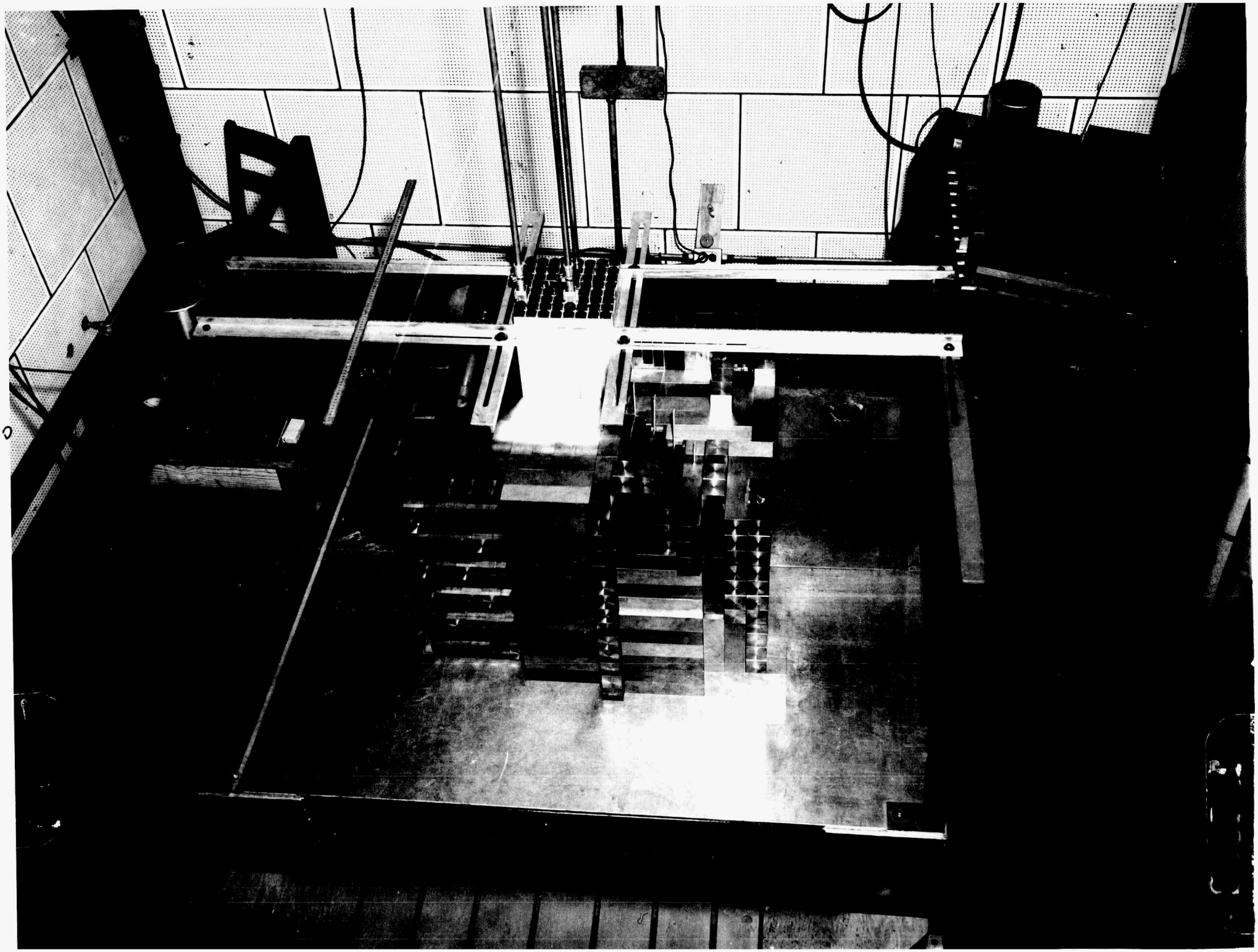

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The operation of the control rod system has been improved by replacing the hand operated control rod counter weights and clamps by small gear boxes (one for each control and safety rod) which were designed to limit the maximum rate of withdrawal of the rods. While the operation of the rods is still basically manual, the use of the gear boxes insures a reasonably slow and constant rate of withdrawal of the rod and also facilitates changing the control rod position in small increments with accuracy.

Experimental Results

A. Bare Pile

While waiting for the arrival of sufficient beryllium to continue the studies for the high flux pile, it was decided to try to obtain a figure for the bare critical size as a check on the fundamental characteristics of this reactor. A bare assembly was built, with cadmium sheets around the sides of the reactor to reduce the effect of nearby objects, and although criticality was not finally reached, a multiplication of about 11.6 was obtained at a load of 5050 grams. The extrapolation of the reciprocal counting rate vs mass curve (see Fig. 1) indicates a critical mass of about 5.5 kg. After correcting for the presence of holes for control rods, it is estimated that the bare critical mass is 5.3±0.1 kg. The Al/H_2O volume in this case was 0.65, the height of the core was 66 cm., the maximum loading attained was 48 cm. by 43 cm. in area, approximating square geometry.

B. Beryllium Reflected Reactors

This report will be limited to a discussion of the experiments which have been done on relatively "clean" Beryllium assemblies; that is, assemblies which have simple, calculable geometries, which contain very small amounts of excess poison in the core, if any, and which have no extraneous materials or irregular configurations in the reflector. A number of experiments which have been performed more recently on larger and less "clean" assemblies, having, for example, 2% water in the Beryllium and holes of appreciable cross section extending through the reflector, will be described in a later report.

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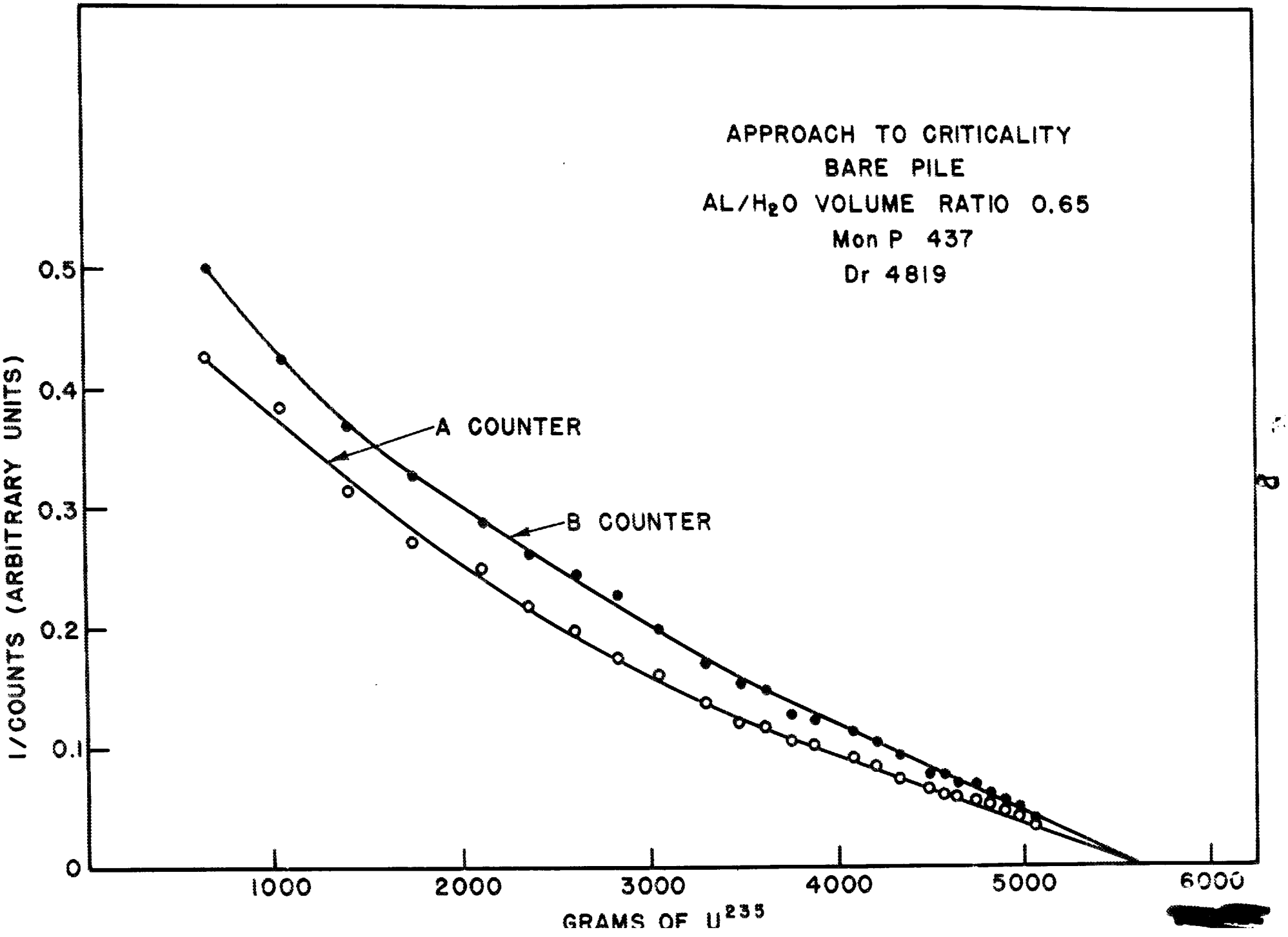

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The first in this series of experiments on Beryllium reflected piles was the measurement of the critical mass of a square assembly having an Al/H_2O volume ratio in the core of 0.65. This assembly was built up to criticality in a manner similar to that which was described in MonP-357. Using the calculated value of the critical mass as a first approximation to the dimensions of core to be expected, a "permanent" Be reflector was stacked, allowing space for a core of 1300 gms of U-235, or an 8 x 8 tube square. By means of a limited number of 1"x1"x26" Be columns which could be used interchangeably with fuel tubes, the dimensions of the core could conveniently be changed from an 8 x 8 tube square to either a 7 x 7 tube or a 9 x 9 tube square. Thus, an error in the calculated value of the critical mass up to about 25% could be taken care of by the use of the interchangeable Be. An error greater than this would necessitate re-stacking the permanent reflector.

Initially, only a few fuel tubes (15 in this case) are placed in the core, the remaining portion of the core volume being filled with identical tubes containing D_2O, whose reflecting properties are very similar to those of Beryllium. The fuel content is then increased by replacing tubes containing D_2O with tubes containing fuel. At appropriate intervals in this build-up process, the control rods are withdrawn and the counting rates of BF_3 proportional counters located near the assembly are observed. The reciprocal counting rate, when plotted vs the mass of U-235 aboard, extrapolates to zero at critical mass.

In this experiment the geometry of sources and BF_3 counters was apparently very good, since the counting rate vs mass plots turned out to be approximately straight lines, showing no tendency to either turn downward or curve upward near the critical mass, as happens in many cases. Two Po-Be sources were used, one (10^7 neutrons per sec.) located directly beneath the lower surface of the pile, below the center of the core, and another (10^5 neutrons per sec.) suspended in an empty tube at the core-reflector boundary, at mid-height of the pile. Two BF_3 proportional counters were used to observed the multiplication of the reactor during the build-up to criticality and are used in subsequent experiments as low level monitors. Both of these counters were located in such a manner that a large portion of the core lies between the sources and the counters; that is, the counters must "look through" the multiplying medium to "see" the sources and the number of neutrons that are able to go directly from source to counter is minimized. One counter was placed on the top surface of

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the reflector, in the immediate vicinity of the core (see Plates 1 and 2); the other was placed about 15 feet from the pile at an elevation about 4 feet higher than the top surface of the assembly.

It was found that the square assembly became critical just three fuel tubes short of an 8 x 8 tube array. In order to complete the square geometry it was necessary to add a small amount of poison (about 60 cm^2) in the form of 31-0.030" diameter gold wires, uniformly distributed throughout the core. The resulting pile then has a core 22.5x22.5 cm in cross section and 66 cm in height, containing 1.21 kg of U-235 at a fuel concentration of 38 gms U per liter of pile. The Al/H_2O ratio in the core is 0.65. The core has reflector on all sides consisting of more than 30 cm thickness of Beryllium, but no reflector top or bottom. When corrections are made for the presence of control rod ports (air holes) and for distributed gold wires in the core, the minimum critical mass of a square reactor of this type turns out to be 1.07 kg.

The second clean Be reflected pile to be built was a thin slab assembly. It was desired to find the critical mass of a rectangular geometry having a length-to-width ratio of approximately 5. The width selected for the core of the pile was 4 fuel tubes, or 11 cm., and the assembly became critical at a length of 19 fuel tubes (51 cm.) with 30 cm^2 of excess poison in the core. The mass of U-235 in this case is 1.35 kg and when corrections are made for excess poison and control rod ports the minimum critical mass for this thin slab geometry is 1.28 kg. The height of the pile, reflector thickness, fuel concentration and Al to H_2O volume ratio in the core are the same in this case as for the square assembly.

In the build-up of the thin slab assembly the geometry of sources and BF_3 counters was essentially the same as in the square pile experiment. The plot of the reciprocal counting rate vs fuel aboard, shown in Figure 2, indicates the linearity of results that can be obtained with reasonably good source and counter geometry.

Spatial distributions of thermal and epithermal neutron flux have been measured in both the square pile and the thin slab pile. These measurements were made with Indium foils, used alternately bare and cadmium covered as described in previous reports. Figure 3 shows the distributions of thermal and epithermal neutron flux along a

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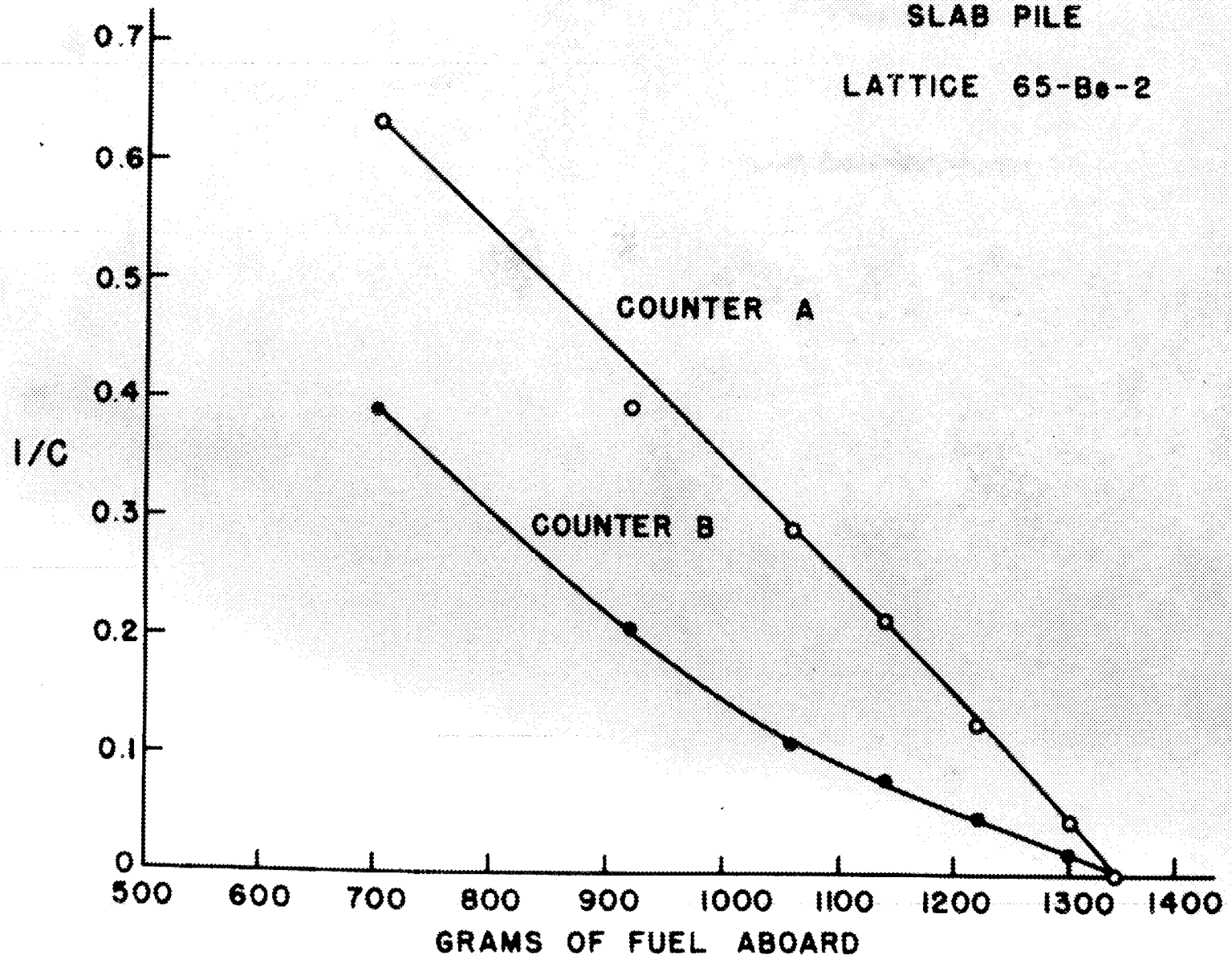
APPROACH TO CRITICAL
SLAB PILE

LATTICE 65-Be-2



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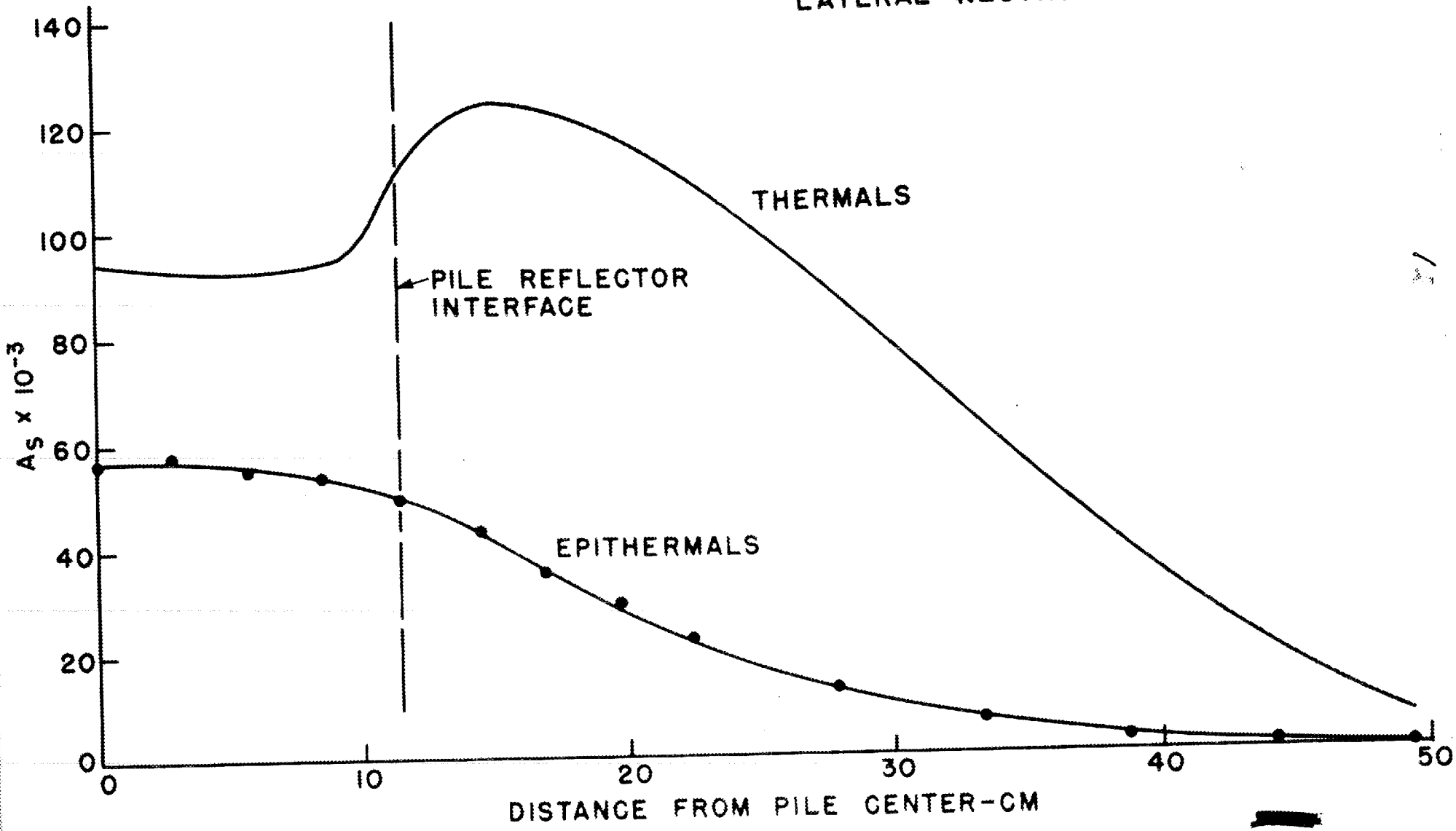
SQUARE Be PILE
LATTICE 65-Be-1
LATERAL NEUTRON DISTRIBUTIONS



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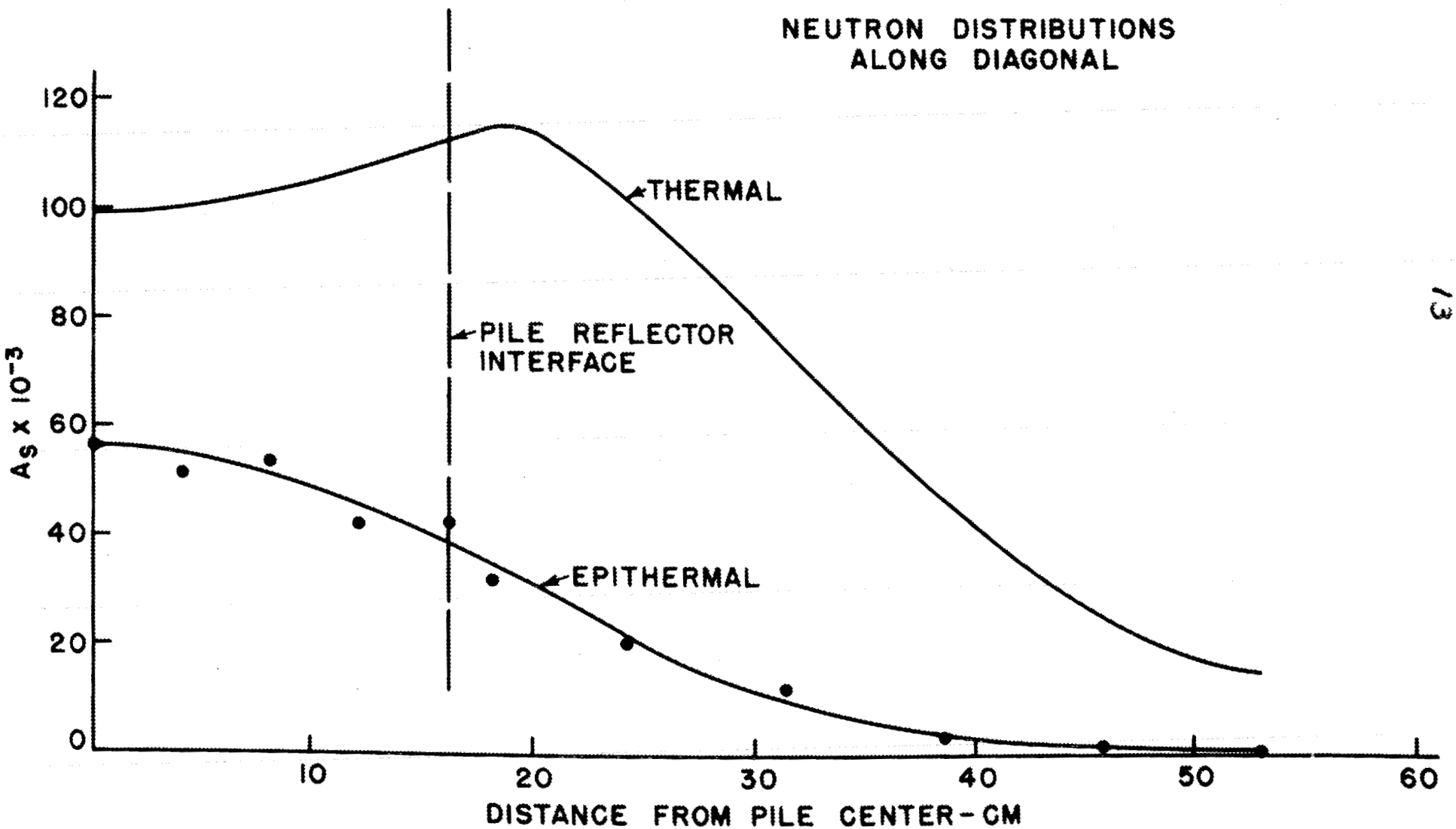
SQUARE Be PILE
LATTICE 65-Be-1
NEUTRON DISTRIBUTIONS
ALONG DIAGONAL



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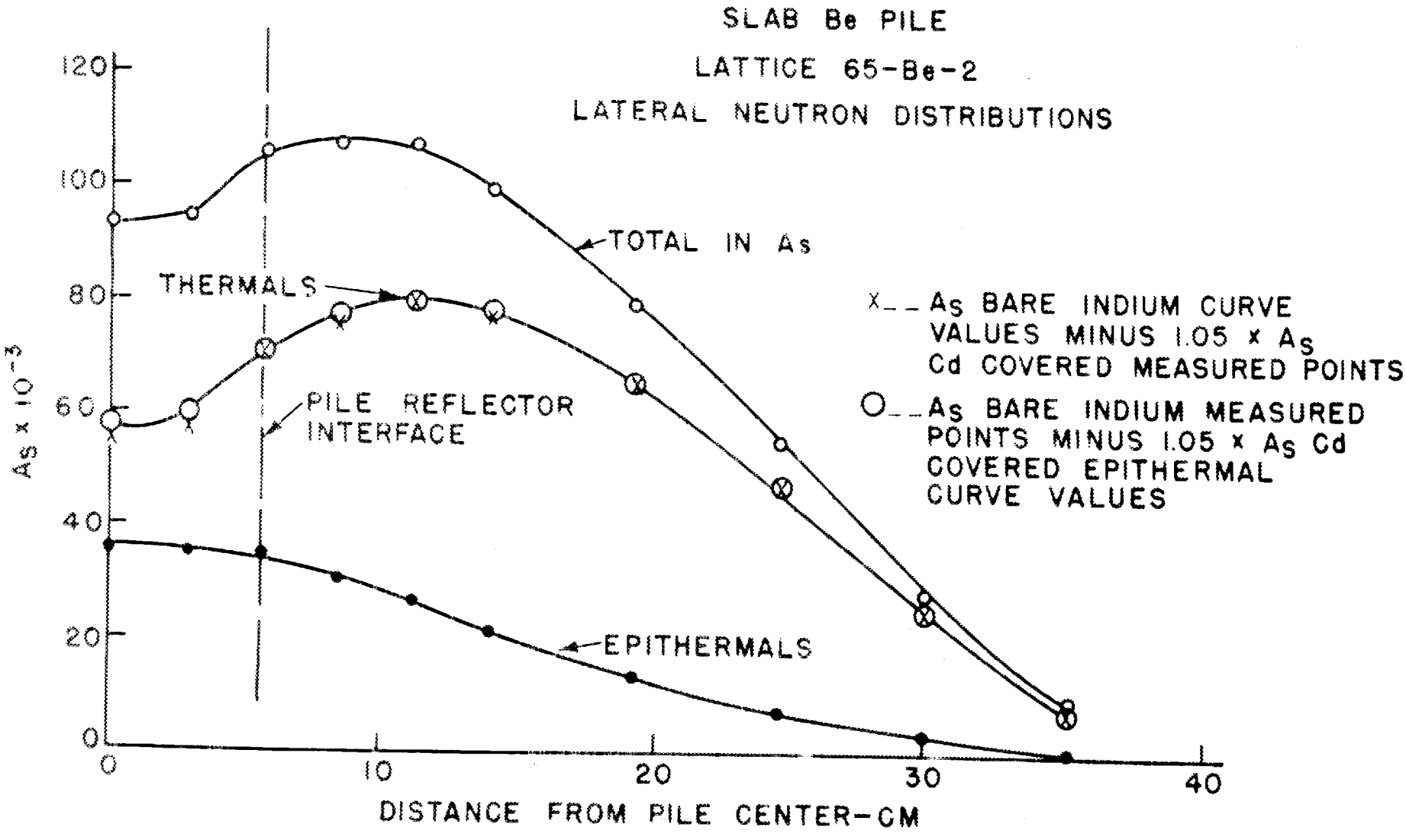
SLAB Be PILE
LATTICE 65-Be-2
LATERAL NEUTRON DISTRIBUTIONS
TOTAL IN As
THERMALS
PILE REFLECTOR INTERFACE
EPITHERMALS
X-- As BARE INDIUM CURVE VALUES MINUS 1.05 x As Cd COVERED MEASURED POINTS
O-- As BARE INDIUM MEASURED POINTS MINUS 1.05 x As Cd COVERED EPITHERMAL CURVE VALUES
As x 10^-3
120
100
80
60
40
20
0
0
10
20
30
40
DISTANCE FROM PILE CENTER-CM

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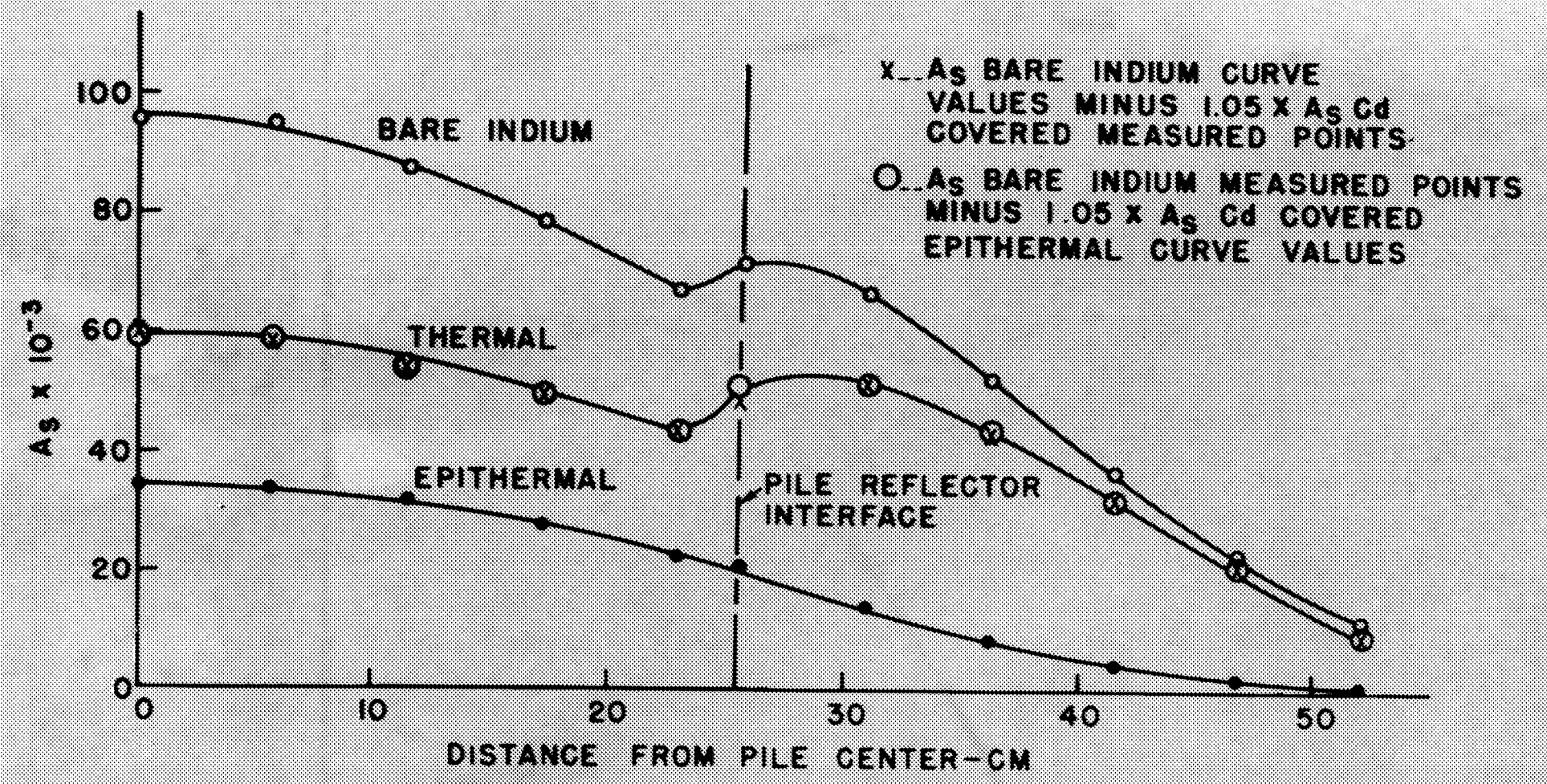
SLAB Be PILE

LATTICE 65-Be-2

LONGITUDINAL NEUTRON DISTRIBUTIONS



perpendicular bisector of the side of the square pile. Figure 4 shows the same distributions along a diagonal of the square assembly. Figure 5 shows the results of a traverse taken along the perpendicular bisector of the long side of the thin slab pile and the measurements shown in Figure 6 were taken along the long axis of the rectangular assembly. All of these foil measurements were taken at mid-heights of the assemblies.

The ratio of the thermal neutron flux at certain points in the pile to that at the center of the core is of interest, and we present these data in Table I.

Table I.

Relations between Thermal Neutron Fluxes at Certain Locations in the Reactor and that at Center of Core

Assembly Number	ϕ_{th} (Peak) / ϕ_{th} (Center)	ϕ_{th} (Edge) / ϕ_{th} (Center)	Distances to Fall to Center Value	
			From Center	From Edge
1 (Lateral)	1.32	1.19	26.5 cm	15 cm
1 (Diagonal)	1.16	1.13	25	9
2 (Lateral)	1.42	1.24	22 cm	16.5 cm
2 (Longitudinal)	0.90	0.85		

The ratio of the peak thermal flux to that at the center is an indication of the maximum slow flux, for a given operating level, that the assembly will provide for experimental purposes. The ratio of a thermal flux at the edge of the core to that at the center is a measure of the maximum heat production per unit volume to be expected in the core. The extent to which the thermal flux holds up in the reflector is of interest in planning experiments which will make use of this flux.

A few preliminary experiments have been carried out which yield an estimate of the fast neutron flux in these reactors. A threshhold type fission chamber was constructed, using 145 mg of uranium from K-25 which was depleted in U-235 content to approximately 1 part in 100,000. The fissionable material was coated uniformly on the inner

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surface of a nickel cylinder of .020" wall thickness, 1" O.D. and 12" length. This cylinder was used as the outer conductor of an Argon filled ion chamber; the ionization collected on the center wire was fed to an A-1 amplifier[1], which in turn operated a conventional scaler circuit.

The fission chamber was first placed in a graphite column containing an Sb-Be source, at a position where the thermal neutron flux and the Cd ratio were known from standard Indium foil measurements. By exposing the chamber alternately bare and Cd covered, it was determined that 93% of the fissions in U-235 were caused by neutrons of energy below the Cd cut off, at a position in the graphite column, approximately 10 cm from the Sb-Be source, where the Cd ratio was 3.7. The results of this experiment also indicated that the U-235 content of the 145 mg. sample was 1 part in 90,000, in good agreement with the enrichment figure obtained from the K-25 analysis.

The chamber was then placed at the center of the active lattice of the thin slab pile, where the counting rate, when corrected for thermal fissions in U-235, indicated that the flux of neutrons having energies above the U-238 threshhold (~ 1 Mev.) is 0.50 $(nv)_{th}$. This result is in reasonably good agreement with the calculated virgin flux in this core, 0.60 $(nv)_{th}$ (see MonP-272). The correction for thermal fissions in U-235 in this case amounts to only 2% of the total counting rate.

[1] MonP-323, P. R. Bell and W. H. Jordan, Instructions for Use of the A-1 Amplifier and Pre-Amplifier.

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