[redacted]

ORNL 167
REACTORS

Classification Changed To: Declassified
By Authority Of: TID-1111
By: Elwood 10/22/56

PHYSICS DIVISION

CRITICAL EXPERIMENTS FOR THE HIGH FLUX REACTOR

By

A.B. MARTIN

M.M. MANN

[redacted]

OAK RIDGE NATIONAL LABORATORY

OPERATED BY
CARBIDE AND CARBON CHEMICALS CORPORATION
FOR THE
ATOMIC ENERGY COMMISSION
POST OFFICE BOX P
OAK RIDGE, TENNESSEE

[redacted]

TRANSMITTAL DATE 10-22-48

[redacted]

ORNL-167

This document consists of 39 pages

Copy 4 of 80, Series A.

ISSUED: 706-B. Library

Contract No. W-7405, eng 26

PHYSICS DIVISION

CRITICAL EXPERIMENTS FOR THE HIGH FLUX REACTOR

Experiments by:
M. M. Mann
A. B. Martin
A. L. Preston
A. H. Toepfer
J. K. Bair (on loan from NEPA)
R. V. McCord

Written by:
A. B. Martin
M. M. Mann

DATE ISSUED: OCT 22 1948

OAK RIDGE NATIONAL LABORATORY
OPERATED BY
Carbide and Carbon Chemicals Corporation
for the
Atomic Energy Commission
Post Office Box P
Oak Ridge, Tennessee

[redacted]

[redacted]

I. Introduction

This report is the third of a series on criticality studies of small thermal reactors. While the earlier reports contained data from relatively simple and "clean" assemblies, the experiments to be described in the present paper involved assemblies which were less simple and less "clean". The term "clean" is used here to imply an experimental arrangement in which the core and reflector are not only of simple, calculable geometry but are also as free as possible of holes, recesses and extraneous materials.

The assemblies to be considered here are of slab geometry, and therefore calculable, but contain (1) various amounts of excess poison in the U-Al-H_2O core, (2) holes of various sizes extending through the reflector and (3) in the later experiments the reflector was a composite of beryllium, containing approximately 2% lucite to simulate cooling water, and graphite.

The experimental facilities used for these studies are described in MonP-357 and ORNL-79. MonP-272 contains general discussions of the physics of the High Flux Reactor, now in final design stage; the experiments now being reported were performed to confirm several of the results derived from theoretical consideration in MonP-272 and also to obtain empirical knowledge of certain features of the high flux reactor which are not readily calculable because of complications of geometry or composition.

In particular, this report will describe studies of (1) the critical mass (or, more directly, the excess $\Delta k/k$) of slab piles as a function of the length to width ratio of the core, (2) the effect of holes in the reflector, and of absorbers in these holes, on the k of the reactor, (3) the heat load in the reflector arising from gamma ray absorption, (4) spatial distributions of thermal, indium resonance and fast ($E > 1$ mev.) neutron flux in the core and in the reflector, particularly the distributions of thermal and indium resonance neutrons in the experimental holes, and (5) the effectiveness of control rods of various materials and of various sizes in terms of $\Delta k/k$.

[redacted]

[redacted]

II. The Excess Reactivity of U-Al-H_2O Reactors, with Be Reflector, as a Function of Geometry and Reflector Composition.

The starting point for these experiments is the small, clean slab reactor which was described in ORNL-79. The core is 51x11 cm in cross-section and 66 cm high. It has a 30 cm beryllium reflector on each face except the top and bottom. The volume ratio of Al to H_2O is 0.65 and the fuel concentration in the core is 37.1 grams of U-235 per liter of core.

The size of the reactor was increased in a series of discrete steps, the final objective being a core of dimensions 71x22.5x66 cm., with a reflector on all sides (except top and bottom) consisting of 30 cm. of beryllium, diluted with about 2% [illegible] lucite to simulate cooling water, backed by a secondary 30 cm. layer of graphite. This final assembly approximates very closely the dimensions and composition of one of the probable configurations of the high flux reactor.

The major steps in building up the small slab to final size were the following:

(1) Increase in length of the slab from 51 cm to 71 cm and addition of 30 cm. graphite layer to one (long) side of the beryllium reflector.

(2) Increase in thickness of the slab from 11 cm. to 17 cm.

(3) Increase in thickness of the slab from 17 cm. to 22.5 cm.

(4) Completion of the mock-up of the high flux reactor, putting 30 cm. of graphite on each side of the Be reflector and introducing the seven large experimental holes in the reflector. Plate I is a photograph of the final assembly.

[redacted]

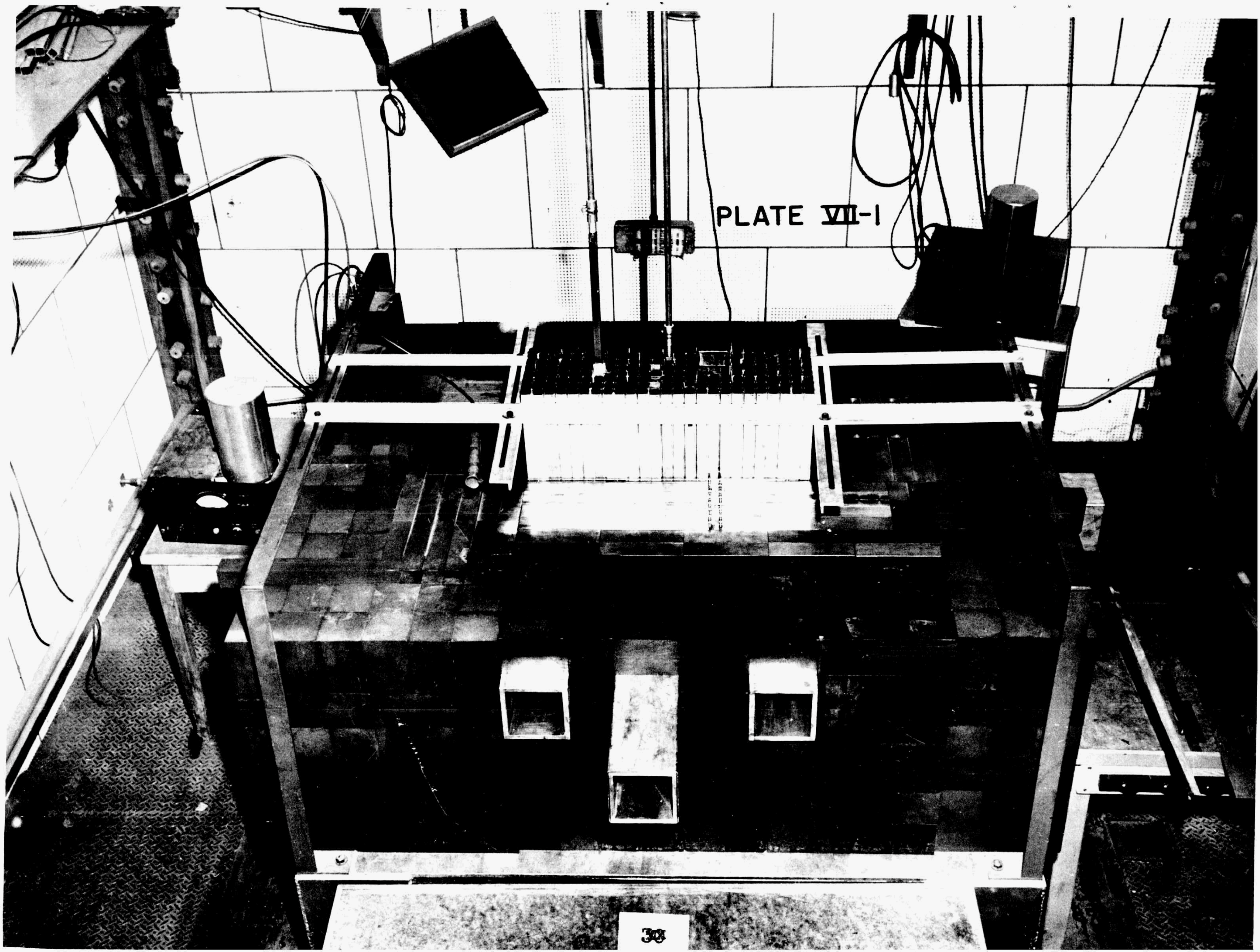


PLATE VII-1

[redacted]

As the size of the reactor is increased over that of the small clean slab it is necessary to add uniformly distributed poison in the core to hold k-effective to a value close to unity. The poison used in these experiments is type 347 stainless steel, in the form of strips 1/8x15/16x26 inches. These are inserted in place of aluminum strips of the same dimensions which are used to attain the desired Al/H_2O volume ratio in the core. Although this substitution changes the Al to H_2O ratio to some extent, the magnitude of the change is small and the effect on the neutron age is also small, and we justify it on these grounds. We are indebted to H. Pomerance for measurements of the thermal absorption cross section of samples of type 347 steel by the pile oscillator method. The results of these measurements yield 3.04 mm^2/gm of steel or 12.3 cm^2 for the cross section of each strip.

Beginning with the 51x11x66 cm. reactor, containing 1.35 kg. of fuel, both poison and fuel were added in appropriate increments until a length of 71 cm. was reached. At this stage the reactor contained 1.94 kg. of fuel, and the excess 0.59 kg. (over the clean critical mass of 1.35 kg.) required 266 cm^2 of uniformly distributed poison to hold the excess reactivity to zero with all control rods removed. Table I shows the excess reactivity, represented by poison cnntent, for each of the assemblies studied. The excess $\Delta k/k$ is obtained by computing the k for each assembly from $k = \eta\, \sigma_{25} / \sigma_{total}$ where $\sigma_{total} = \sigma_{25} + \sigma_{Al} + \sigma_{H_2O} + \sigma_{poison}$; then $\Delta k/k = \frac{k_o - k_i}{k_i}$ where k_o refers to the clean, unpoisoned core and k_i to the poisoned assembly.

When the reactivity is changed by a means which does not alter the total amount of fuel in the core or the concentration of fuel, it can easily be shown that the fractional change in k is given smmply by $\Delta k/k = -\Delta\sigma/\sigma$, where $\Delta\sigma$ is the amount of uniform poison added to or removed from the core and σ is the total cross section of the reactor having the smaller amount of poison. For example, when graphite is added to one side of the beryllium reflector of assembly 3 (refer to Table I), 37 cm^2 additional poison

[redacted]

[redacted]

are required to offset the increased reactivity and the effect of the graphite layer is given by

$$\frac{37}{4384} = \frac{\Delta\sigma}{\sigma} = \frac{\Delta k}{k} = 0.9\% .$$

Table I summarizes the pertinent criticality data for each of the beryllium reflected reactors in this series. Column 3 indicates the amount of U-235 required to fill the core having the dimensions shown in column 2, at a fuel concentration of 37.1 grams per liter of core. Column 4 shows the amount of uniformly distributed poison required to hold the excess k of the assembly to zero; that is, to hold the reactor just at criticality with all control rods withdrawn. For each assembly, the $\sigma_{pile} = \sigma_{25} + \sigma_{Al} + \sigma_{H_2O}$ is given in column 5, the experimental k is shown in column 6 and in column 7 is shown the excess $\Delta k/k$ which can be made available by the removal of distributed poison.

[redacted]

[redacted]

Table I

Critical Mass and Poison Content (Excess k) of U-Al-H_2O Reactors with Be Reflector - Al/H_2O (Volume) = 0.65; Be ~ 30 cm Thick - Reactor Bare Top and Bottom

Assembly Number	Dimensions L x W x H	Mass Kg.	Σ Poison cm^2	Σ Pile cm^2	k	Δk/k Excess
1	22x22x66	1.21	66	2591*	1.5626	3.5%
2	51x11x66	1.35	30	2882*	1.5849	2.0%
3a	71x11x66	1.94	266	4118	1.5184	6.5%
3b	71x11x66 (30 cm. graphite on one side)	1.94	303	4118	1.5057	7.4%
4	71x14x66 (30 cm. graphite on one side)	2.44	640	5179	1.4388	12.4%
5	71x17x66 (30 cm. graphite on one side)	2.94	1140	6240	1.3670	18.3%
6	71x22.5x66 (30 cm graphite on one side; 2% water in Be)	3.95	1848	8384	1.3247	22.0%
7	71x22.5x66 (30 cm. graphite on all sides of Be. Seven 6" holes in reflector; 2% water in Be)	3.95	1580	8384	1.3603	18.8%

* contain fractional fuel tubes

k_o = 1.6167 (clean core)

[redacted]

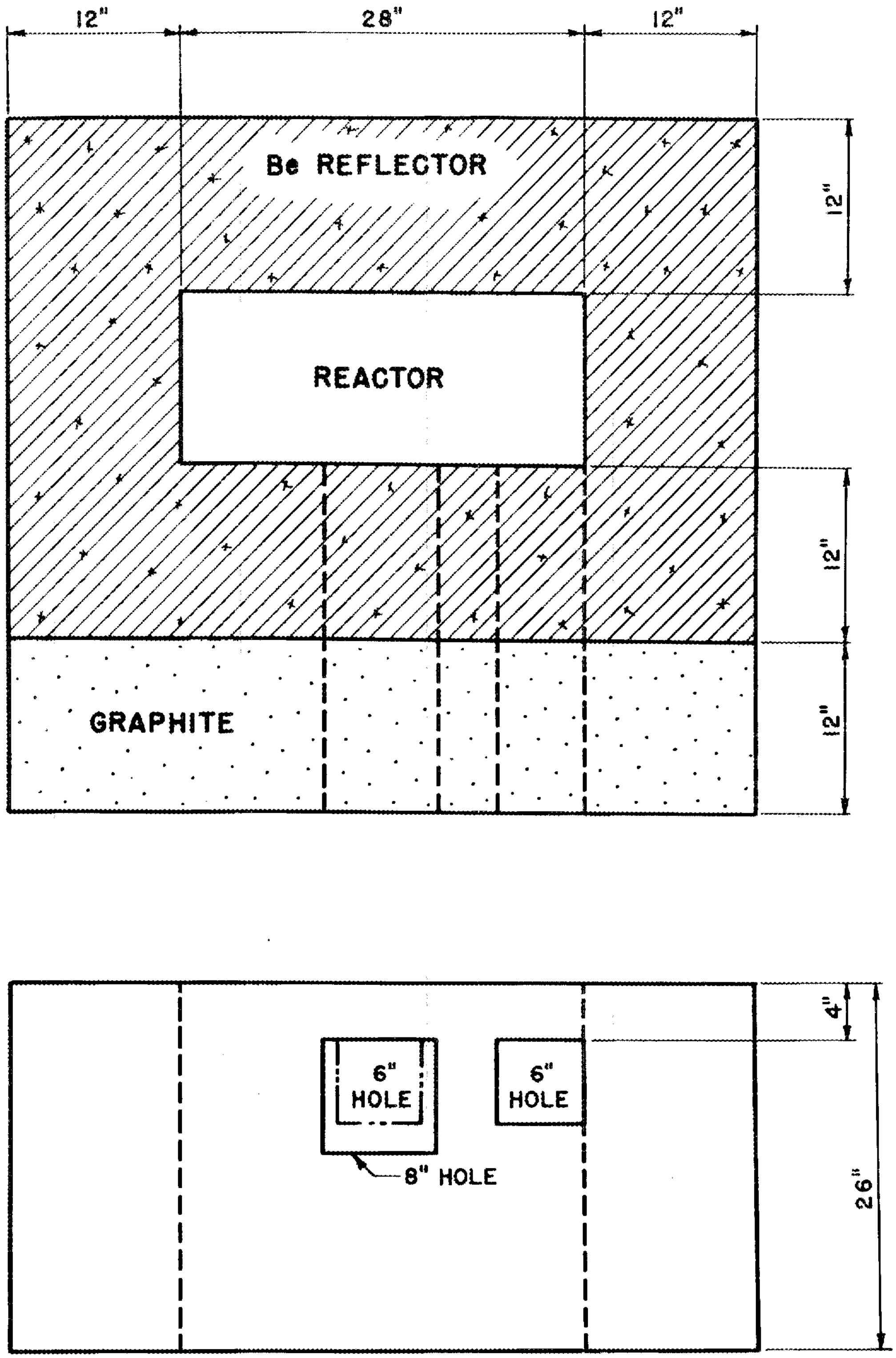
III. Effects of the Experimental Holes Through the Reflector.

It will be recalled that the research facilities of the high flux reactor include seven large experimental holes, four of which begin at the core-reflector interface and extend through the entire thickness of reflector. The other three holes begin 15 cm. out in the beryllium and extend through the remainder of the reflector. In connection with these irregularities in the reflector a number of experiments are of interest: (1) the cost of the holes in terms of $\Delta k/k$, or in terms of additional fuel, (2) the effect on the reactivity of the core of filling any one or all of the holes with water, and (3) the effect of various absorbers, such as experimental apparatus, at various positions in the holes. Item (2) is of interest from the standpoint of safety, since it is conceivable that an accident might occur in which the wall of the hole would collapse or otherwise fail, causing the hole to fill with water and thereby increasing the reactivity; furthermore, it is likely that water-cooling will be desired for experimental apparatus in one or more of the holes on certain occasions, and the data obtained here will indicate the maximum effect of water cooling on $\Delta k/k$.

The location of the holes is shown in Plate I and also in Fig. 1, which is a sketch of assembly 3b. The so-called six inch hole is made up of a hollow aluminum tube of square cross section, having $\frac{1}{2}$ inch wall thickness and measuring six inches overall along the edge; the eight inch hole is of similar construction and measures eight inches along the outer edge.

The effects of the various holes were measured by the following procedure. We begin with a reactor which is just critical with a given amount of poison and with no holes in the reflector. A portion of the graphite and beryllium in the region of the hole to be studied is removed, the square aluminum shell is inserted at the proper place and the reflector is re-stacked around it. We now observe that in order to offset the leakage through the hole and bring the reactor back to the point of criticality an amount of distributed poison $\Delta\sigma$ must be removed from the core. The effect of the hole on the reactivity of the reactor is given by $\Delta k/k=\Delta\sigma/\sigma$.

[redacted]



CRITICAL ASSEMBLIES

LOCATION OF HOLES IN REFLECTOR

[redacted]

Before inserting a close-fitting paraffin block into the aluminum shell to simulate water-filling, the core is poisoned excessively to offset the expected increase in reactivity. When the hole is filled with paraffin the distributed poison is again adjusted until the reactor is just critical and the reactivity change due to the introduction of paraffin is determined as before.

In Table II we present the results of the experiments just described, for assemblies 3, 5 and 6. Measurements were taken for six inch holes at the edge positions and for both six inch and eight inch holes at the center position. It was thought at one time that some interaction between the holes might take place, but measurements made on individual holes and on various combinations of two or more holes indicate that the effects are approximately additive.

[redacted]

Table II

Effect of Experimental Holes in the High Flux Pile Critical Assemblies

Assembly No.		III	V	VI
Reactor Dimensions	(cm)	71x11x66	71x17x66	71x22.5x66
Critical Mass	(kg)	1.94	2.94	3.95
Σ (pile)	(cm^2)	4118	6240	8384
Σ (poison)	(cm^2)	303	1140	1848
Σ (total)	(cm^2)	4421	7380	10232

Effect of the Holes in Δk/k (in percent) where k is the k of the Pile with Solid Reflector

Assembly No.	III	V	VI
Holes extending to reactor - reflector interface			
6 inch hole on edge	1.17	0.75	0.49
6 inch hole in center	2.20	----	0.86
8 inch hole in center	4.80	2.84	1.71
Holes beginning 15 cm. from reactor			
6 inch hole on edge	0.17	0.12	0.08
6 inch hole in center	0.34	----	0.13
8 inch hole in center	0.68	0.40	0.22
Holes extending to reactor - water filled			
6 inch hole on edge	0.90	0.65	0.42
6 inch hole in center	----	----	0.84
8 inch hole in center	3.88	2.45	1.53
Holes beginning 15 cm. from reactor - water filled			
6 inch hole on edge	----	0.08	0.06
6 inch hole in center	0.24	----	0.06
8 inch hole in center	0.37	0.23	0.11

[redacted]

It is interesting to note that the effect of the holes decreases percentagewise as the thickness of the slab is increased. This is expected on theoretical grounds.

Table III contains a summary of the total cost in $\Delta k/k$ for two alternate provisions for experimental holes. This table shows the change in $\Delta k/k$ that would be expected if the holes in these two cases should be filled with water. An estimate of the cost of the holes in terms of critical mass can be obtained by use of the empirical relation $\Delta M/M = 4.5\ \Delta k/k$. However, this relation leads to a reasonably accurate result only in the case of fuel ΔM added to the periphery of a cylindrical core. In the case of a rectangular geometry the cost in critical mass (ΔM) corresponding to a given Δk will depend strongly on the statistical weight of the position at which the additional fuel is added and the figure obtained from 4.5 $\Delta k/k$ is a reasonable approximation only for positions of average statistical weight.

Table III

Summary of Total Effect of Experimental Holes

Assembly No.	III	V	VI
Reactor Dimensions (cm)	71x11x66	71x17x66	71x22.5x66
Mass (kg)	1.94	2.94	3.95
Cost in $\Delta k/k$ of two 8 inch holes plus five 6 inch holes	9.33%	5.73%	3.56%
Cost in $\Delta k/k$ of seven six inch holes	6.39%	4.23%	2.62%
Effect in $\Delta k/k$ of water filling two 8 inch holes and five 6 inch holes	2.14%	0.94%	0.54%
Effect in $\Delta k/k$ of water filling seven 6 inch holes	1.41%	0.66%	0.34%

[redacted]

[redacted]

The effect of possible absorbers (experimental apparatus) in the holes on the excess k of the pile has been studied by taking the extreme case of a cubicle Cd box (.020" Cd, 10 cm along an edge). The effect of this relatively large absorber on the k of the pile when it is placed at various positions in the holes is shown in Figure 2. From these measurements it is estimated that the maximum excess k required to offset the effect of experimental apparatus in the holes is 1.5%.

Finally the excess k of the 3.95 kg mock-up of the high flux reactor has been measured. The characteristics of this mock-up include: (1) a core of dimensions 71x22.5x66 cm. containing 3.95 kg of U-235 in water solution at a concentration of 37.1 grams U per liter of pile; (2) Al/H_2O (volume) in the core = 0.65; (3) a reflector on all sides consisting of 30 cm of Be plus 30 cm of graphite; (4) no reflector top of bottom; (5) lucite distributed throughout the Be to simulate 2% in cooling water; and (6) seven 6 inch experimental holes through the reflector as prescribed in the design of the high flux reactor. The excess k of this mock-up assembly is found to be 18.8%. When allowance is made for the top and bottom water reflectors of the high flux machine the total available excess k is increased to about 20% for this loading. Therefore it appears that a comfortable margin exists over the total k requirements which are estimated to be as follows:

Xenon - - - - - - - - - - - - - - - - - - - 9.6%

Depletion - - - - - - - - - - - - - - - - - -3.5%

Temperature coefficient - - - - - - - - - -0.5%

Experimental apparatus in holes - - - - -1.5%

Total $\Delta k/k$ required - - - - - - - - - - 15.1%

IV. Neutron Distributions

We have measured the spatial distributions of thermal and

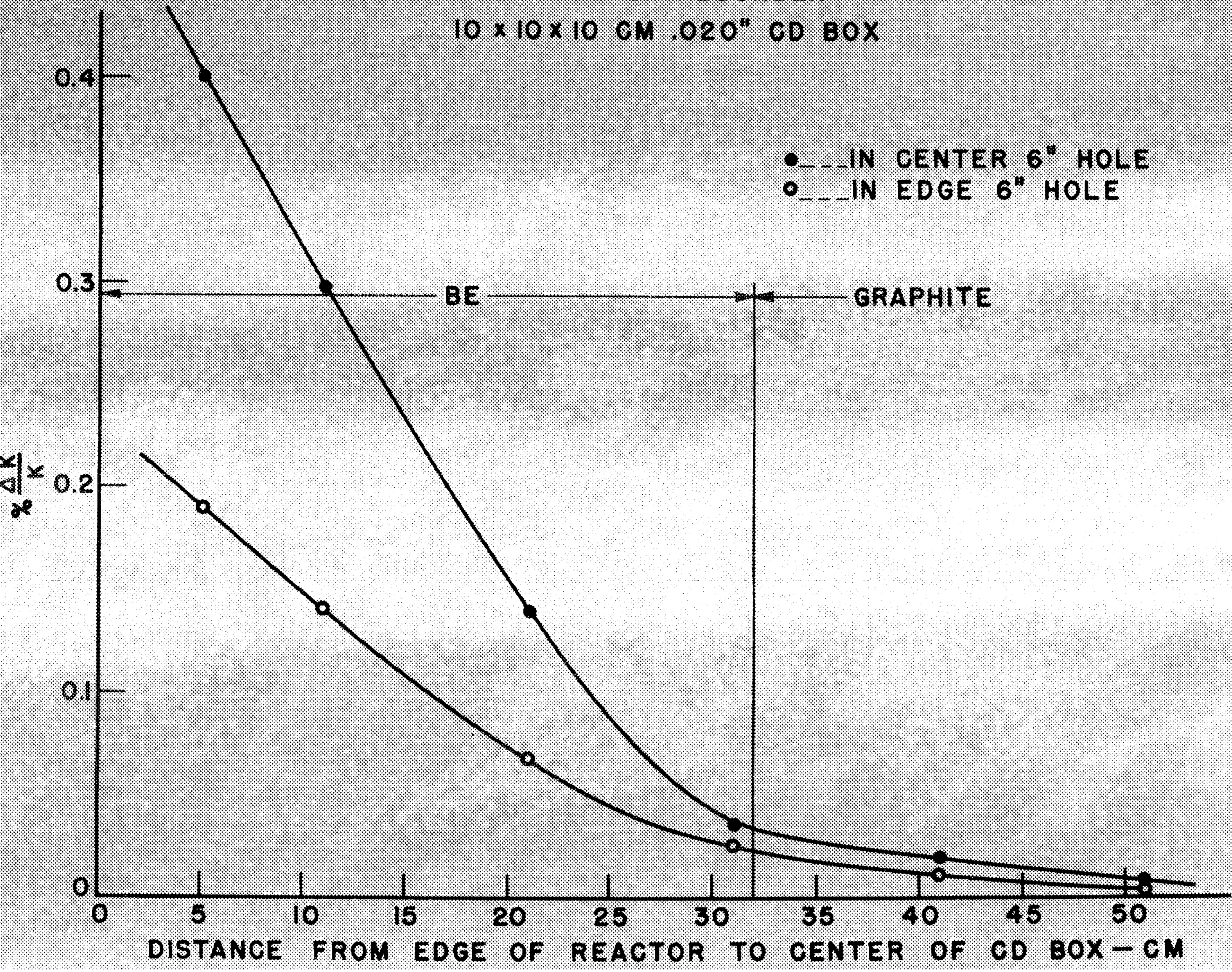
[redacted]

—FIG. VII-2—

Dr 5643

EFFECT OF ABSORBER

10 x 10 x 10 CM .020" CD BOX



[redacted]

epithermal neutron flux in the 2.94 kg pile, the 3.95 kg pile and in the various experimental holes of the mock-up assembly as indicated in the listing below. These measurements were made with indium foils, used alternately bare and cadmium covered as described in previous reports. A calibration of our foils in the standard (sigma) pile indicates that the absolute flux (nv) is obtained from the measured saturated activities shown in the attached figures by the following relations:

$$(nv)_{thermal} = 6.50\ A_{thermal}$$

$$(nv)_{epithermal} = 1.66\ A_{epithermal}.$$

Neutron distributions have been measured as follows:

(a) Figure 3 - A lateral traverse across the 2.94 kg pile (along the short axis of the slab, at mid-height).

(b) Figure 4 - A lateral traverse across the 3.95 kg pile (along the short axis of the slab, at mid-height).

(c) Figure 5 - A series of measurements along the center line of the six inch hole which is located at the edge of the long side of the core:

(1) with solid reflector in place;

(2) with hole extending in to the core-reflector interface; and

(3) with the hole beginning 15 cm out from the edge of the core.

These curves show the depressions in the "solid reflector" neutron distributions caused by the presence of a single six inch hole in the reflector.

[redacted]

[redacted]

(d) Figures 6 through 8 show the neutron distributions along the axes of the various experimental holes that are planned for the high flux pile. These measurements were made with all seven 6 inch holes (or equivalent) in the reflector.

These figures are composite curves; the original data were reported in ORNL-51. The complete curves are presented here because it is believed that they offer a better perspective of the spatial variation of thermal and indium resonance neutrons in the high flux reactor.

(e) Figure 9 - A comparison of the thermal and indium resonance neutron flux measured (1) along the axis of the deep center hole and (2) along the edge of the same hole.

(f) Figure 10 - The fast neutron flux (E>1 mev.) and the indium resonance flux, measured along a line midway between two of the large experimental holes that extend through the reflector.

(g) Figure 11 - The fast neutron flux (E>1 mev) and the indium resonance flux along the edge of one of the experimental holes. Unfortunately, the shape and size of the fission chamber made it impractical to obtain useful data along the central axis of an experimental hole.

The U-238 fission chamber which was used to measure the flux of fast neutrons has been described in ORNL-51 and in ORNL-79.

The results of these experiments indicate that the $(nv)_{fast}$ near the center of the 3.95 kgm. assembly is 40% of the $(nv)_{thermal}$, in reasonably good agreement with the calculated value of $(nv)_{virgin}$ = 60% of $(nv)_{thermal}$ given in MonP-272.

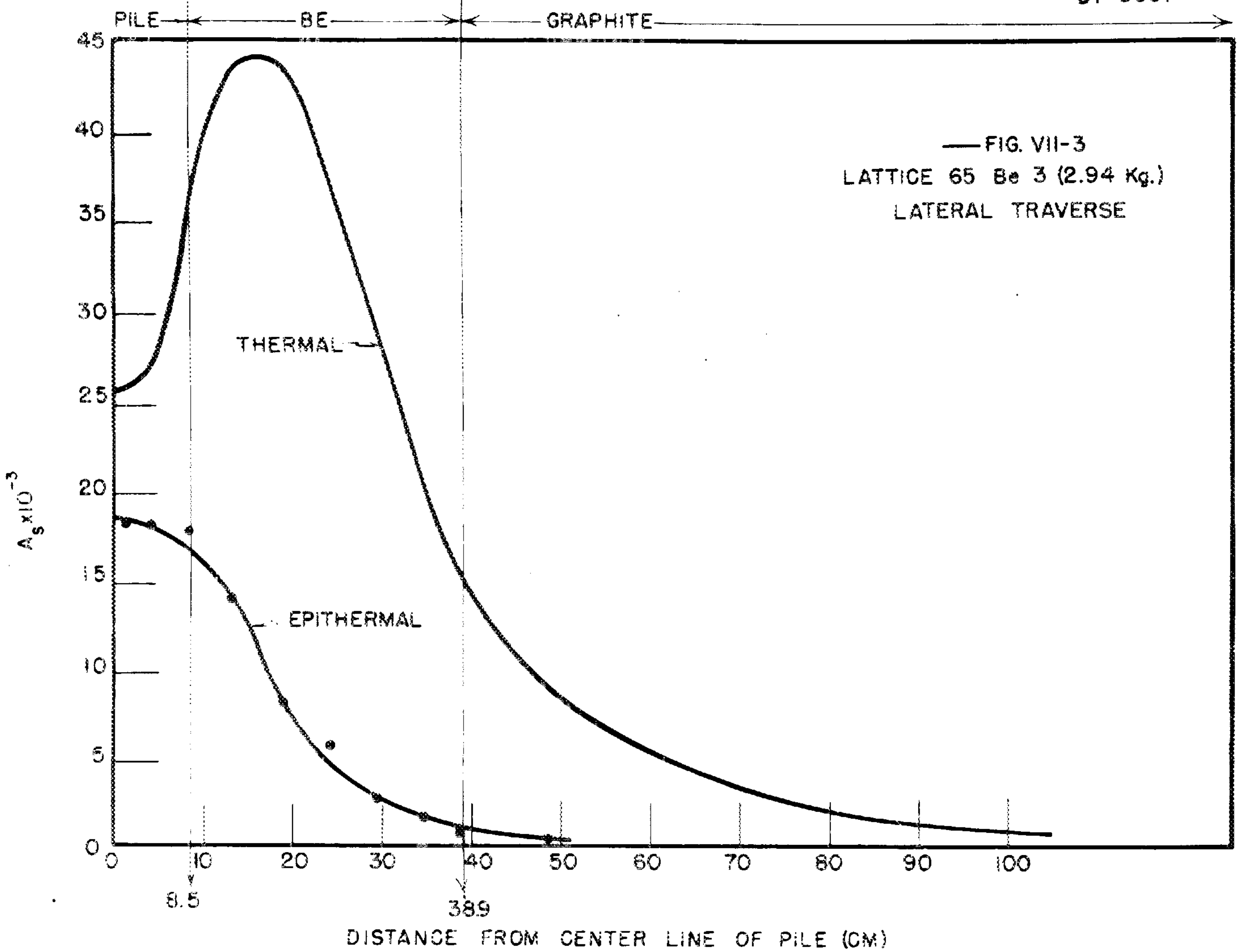
V. <u>Gamma Heat Production in the Reflector.</u>

In the high flux reactor the beryllium is water-cooled and there is no concern regarding the possibility of excessive heating in this portion of the reflector. The graphite, however, is cooled

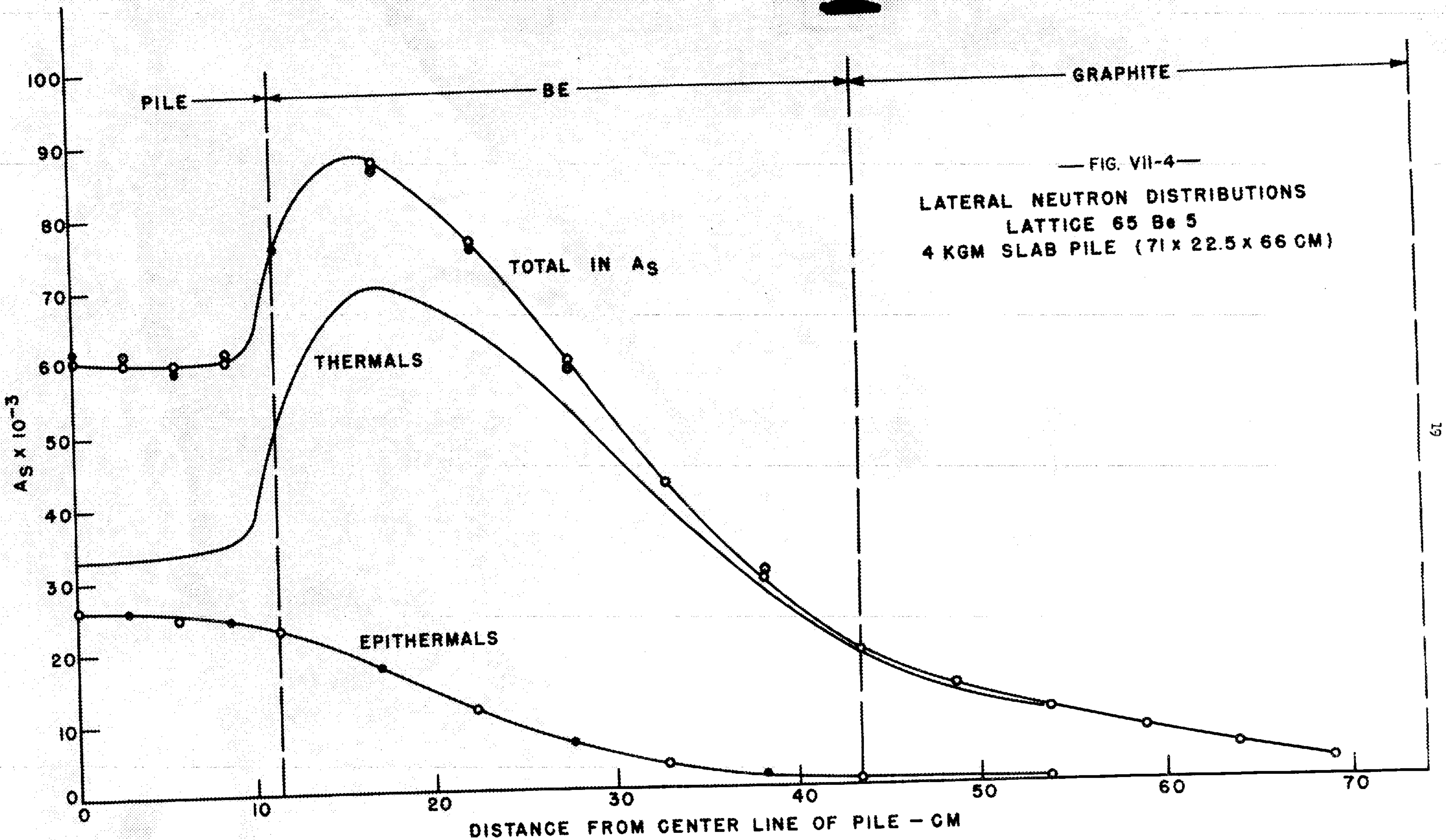
[redacted]

[redacted]

Dr 5691



Dr. 5578



— FIG. VII-4 —

LATERAL NEUTRON DISTRIBUTIONS
LATTICE 65 Be 5
4 KGM SLAB PILE (71 x 22.5 x 66 CM)

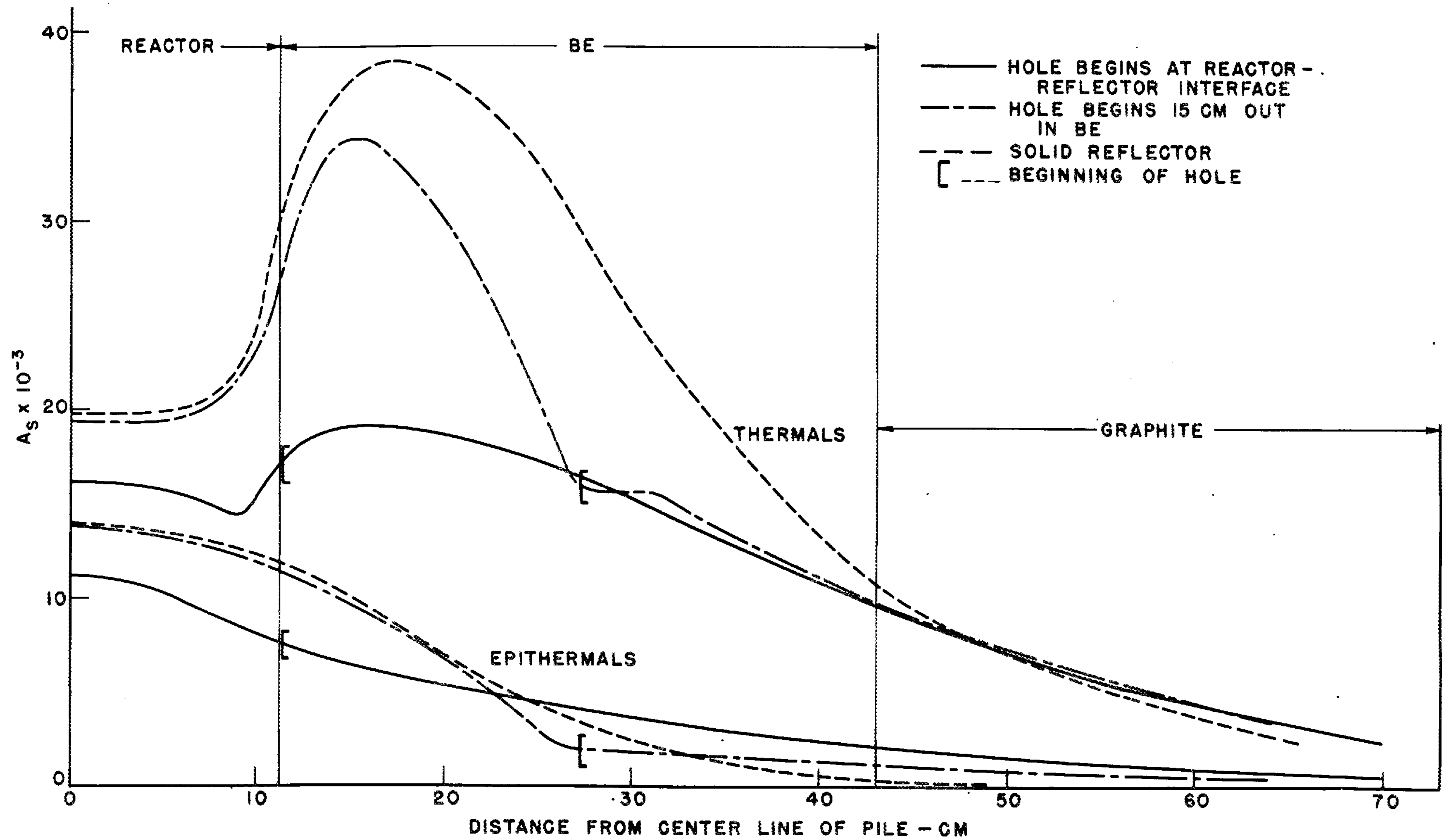
— FIG. VII-5 — [redacted]

4 KG SLAB PILE (71 x 22.5 x 66 CM)

Dr 5640

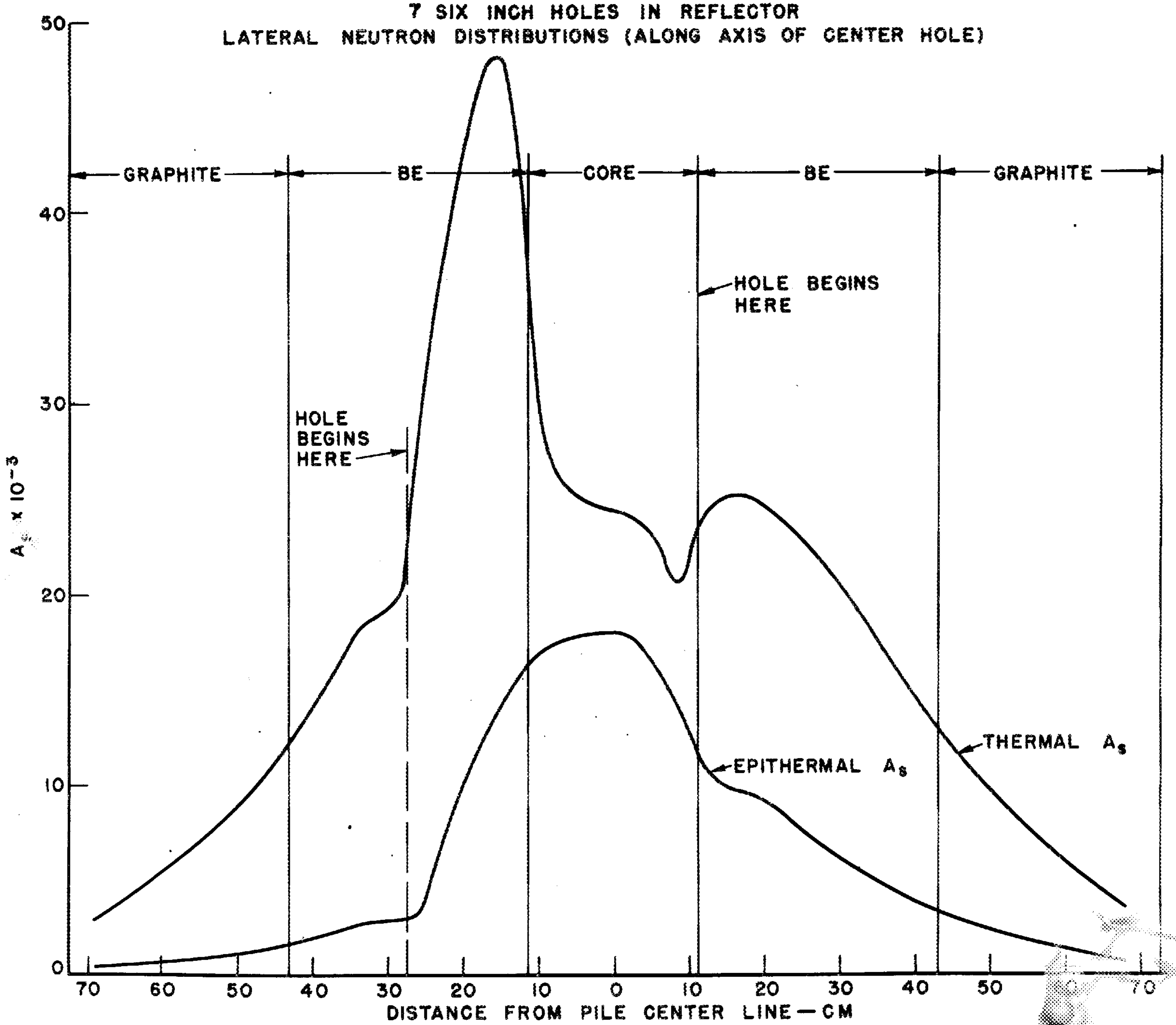
2% H_2O IN BE

NEUTRON DISTRIBUTIONS ALONG AXIS OF 6" HOLE AT EDGE OF REACTOR



[redacted]

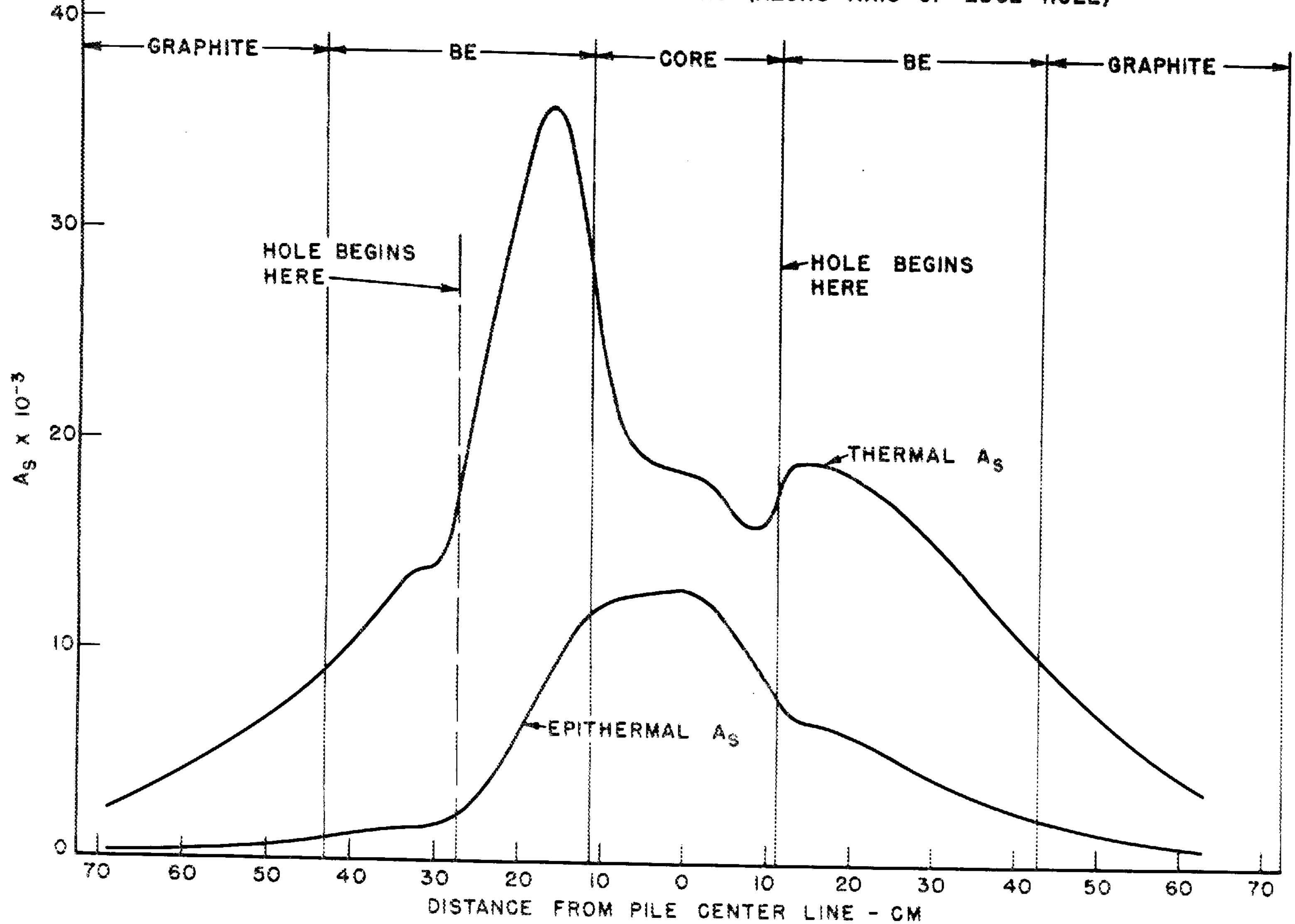
FIG. VII-1
4 Kg SLAB PILE (71 x 22.5 x 66 CM)
7 SIX INCH HOLES IN REFLECTOR
LATERAL NEUTRON DISTRIBUTIONS (ALONG AXIS OF CENTER HOLE)



[redacted]

Dr 6080

FIG. VII-2
4 KG SLAB PILE (71 X 22.5 X 66 CM)
7 SIX INCH HOLES IN REFLECTOR
LATERAL NEUTRON DISTRIBUTIONS (ALONG AXIS OF EDGE HOLE)



[redacted]

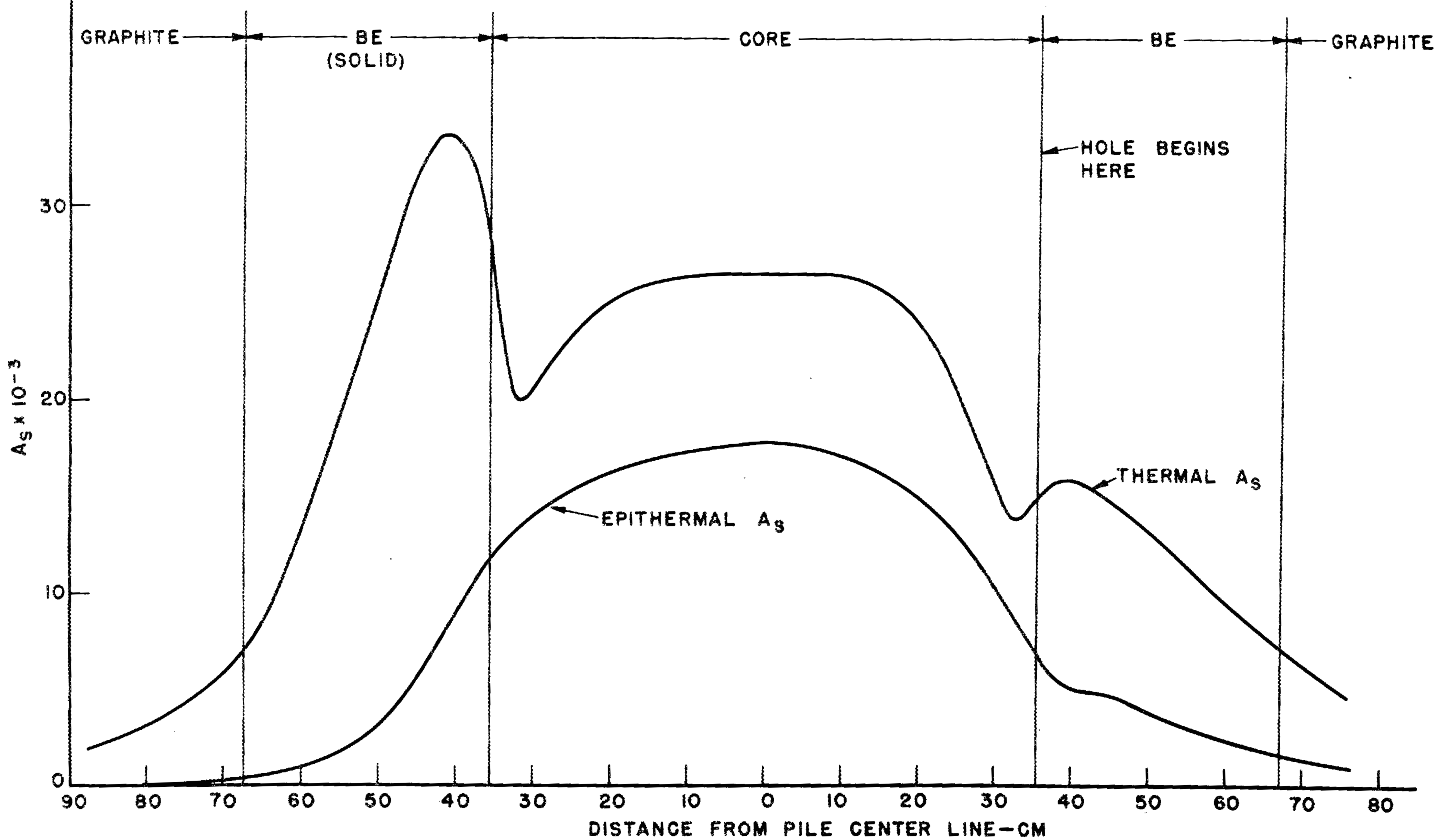
Dr 6081

FIG. VII-3

4 Kg SLAB PILE (71 X 22.5 X 66 CM)

7 SIX INCH HOLES IN REFLECTOR

LONGITUDINAL NEUTRON DISTRIBUTIONS (ALONG AXIS OF END HOLE)

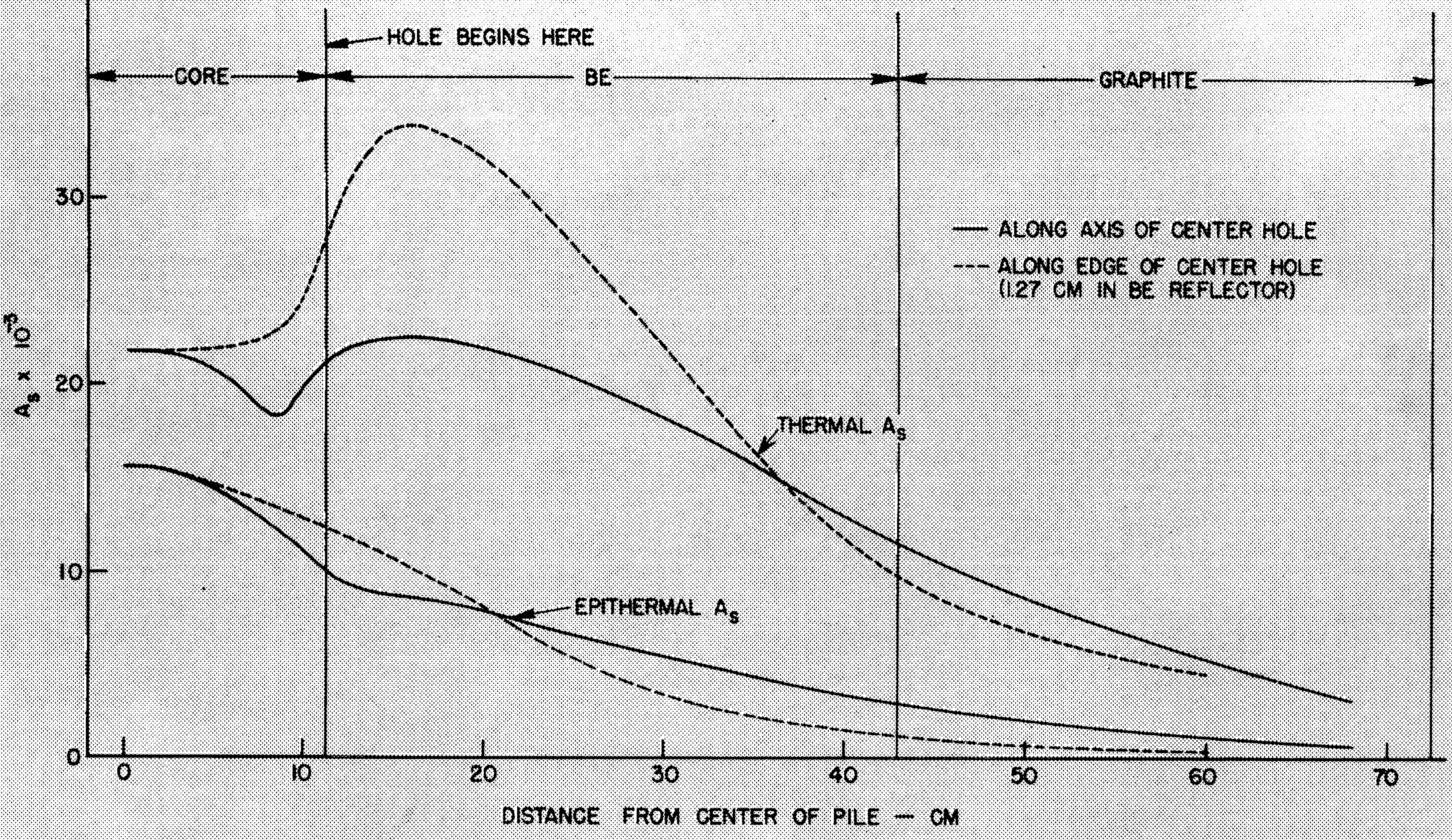


[redacted]

Dr 6082

FIG. VII – 4

NEUTRON DISTRIBUTIONS IN 4 Kg PILE



[redacted]

Dr 6087

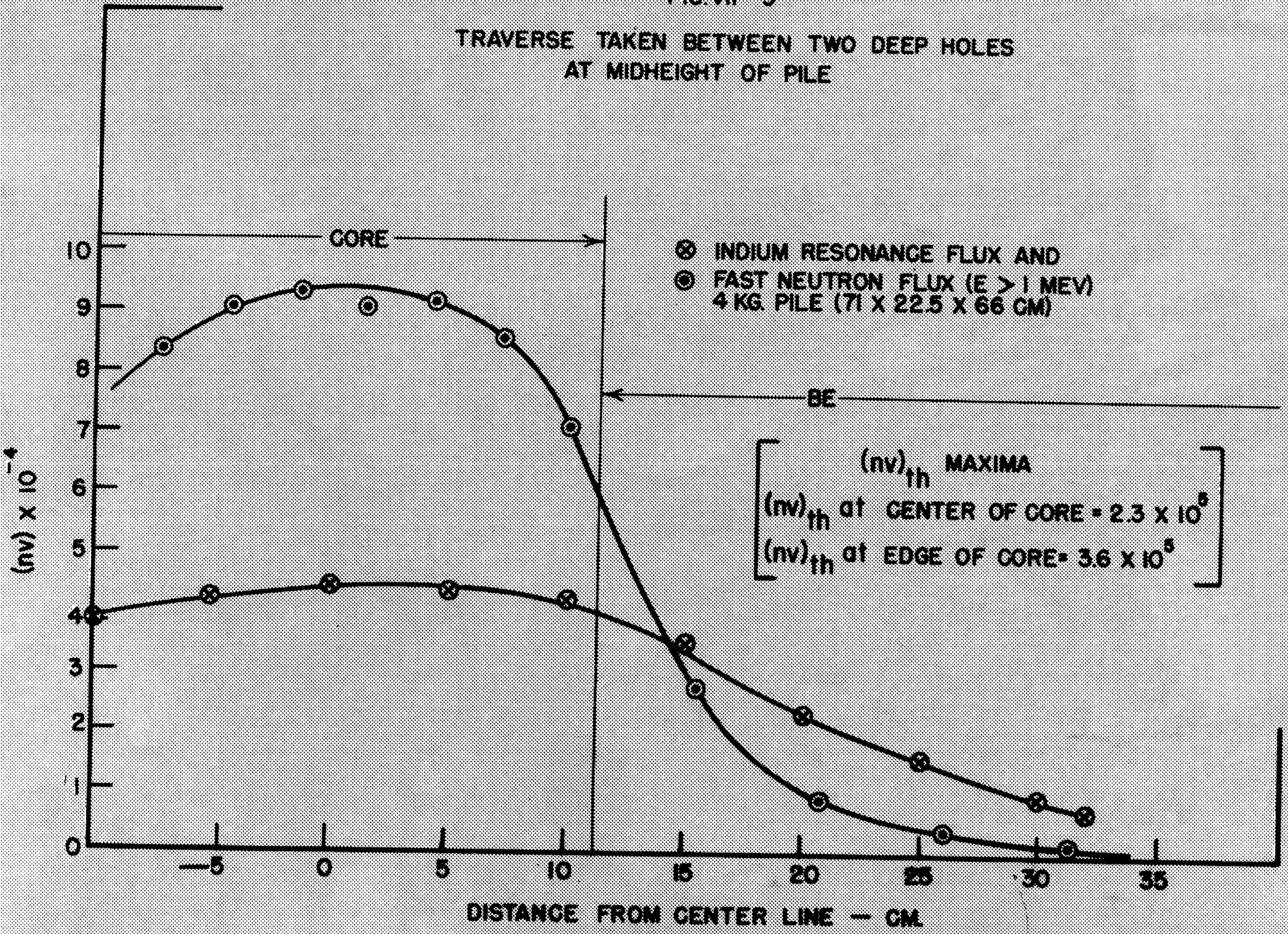


FIG. VII — 9

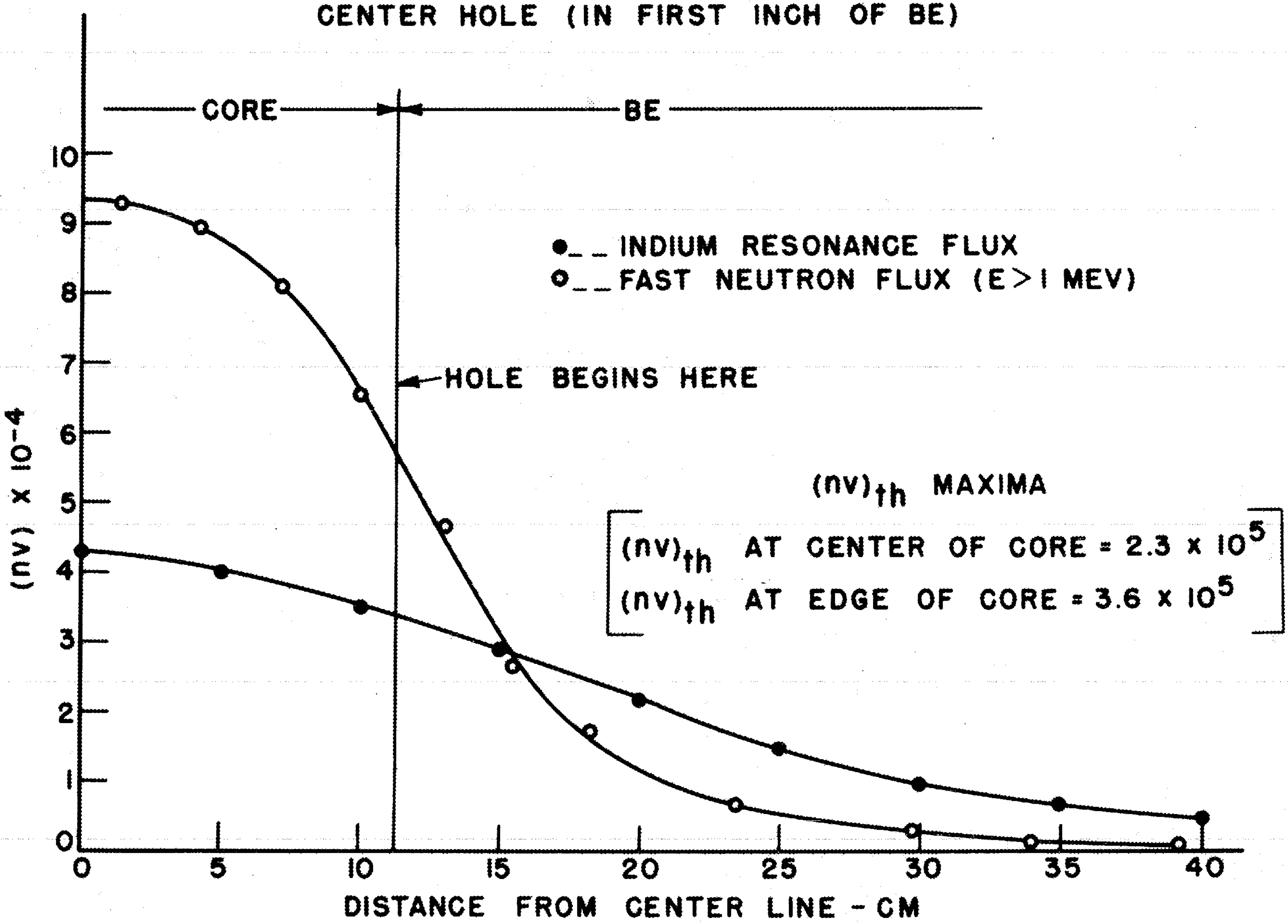
TRAVERSE TAKEN BETWEEN TWO DEEP HOLES AT MIDHEIGHT OF PILE

[redacted]

FIG. VII-10

4 KG PILE (71 x 22.5 x 66 CM)

TRAVERSE TAKEN ALONG EDGE OF CENTER HOLE (IN FIRST INCH OF BE)



only by air and empirical information on the heat production in graphite was desired to substantiate theoretical calculations which have been reported in MonP-272. In the reflector, heat production is primarily from absorption of gamma rays. Most of these come from the core of the reactor, but some arise from neutron capture in beryllium and in graphite.

The gamma ray absorption measurements were made in the rectangular assembly having core dimensions 71x17x66 cm. and loaded to 2.94 kg. of fuel. Measurements were made in the core and in the reflector along a line perpendicular to the long dimension of the reactor. Three graphite ion chambers having volumes of approximately 1, 10 and 200 cc., were used to cover the range of gamma flux encountered in going from the interior of the core through the Be reflector and out to the edge of the graphite portion of the reflector. In order to minimize the possibility of measuring ionization due to unforeseen neutron reactions in the gas of the ion chamber the measurements were taken with each of four filling gases: air, argon, CO_2 and He.

The data taken with the air-filled chamber have been corrected for ionization produced by protons from the (n,p) reaction in nitrogen. This is a thermal neutron reaction which is exothermic by 0.62 Mev., producing a proton of 1.1 cm range in air. Since these data were taken with the 10 cc. and 200 cc. ion chambers it was assumed that the fraction of protons not traversing their full path in the chamber is small. This assumption probably introduces an error of the order 20-30% in the corrections applied to the air chamber data. The probable errors in the corrected data are of course smaller. The data obtained from the CO_2 filled chamber, after correction for differences in electron density, are in good agreement with the corrected data for air (see Figure 12).

In the case of the He filling an error is introduced in the ionization measured in and near the core of the reactor, where the flux of fast neutrons is relatively high, by recoil He nuclei. It is not feasible to calculate corrections for this effect and in Figure 12 we show only data taken with the He chamber at points sufficiently distant from the core that the fast neutron effect is not appreciable. At the Be-graphite interface the contribution from He recoils is apparently negligible and the He data, after correction for electron density, are in good agreement with the results obtained with air and CO_2.

The data obtained with argon in the chamber are not in good agreement with those taken with the other three gases. While the reasons for this disagreement are not known with certainty, it is probably due in part to the fact that argon has appreciably higher atomic number than graphite or beryllium and therefore does not satisfy the Bragg-Gray criteria to the same extent as do air, CO_2 and He. The argon results have been omitted from Figure 12.

The absolute ionization currents were measured by means of a calibrated potentiometer - electrometer setup. Figure 12 shows the values obtained from these measurements for the total gamma ray heat production in the beryllium and in the graphite of the high flux pile, assuming a maximum thermal neutron flux of 2×10^{14} in the core. It should perhaps be pointed out that the calculation of these results from the measured quantities requires a normalization factor of the order 10^9 to extend our measurements, taken at a thermal flux of 1.6×10^5, to the case of the high flux pile operating at a thermal flux of 2×10^{14} in the core. The upper experimental curve has been normalized to a thermal neutron flux of 2×10^{14} at the <u>center</u> of the core. The dot-dash experimental curve has been normalized to a thermal neutron flux of 2×10^{14} at the <u>edge</u> of the core, that is, at the point of maximum flux in the core.

The lower solid curve in Figure 12 represents the total heat production in the reflector calculated from theoretical considerations (see MonP-272). This calculation was based on the neutron distribution for a thinner slab pile (70x11x60 cm.) where the heat load in the reflector is somewhat heavier than in the case of the assembly in which our measurements were made (71x17x66 cm.). The measured spatial thermal neutron distribution in this assembly is shown as a dotted curve.

[redacted]

Dr 5690

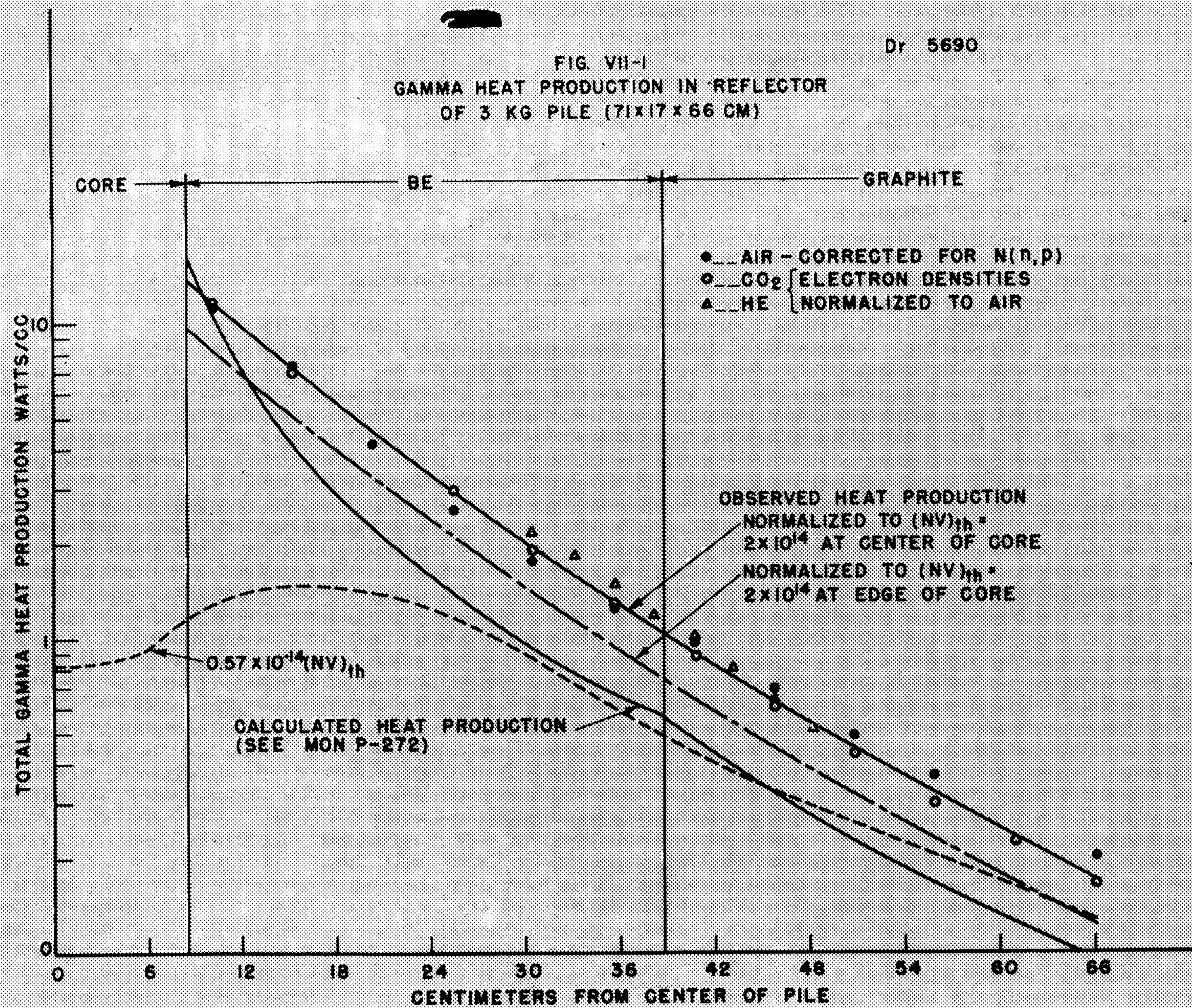


FIG. VII-1
GAMMA HEAT PRODUCTION IN REFLECTOR
OF 3 KG PILE (71 x 17 x 66 CM)

[redacted]

The discussion of gamma heating in the preceding paragraphs pertains to a solid reflector. It is expected that the presence of experimental holes will add to the heat load in the graphite due to the streaming of gamma rays from the core through these holes. An attempt was made to observe this effect by measuring gamma ray absorption along the edge of one of the deep holes in the 3.95 kg assembly. The 10 cc. and 200 cc. ion chambers were used with a filling of air at one atmosphere and corrections were made as before for the ionization due to protons from the nitrogen (n,p) process. The chamber was placed as near the edge of the deep center hole as practicable; in the beryllium the 10 cc. chamber was used and the center was in the reflector, $\frac{1}{2}$ inch from the surface of the aluminum shell. In the graphite portion of the reflector the 200 cc. chamber was used and the center of the chamber was in the graphite, one inch from the edge of the hole.

The results of these measurements are shown in Figure 13, where the heat production along the edge of the hole, in watts per cc., is compared to (1) the average gamma heat production in the solid reflector as measured with air, helium and CO_2 fillings in the ion chamber and (2) the data obtained in the solid reflector with the air-filled chamber alone. It is seen that the heat production falls off more rapidly along the edge of the hole than in the solid reflector.

The interpretation of these results is not straightforward, however, because the chamber, in positions along the edge of the hole, is backed on only three sides by the reflector. On the fourth side only the $\frac{1}{2}$ inch wall of the aluminum shell and the 1/8 inch graphite wall of the ion chamber are effective in absorbing gamma rays and therefore the Bragg-Gray criteria for the determination of gamma ray energy loss by measurements of this type are not fulfilled to the same degree as in the case of the data taken in the solid reflector.

VI. Control Rod Experiments.

A number of experiments have been carried out to study the

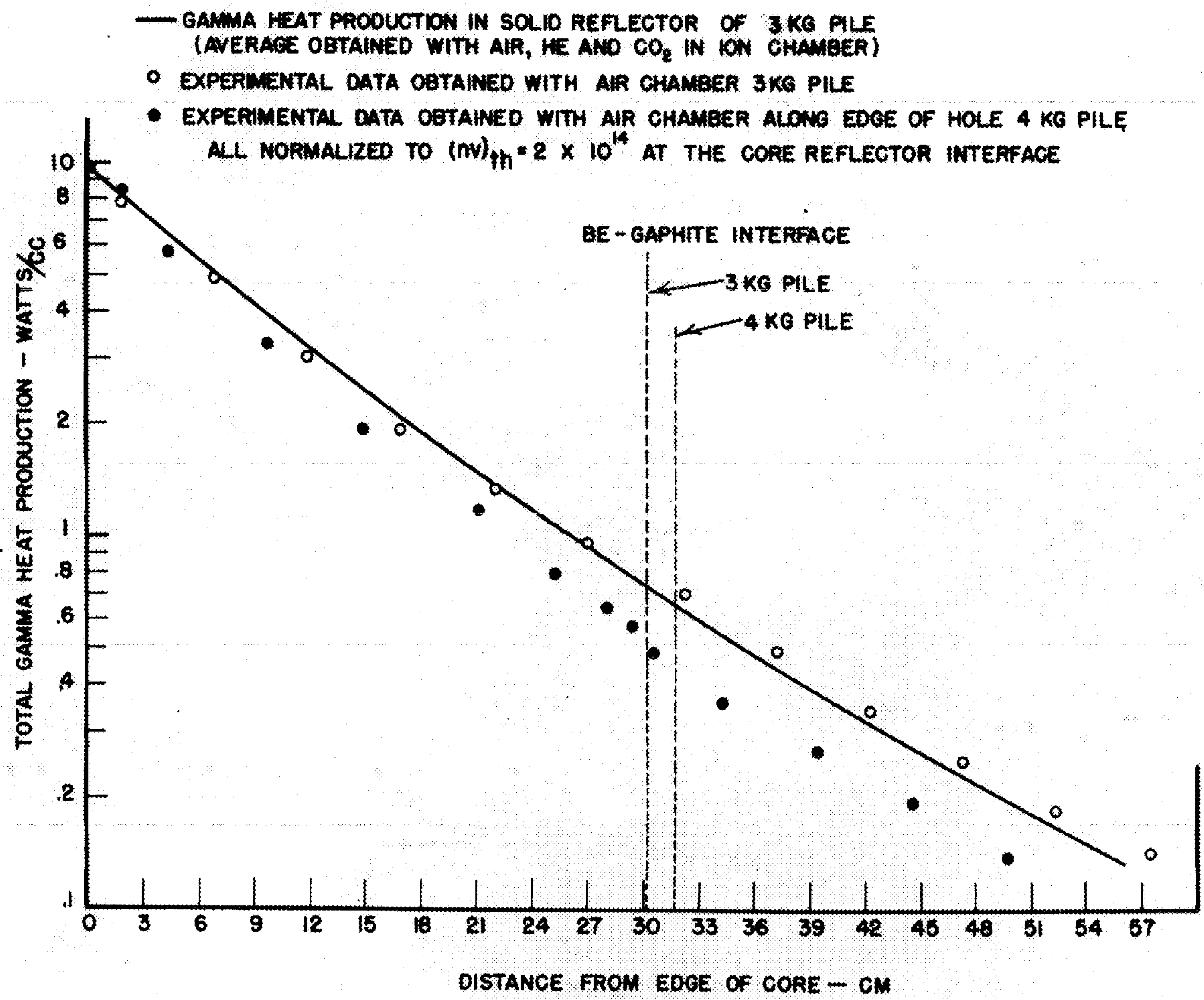
[redacted]

Dr 6086

FIG. VII-8

[redacted]

GAMMA HEAT PRODUCTION



[redacted]

effectiveness of control rods of various sizes in the 4 kgm. mock-up of the high flux reactor. The experiments are performed in the following way: the uniform poison in the "clean" core (before the control rod is inserted) is adjusted until the assembly is just critical. The control rod is inserted and the amount of uniformly distributed poison in the core is reduced until the assembly is again just critical. When the experiment involves no change in the amount or concentration of fuel in the core, the percentage change in k, ($\Delta k/k$), is given simply by $\Delta\Sigma/\Sigma$ where $\Delta\Sigma$ is the change in uniform poison and Σ is the total cross-section of the active portion of the core after the rod is inserted. In experiments which entail the removal of fuel and the insertion of a control rod, the k of the clean core (k_1) is calculated, the k of the active portion of the core after insertion of the rod (k_2) is calculated and $\Delta k/k$ is then given directly by $\frac{k_1 - k_2}{k_2}$.

Fig. 14 is a horizontal section through the core of the 4 kgm. mock-up Be assembly, showing the positions at which control rods were inserted for study. Our standard 3/4 inch square Cd control rods which are normally located at (a) and at (b) were replaced by fuel tubes for these studies, so that the rods to be tested were inserted in clean fuel.

The Cd control rods tested in these experiments were essentially replicas of those designed for the high flux reactor insofar as dimensions and composition are concerned. They were in the form of hollow cylinders of square cross-section ($3\frac{1}{2}$"x$3\frac{1}{2}$"x26" in length) and were filled with water to duplicate the conditions that will obtain in the case of the high flux reactor.

The Th rods for the high flux reactor are made up of several plates, stacked in a sandwich-like assembly, with spaces between plates for the passage of cooling water. In our experiments Fe was used instead of Th for reasons of availability and ease of fabrication, the amount of Fe being adjusted to give the same total thermal cross section as that provided by the current design of Th rods. The test rod then consisted of a rectangular sandwich of Fe

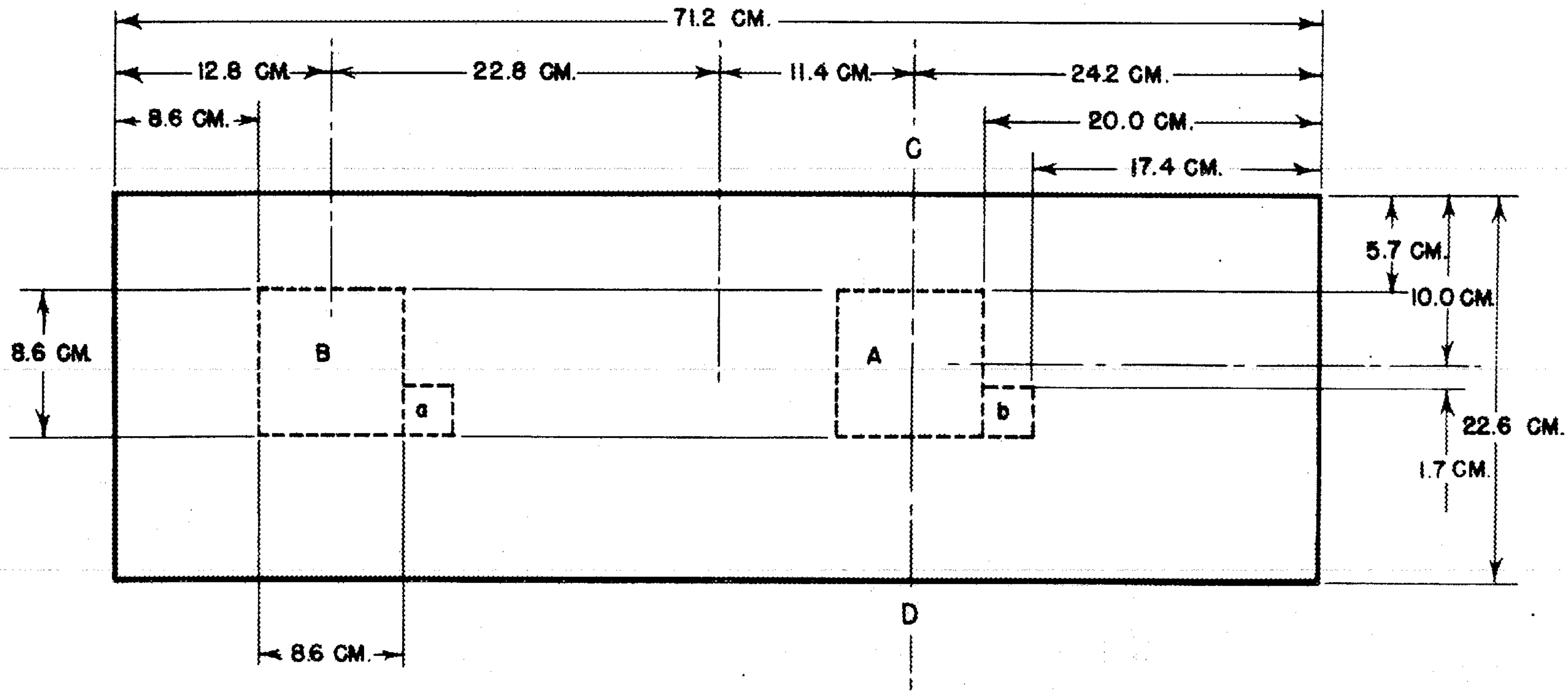
[redacted]

[redacted]

Dr 6083

FIG. VII - 5

TEST POSITIONS OF LARGE CD AND TH RODS
IN THE CORE OF THE 4 KG MOCK-UP ASSEMBLY



[redacted]

and lucite plates having the same dimensions as the Cd rods described above.

For use in the high flux reactor, it is planned that these rods be attached at one end to fuel assemblies, so that as a rod is withdrawn fuel is inserted in its place and vice versa. Therefore, the measurement of interest is the effect of the rod vs. fuel in the same position. The percentage changes in reactivity of the active portion of the core when these rods were inserted in place of fuel at positions A and B of Fig. 14 were as follows:

	$\Delta k/k$
Cd rod at A	7.3%
Cd rods at A and B	20.7%
Th Rod at A	4.2%
Th rods at A and B	9.0%.

It was also observed that the reactivity change due to the removal of 180 grams of fuel (9 tubes or a $3\frac{1}{2}$ inch x $3\frac{1}{2}$ inch section) from a central position such as A amounted to about 3%.

At first glance, a comparison of the effect of a single rod at A with the effect of rods at both A and B indicates that the effect of a rod at B (a position of relatively low statistical weight) is greater than the effect of a similar rod at A (a position of relatively high statistical weight). It is apparent, however, that this anomaly comes about as a result of the change in neutron flux distributions caused by the introduction of the first rod at A. The neutron flux is depressed in this region and the statistical weight distribution in the core is shifted in such a way that the maximum is now in the vicinity of position B. Hence it is true that the second control rod, introduced at B, has a greater effect on the asymmetrical core than the control rod at A has on the clean pile. Also, this anomaly is more pronounced in the case of the Cd rods than in the case of the Th rods, as one would expect,

[redacted]

since the depression in the neutron distribution and the asymmetry caused in the statistical weight distribution are considerably greater in the case of Cd. Also, the statistical weight at A is reduced by a small amount due to the presence of the large experimental hole through the end reflector on the A end of the reactor.

In order to determine the effectiveness of control rods as a function of position in the reactor, a traverse was made along the line indicated by C-D in Fig. 14 with one of our standard 3/4 inch square Cd rods. In the core the rod replaces one fuel tube (20 grams of fuel) and in the reflector the rod replaces a 1 inch x 1 inch x 26 inch column of Be. Fig. 15 shows the data obtained from this experiment. The marked asymmetry in the statistical weight distribution is due to the presence of the large experimental holes which extend completely through the reflector on one side of the reactor and begin 15 cm. out in the Be on the opposite side.

VII. Neutron Flux Measurements Between Two Thorium Rods

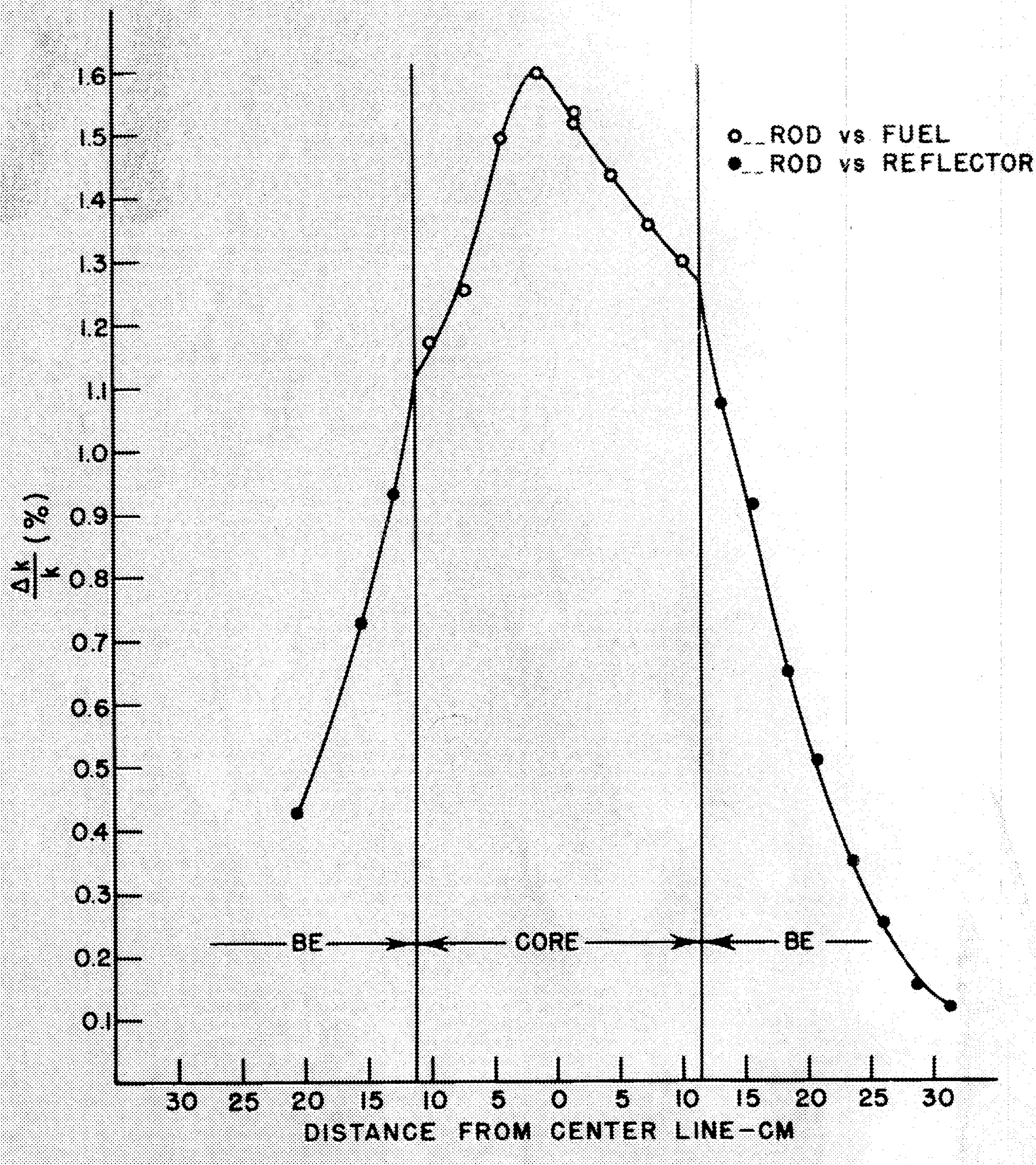
In order to determine the extent of the depression in the thermal neutron flux between two Thorium rods closely spaced, a traverse was taken with Indium foils along a line midway between two $3\frac{1}{4}$" square Thorium rods placed in the core of the 4 kg. mock-up assembly and separated by a distance of about 3-5/8" between inner edges, or about 6-7/8" between centers. The results are shown in Fig. 16, where the thermal neutron flux between the two rods is compared to the thermal flux observed in the clean assembly with solid reflector and also with the thermal flux obtained along the same line after the seven large experimental holes have been introduced through the reflector. For this comparison the three flux distributions have been normalized at the edge of the core since this is the point of maximum heat production in the reactor.

VIII. Thermal Flux in a Beryllium Block Placed in the Core of the Mock-Up Assembly.

It was suggested by Henry Newson that it might be possible

[redacted]

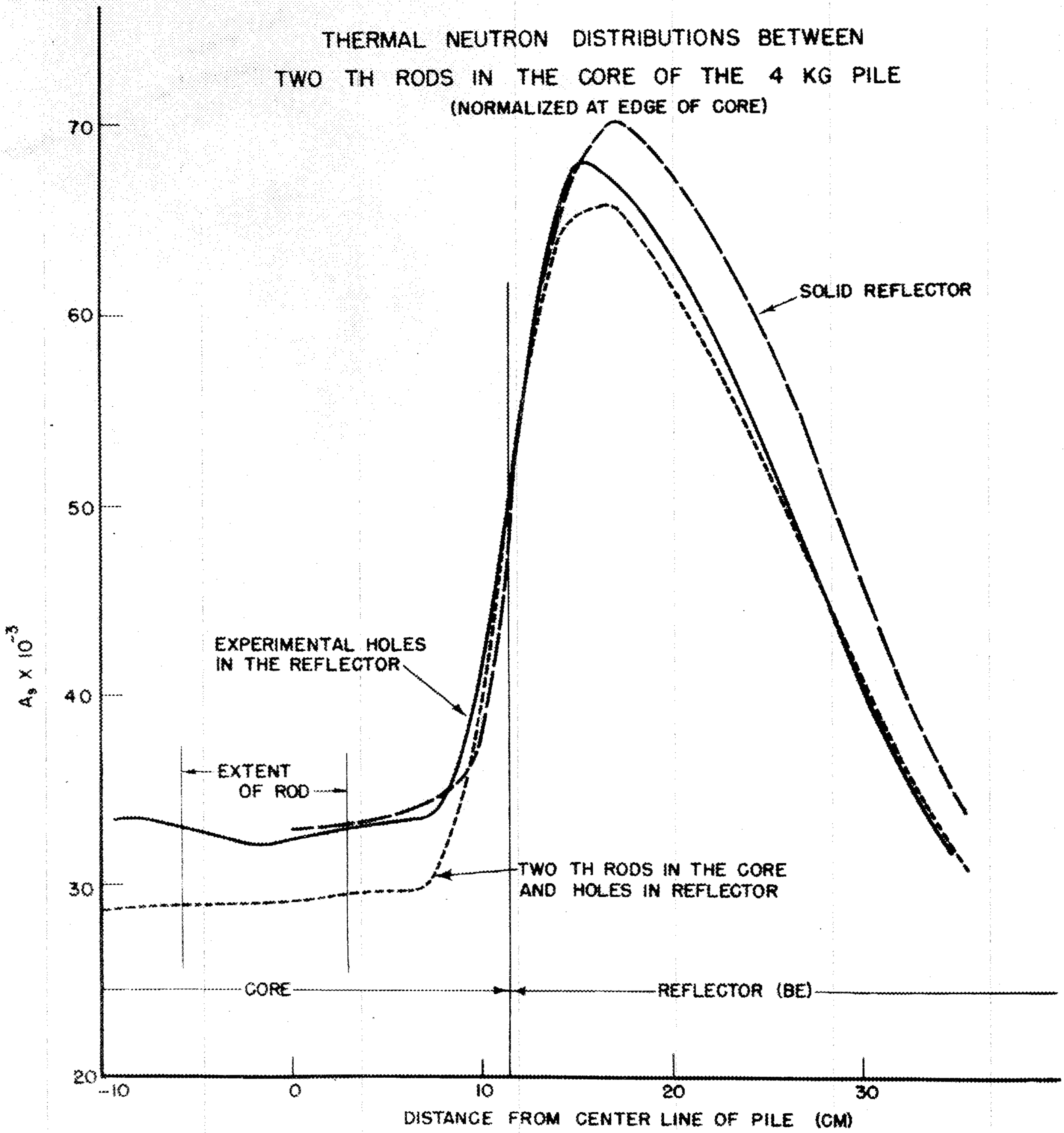
FIG. VII-6
STATISTICAL WEIGHT TRAVERSE WITH 3/4" SQUARE CD CONTROL ROD ALONG LINE C-D OF FIG. VII-5



[redacted]

Dr 6085

FIG. VII-7



to establish a thermal flux considerably greater than that attained at the maximum of the thermal distribution in the reflector by replacing a fuel assembly near the center of the core of the high flux pile by a block of beryllium. It was reasoned that the pile-up of thermals observed in the Be reflector should take place from each side of the Be block and hence the flux at the center of the block should be increased by perhaps two or three-fold over the maximum on any one side of the reflector. Since such a block would require water-cooling if inserted in the high flux pile, the block investigated was made up of 1 inch x 1 inch Be columns, 26 inches long, separated by 1/8 inch strips of lucite. The ratio of Be to lucite by volume was therefore 6/1, and this was estimated to be the optimum ratio to produce the pile-up of thermals at the center of the block. The thermal neutron flux was measured through the center of the block by the use of indium foils and Fig. 17 shows the distribution obtained, compared to the thermal distribution measured along the same line with the Be block not present in the core. It is seen that the gain in thermals at the center of the block over the maximum in the reflector is not appreciable.

[redacted]

FIG. VII - 11

THERMAL NEUTRON FLUX IN A 3½" X 3½" WATER COOLED BE BLOCK REPLACING A FUEL ASSEMBLY IN THE CORE OF THE 4 KG BE REFLECTED PILE