RETURN COEFFICIENT MEASUREMENTS FOR THE MIT ENRICHED URANIUM - D_2O LATTICE

by

Lt(jg) David M. Goebel, USN

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DAVID MAXWELL GOEBEL

B.S., United States Naval Academy

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ABSTRACT

Experimental and analytical bases for the determination of the variation in the return coefficient (or reflector effect) with height along the MIT Lattice Facility core are presented. The return coefficient is found to increase approximately exponentially with height along the core, and is very nearly equal to unity at a distance ~50.3 inches above the lattice tank bottom.

The variation of the return coefficient prompted an investigation of the variation in the activities of the outer-most foils of a radial buckling measurement with height. The relative activities of the outer-most foils were found to increase with height. This effect rapidly died out as foils further from the core edge were considered however. And, since the two end foils are dropped in all radial buckling measurements performed at MIT, the effect of the relative activity increase on α is non-consequential.

Thesis Supervisor: Dr. D. D. Lanning
Title: Associate Professor of Nuclear Engineering

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CHAPTER I

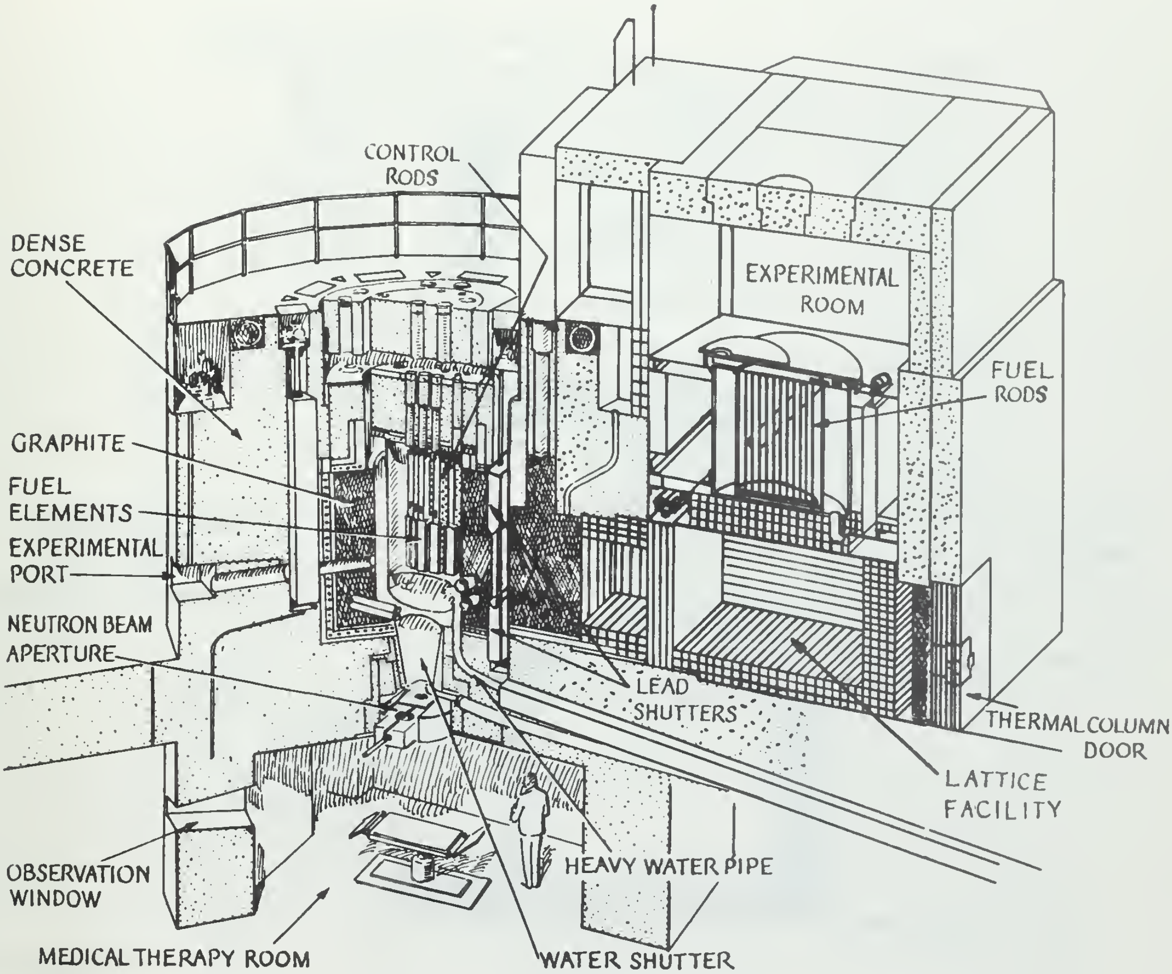
INTRODUCTION

1.1 The MIT Heavy Water Lattice Facility

Under the sponsorship of the United States Atomic Energy Commission, the Nuclear Engineering Department of MIT is conducting a research program on the physics of lattices of slightly enriched uranium rods in heavy water. Several reports describing the results of investigations associated with this project have been published (B1, D2, H1, H2, M1, M2, P1, P2, S1, W2, and W3).

It is of interest, however, to describe briefly that portion of the lattice facility pertinent to the following report. A more detailed description of its construction may be found in reference (M1). For this discussion, attention is directed to Figs. 1.1A and 1.1B.

The subcritical lattice facility consists of two concentric aluminum tanks, the outer tank being 72 inches in diameter and is stationary while the inner tank is of variable size, and is presently 36 inches in diameter. The tanks are 67 inches in height. The fuel rods are slightly enriched uranium and the moderator is D_2O. The MIT reactor is utilized as the source of neutrons for the assembly. The neutrons traverse a thermal column of reactor grade graphite (52 inches long, 63 inches x 63 inches), are reflected within the graphite lined cavity, or hohlraum (72 inches x 60 inches), and then enter the lattice tank through its bottom. The shape of the flux distribtution entering the assembly closely resembles that of the zeroth order Bessel function (M1). That this source is



CUT-AWAY VIEW OF THE MIT RESEARCH REACTOR

FIG. 1.1A

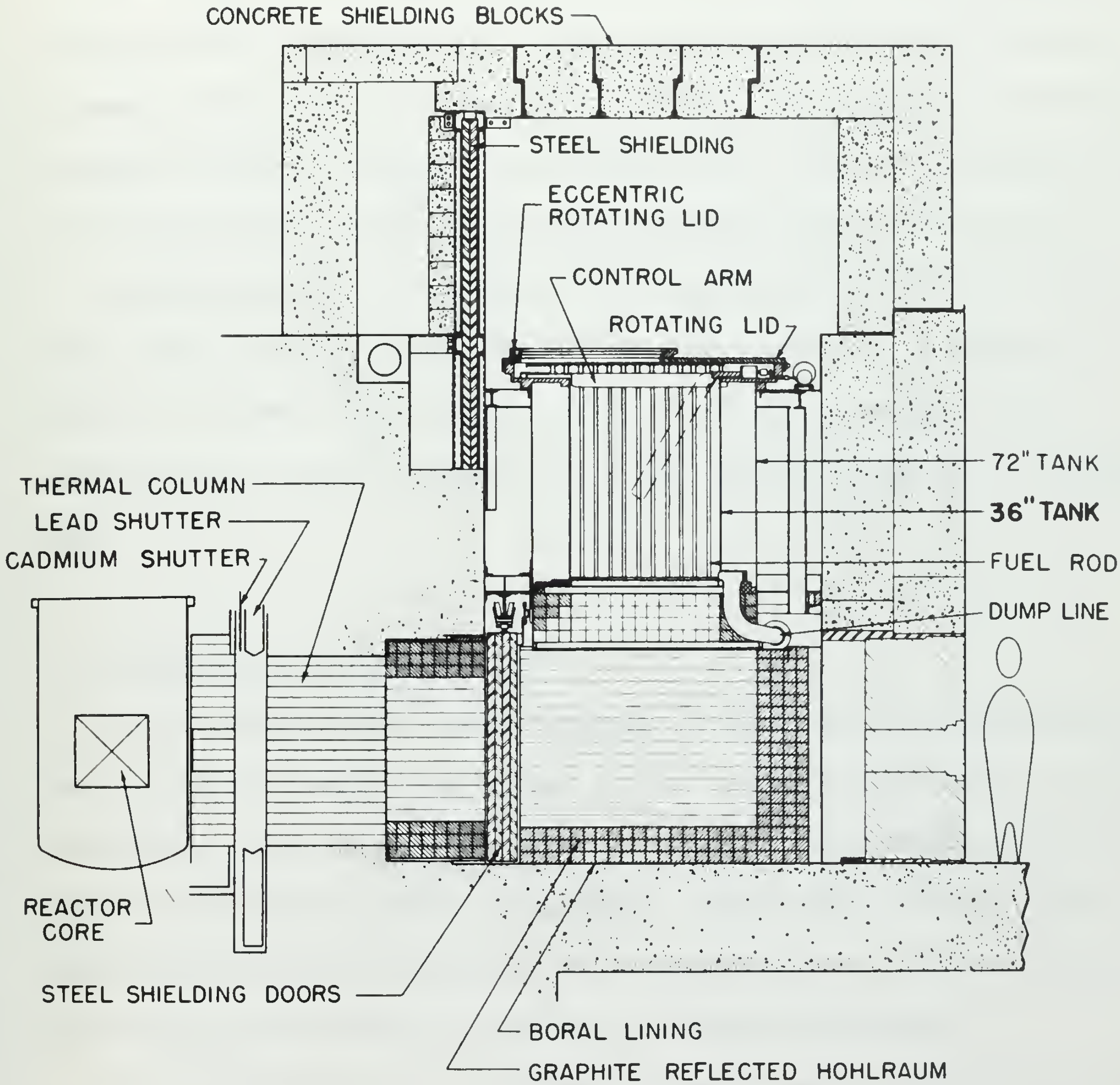


FIG. 1.1B VERTICAL SECTION OF THE SUBCRITICAL ASSEMBLY

virtually purely thermal has been shown by Palmedo (Pl), who obtained cadmium ratios of 1000 to 3000 with gold foils in pure moderator.

The inner tank of the lattice, which contains the core, is covered by a 0.020 inch cadmium cover. This cover is held flush with the tank by means of two stainless steel bands which are separated by a vertical distance of 53-13/16 inches. The cadmium cover serves the purpose of preventing thermal neutrons from being reflected back into the tank.

During the period within which this investigation was made (November 1964 to January 1965), the MIT reactor operated at a power of (1.95 ± 0.02) MW. This operating power level gave a thermal flux of approximately 5×10^9 neutrons per cm^2/sec. at the bottom of the lattice tank.

1.2 History and Purpose of Work

The concept of room return has been of interest to those engaged in work on the MIT Heavy Water Lattice Project since its inception in 1959. Experimental evidence has indicated that lattice measurements can be made by considering the assembly as bare, i.e. unreflected. However, this consideration will be inaccurate in the absolute sense if there is any scattering back of neutrons from the surrounding shielding.

The possibility of the existence of such a neutron return into the MIT lattice, and the further possibility that this return might cause perturbation of the J_o distribution prompted the theoretical investigation of Palmedo, et al (Pl). To summarize this work, the authors considered placing a solution of B_2O_3 in H_2O between the inner and outer tanks of the lattice facility. The results, as were to be expected, indicated

that only the thermal component of the reflected spectrum could be eliminated, and even this required very high concentrations of boron in the water (about 90 grams/liter). Furthermore, because of the efficient reflection of fast neutrons by the water, even at this high boron concentration, the experimental points recorded would not correspond to those of a bare system. Thus, not only would this method not have produced the desired result of eliminating the neutron return but, in addition, the possible contamination of the D_2O moderator by this B_2O_3 solution would be an ever present problem. Consequently, the solution as initially reported in the Lattice Project's First Annual Progress Report (T1), that is, wrapping the inner tank (the core) of the assembly with 0.020 inch thick cadmium, has been used. Although the latter scheme is cleaner, it is still only a partial solution to the problem since fast neutron reflection will not be eliminated by the cadmium and, hence, may cause a perturbation of the neutron flux distribution near the outer edge of the inner tank.

This concern over the possible existence of a reflected neutron current is not peculiar to MIT. The need for a correction due to this phenomenon has been recognized by several facilities. For example, Girard et al(G1), in their paper presented to the Second Geneva Conference, talk of "reflector coefficients" for France's Aquilon. They observed this reflector effect to be of the order of 3 per cent and to be practically the same for all measurements carried out with the same reference lattice. Dessauer (D1), in a similar paper, reported that corrections had to be made for "irregularities at the boundary region between the test region and the outer region." This resulted in a correction to the buckling, the maximum value of which was $-0.35\ m^{-2}$.

Direct measurements of the room return have not been made previously at MIT because the design of the proper detector which would most adequately fit the needs of the project has been an elusive problem. Weinstock and Phelps of the Brookhaven National Laboratory have recently developed such a detector (W1), and it is of interest to try this detector for the measurement of room return at MIT.

It has been, therefore, the primary aim of this investigation to determine by experimental measurement, the current of fast neutrons which are reflected back into the inner, cadmium covered tank. A detailed description of the procedures utilized in making this measurement are given in Chapter II.

CHAPTER II

EXPERIMENTAL TECHNIQUES

2.1 Preparation for the Measurement

In preparation for measuring the current of fast neutrons reflected back into the inner, cadmium covered tank, several considerations were necessary.

(1) Access had to be gained to the space between the two lattice tanks, as this is where the measurement was to be made. It was desirable that the method devised be such that any required mechanical work could be accomplished within the lattice room, that is without recourse to complete dismantling of the lattice tank structure.

(2) A method for guiding the detector in its descent between the tanks which would involve a minimum amount of equipment was required. The presence of extraneous material could cause unnecessary perturbation of the neutron flux and thus yield results which were not characteristic of the flux normally present.

(3) Additional care must be taken to insure that leakage of the nitrogen blanket which covers the D_2O moderated core would be prevented. If this were not done, the system would become contaminated with air, and subsequently bring about a reduction in the D_2O purity.

As a solution to these problems it was decided to saw a 3 inch hole in the 6.75 inch wide lip of the 3 foot diameter lattice tank (M3) with the appropriate size hole saw (Fig. 2.1A). A portable drill was used so that the hole could be made in the lattice room, thus avoiding the problem of dismantling the tank structure. To guide the detector, 72 pound test nylon line was suspended between and secured to the stainless steel bands surrounding the cadmium covered 3 foot tank described in Section 1.1. These nylon lines were placed approximately $1\frac{1}{2}$ inches apart, as the detector, being greater than 2 inches in diameter when fully assembled, would then be subjected to a definite holding power (Fig. 2.2.2A). The fact that the nylon lines were secured to the stainless steel bands made it possible for the detector to be flush with the side of the 3 foot tank for all measurements.

Finally, in order to prevent leakage of the nitrogen blanket, the hole in the tank lip was plugged with a No. 15 standard laboratory rubber stopper. The method used for controlling the depth of descent of the detector with this plug inserted will be explained in Section 2.2.2.

2.2 Description of the Detector

2.2.1 Description

The detector utilized in this experiment consisted of a solid cylinder of indium (99.99 per cent pure), 2 inches in diameter by 1 inch thick (Fig. 2.2.1A). It was completely surrounded with 0.020 inch cadmium, thereby precluding the possibility of activation by thermal neutrons. Two depressions approximately 0.780 inches in diameter by 0.020 inches deep were milled on the flat faces of this cylinder. Each

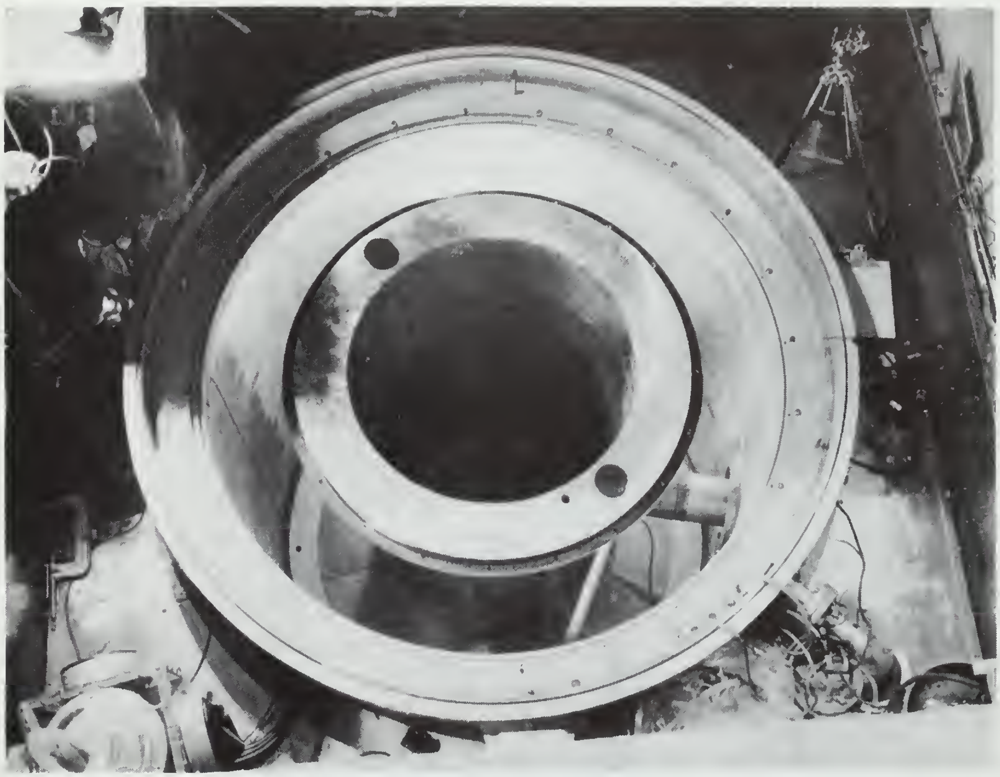


Fig. 2.1A TOP VIEW OF LATTICE TANK STRUCTURE

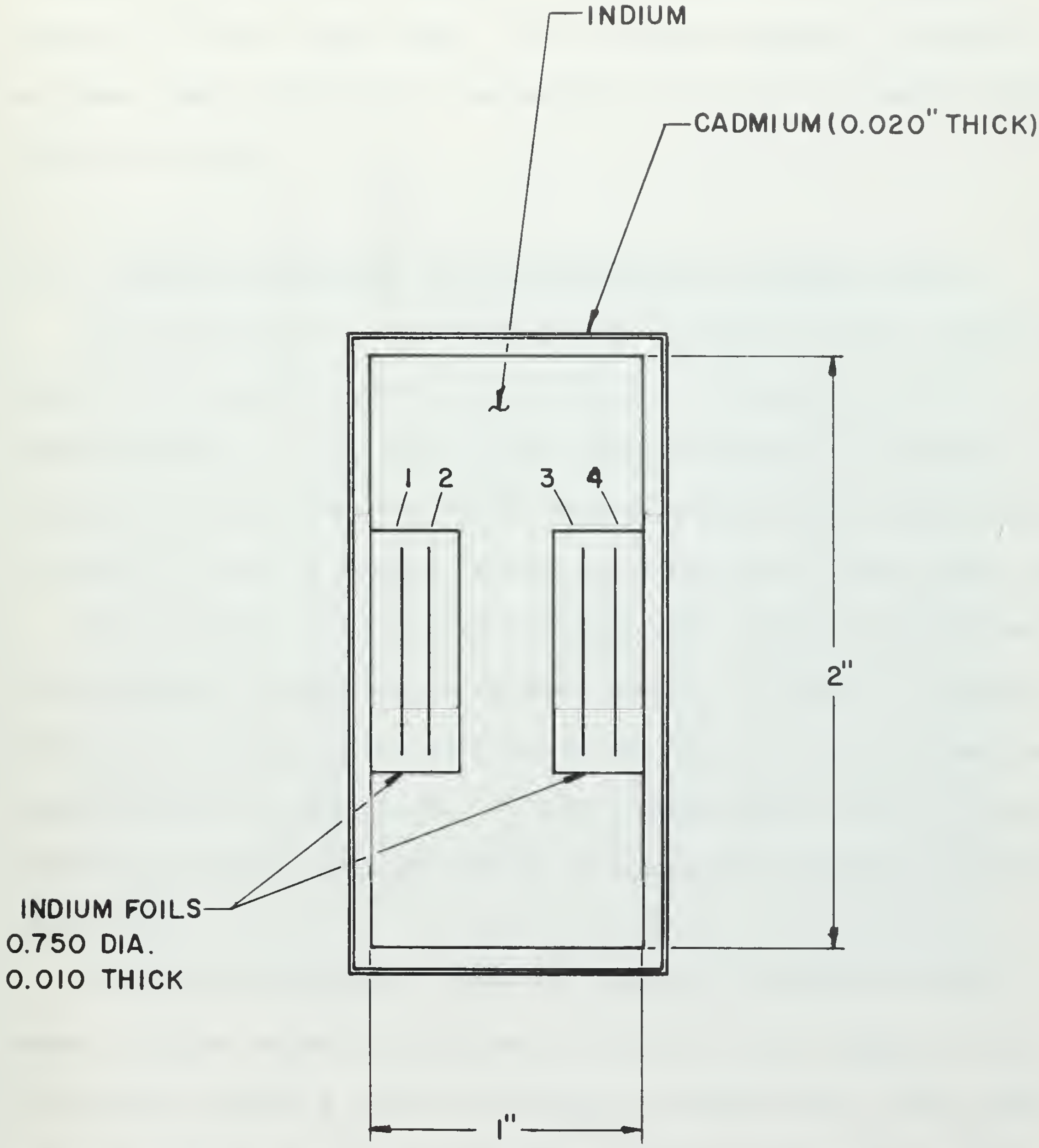


Fig. [illegible].[illegible].1[illegible]

SCHEMATIC SKETCH OF
INDIUM DETECTOR

of these depressions held 2 indium foils which were 0.750 inches in diameter and 0.010 inches thick. The foils were numbered 1 through 4, as shown, where foil number 1 was nearest to the 3 foot diameter lattice tank for all runs.

2.2.2 Method for Lowering the Detector Between the Lattice Tank

Once the detector, as described in the previous section, had been assembled, a stainless steel clamping device was secured around its circumference (Figs. 2.2.2A and 2.2.2B). This served the dual purpose of holding the cadmium cover in place while also providing a means whereby the detector could be lowered between the 3 foot and 6 foot lattice tanks.

To accomplish this lowering procedure while regulating the detector's path of descent, hollow stainless steel tubing, 3/16 inch O.D. and approximately ½ inch long was soldered to the sides of the stainless steel clamping device as shown in Fig. 2.2.2A. These pieces were cut in half lengthwise thereby providing runners to engage the nylon line mentioned previously.

To regulate the depth to which the detector was lowered another piece of hollow tubing was soldered to the top of the clamping device. To this was attached a 0.032 inch diameter stainless steel cable, appropriately marked so that the vertical position of the detector would be known at all times. This cable was then fed through a hole in the rubber stopper, and secured at the desired location by means of a flat piece of aluminum stock (1½ inch x 3/8 inch x ½ inch) equipped with a stainless steel set screw. The arrangement proved to be satisfactory, as the cable was sufficiently strong to preclude the possibility of snapping if

Fig. 2.2.2A FRONT VIEW OF THE INDIUM DETECTOR

Fig. 2.2.2B SIDE VIEW OF THE INDIUM DETECTOR

subjected to a sudden jerk, and the combination of the nylon lines and the set screw device permitted exact knowledge of the detector's position for each run. Fig. 2.2.2C is a view of the experimental set up.

2.3 Foil Preparation and Irradiation Techniques

Following the procedure of Weinstock and Phelps (W1), indium foils were chosen for this experiment. The neutron bombardment of indium produces the reaction In^{115} (n,γ) In^{116*}. The resulting excited level of In^{116} which decays by gamma emission with a half life of 54.12 minutes is the decay process that was observed. There are three primary reasons why indium was chosen as the most suitable material to be irradiated.

(1) Indium has a large value of the neutron absorption cross section at its 1.48 ev resonance (approximately 30,000 barns).

(2) The observed decay process of In^{116} has a relatively short half life, thus requiring runs of only 30 minutes to 1 hour duration in order to yield a high count rate.

(3) Indium is a relatively low cost material (as compared with gold, for example, the other material given primary consideration).

The 0.010 inch indium sheets from which the foils were cut were all taken from the same manufactures lot. The foils to be irradiated were punched to 0.750 inches in diameter.

For each irradiation the indium cylinder, the cadmium covers, as well as the individual foils to be used were washed with acetone and wiped clean before being assembled. Once the foils had been inserted in

Fig. 2.2.2C DETECTOR SUSPENDED ALONG THE SIDE OF THE THREE FOOT LATTICE TANK

the milled depressions on the faces of the indium cylinder they were held secure by the application of a small strip of mylar tape, shown by Simms, et al (S1) to have negligible effect on the foil activation. The cadmium covers were then put in place and held secure by the stainless steel clamping device previously described.

When the run had terminated, the detector was dismantled and a foil 0.387 inches in diameter was cut from the center of each irradiated foil. This procedure negated any effects which might be caused by streaming or by the presence of burrs on the irradiated foil. The foils were then gamma counted on both sides with a NaI (Tl) well type scintillator in conjunction with Hamner electronic equipment (Appendix A). After a suitable time delay for de-activation of the foils, their weights were determined with a precission balance, accurate to 1 part in 10^5 (grams).

CHAPTER III

DATA ANALYSIS

In analyzing the data obtained by counting both sides of each of the four foils shown in Fig. 2.2.1A, it is necessary to look at the neutron currents incident on each side of each foil. The reader is referred to Fig. 3.1A, in which the foils are shown to be considerably larger than they actually are. Recall that the 3 foot lattice tank (the core) is located to the left of the sketch, while the reflecting 6 foot tank is located to the right. Also, the detector is flush with the side of the 3 foot tank.

We wish to determine the albedo-like quantity β,

$$\beta \equiv \frac{\text{activity of the right side of foil number 4 due to the room-reflected neutron component}}{\text{activity of the left side of foil number 1 due to the neutron leakage from the core}} . \qquad (1)$$

It is to be noted that the activity of any side of any one foil will be attributable to two separate components of neutron current. First there is the leaving component, i.e. those neutrons which leave the 3 foot lattice tank and travel outward, and secondly, a returning component due to neutrons which having left the 3 foot lattice tank, are reflected from the exterior surroundings, and are then capable of re-entering the 3 foot tank. An expression for the quantity, β, will now be derived in terms of measureable quantities.

In the following derivation the subscript "L" implies that the quantity so subscripted is applicable to neutrons which travel from left to

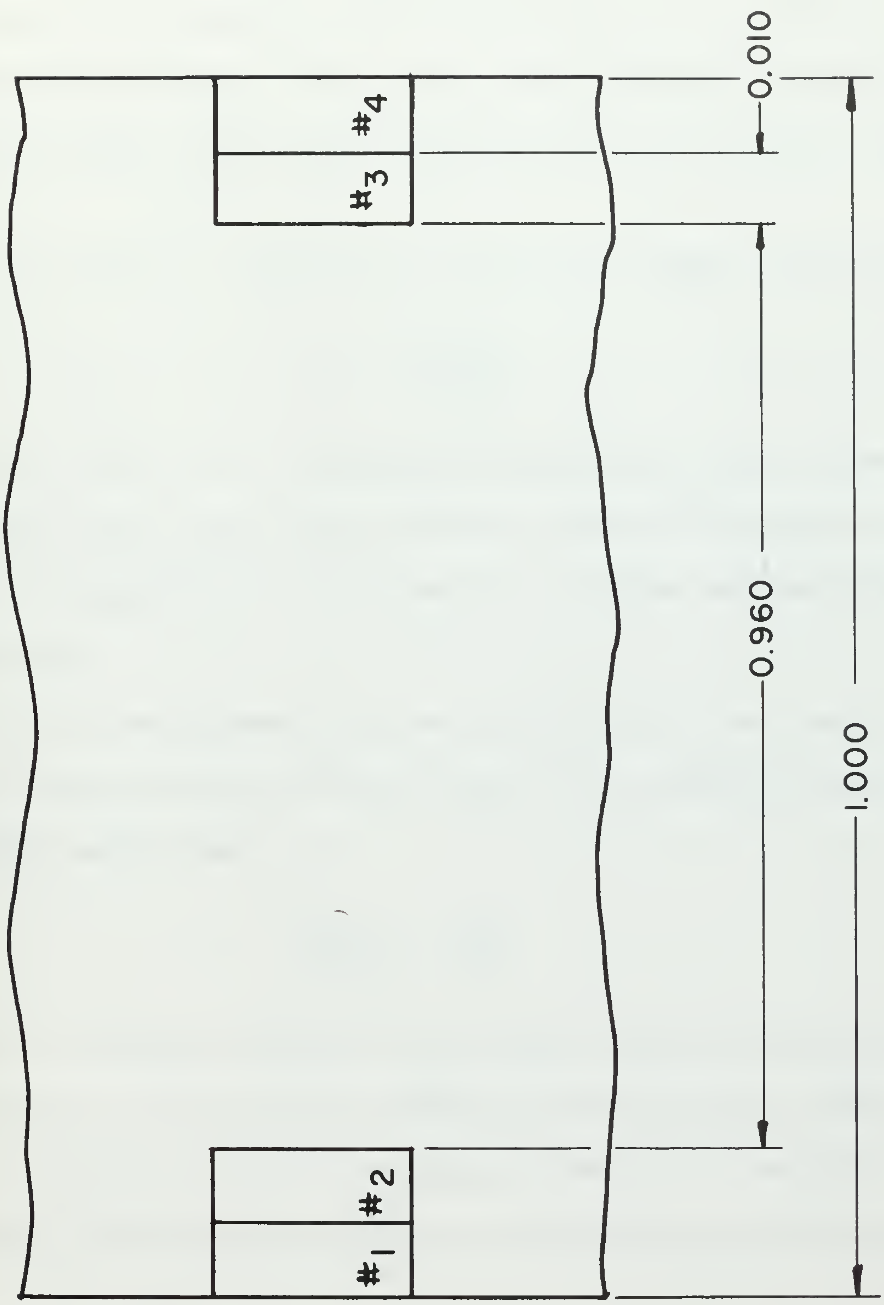


FIG. 3.1A ENLARGED SCHEMATIC SKETCH OF THE DETECTOR

right while the subscript "R" implies that the quantity so subscripted is applicable to neutrons which travel from right to left. Also, the small letter "ℓ" subscripted with the numbers 1 to 4 refers to the activity of the left side of foil 1 to 4 while the small letter "r" subscripted with the numbers 1 to 4 refers to the activity of the right side of foil 1 to 4.

First define a transmission factor for a single outer foil

$$f_1 = \frac{\ell_{2,L}}{\ell_{1,L}} , \qquad (2)$$

where $\ell_{1,L}$ and $\ell_{2,L}$ are measured activities and $\ell_{2,L}/\ell_{1,L}$ gives the ratio of neutrons which pass through the first foil and activate the second, i.e. the "transmission" of foil number 1 by those neutrons leaving the lattice core.

If it is now assumed that the contribution to the observed activities of the left side of foils 1 and 2 of the reflected neutrons is negligibly small, then

$$\frac{\ell_{2,L}}{\ell_{1,L}} = \frac{\ell_2}{\ell_1} .$$

This is a reasonable assumption and implies that the activation produced by neutrons in the reflected component which escape the indium resonances while traversing the inch thick indium block will be negligibly small compared with the activation produced by the component leaving the lattice core.

Next the assumption is made that any neutron which traverses the entire block of indium (the detector), traveling from left to right, will activate the right side of foil number 4 to the same extent that it activates the right side of foil number 3, i.e.

$$r_{3,L} = r_{4,L} = \theta_L \quad . \tag{3}$$

This again is a reasonable assumption since any neutrons which have penetrated the block must have energies at which the indium cross section is small and for which the attenuation is therefore low (W1).

The following expression may now be written for the measured activity ratio r_4^m/r_3^m:

$$\frac{r_4^m}{r_3^m} = \frac{r_{4,L} + r_{4,R}}{r_{3,L} + r_{3,R}} \text{ , or}$$

$$= \frac{\theta_L + \theta_R}{\theta_L + \theta_R'} \tag{4}$$

where the quantity θ_L is defined by Eq. (3) above and θ_R represents the activation of the right side of foil number 4 due to the reflected neutrons only while θ_R' represents the activation of the right side of foil number 3 due to this same component. θ_R' is different from and less than θ_R due to passage through foil number 4. The superscript "m" implies a measured quantity.

Eq. (4) may be rewritten as:

$$\frac{r_4^m}{r_3^m} = \frac{\dfrac{\theta_L}{\theta_R} + 1}{\dfrac{\theta_L}{\theta_R} + \dfrac{\theta_R'}{\theta_R}} \quad . \tag{5}$$

The quantity θ_R'/θ_R represents the transmission through foil number 4 of those neutrons which travel from right to left only, i.e. the reflected component. If it is now assumed that the spectral distribution of the outgoing and the returning components in the indium resonance activation

region are identical, then

$$\frac{\theta_R^1}{\theta_R} = \frac{\ell_2}{\ell_1} ,$$

and Eq. (5) becomes

$$\frac{r_4^m}{r_3^m} = \frac{\frac{\theta_L}{\theta_R} + 1}{\frac{\theta_L}{\theta_R} + \frac{\ell_2}{\ell_1}} . \tag{6}$$

Hence, the result is an equation with only one unknown, θ_L/θ_R. The equation may consequently be solved for this unknown and thereby obtain θ_R, the activation of the right side of the fourth foil produced by the returning neutrons only. From this it is possible to determine the return coefficient, β, as defined by Eq. (1),

$$\beta = \frac{\theta_R}{\ell_1} .$$

The procedure follows.

Rewriting Eq. (6) gives

$$\frac{r_4^m}{r_3^m} = \frac{x + 1}{x + \frac{\ell_2}{\ell_1}} ,$$

where $x = \theta_L / \theta_R$ is the quantity to be determined. Eq. (6) may be solved for x, obtaining

$$x = \frac{1 - \frac{r_4^m}{r_3^m} \cdot \frac{\ell_2}{\ell_1}}{\frac{r_4^m}{r_3^m} - 1} . \tag{7}$$

Now add 1 to both sides of Eq. (7) for simplification of the solution; thus

$$x + 1 = \frac{\frac{r_4^m}{r_3^m}\left(1 - \frac{\ell_2}{\ell_1}\right)}{\frac{r_4^m}{r_3^m} - 1} . \qquad (8)$$

Recall now, from Eq. (4), that

$$r_4^m = r_{4,L} + r_{4,R} = \theta_L + \theta_R .$$

This may be rewritten as

$$r_4^m = \theta_R\left(\frac{\theta_L}{\theta_R} + 1\right) = \theta_R(x + 1)$$

or

$$r_4^m = r_4^a \; (x + 1) \qquad (9)$$

where the superscript "a" implies the actual activity of the right side of the fourth foil which is due to returning neutrons only, (i.e. $r_m^a = \theta_R$). Eq. (8) may now be combined with Eq. (9) to yield r_4^a in terms of quantites which may all be determined experimentally:

$$r_4^a = \frac{r_4^m}{x + 1} = \frac{r_4^m\left(1 - \frac{r_3^m}{r_4^m}\right)}{1 - \frac{\ell_2}{\ell_1}}$$

$$= \frac{r_4^m - r_3^m}{1 - \frac{\ell_2}{\ell_1}} . \qquad (10)$$

If Eq. (10) is then evaluated from the experimental data recorded for each

run, the return coefficient may be determined as

$$\beta = \frac{r_4^a}{\Sigma_1} \quad . \tag{11}$$

CHAPTER IV

EXPERIMENTAL RESULTS

4.1 Introduction

In determining the return coefficient as given by Eq. (11) of Chapter III, it must be recognized that there are three primary sources of neutrons which can contribute to this return effect:

(1) Those neutrons which leave the lattice core are reflected and then return to the core.

(2) Those neutrons which enter the $1\frac{1}{2}$ foot wide annular ring between the two lattice tanks from the graphite cavity (Fig. 1.1B).

(3) Those neutrons which are due to sources external to the lattice room itself, such as leakage neutrons from the MITR.

Since an important part of this investigation was to determine the extent to which the lattice core contributed to the neutron return, the method used to determine this component, separate from the latter two sources mentioned above, will be presented in this chapter and the subsequent results discussed.

4.2 Description of Lattice Configuration

The core of the lattice under investigation at MIT during the period in which this work was performed, consisted of 361 cylindrical rods

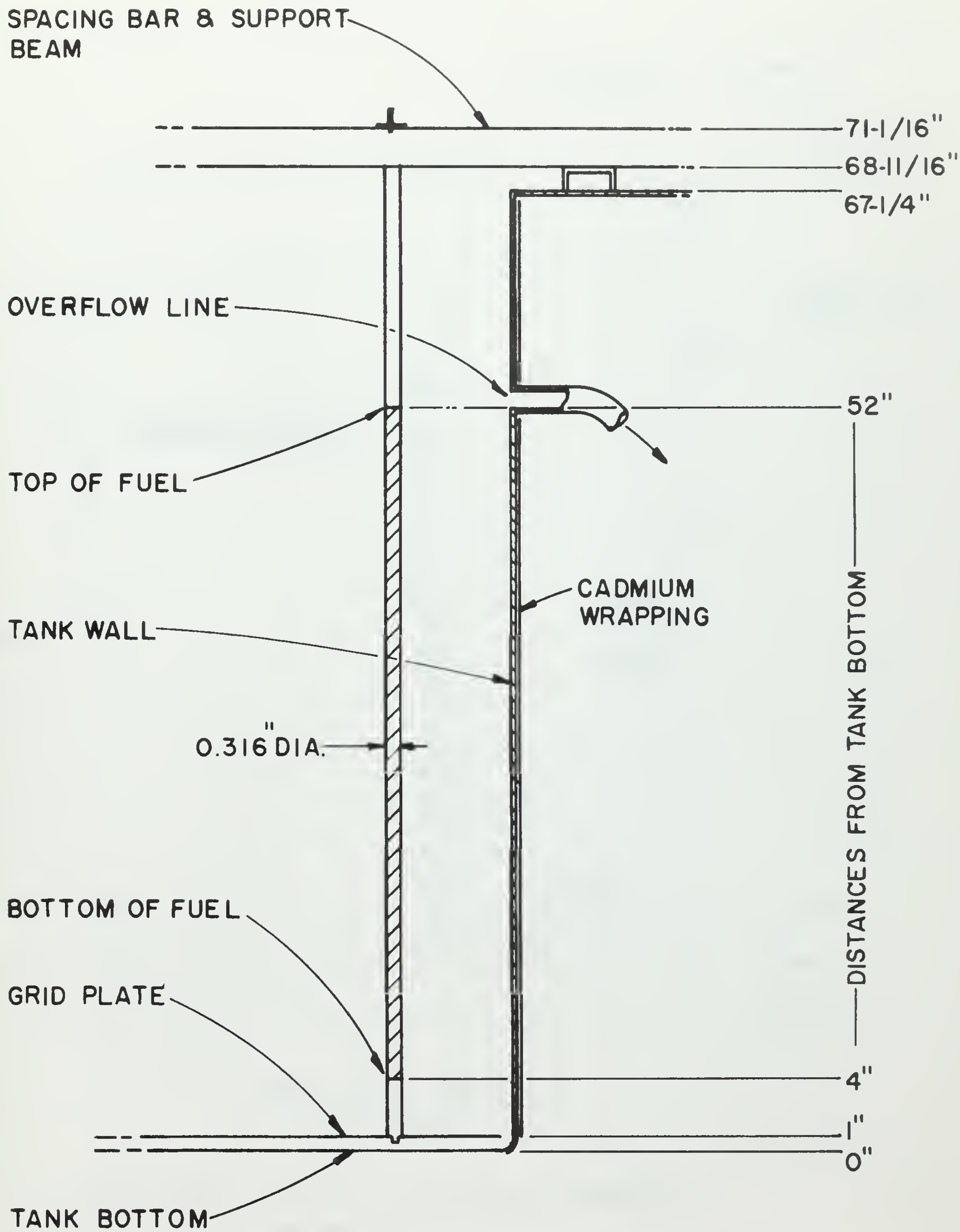


FIG. 4.2A VERTICAL CONFIGURATION OF A FUEL ROD IN THE TANK

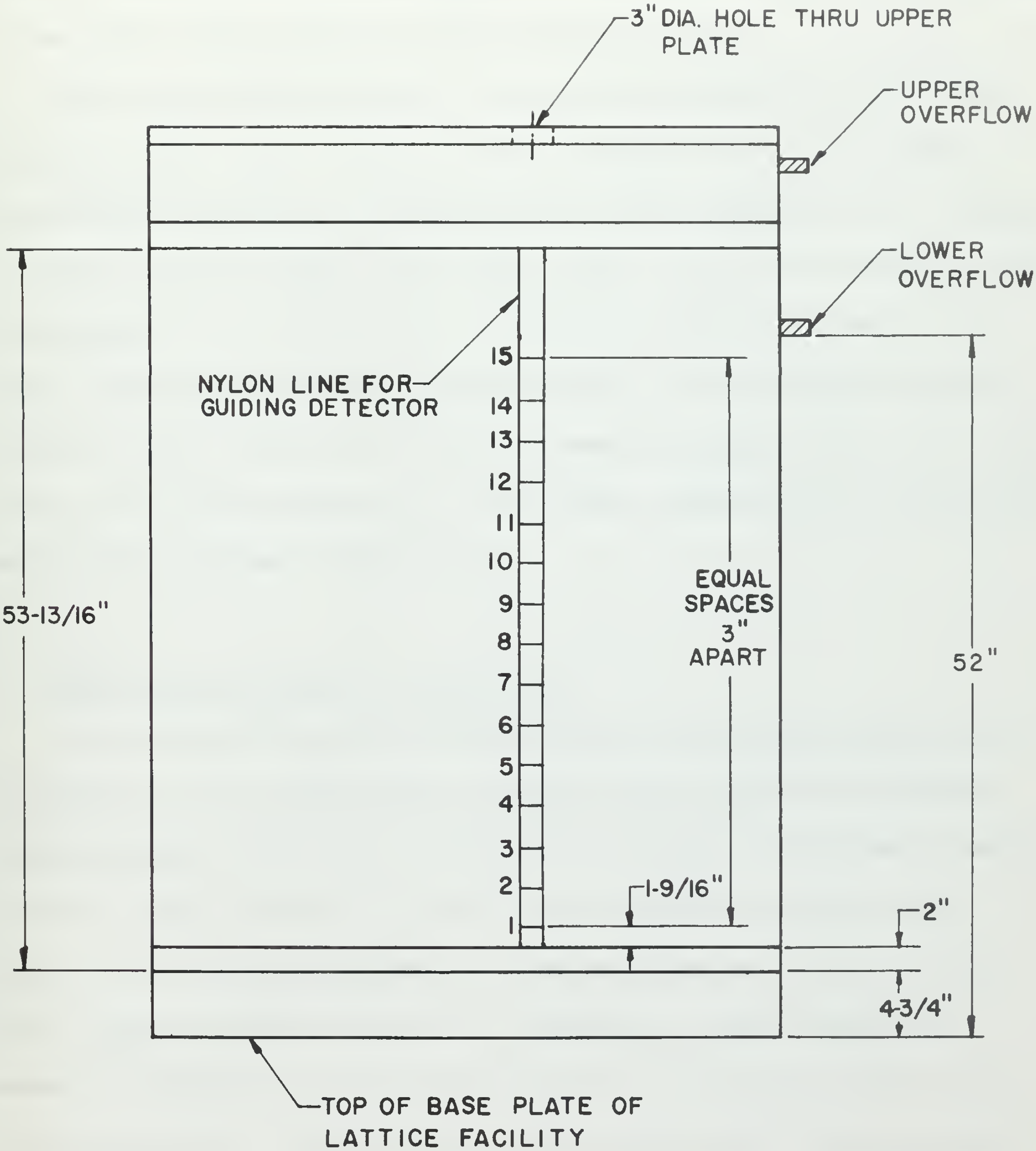


FIG. 4.2B DETECTOR LOCATION NUMBERS FOR RUNS

of metallic uranium enriched to 1.143 w/o U^{235}. The rods were each 0.25 inches in diameter and were arranged in a triangular pitch of 1.75 inches. The moderator was D_2O with a purity of 99.6 per cent.

The vertical configuration of one fuel rod within the lattice core is shown in Fig. 4.2A. In Fig. 4.2B the locations are shown at which measurements were made in determining the return coefficient as a function of height along the side of the lattice core. It is to be noted that the measurements did not extend the full length of the fuel element. The range of the measurements was limited owing to the location of the two stainless steel bands used to hold the cadmium wrapping flush to the side of the 3 foot tank (Section 1.1), and between which the return coefficient measurements were made (Section 2.1).

4.3 Experimental Runs with a Loaded Core

To determine the return coefficient due to all three sources listed in Section 4.1, two experimental runs were made at each of the fifteen locations shown in Fig. 4.2B. The core was loaded as described in Section 4.2. Each side of each of the four foils irradiated was then gamma counted as described in Appendix A. The resulting activities were fed into a computer program, ACTOR (see Appendix B), which corrected the observed activities to the saturated activity and normalized this value as to foil weight. The output from ACTOR was fed into a second computer program, BETA (see Appendix B), which determined the return coefficient, β, by solving Eq. (11) of Chapter III.

In both computer programs the statistical fluctuations were determined in the usual manner (E1), assuming a Poisson distribution.

The resulting return coefficient for the fuel runs, plotted as a function of vertical distance along the side of the lattice core tank, is shown in Fig. 4.3C. In Fig. 4.3D are recorded the same data plotted with the return coefficient on a log scale. Note the closeness to which the return coefficient, as a function of height, approaches a straight line in the latter plot. In both plots, the standard deviation due to counting statistics is less than the size of the points through which the curves are drawn. TABLE 4.3 gives the values of β which are plotted.

Figs. 4.3A and 4.3B are presented to indicate the manner in which the component of neutrons which leave the core (ℓ_1) and the component of neutrons returning to the core (r_4^a) vary with core height. The ratio of the points recorded on the two plots at any one detector position will give the return coefficient at that position as plotted in Figs. 4.3C and 4.3D.

It is to be noted that Figs. 4.3A and 4.3B do not represent the absolute magnitude of the leaving and returning neutron components as these components vary with height. There are two primary reasons for this:

(1) The equation used to determine the plotted activities (Appendix B) lacks a multiplicative factor of λT_4, λ being the decay constant for In^{116} and T_4 being the duration of the counting period. Since this value was the same for all foils, it would cancel when foil ratios were taken to determine β. Hence, it was not included in the defining equation for activity.

(2) It was found that an inconsistency in the activity data existed for runs made at detector positions 11

Fig. 4.3A

ACTIVITY OF THE LEFT SIDE OF FOIL #1 vs DETECTOR POSITION, FOR FUELED RUNS

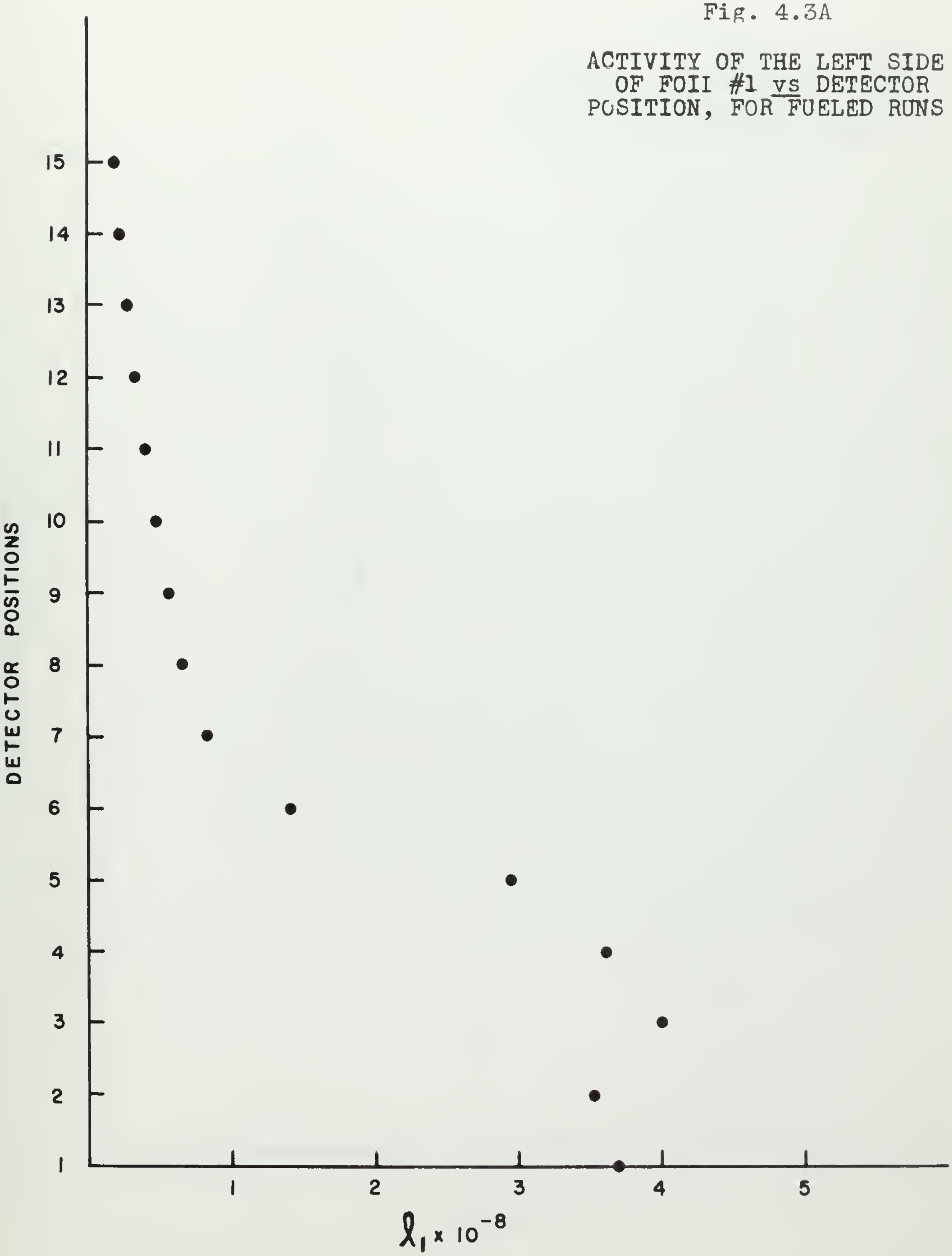
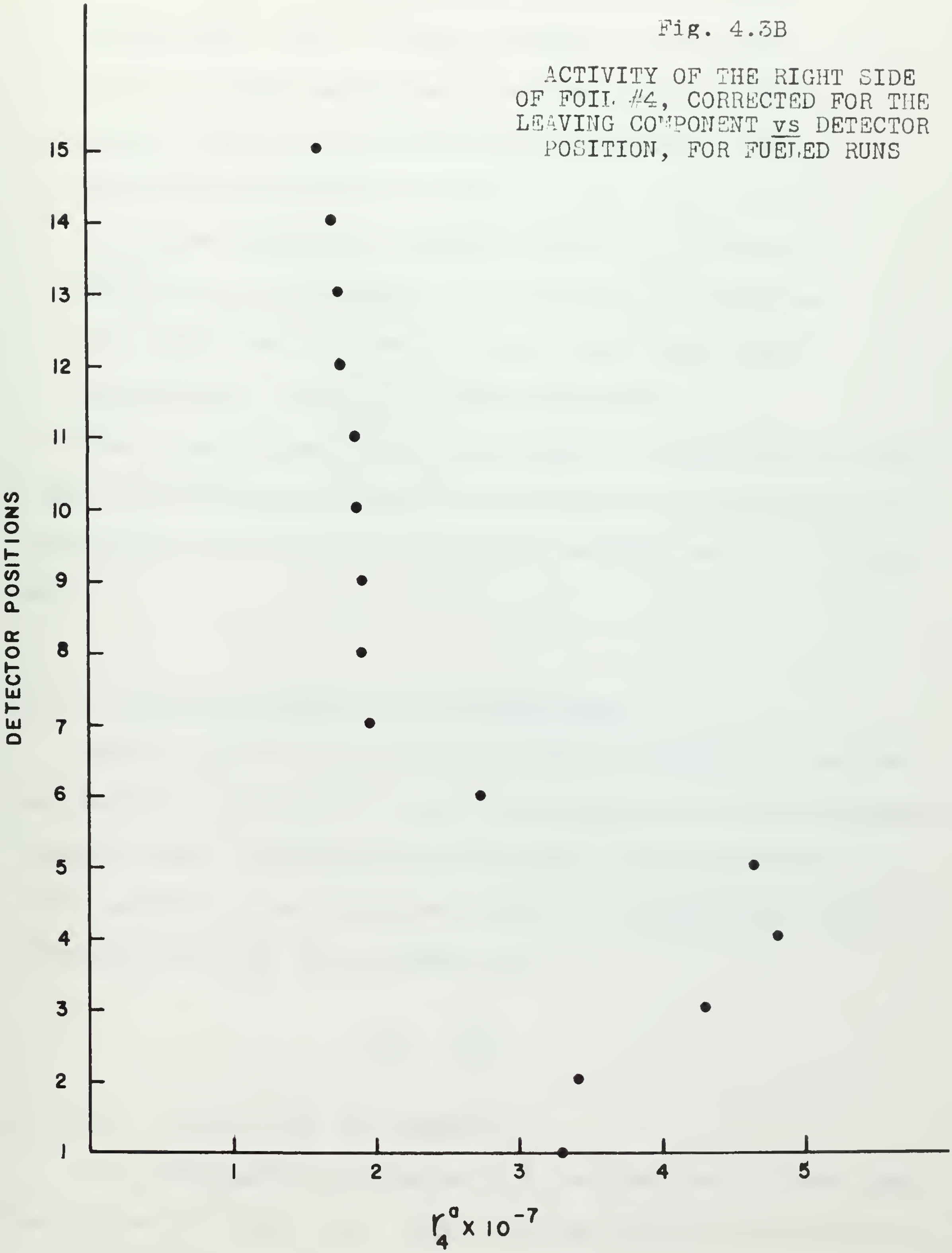


Fig. 4.3B

ACTIVITY OF THE RIGHT SIDE OF FOIL #4, CORRECTED FOR THE LEAVING COMPONENT *vs* DETECTOR POSITION, FOR FUELED RUNS



to 15. This was attributed to a change in the effective sensitivity of the counting equipment caused by discriminator drift. Thus, in order that Figs. 4.3A and 4.3B appear as smooth variations, it was necessary to multiply the activities at these positions by a "shifting factor." The shifting factor was set equal to 0.64. Again, this inno manner affects the variation exhibited by the return coefficient, as the change in the sensitivity would appear as an additional efficiency term and would thereby cancel when the foil ratio $r_4^a/\ell_1 = \beta$ was calculated.

For these reasons, Figs. 4.3A and 4.3B should be consulted only to gain insight into the manner in which the leaving and returning neutron components vary, or, the manner in which the resulting return coefficient varies.

4.3.1 Discussion of Results for the Fueled Runs

From Fig. 4.3C it is seen that the return coefficient is smallest near the bottom of the lattice core and increases with vertical distance along the tank. To interpret this phenomenon, it is necessary to look at the magnitude of the activities involved in the definition of β, which is given by Eq. (11) of Chapter III:

$$\beta = \frac{r_4^a}{\ell_1} .$$

(see Figs. 4.3A and 4.3B, and Appendix C)

First investigate the variation of ℓ_1 with vertical distance along the lattice core (Fig. 4.3A). Recall that the lattice facility with its

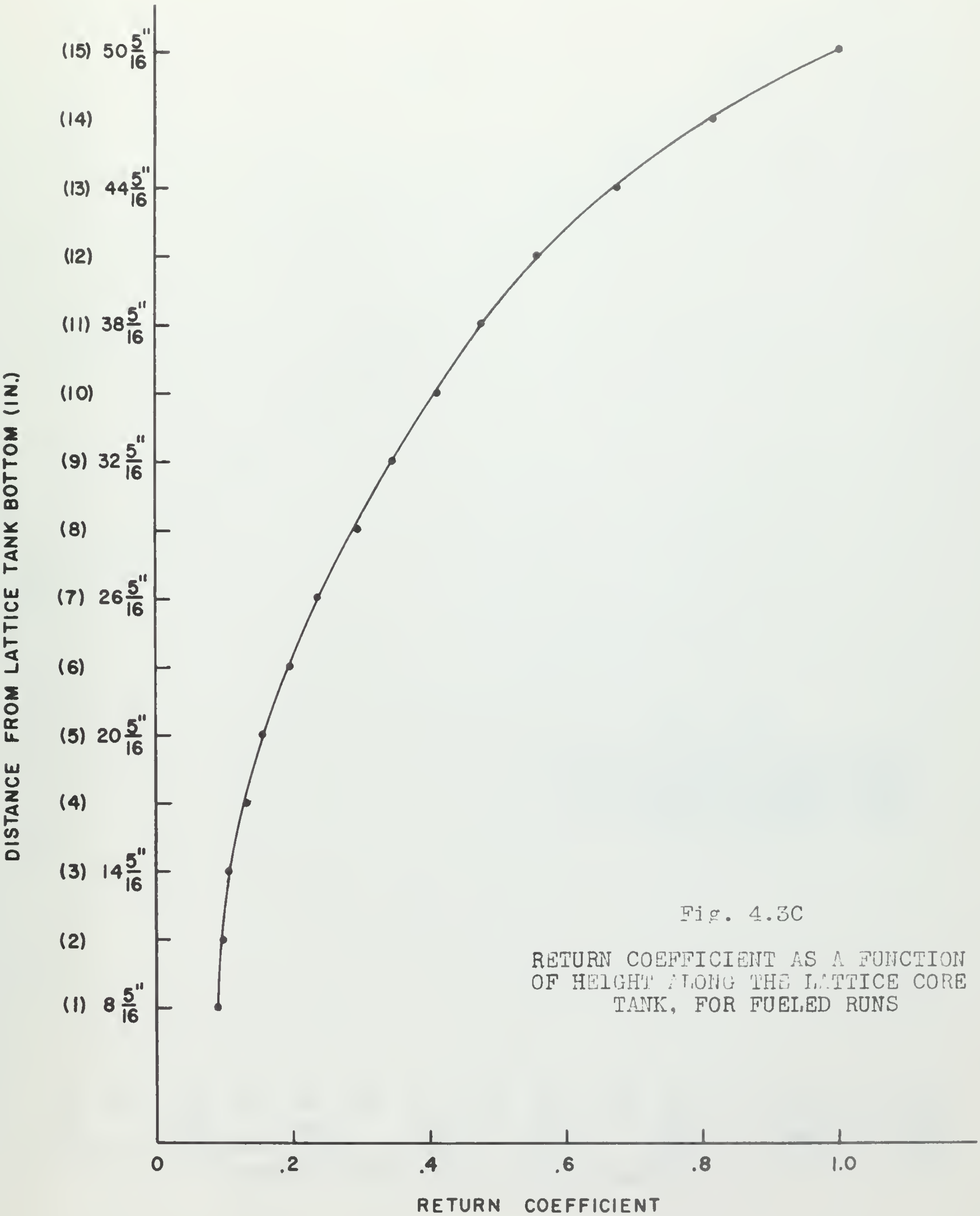


Fig. 4.3C

RETURN COEFFICIENT AS A FUNCTION OF HEIGHT ALONG THE LATTICE CORE TANK, FOR FUELED RUNS

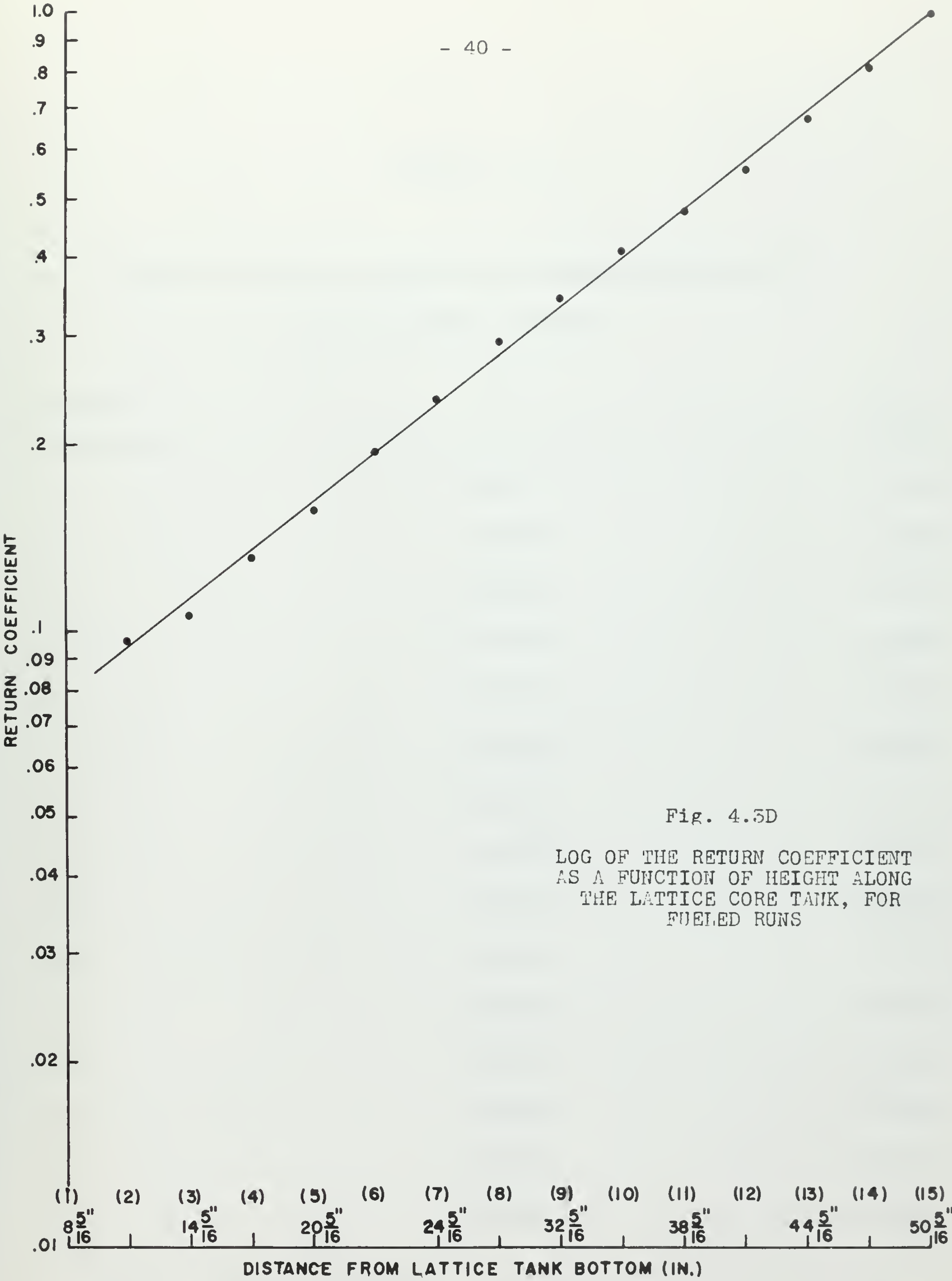


Fig. 4.3D

LOG OF THE RETURN COEFFICIENT AS A FUNCTION OF HEIGHT ALONG THE LATTICE CORE TANK, FOR FUELED RUNS

TABLE 4.3

TABULATED VALUES OF β AND THE STANDARD DEVIATION IN β
FOR THE FUELED CORE RUNS

Location	β	$\beta_{S.D.}$
1	0.08973	0.00046
2	0.09663	0.00043
3	0.10652	0.00057
4	0.13224	0.00062
5	0.15702	0.00069
6	0.19449	0.00096
7	0.23014	0.00136
8	0.29418	0.00185
9	0.34530	0.00226
10	0.41141	0.00307
11	0.47714	0.00261
12	0.55801	0.00321
13	0.67166	0.00371
14	0.81493	0.00434
15	1.00340	0.00628

source, the MITR, removed is subcritical. Hence, insufficient neutrons are generated by the lattice core itself to maintain $k_{eff} = 1$. When the neutrons from the MITR are made available to the lattice core, they enter the tank bottom with a shape closely resembling a J_o distribution and are almost totally thermalized, as discussed in Section 1.1. These thermal neutrons cause fissions in the fuel, thus producing epithermal and fast neutrons. Some of the higher energy neutrons produced are slowed down so that they too assist in sustaining the fission process, thus further increasing the quantity of fission produced neutrons. The leaving component of neutrons is therefore a "dual component" and will consist of contributions from fissions caused by both source neutrons and thermalized fission produced neutrons. This "dual contribution" will not be present for the entire length of the core however, since the contribution from the source neutrons will quickly die out with increasing height. In fact, at a height greater than approximately 20 inches above the lattice tank bottom, the observed leaving component is due almost totally to fission produced neutrons. This latter component then decreases with height approximately exponentially.

As would be expected, r_4^a shows the same variation with height as ℓ_1, for small vertical distances. For vertical distances greater than approximately 20 inches above the lattice core bottom, r_4^a also decreases in an exponential manner with height, but in such a sluggish manner that it may be said to be approximately constant. This slower decrease can be attributed to external sources as given by factors (2) and (3) in Section 4.1. An additional contribution is also present from these neutrons which leave the lattice core at some location other than that of the detector and are subsequently scattered into the detector.

In summary, it may be said that the variation of the return coefficient with height is most strongly affected by the variation in ℓ_1. This, of course, is due to the relative variation of the magnitudes of the activities involved.

It is also to be noted that the return coefficient is greater than 1 at position fifteen. This implies that more neutrons are returning to the core than are leaving, i.e. that the returning component of neutrons contains contributions from sources in addition to that component leaving the lattice core which is reflected. This fact complements the discussion of the variation of r_4^a with height, which is given above. The following section, which reports the results of the moderator runs, will give further insight into the external sources involved.

4.4 Experimental Runs with Moderator Only

In order to separate the effect of the fueled lattice core on the return coefficient from the other two sources listed in Section 4.1, a series of runs were made in which the core tank (the 3 foot tank) was filled with D_2O moderator only. The recorded activities were analyzed with the computer codes ACTOR and BETA in a manner identical to that followed in analyzing the data from the fueled core runs described in the previous section. The results are presented in Figs. 4.4C and 4.4D. TABLE 4.4 gives the values of β which are plotted. Figs. 4.4A and 4.4B show the variation of ℓ_1 and r_4^a with height along the lattice core for the moderator runs.

4.4.1 Discussion of Results for the Moderator Runs

From Fig. 4.4C it is noted that the return coefficient is considerably

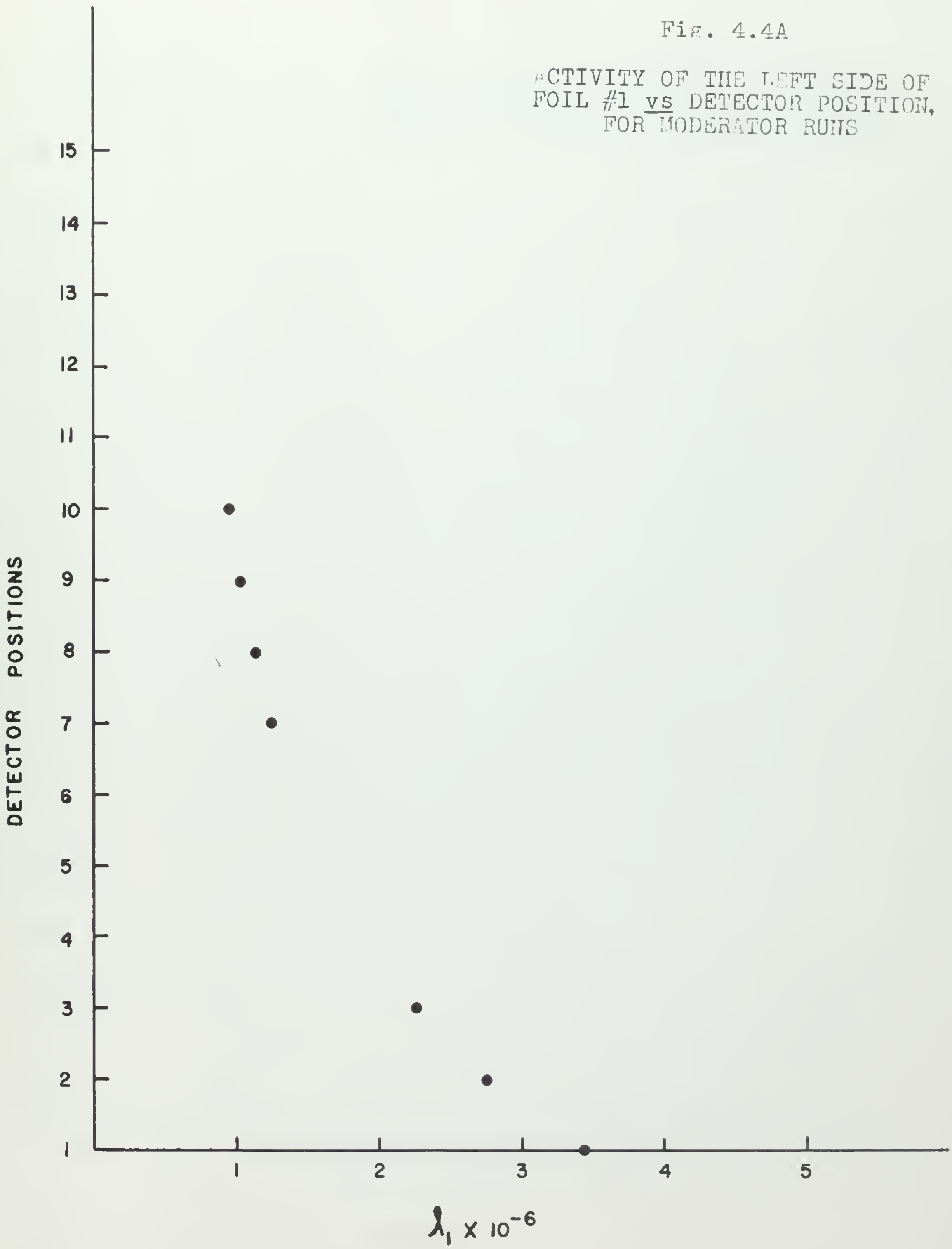


Fig. 4.4A

ACTIVITY OF THE LEFT SIDE OF FOIL #1 vs DETECTOR POSITION, FOR MODERATOR RUNS

Fig. 4.4B

ACTIVITY OF THE RIGHT SIDE OF FOIL #4, CORRECTED FOR THE LEAVING COMPONENT *vs* DETECTOR POSITION, FOR MODERATOR RUNS

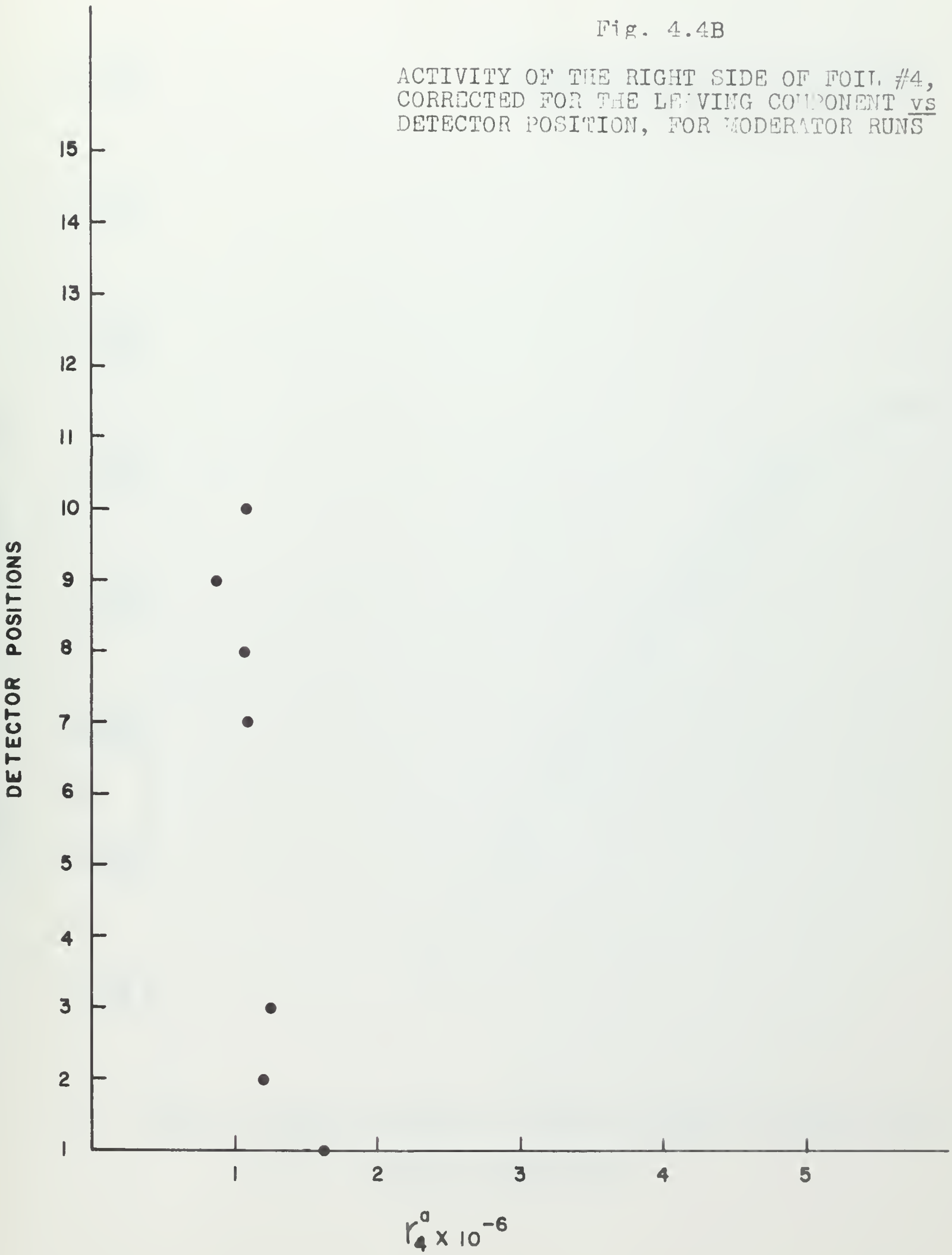
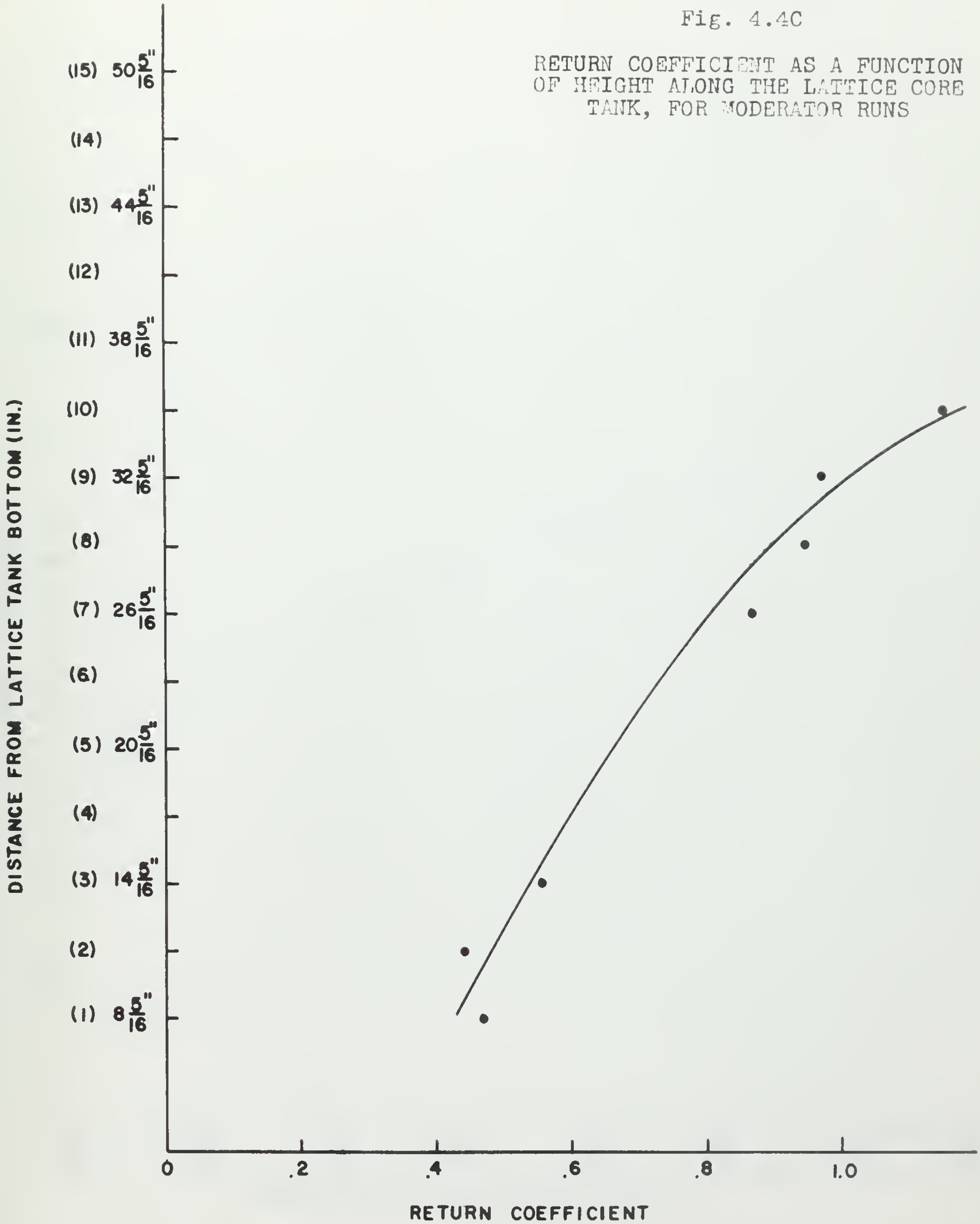


Fig. 4.4C

RETURN COEFFICIENT AS A FUNCTION OF HEIGHT ALONG THE LATTICE CORE TANK, FOR MODERATOR RUNS



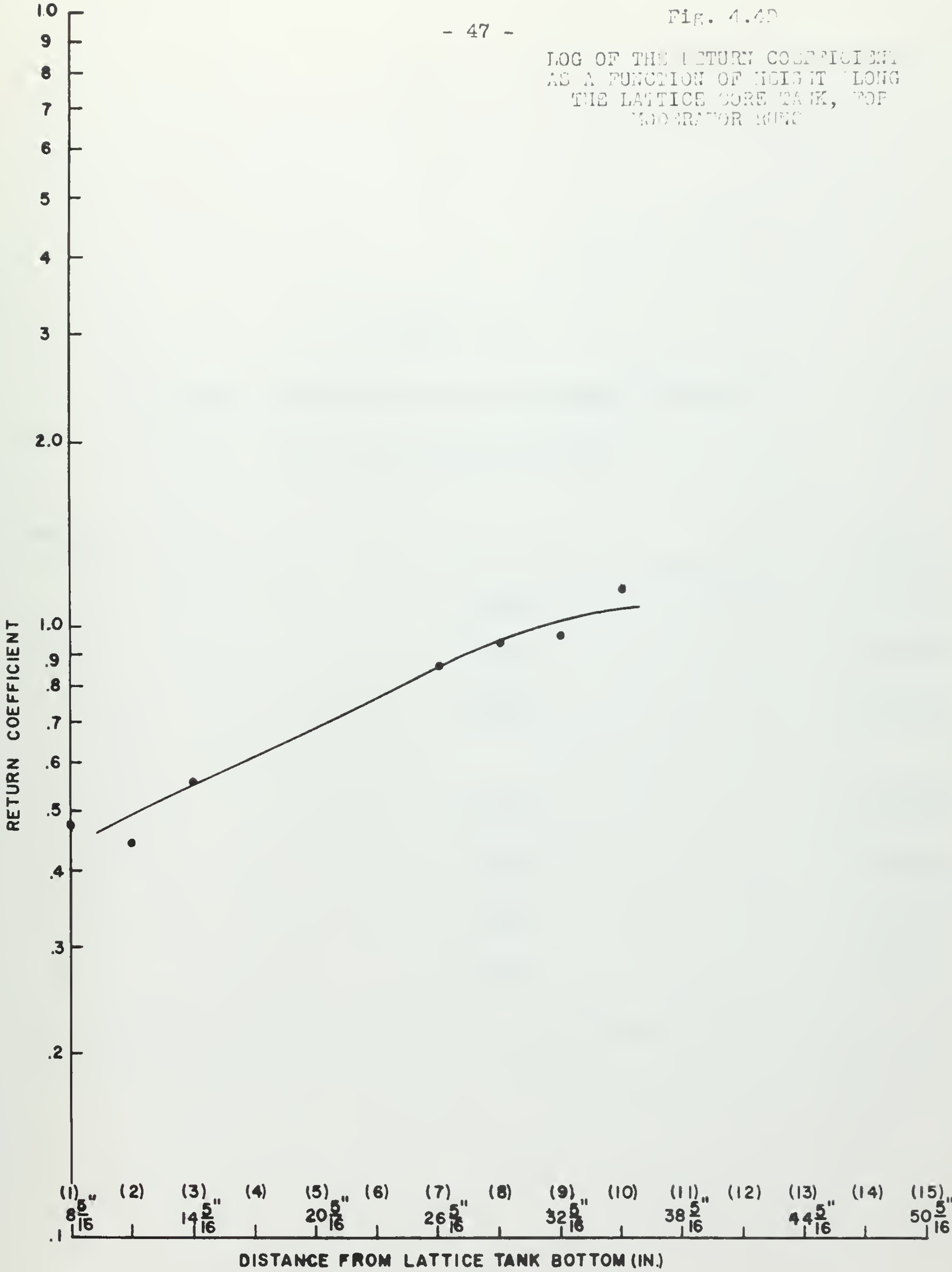


Fig. 4.4D

LOG OF THE RETURN COEFFICIENT AS A FUNCTION OF HEIGHT ALONG THE LATTICE CORE TANK, TOP MODERATOR RUNS

TABLE 4.4

TABULATED VALUES OF β AND THE STANDARD DEVIATION IN β FOR THE MODERATOR RUNS

Location	β	$\beta_{S.D.}$
1	0.47208	0.01065
2	0.44015	0.00909
3	0.55506	0.01130
7	0.86337	0.01999
8	0.94228	0.02169
9	0.96642	0.02347
10	1.15384	0.02786

greater for the moderator runs than for the fueled runs, if a point-by-point comparison is made with Fig. 4.3C. Since no fuel is present, the only sources of neutrons for the leaving component are (1) source neutrons coming from the graphite cavity, and (2) the photo-neutron reaction in D_2O. The returning component appears to be dominated, not by the core generated neutrons, but by neutrons which enter the $1\frac{1}{2}$ foot wide annular ring between the two tanks from the graphite cavity. Although neutrons from a source external to the lattice room could also be a part of the returning component, this is considered to be a small, constant contribution.

From Fig. 4.4D it is seen that the return coefficient varies approximately exponentially with vertical distance along the lattice core. This is as expected, for if it is assumed that the contribution to the returning component of neutrons from (1) those neutrons which enter the $1\frac{1}{2}$ foot wide annulus, and (2) those which are generated totally external to the lattice room are nearly constant (which is a good assumption - see Fig. 4.4B), then the variation in the return coefficient with height goes as $e^{-\lambda z}$, which is aproximately the manner in which the quantity of source neutrons within the lattice core decreases. The photo-neutron reaction in the D_2O moderator also contributes to the leaving component, but sufficient information is not available at the present to determine the extent to which this phenomenon contributes to the total neutron population within the MIT lattice core. Further work is in progress at MIT to determine the magnitude of this reaction.

4.5 Return Coefficient Due to Lattice Generated Neutrons

To determine the return coefficient as a function of vertical

distance along the lattice core due to lattice fuel generated neutrons only, it was necessary to combine the return effects illustrated by the fueled runs and the moderator runs.

To understand how this combined return coefficient was determined, it was necessary to recall one of the basic assumptions made in Chapter III. In that chapter it was assumed that any neutron traveling from left to right (i.e. leaves core and travels outward) which activates the right side of foil number 3 will also activate the right side of foil number 4 to the same extent (ref. Fig. 2.2.1A). Then it may be said that

$$r_4 - r_4^a = r_{4,L} = r_{3,L} , \qquad (1)$$

where r_4 is the total activity of the right side of foil number 4, r_4^a is that portion of the activity which is due to the returning component of neutrons, and $r_{4,L}$ is that portion of the activity which is due to the leaving component of neutrons, using the notation established in Chapter III. So follows that

$$r_3^a = r_3 - r_{3,L} = r_3 - r_{4,L} , \qquad (2)$$

where the expressions have the same meaning as above, with only the subscripts changed.

Thus if r_3^a and r_4^a are determined for both the fueled and the moderator runs (performed by BETA) a net R_3 and R_4, due to lattice born neutrons, may be obtained as follows:

$$r_{3,F}^a - r_{3,M}^a = R_3 \text{ , and} \qquad (3)$$

$$r_{4,F}^a - r_{4,M}^a = R_4 , \qquad (4)$$

where the additional subscripts "F" and "M" refer to fueled and moderator runs respectively.

Note that both R_3 and R_4 are functions only of the epithermal and fast leakage flux generated within the lattice core by the fuel. That is, since $r^a_{4,F}$ consists of reflected neutrons due to

(1) leakage neutrons generated by the fuel

(2) source neutrons which leak out and neutrons from the photoneutron reaction in the D_2O moderator, and

(3) neutrons which enter the $1\frac{1}{2}$ foot wide annular ring between the two tanks and any external source which might be present,

while $r^a_{4,M}$ contains only contributions from the latter two sources, then $r^a_{4,F} - r^a_{4,M}$ will leave only the contribution from the reflection of the fuel generated neutrons which leak out. The same considerations would be true for R_3.

Now, using these values of R_3 and R_4, the return coefficient β may be determined utilizing Eq. (11) of Chapter III as before. However, ℓ_1 and ℓ_2 will be replaced by $L_1 = \ell_{1,F} - \ell_{1,M}$ and $L_2 = \ell_{2,F} - \ell_{2,M}$ to be consistent with the above considerations.

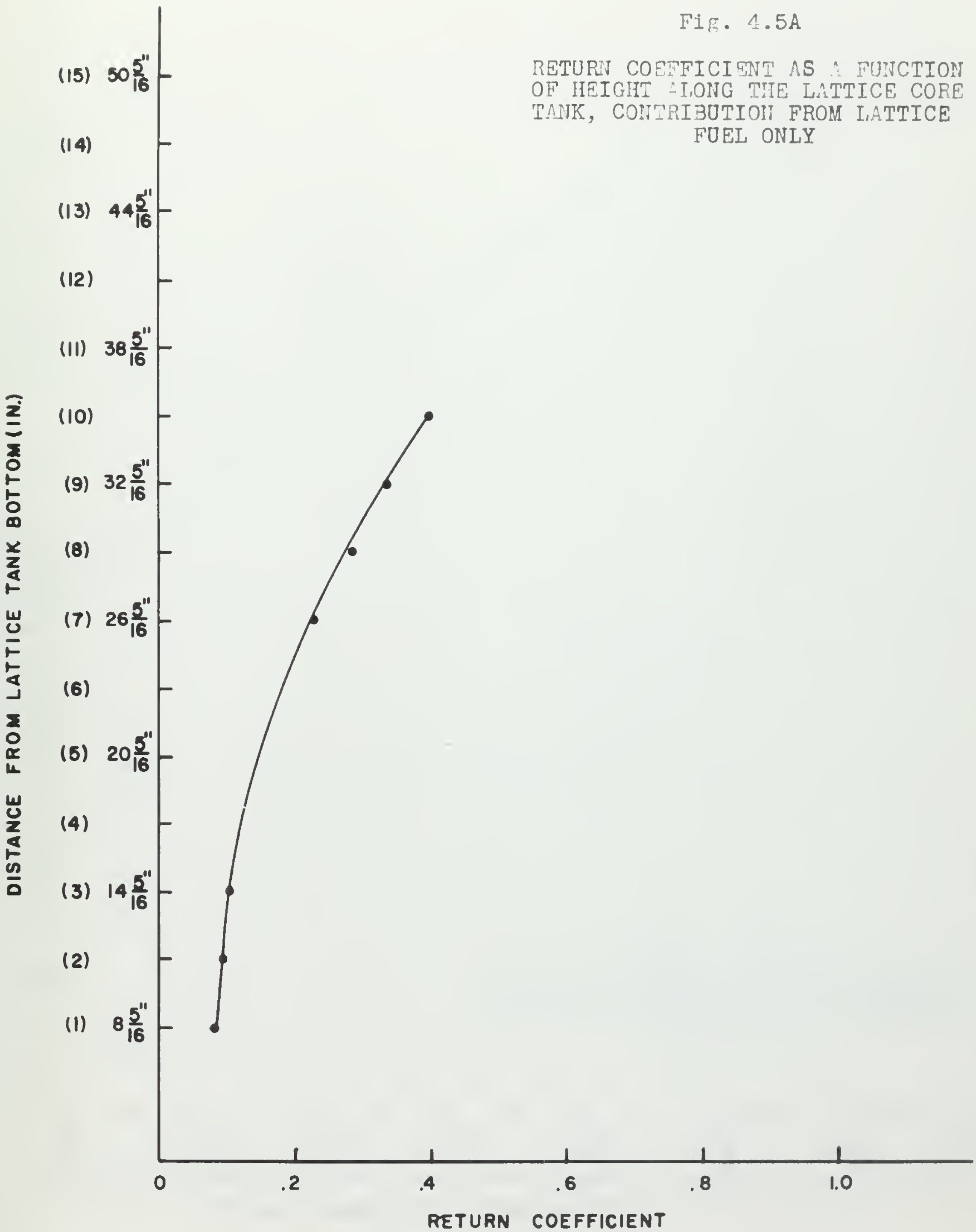
In the new notation then, the defining equation for the return coefficient becomes

$$\beta = \frac{\dfrac{\dfrac{R_4 - R_3}{1 - \dfrac{L_2}{L_1}}}{}}{L_1} .$$

The values of the return coefficient so obtained are plotted in Figs. 4.5A and 4.5B, and one tabulated in TABLE 4.5. Fig. 4.5C shows Figs. 4.3C, 4.4C, and 4.5A combined to illustrate the relative magnitudes of the

Fig. 4.5A

RETURN COEFFICIENT AS A FUNCTION OF HEIGHT ALONG THE LATTICE CORE TANK, CONTRIBUTION FROM LATTICE FUEL ONLY



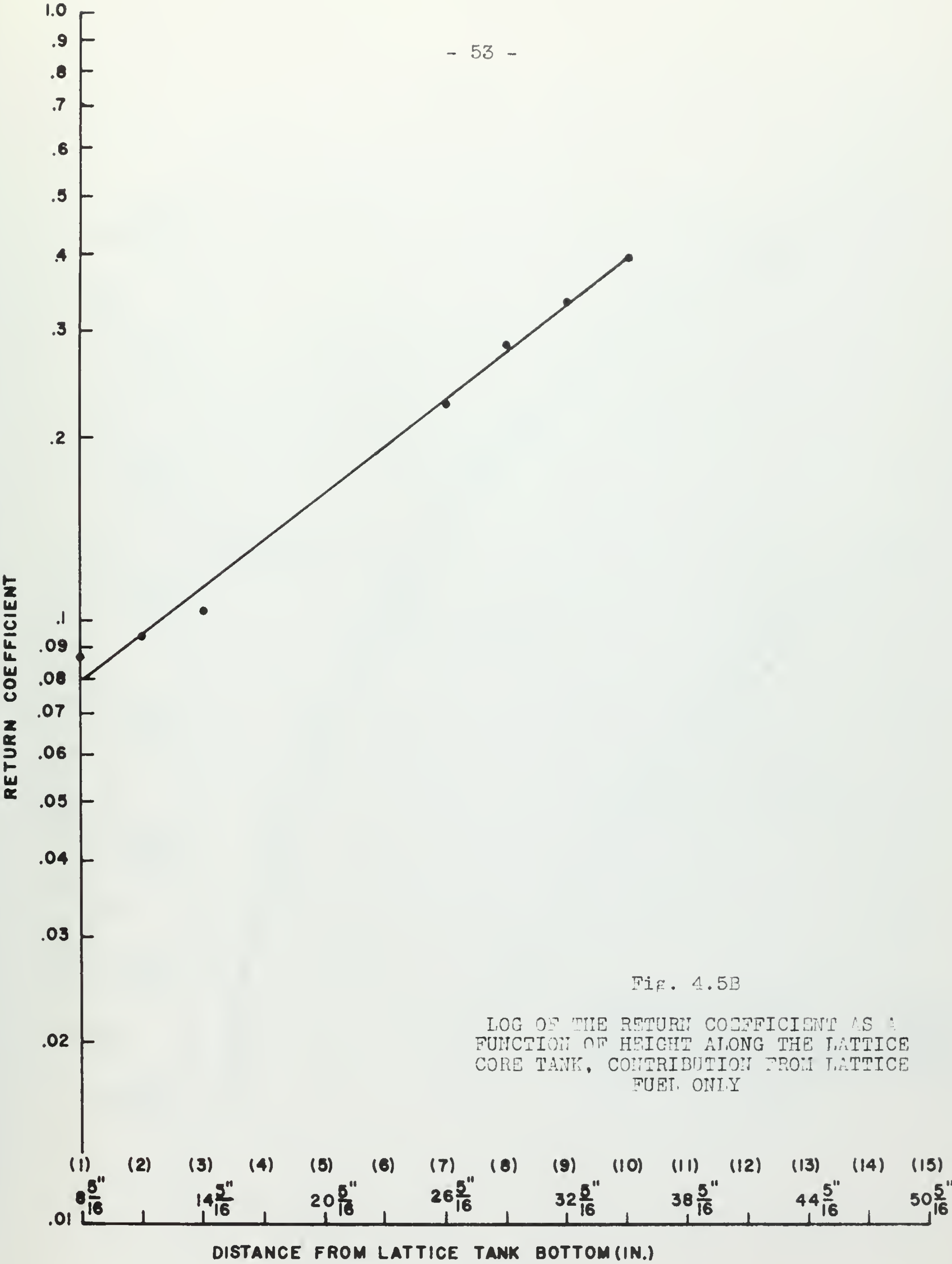


Fig. 4.5B

LOG OF THE RETURN COEFFICIENT AS A FUNCTION OF HEIGHT ALONG THE LATTICE CORE TANK, CONTRIBUTION FROM LATTICE FUEL ONLY

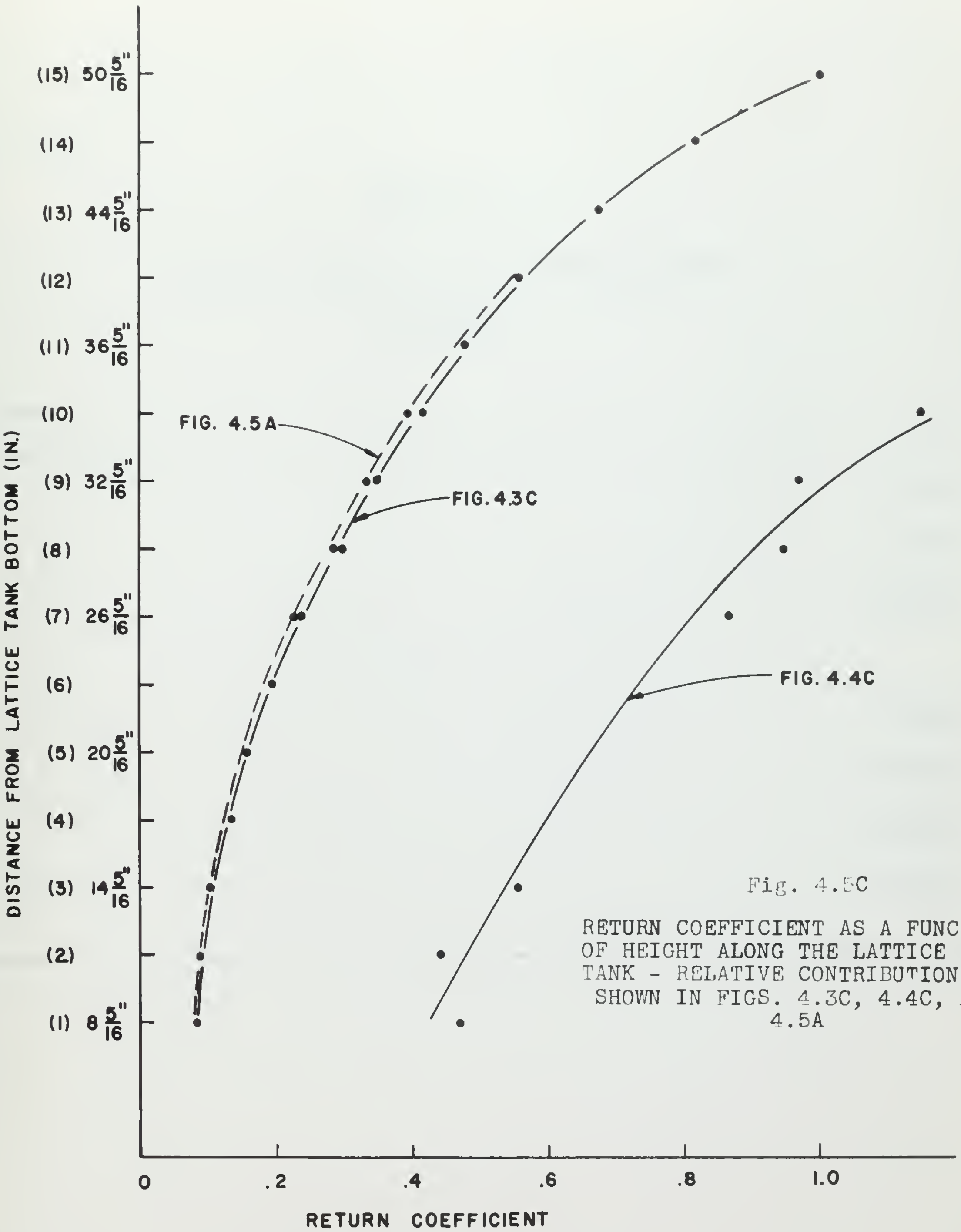


Fig. 4.5C

RETURN COEFFICIENT AS A FUNCTION OF HEIGHT ALONG THE LATTICE CORE TANK - RELATIVE CONTRIBUTIONS AS SHOWN IN FIGS. 4.3C, 4.4C, AND 4.5A

TABLE 4.5

TABULATED VALUES OF $\sqrt{\beta}$ DUE TO THE LATTICE

FUEL ONLY

Location	$\sqrt{\beta}$
1	0.08640
2	0.09390
3	0.10391
7	0.22868
8	0.28320
9	0.33346
10	0.39674

contributions of the various sources of the returning component of neutrons.

4.5.1 Discussion of Results for the Determination of β Due to Lattice Fuel Only

From Fig. 4.5A it is seen that the contributions of sources other than the lattice fuel have little effect on the approximately exponential variation of the return coefficient with vertical distance along the lattice core. The exact magnitude of this effect is seen in Fig. 4.5C. This is due to the relatively small count rates which were obtained for the moderator runs.

CHAPTER V

DETERMINATION OF THE EFFECT ON LATTICE MEASUREMENTS PRODUCED BY THE NEUTRON RETURN PHENOMENON

5.1 Introduction

As mentioned in Section 1.2, the MIT lattice core is treated as a bare cylinder for all experimental measurements performed. In making this assumption, the possible existence of a reflector effect is recognized, but any perturbation this might cause is assumed to be damped out near the core edge. In this paper the magnitude of the reflector effect has been determined, and it now remains to determine the range of validity of the assumption that this effect is damped out near the core edge.

5.2 Procedure

It was decided that the investigation of radial buckling measurements made at various heights within the lattice core would yield the desired information. Since the return coefficient increases with height, a similar increase in the activities of the outer foils in a radial buckling measurement would complement the return coefficient measurements and also allow the range of validity of the assumption that the return effect is damped out near the core edge to be determine. Time did not permit making these radial measurements on the same lattice utilized for the return coefficient measurements, and it was therefore necessary to

look at similar data previously obtained on another lattice. This latter lattice (to be referred to as the reference lattice) had the same characteristics as the lattice utilized for the return coefficient measurements, excepting that the enrichment was 1.03 $^{w}/o$ U^{235} in lieu of 1.143 $^{w}/o$ U^{235} (Section 4.2). In both cases the MITR operated at a power level of (1.95 $\pm$ 0.02)MW. Thus, although the comparison will not be exact, the possible existence of a general trend may be established.

The particular radial buckling measurements investigated consisted of the irradiation of cadmium covered gold foils (99.9 per cent pure), 1/8 inch in diameter and 0.010 inch thick. The distances above the bottom of the lattice tank and the run number involved are given in TABLE 5.2.1. The radial buckling values obtained are included for future reference. For each of the radial bucklings listed in TABLE 5.2.1, twenty points were used in the computation. The measurements were made in a direction parallel to the girders (Fig. 5.2A).

To determine the relative activities at various heights of the outside foils used in the buckling measurements, it is necessary to normalize the activity of the outer most foil to that of the central foil. Since the reference lattice was a rod-centered lattice, there was no central foil; but there were two foils approximately equi-distant from the center (of the foil holder). Consequently, the activity of the outer most foil was normalized to the arithematic average of the two foils equi-distant from the center. The particular outer foil used was that foil located nearest the black plug to the right of the girders (B - end), visable in Fig. 5.2A. This black plug marks the location of the return coefficient measurements. Note that the radial buckling measurements were not made

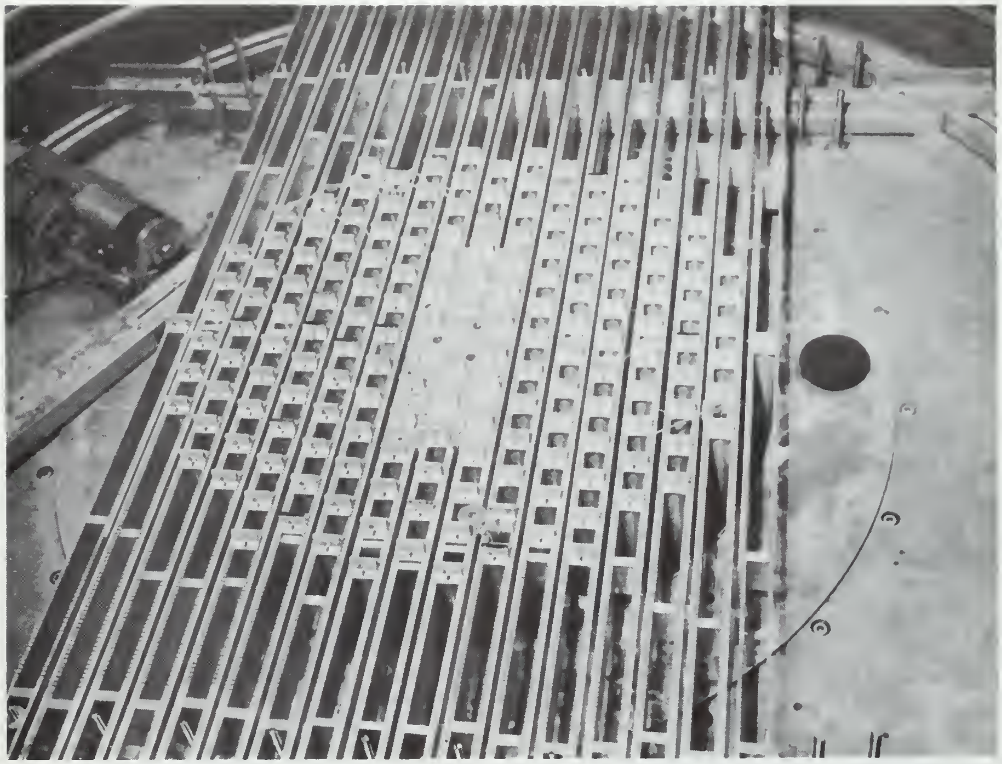


Fig. 5.2A VIEW OF LATTICE TANK WITH CORE INSERTED

TABLE 5.2.1

RADIAL BUCKLING VALUES AT VARIOUS DISTANCES ABOVE THE LATTICE TANK BOTTOM FOR THE REFERENCE LATTICE

Run Number	Distance (in.)	Radial Buckling (μB) (no points dropped)
12	21.795	2374.0
13	21.795	2384.3
17	25.181	2379.4
18	25.181	2387.8
40	28.173	2358.3
45	28.173	2405.8
47	28.173	2393.4

in a direction such that the location of the outer foil corresponded to the location of the return coefficient measurements, but again, the results are being reviewed to look for a general trend.

The results of normalizing the activity of the outer foil to that of the two central foils, and then normalizing these results such that the activity of the outer foil at the lowest vertical distance is taken as one, are given in TABLE 5.2.2.

TABLE 5.2.2

RELATIVE ACTIVITIES OF THE OUTER, CADMIUM COVERED, FOIL AT VARIOUS HEIGHTS IN THE REFERENCE LATTICE

Distance From Tank Bottom (in.)	Distance of Foil From Tank Edge (in.)	Relative Activities Normalized to Lowest Position
21.795	1.30	1.000
25.181	1.30	1.284
28.173	1.30	1.345

The results listed in TABLE 5.2.2 indicate that the activity of the outer foil in a radial buckling measurement definitely increases with an increase in vertical distance from the lattice tank bottom, and this was the trend it was desired to establish.

To determine just how many of the foils in a radial buckling measurement might be affected by this return coefficient, TABLE 5.2.3 is presented.

TABLE 5.2.3

RELATIVE ACTIVITIES OF RADIAL BUCKLING FOILS AS A FUNCTION OF RADIAL AND VERTICAL POSITION

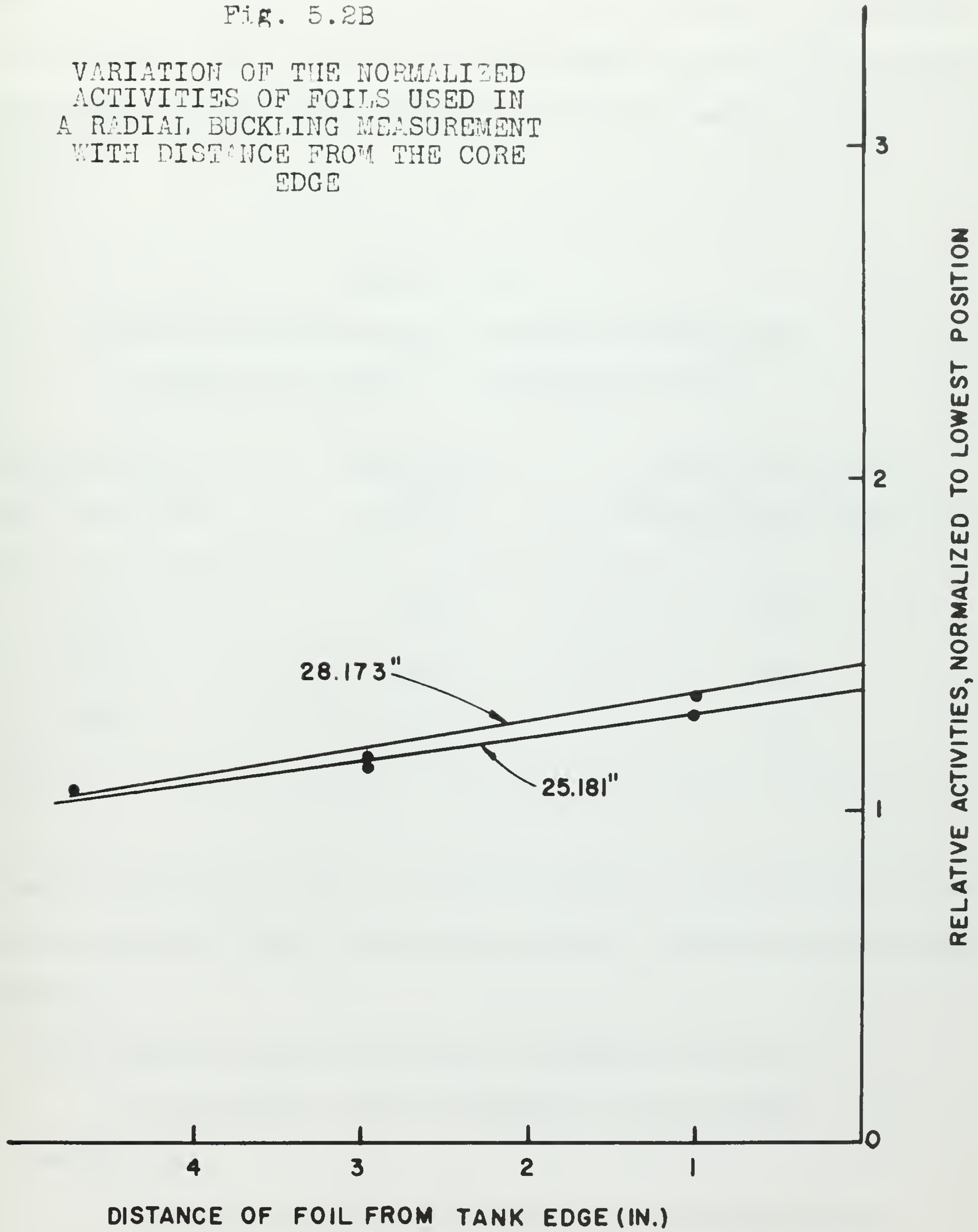
Distance From Tank Bottom (in.)	Distance of Foil From Tank Edge (in.)	Relative Activities Normalized to Lowest Position
21.795	2.95	1.000000
25.181	2.95	1.128880
28.173	2.95	1.134014
21.795	4.80	1.000000
25.181	4.80	1.065686
28.173	4.80	1.079060

From TABLE 5.2.3 it is seen that the magnitude of the return effect decreases quickly with distance away from the core edge, and that only the increase in the activity of the end foil, and to a lesser extent the second foil in from the core edge need be closely observed.

Now, although not strictly correct, it seems of interest to compare the relative increase in activity with the increase in the return coefficient. To do this, Fig. 5.2B was prepared, where distance from core edge, at constant height, is plotted against the normalized activity. The data was then extrapolated to the core edge, and the resulting value of the normalized activity compared with the return coefficient, normalized to one at the lowest position to correspond to the normalization

Fig. 5.2B

VARIATION OF THE NORMALIZED ACTIVITIES OF FOILS USED IN A RADIAL BUCKLING MEASUREMENT WITH DISTANCE FROM THE CORE EDGE



procedure performed for the foil activities. This comparison is made in TABLE 5.2.4. In studying this comparison, the existence of differences in the lattice cores utilized for the two types of measurements, and the differences in the relative directions of the measurements must be held in mind.

TABLE 5.2.4

LISTING OF NORMALIZED FOIL ACTIVITIES AND NORMALIZED RETURN COEFFICIENTS AS A FUNCTION OF HEIGHT

Distance From Tank Bottom (in.)	Normalized Activity	Normalized Epithermal Neutron Return Coefficient
21.795	1.000	1.000
25.181	1.360	1.235
28.173	1.440	1.558

A precise explanation of the variations between the normalized activities and the normalized return coefficients cannot be given for reasons stated previously.

Although it has been definitely established now that:

(1) the neutron return coefficient increases with height, and

(2) the activity of the outer foil in a radial buckling measurement increases with height,

it remains to see exactly what effect there is on the overall results of

measurements made within the lattice core. The measurement of particular interest is the radial buckling, and it can be seen from TABLE 5.2.1 that the determined values of α, as a function of height, do not appear to be systematically affected by the neutron return effect. In this tabulation none of the experimental points have been dropped. It must be remembered, however, that the highest vertical distance at which buckling measurements were made in the reference lattice corresponds to a height approximately midway between positions 7 and 8 used for the return coefficient measurements, where $\beta \simeq 0.27$ (ref. Fig. 4.3A). As the height is increased beyond this point, β increases markedly. Hence, the values of the radial buckling obtained might also change. This is a point which should be further investigated.

CHAPTER VI

SUMMARY AND RECOMMENDATIONS

In general, the purpose of this work has been to determine the return coefficient, as a function of height, for the MIT Lattice Facility. A secondary objective was to determine the extent to which the return effect, if it existed, affected measurements made within the lattice core. Both of these objectives have been accomplished. The return coefficient was determined to increase approximately exponentially with height, reaching a value very close to unity at a height of 50.3 inches above the bottom of the lattice core tank. By investigating the results of radial buckling measurements, it was found that the outer-most foil in this measurement (1.30 inches from core edge) is most strongly affected by the return effect. However, for the radial runs investigated, the effect was not enough to create any systematic variation in the value of α as a function of height. It must be remembered however, that the values of α given in TABLE 5.2.1 were determined without dropping any experimental points. The value of α which is reported is determined by dropping the two end foils. Thus, at the particular heights investigated, the effect of the returning neutrons on the radial buckling measurements is non-consequential. As the height at which such radial measurements are made is increased however, the increase in the activity of the outer-most foils might further reduce the number of valid points.

An additional comment should be made concerning the derivation of the return coefficient equation (Chapter III). In this derivation the assumption was made that the contribution to the observed activities of the left side of foils 1 and 2 of the reflected neutrons is negligibly small (ref. Fig. 2.2.1A). It is intuitive that this assumption would be good for all runs in which the magnitude of the leaving component of neutrons is considerably greater than the magnitude of the returning component of neutrons. However, when these two components are of similar magnitude (e.g., at detector positions 14 and 15, where it is to be recalled that the magnitude of the components is much smaller), the worth of this assumption is somewhat hidden. It is felt that a reasonable amount of validity still exists since the number of returning neutrons which penetrate the inch thick block of indium will be considerably less than the total number which initially strike foil number 4. However, the definition of "a reasonable amount of validity" cannot be made precisely. It would therefore seem advisable that an experimental verification of this assumption, for which time was not available during the course of this work, be performed before the return coefficients, as determined at detector positions 14 and 15, be applied in other experimental work.

APPENDIX A

DESCRIPTION OF THE COUNTING EQUIPMENT AND THE COUNTING PROCEDURE

The activities of the irradiated foils were obtained by counting the gamma rays emitted in the decay of In^{116}, the specific nuclear reaction being In^{115} (n,γ) In^{116*}. The particular excited level of In^{116} observed had a half life of 54.12 minutes. The pulse height analyzer was calibrated to pass signals from gamma rays of energies between 0.84 to 2.34 Mev. The dead time of the counting set up was determined by the two-source method utilizing two Co^{60} foils and was found to be 0.148 x 10^{-6} minutes.

A Harshaw NaI (Tl) well-type scintillator with the following characteristics was utilized:

Crystal diameter - 1 3/4 inches

Crystal height - 2 inches

Well inside diameter - 21/32 inches

Well depth - 1 35/64 inches

In conjunction with the Harshaw scintillator, Hamner electronic equipment was used as follows:

Amplifier - Model N-380

Pulse height analyzer - Model N-685

Scaler - Model N-251

Mechanical timer - Model N-821

The high voltage supply used was a product of Cosmic Radiation Labs., Inc. The Model was Spectrostrat 1001 B.

Each side of each of the four foils irradiated was counted for a 3 minute period. Background counts with a minimum duration of 30 minutes were taken upon completion of counting the foils for each run.

It is to be noted that it was not necessary to recalibrate the counting equipment before each day's runs. Since only activity ratios were utilized, any change in efficiency due to possible gain shifts cancelled for any one run.

APPENDIX B

DESCRIPTION OF THE COMPUTER CODES ACTCOR AND BETA

B.1 ACTCOR

ACTCOR performs the task of correcting the observed foil activities to the saturated activities and then normalizes this quantity as to foil weight. To carry out this function, ACTCOR solves the following equation:

$$ACT = \frac{\dfrac{\left(\dfrac{\frac{N}{T_4}}{1 - \frac{N}{T_4} \cdot \tau} - \text{bkgnd.}\right) e^{\lambda(T_2 + T_3)}}{(1 - e^{-\lambda T_1})(1 - e^{-\lambda T_4})}}{\text{Weight}} \qquad (1)$$

where N = Total observed count rate

T_1 = Waiting time, or time from end of run until start of first count

T_3 = Clock time, or time from start of first count until start of count for particular foil whose decay process is being observed

T_4 = Duration of the counting period (3 minutes for each side of each foil)

λ = Decay constant for the decay of In^{116} (λ = 0.69315/ half period)

τ = Dead time of the counting set up (τ = 0.148×10^{-6} minutes)

bkgnd. = Background, in counts/minute

Weight = Foil weight

The multiplicative factor λT_4 was omitted from the numerator of Eq. (1) since this is a constant for all runs.

To determine the standard deviation of the corrected activity, two assumptions were made:

(1) that the background is small compared to the total number of counts recorded and

(2) that the counter dead time is acceptably small such that little or no correction is introduced into the ACT term.

Both of these assumptions were valid throughout the course of this experiment. After making these two assumptions, it was possible to determine the standard deviation (S.D.) as

$$S.D. = \frac{\sqrt{N}}{N} \cdot ACT$$

where N is as defined above and ACT is given by Eq. (1).

A copy of the computer program ACTCOR is presented following this section.

```
C         ACTCOR  BY  DAVID M. GOEBEL
C         THIS PROGRAM YIELDS A FOIL ACTIVITY WHICH IS CORRECTED FOR
C         IRRADIATION TIME,  DELAY TIME BEFORE COUNTING, LENGTH OF COUNT,
C         COUNTER DEAD TIME, AND WHICH IS NORMALIZED AS TO FOIL WEIGHT
C         ALL TIMES ARE IN MINUTES
C         FOIL WEIGHTS ARE IN GRAMS
C         BACKGROUND IS IN COUNTS/MIN
C
C         IDENTIFICATION OF SYMBOLS
C
C         RTIME = IRRADIATION TIME
C         WTIME = WAITING TIME, TIME FROM END OF RUN UNTIL START OF FIRST COUNT
C         RCOR = RADIATION CORRECTION
C         TAU = HALF LIFE OF INDIUM 116M
C         DCOR = DELAY CORRECTION
C         BKGND = BACKGROUND
C         CTIME = CLOCK TIME
C         DTIME = DURATION OF COUNT
C         COUNTS = NUMBER OF COUNTS
C         DTAU = COUNTER DEAD TIME
C         COR = CORRECTIONS
C         UACT = UNCORRECTED ACTIVITY
C         ACT = CORRECTED ACTIVITY
C         WEIGHT = FOIL WEIGHT
C
  999 READ 600
  600 FORMAT (72H1
     1                         )
      PRINT 600
      READ 100, SW, RTIME, WTIME, TAU, DTAU
  100 FORMAT (4(F10.5), F11.10)
      READ 101, NFOILS
  101 FORMAT (I3)
      RCOR = (1.0-EXPF(-0.69315*RTIME/TAU))
      DCOR = EXPF(0.69315/TAU*WTIME)
      READ 102, BKGND
  102 FORMAT (F10.5)
      PRINT 300, RTIME
  300 FORMAT (22H IRRADIATION TIME WAS    ,F10.3,  5H MIN.)
      PRINT 301, WTIME
  301 FORMAT (18H WAITING TIME WAS    ,F10.3,  5H MIN.)
      PRINT 302, TAU
  302 FORMAT (9H HALFLIFE    , F10.3,  5H MIN.)
      PRINT 303, DTAU
  303 FORMAT (18H COUNTER DEADTIME    , E10.5,  5H MIN.)
      PRINT 304, BKGND
  304 FORMAT (15H BACKGROUND IS    , F10.3, 13H COUNTS/MIN , ///)
      PRINT 160
  160 FORMAT (70H  CTIME            DTIME            WEIGHT        COUNTS
     1      FOILNO      )
      DO 200  I=1, NFOILS
      READ 105, CTIME, DTIME, WEIGHT, COUNTS, FOILNO
      COR = EXPF(0.69315/TAU*CTIME)/(1.0 - EXPF(-0.69315/TAU*DTIME))
      UACT = (COUNTS/DTIME)/(1.0 - COUNTS*DTAU/DTIME) - BKGND
      ACT = UACT*COR*DCOR/RCOR/WEIGHT
```

```
      SDCNT = SQRTF(COUNTS)
      SDMLT = SDCNT/COUNTS
      SD = SDMLT*ACT
      PRINT 104, CTIME, DTIME, WEIGHT, COUNTS, FOILNO
      PRINT 103, ACT
  103 FORMAT (23H FLUX PROPORTIONAL TO     , E15.9, /)
      PRINT 107, SD
  107 FORMAT (25H STANDARD DEVIATION IS     , E15.9, ///)
  200 CONTINUE
  104 FORMAT (2(F10.5,5X), F10.6,5X, F10.2,5X, F10.5)
  105 FORMAT (2F10.5, F10.6, F10.1, F10.5)
      IF (SW) 999, 500, 999
  500 CALL EXIT
      END
                                                             69

                                                   TOTAL     69*
```

B.2 BETA

BETA, using the output of ACTCOR as input data, performs the task of solving Eq. (11) of Chapter III for the fueled and moderator runs, thereby producing the values of β shown plotted in Chapter IV. The standard deviation in β was determined in the usual manner (E1), assuming a Poisson distribution.

A copy of the computer program BETA is presented following this section.

```
C     BETA, RETURN COEFFICIENT FOR THE MIT LATTICE BY DAVID M. GOEBEL
C     THIS PROGRAM COMPUTES THE REFLECTION QUANTITY FOR EPI-THERMAL
C         AND FAST NEUTRONS
C     TO TRANSFER FROM ACTCOR TO BETA, THE FOLLOWING APPLIES
C             01 = R1
C             91 = Y1
C             02 = R2
C             92 = Y2
C             03 = R3
C             93 = Y3
C             04 = R4
C             94 = Y4
C     0( ) IMPLIES THE RIGHT SIDE OF FOIL NUMBER ( )
C     9( ) IMPLIES THE LEFT SIDE OF FOIL NUMBER ( )
      READ 500, NRUNS
  500 FORMAT (I3)
      DO 600 I=1, NRUNS
      READ 111
  111 FORMAT (42H1                                        )
      PRINT 111
      READ 501, R3, R3SD
      READ 501, R4, R4SD
      READ 501, Y1, Y1SD
      READ 501, Y2, Y2SD
  501 FORMAT (2F15.1)
      BETA = ((R4-R3)/(1.0 - (Y2/Y1)))/Y1
      A = R3SD*R3SD
      B = R4SD*R4SD
      TOPSD = SQRTF(A+B)
      D = (Y1SD/Y1)*(Y1SD/Y1)
      E = (Y2SD/Y2)*(Y2SD/Y2)
      F = SQRTF(D+E)
      BODSD = (Y2/Y1)*F
      G = (TOPSD/(R4-R3))*(TOPSD/(R4-R3))
      H = (BODSD/(1.0-(Y2/Y1)))*(BODSD/(1.0-(Y2/Y1)))
      R = SQRTF(G+H)
      R4ASD = (Y1*BETA)*R
      P = (R4ASD/(Y1*BETA))*(R4ASD/(Y1*BETA))
      Q = (Y1SD/Y1)*(Y1SD/Y1)
      S = SQRTF(P+Q)
      BETAD = BETA*S
      R4A = BETA*Y1
      R4L = R4-R4A
C         R3L = R4L, R3LSD = R4LSD
      R3A = R3 - R4L
      BB = R4ASD*R4ASD
      R4LSD = SQRTF(B + BB)
      AA = R4LSD*R4LSD
      R3ASD = SQRTF(A + AA)
      PRINT 502, BETA
  502 FORMAT (13H ALBEDO IS    , F10.5, /)
      PRINT 503, BETAD
  503 FORMAT (27H THE S.D. OF THE ALBEDO IS   , F10.8, /////)
      PRINT 504, R4A
  504 FORMAT (10H R4A IS   , E15.9, /)
```

2

```
      PRINT 505, R4ASD
  505 FORMAT (10H R4ASD IS , E15.9, /)
      PRINT 506, R3A
  506 FORMAT (10H R3A IS   , E15.9, /)
      PRINT 507, R3ASD
  507 FORMAT (10H R3ASD IS , E15.9, /////)
  600 CONTINUE
      CALL EXIT
      END
```

64

TOTAL 64*

APPENDIX C

TABULATION OF FOIL ACTIVITIES

In the computer print out contained in this Appendix, certain alphabetical letters have been placed adjacent to the run location numbers. These letters have the following meanings:

M = Moderator run

P = Pipe side - i.e. several runs were made at a location 180° from the location of the runs reported (pipe side implies that the overflow lines were located here)

(blank) = fueled core runs

It should also be noted that data from several of the 61 runs performed were not utilized. A list of these runs is given below, included in which is a short explanation as to why the data was not considered of value.

Runs 1 to 6: These were preliminary runs made for orientation purposes. They served to polish the experimental procedures and establish irradiation times.

Run 7: Lattice scrammed after start of the run.

Runs 8 and 9: During the course of counting the foils for these runs, the scaler was noted to throw in spurious counts. The scaler module was subsequently replaced.

Run 19: This was one of three runs made at location number 6. The data for this run was invalidated as it proved to be inconsistent with the results for the other two runs (21 and 47).

RUN NUMBER IS 8
LOCATION NUMBER IS 2.1

ACTIVITY	S.D.	FOILNO
.3805784760E 08	.6264447710E 05	4
.3800634740E 08	.6418947130E 05	94
.1883060090E 08	.4615856330E 05	3
.1875254620E 08	.4723533160E 05	93
.1316041980E 09	.1311459850E 06	92
.1325074760E 09	.1348597830E 06	2
.2971383920E 09	.2127965700E 06	91
.3004601780E 09	.2191163220E 06	1

RUN NUMBER IS 9
LOCATION NUMBER IS 1.1

ACTIVITY	S.D.	FOILNO
.3912661960E 08	.6711522040E 05	4
.3909872320E 08	.6879485100E 05	94
.1949940730E 08	.4953285860E 05	3
.1953548540E 08	.5084315310E 05	93
.1407199890E 09	.1432565240E 06	92
.1409986720E 09	.1469452230E 06	2
.3192197790E 09	.2333683660E 06	91
.3223736910E 09	.2401490450E 06	1

RUN NUMBER IS 10
LOCATION NUMBER IS 1.2

ACTIVITY	S.D.	FOILNO
.4208960530E 08	.1276567360E 06	4
.4225345580E 08	.1332227340E 06	94
.2352581090E 08	.1047912490E 06	3
.2355768510E 08	.1075032350E 06	93
.1629458510E 09	.2952935320E 06	92
.1635732290E 09	.3034007170E 06	2
.3953609160E 09	.4885890260E 06	91
.3944766480E 09	.5002573650E 06	1

RUN NUMBER IS 11
LOCATION NUMBER IS 2.2

ACTIVITY	S.D.	FOILNO
.3731182770E 08	.8145075810E 05	4
.3727751970E 08	.8348791820E 05	94
.1806470780E 08	.5906717330E 05	3
.1800408410E 08	.6046338750E 05	93
.1336142770E 09	.1721357590E 06	92
.1341852320E 09	.1768481710E 06	2
.3229560920E 09	.2865015750E 06	91
.3239183680E 09	.2959879670E 06	1

RUN NUMBER IS 12
LOCATION NUMBER IS 1.3

ACTIVITY	S.D.	FOILNO
.3957119880E 08	.9293598230E 05	4
.3969390390E 08	.9545582750E 05	94
.1942623250E 08	.6769215160E 05	3
.1945509740E 08	.6946123010E 05	93
.1432330900E 09	.1984866140E 06	92
.1432700510E 09	.2035182450E 06	2
.3455043730E 09	.3275620490E 06	91
.3464198740E 09	.3360576620E 06	1

RUN NUMBER IS 13
LOCATION NUMBER IS 2.3

ACTIVITY	S.D.	FOILNO
.4291662120E 08	.1330723930E 06	4
.4316765060E 08	.1368960580E 06	94
.2192424420E 08	.9981147340E 05	3
.2215679930E 08	.1029202640E 06	93
.1537520620E 09	.2806989430E 06	92
.1537674510E 09	.2878803380E 06	2
.3828985240E 09	.4720811060E 06	91
.3842143230E 09	.4847868710E 06	1

RUN NUMBER IS 14
LOCATION NUMBER IS 3.1

ACTIVITY	S.D.	FOILNO
.4259222370E 08	.1353273350E 06	4
.4227715090E 08	.1382891680E 06	94
.2065112960E 08	.9878159800E 05	3
.2072822840E 08	.1017128890E 06	93
.1358198950E 09	.2693847750E 06	92
.1359460050E 09	.2764072380E 06	2
.3399653320E 09	.4555604640E 06	91
.3395566530E 09	.4667636080E 06	1

RUN NUMBER IS 15
LOCATION NUMBER IS 4.1

ACTIVITY	S.D.	FOILNO
.5309770250E 08	.1532575130E 06	4
.5312264040E 08	.1572364040E 06	94
.2389765490E 08	.1051119310E 06	3
.2416932020E 08	.1084305790E 06	93
.1427343410E 09	.2728049190E 06	92
.1427833640E 09	.2798286300E 06	2
.3609762710E 09	.4674376320E 06	91
.3596594180E 09	.4783068740E 06	1

RUN NUMBER IS 16
LOCATION NUMBER IS 3.2

ACTIVITY	S.D.	FOILNO
.5589557140E 08	.1702014650E 06	4
.5552361680E 08	.1739928250E 06	94
.2597303240E 08	.1216992790E 06	3
.2616539330E 08	.1252908290E 06	93
.1827242090E 09	.3417220970E 06	92
.1806524580E 09	.3484325660E 06	2
.4661749300E 09	.5795058600E 06	91
.4640551430E 09	.5926659100E 06	1

RUN NUMBER IS 17
LOCATION NUMBER IS 4.2

ACTIVITY	S.D.	FOILNO
.5246289740E 08	.1493524270E 06	4
.5243675550E 08	.1531550230E 06	94
.2367241410E 08	.1058376800E 06	3
.2389199710E 08	.1090651810E 06	93
.1413386870E 09	.2731214160E 06	92
.1402539900E 09	.2790147810E 06	2
.3616582150E 09	.4626291020E 06	91
.3589005500E 09	.4724044350E 06	1

RUN NUMBER IS 18
LOCATION NUMBER IS 5.1

ACTIVITY	S.D.	FOILNO
.5023703790E 08	.1292367540E 06	4
.4977779940E 08	.1319437990E 06	94
.2221231530E 08	.8972420990E 05	3
.2206399640E 08	.9172018840E 05	93
.1134171850E 09	.2148580710E 06	92
.1135896040E 09	.2205195200E 06	2
.2927246200E 09	.3666415140E 06	91
.2910254440E 09	.3747279900E 06	1

RUN NUMBER IS 19
LOCATION NUMBER IS 6.1

ACTIVITY	S.D.	FOILNO
.4852767060E 08	.1192077800E 06	4
.4813245980E 08	.1217657820E 06	94
.2110057800E 08	.8266033230E 05	3
.2090649560E 08	.8439305640E 05	93
.9041001340E 08	.1806203700E 06	92
.7176945130E 08	.1470762640E 06	2
.2097522090E 09	.2916117900E 06	91
.2311119670E 09	.3142336560E 06	1

RUN NUMBER IS 20
LOCATION NUMBER IS 5.2

ACTIVITY	S.D.	FOILNO
.5104348510E 08	.1432123030E 06	4
.5070244890E 08	.1463989140E 06	94
.2265032540E 08	.1000983080E 06	3
.2276769980E 08	.1029391000E 06	93
.1166654970E 09	.2411602560E 06	92
.1170486180E 09	.2477476030E 06	2
.2966441810E 09	.4078439660E 06	91
.2963356410E 09	.4179233310E 06	1

RUN NUMBER IS 21
LOCATION NUMBER IS 6.2

ACTIVITY	S.D.	FOILNO
.2267022540E 08	.7532342890E 05	4
.2251903410E 08	.7700176460E 05	94
.9772648060E 07	.5150065490E 05	3
.9758772320E 07	.5278406060E 05	93
.4184634080E 08	.1125809080E 06	92
.4220904670E 08	.1159790540E 06	2
.1073394810E 09	.1909532020E 06	91
.1072925210E 09	.1957827500E 06	1

RUN NUMBER IS 22
LOCATION NUMBER IS 7.1

ACTIVITY	S.D.	FOILNO
.2050213140E 08	.7359646480E 05	4
.2029971660E 08	.7511410340E 05	94
.8587491060E 07	.4927858180E 05	3
.8649378190E 07	.5072534680E 05	93
.3185651740E 08	.1019681370E 06	92
.3182162340E 08	.1045345310E 06	2
.8115855080E 08	.1720248570E 06	91
.8090585990E 08	.1761551530E 06	1

RUN NUMBER IS 23
LOCATION NUMBER IS 8.1

ACTIVITY	S.D.	FOILNO
.1962287480E 08	.8289218090E 05	4
.1962932680E 08	.8503841230E 05	94
.8310020710E 07	.5652682930E 05	3
.8250486100E 07	.5775787830E 05	93
.2522591420E 08	.1037857420E 06	92
.2510322890E 08	.1061943420E 06	2
.6445665350E 08	.1750570250E 06	91
.6369457310E 08	.1784841040E 06	1

RUN NUMBER IS 24
LOCATION NUMBER IS 7.2

ACTIVITY	S.D.	FOILNO
.2058481290E 08	.7261510190E 05	4
.2062083220E 08	.7454746730E 05	94
.8784484930E 07	.4975149140E 05	3
.8752247690E 07	.5092735360E 05	93
.3255205970E 08	.1015938140E 06	92
.3259374530E 08	.1042728920E 06	2
.8284770540E 08	.1713434530E 06	91
.8293990930E 08	.1758294880E 06	1

RUN NUMBER IS 25
LOCATION NUMBER IS 8.2

ACTIVITY	S.D.	FOILNO
.2014427110E 08	.7099172990E 05	4
.2031166080E 08	.7312221220E 05	94
.8364429540E 07	.4788673400E 05	3
.8453057550E 07	.4937486420E 05	93
.2546809500E 08	.8855321330E 05	92
.2547377190E 08	.9084113460E 05	2
.6473548330E 08	.1492179400E 06	91
.6451128340E 08	.1527781410E 06	1

RUN NUMBER IS 26
LOCATION NUMBER IS 9.1

ACTIVITY	S.D.	FOILNO
.1942209990E 08	.7104177770E 05	4
.1926705480E 08	.7257525020E 05	94
.8025242230E 07	.4808466130E 05	3
.8125626290E 07	.4962590410E 05	93
.2152694940E 08	.8271096640E 05	92
.2152098240E 08	.8482628680E 05	2
.5501112260E 08	.1397793490E 06	91
.5500819230E 08	.1433662450E 06	1

RUN NUMBER IS 27
LOCATION NUMBER IS 10.1

ACTIVITY	S.D.	FOILNO
.1950125200E 08	.9430252760E 05	4
.1931869660E 08	.9626673010E 05	94
.7998026680E 07	.6390655040E 05	3
.8097699730E 07	.6594401520E 05	93
.1836983240E 08	.1029320140E 06	92
.1806219590E 08	.1046718920E 06	2
.4623228680E 08	.1708631080E 06	91
.4579139570E 08	.1744158860E 06	1

RUN NUMBER IS 28
LOCATION NUMBER IS 9.2

ACTIVITY	S.D.	FOILNO
.2004316050E 08	.8698482210E 05	4
.1984004800E 08	.8876379280E 05	94
.8184683620E 07	.5831937640E 05	3
.8328526540E 07	.6033738470E 05	93
.2193268910E 08	.1003440270E 06	92
.2195407630E 08	.1029732300E 06	2
.5579060240E 08	.1690515610E 06	91
.5535467190E 08	.1727162170E 06	1

RUN NUMBER IS 29
LOCATION NUMBER IS 10.2

ACTIVITY	S.D.	FOILNO
.1914692390E 08	.7799623310E 05	4
.1888533160E 08	.7944907690E 05	94
.7815862370E 07	.5214052050E 05	3
.7837847620E 07	.5354715360E 05	93
.1755492070E 08	.8259150160E 05	92
.1744573710E 08	.8444660600E 05	2
.4519462920E 08	.1401419210E 06	91
.4481788240E 08	.1431421040E 06	1

RUN NUMBER IS 30
LOCATION NUMBER IS 12.1

ACTIVITY	S.D.	FOILNO
.2837689510E 08	.1057779500E 06	4
.2847514590E 08	.1086893040E 06	94
.1172224100E 08	.7133532380E 05	3
.1172117380E 08	.7315738420E 05	93
.1898994870E 08	.9647401420E 05	92
.1910738680E 08	.9925948750E 05	2
.4906876530E 08	.1624081390E 06	91
.4889956410E 08	.1662981130E 06	1

RUN NUMBER IS 31
LOCATION NUMBER IS 11.1

ACTIVITY	S.D.	FOILNO
.3097817300E 08	.1069351480E 06	4
.3127425980E 08	.1102142760E 06	94
.1259078190E 08	.7119119310E 05	3
.1272815570E 08	.7341754950E 05	93
.2462738710E 08	.1054234850E 06	92
.2475095310E 08	.1084078070E 06	2
.6348196040E 08	.1787224690E 06	91
.6342227830E 08	.1832317520E 06	1

RUN NUMBER IS 32
LOCATION NUMBER IS 12.2

ACTIVITY	S.D.	FOILNO
.2863959700E 08	.8225016370E 05	4
.2847227490E 08	.8411646630E 05	94
.1164481960E 08	.5512128320E 05	3
.1163095980E 08	.5650292630E 05	93
.1915084440E 08	.7456094320E 05	92
.1931359710E 08	.7680592160E 05	2
.4937283540E 08	.1259171060E 06	91
.4904330520E 08	.1287163770E 06	1

RUN NUMBER IS 33
LOCATION NUMBER IS 11.2

ACTIVITY	S.D.	FOILNO
.2919819090E 08	.8796750900E 05	4
.2899550190E 08	.8991425930E 05	94
.1200304130E 08	.5921600160E 05	3
.1185843950E 08	.6036568800E 05	93
.2302729540E 08	.8627965670E 05	92
.2282801770E 08	.8811279750E 05	2
.5877321360E 08	.1451491340E 06	91
.5850158920E 08	.1485295140E 06	1

RUN NUMBER IS 34
LOCATION NUMBER IS 14.1

ACTIVITY	S.D.	FOILNO
.2708541040E 08	.7966124930E 05	4
.2706148920E 08	.8167405940E 05	94
.1079855490E 08	.5246841080E 05	3
.1086091480E 08	.5677944340E 05	93
.1262059150E 08	.5849703550E 05	92
.1256416840E 08	.5986467740E 05	2
.3244711190E 08	.1009267050E 06	91
.3216784370E 08	.1030734760E 06	1

RUN NUMBER IS 35
LOCATION NUMBER IS 13.1

ACTIVITY	S.D.	FOILNO
.2666362000E 08	.7379450420E 05	4
.2658184200E 08	.7557486740E 05	94
.1065572680E 08	.4886765660E 05	3
.1070805240E 08	.5024763270E 05	93
.1532876280E 08	.6190976420E 05	92
.1532595390E 08	.6349649130E 05	2
.3938023960E 08	.1050378760E 06	91
.3940526990E 08	.1077725320E 06	1

RUN NUMBER IS 36
LOCATION NUMBER IS 13.2

ACTIVITY	S.D.	FOILNO
.2887786400E 08	.9833387060E 05	4
.2873186430E 08	.1006075380E 06	94
.1166700400E 08	.6540474510E 05	3
.1162870900E 08	.6697005250E 05	93
.1658420090E 08	.8670359030E 05	92
.1649413030E 08	.8868452900E 05	2
.4197801460E 08	.1456069770E 06	91
.4207757180E 08	.1495331320E 06	1

RUN NUMBER IS 37
LOCATION NUMBER IS 14.2

ACTIVITY	S.D.	FOILNO
.2683979230E 08	.7786718530E 05	4
.2692550830E 08	.7999879640E 05	94
.1087551190E 08	.5188235490E 05	3
.1091233450E 08	.5330642610E 05	93
.1276283110E 08	.5888934730E 05	92
.1275438440E 08	.6038292940E 05	2
.3251096860E 08	.1003611390E 06	91
.3263521860E 08	.1031418170E 06	1

RUN NUMBER IS 38
LOCATION NUMBER IS 15.1

ACTIVITY	S.D.	FOILNO
.2563710540E 08	.9343735270E 05	4
.2554951230E 08	.9567696520E 05	)4
.1011969560E 08	.6148411850E 05	3
.1019147660E 08	.6328400890E 05	)3
.9726241970E 07	.6326688450E 05	)2
.9624254100E 07	.6453710040E 05	2
.2482934310E 08	.1069803050E 06	)1
.2510352020E 08	.1103411440E 06	1

RUN NUMBER IS 39
LOCATION NUMBER IS 15.2

ACTIVITY	S.D.	FOILNO
.2526972740E 08	.7228128380E 05	4
.2521817190E 08	.7406417500E 05	)4
.1019302220E 08	.4840993580E 05	3
.1007249010E 08	.4935657150E 05	)3
.9763352720E 07	.4984417250E 05	)2
.9732156240E 07	.5104121710E 05	2
.2515749740E 08	.8429923870E 05	)1
.2497903680E 08	.8615919940E 05	1

RUN NUMBER IS 40
LOCATION NUMBER IS 10.1 P

ACTIVITY	S.D.	FOILNO
.3634847880E 08	.1028489350E 06	4
.3625080840E 08	.1053508790E 06	)4
.1493189520E 08	.6915731280E 05	3
.1508756290E 08	.7130670840E 05	)3
.2764041830E 08	.9919008910E 05	)2
.2762657990E 08	.1017169000E 06	2
.7112447760E 08	.1654200750E 06	)1
.7134782590E 08	.1699345480E 06	1

RUN NUMBER IS 41
LOCATION NUMBER IS 11.1 P

ACTIVITY	S.D.	FOILNO
.3425044190E 08	.9653720250E 05	4
.3436935020E 08	.9919303870E 05	)4
.1387630380E 08	.6473449460E 05	3
.1394727800E 08	.6656900040E 05	)3
.2522012660E 08	.9162054880E 05	)2
.2506412110E 08	.9368472240E 05	2
.6401606640E 08	.1568503060E 06	)1
.6424451170E 08	.1611682690E 06	1

RUN NUMBER IS 42
LOCATION NUMBER IS 10.2 P

ACTIVITY	S.D.	FOILNO
.3658611210E 08	.1033505980E 06	4
.3639560930E 08	.1057297340E 06	94
.1490452530E 08	.6923954180E 05	3
.1509401180E 08	.7147301800E 05	93
.2871145190E 08	.1018886370E 06	92
.2872616050E 08	.1045375860E 06	2
.7418609630E 08	.1723018360E 06	91
.7449380750E 08	.1770938480E 06	1

RUN NUMBER IS 44
LOCATION NUMBER IS 11.2 P

ACTIVITY	S.D.	FOILNO
.3844058210E 08	.1076636070E 06	4
.3814806110E 08	.1100076020E 06	94
.1441685590E 08	.6641103770E 05	3
.1462508270E 08	.6861247120E 05	93
.2562406390E 08	.9395753070E 05	92
.2564888140E 08	.9642232060E 05	2
.6578139510E 08	.1577282860E 06	91
.6557367290E 08	.1615198360E 06	1

RUN NUMBER IS 45
LOCATION NUMBER IS 9.1 P

ACTIVITY	S.D.	FOILNO
.3531909470E 08	.1000320190E 06	4
.3526162690E 08	.1025207570E 06	94
.1482057960E 08	.6795643120E 05	3
.1482599260E 08	.6971632610E 05	93
.3402422620E 08	.1082159140E 06	92
.3406049230E 08	.1110605890E 06	2
.8862761850E 08	.1850517480E 06	91
.8789516160E 08	.1889973780E 06	1

RUN NUMBER IS 46
LOCATION NUMBER IS 9.2 P

ACTIVITY	S.D.	FOILNO
.3489996670E 08	.1089024550E 06	4
.3457242170E 08	.1111756870E 06	94
.1444503980E 08	.7476452140E 05	3
.1442168150E 08	.7662331980E 05	93
.3231935200E 08	.1190700590E 06	92
.3191163270E 08	.1213563070E 06	2
.8353465270E 08	.2019767200E 06	91
.8369805660E 08	.2073685220E 06	1

RUN NUMBER IS 47
LOCATION NUMBER IS 6.3

ACTIVITY	S.D.	FOILNO
.3591071960E 08	.9861675570E 05	4
.3575877130E 08	.1009361830E 06	94
.1581054870E 08	.6889863750E 05	3
.1559206060E 08	.7017543910E 05	93
.6867181880E 08	.1520039640E 06	92
.6847491560E 08	.1556758760E 06	2
.1733253740E 09	.2552072550E 06	91
.1732924460E 09	.2616498910E 06	1

RUN NUMBER IS 48
LOCATION NUMBER IS 1.1 M

ACTIVITY	S.D.	FOILNO
.1485874910E 07	.1926623110E 05	4
.1509859580E 07	.1989760130E 05	94
.6634537130E 06	.1287592250E 05	3
.1160285490E 07	.1851545570E 05	93
.1811689710E 07	.2427047430E 05	92
.1370457520E 07	.2131733330E 05	2
.3534828750E 07	.3627612470E 05	91
.4018383800E 07	.3975286740E 05	1

RUN NUMBER IS 49
LOCATION NUMBER IS 2.1 M

ACTIVITY	S.D.	FOILNO
.1323642150E 07	.1432996610E 05	4
.1410133270E 07	.1517940550E 05	94
.6220541220E 06	.1007912140E 05	3
.6143249570E 06	.1023590620E 05	93
.1109567110E 07	.1449578790E 05	92
.1095894270E 07	.1474223110E 05	2
.2659486230E 07	.2392634540E 05	91
.2692653680E 07	.2468144120E 05	1

RUN NUMBER IS 50
LOCATION NUMBER IS 1.2 M

ACTIVITY	S.D.	FOILNO
.1732074200E 07	.1907760460E 05	4
.1618896350E 07	.1885627210E 05	94
.7926839880E 06	.1308301640E 05	3
.7738753700E 06	.1319830260E 05	93
.1318317670E 07	.1821186500E 05	92
.1322629370E 07	.1867494780E 05	2
.3330361430E 07	.3128375820E 05	91
.3295837300E 07	.3188740230E 05	1

RUN NUMBER IS 51
LOCATION NUMBER IS 2.2 M

ACTIVITY	S.D.	FOILNO
.1364016550E 07	.1552828620E 05	4
.1354019150E 07	.1585302550E 05	94
.6268436830E 06	.1079002290E 05	3
.6205459080E 06	.1098182330E 05	93
.1104435780E 07	.1693529500E 05	92
.1139461270E 07	.1763483190E 05	2
.2828204660E 07	.2636512140E 05	91
.2856051100E 07	.2716601150E 05	1

RUN NUMBER IS 52
LOCATION NUMBER IS 3.1 M

ACTIVITY	S.D.	FOILNO
.1377605550E 07	.1562537840E 05	4
.1355577800E 07	.1587889470E 05	94
.5713590750E 06	.1019796360E 05	3
.5975468750E 06	.1069609110E 05	93
.9395271310E 06	.1412862660E 05	92
.9070926530E 06	.1419586800E 05	2
.2316414990E 07	.2385016810E 05	91
.2328655960E 07	.2451352570E 05	1

RUN NUMBER IS 53
LOCATION NUMBER IS 8.1 M

ACTIVITY	S.D.	FOILNO
.1054561040E 07	.1237154730E 05	4
.1066968600E 07	.1275544740E 05	94
.4221499590E 06	.7881365560E 04	3
.4272283240E 06	.8115994930E 04	93
.4555990130E 06	.8597736220E 04	92
.4509725120E 06	.8743981790E 04	2
.1081998710E 07	.1447044870E 05	91
.1123951030E 07	.1512513210E 05	1

RUN NUMBER IS 54
LOCATION NUMBER IS 3.2 M

ACTIVITY	S.D.	FOILNO
.1236308710E 07	.1463522850E 05	4
.1262920230E 07	.1516535850E 05	94
.5491468160E 06	.9919121930E 04	3
.5327680110E 06	.9979659160E 04	93
.8968152700E 06	.1357409450E 05	92
.8877334890E 06	.1382366710E 05	2
.2206795920E 07	.2280263800E 05	91
.2188476770E 07	.2327245100E 05	1

RUN NUMBER IS 55
LOCATION NUMBER IS 8.2 M

ACTIVITY	S.D.	FOILNO
.1026397700E 07	.1298613490E 05	4
.1007955340E 07	.1317842020E 05	94
.4253240820E 06	.8445888530E 04	3
.4084676540E 06	.8440423160E 04	93
.4662419480E 06	.9311811320E 04	92
.4546027030E 06	.9385728830E 04	2
.1153211460E 07	.1599831990E 05	91
.1109480690E 07	.1605247960E 05	1

RUN NUMBER IS 56
LOCATION NUMBER IS 7.1 M

ACTIVITY	S.D.	FOILNO
.1082278250E 07	.1379398100E 05	4
.1052639420E 07	.1392180450E 05	94
.4547409150E 06	.8989362260E 04	3
.4399692370E 06	.9062385110E 04	93
.4865424930E 06	.9791748000E 04	92
.4935292000E 06	.1008884610E 05	2
.1250185610E 07	.1727725230E 05	91
.1256604230E 07	.1774093320E 05	1

RUN NUMBER IS 57
LOCATION NUMBER IS 9.1 M

ACTIVITY	S.D.	FOILNO
.9870120730E 06	.1287930580E 05	4
.1012811750E 07	.1337402140E 05	94
.3795563760E 06	.7966422960E 04	3
.3817974030E 06	.8165971930E 04	93
.3955917990E 06	.8505875310E 04	92
.4140573400E 06	.8923566630E 04	2
.1029650160E 07	.1518466470E 05	91
.9846942050E 06	.1517250200E 05	1

RUN NUMBER IS 58
LOCATION NUMBER IS 7.2 M

ACTIVITY	S.D.	FOILNO
.1094473190E 07	.1337012030E 05	4
.1082499430E 07	.1362092530E 05	94
.4395007190E 06	.8557012900E 04	3
.4574184080E 06	.8950082730E 04	93
.4944911110E 06	.9593182420E 04	92
.4637349170E 06	.9462007430E 04	2
.1218242360E 07	.1638067770E 05	91
.1173040460E 07	.1644682670E 05	1

RUN NUMBER IS 59
LOCATION NUMBER IS 9.2 M

ACTIVITY	S.D.	FOILNO
.1032143250E 07	.1373994360E 05	4
.1081885990E 07	.1443027810E 05	94
.4223453400E 06	.8829572870E 04	3
.4164390300E 06	.8997910840E 04	93
.3881681150E 06	.8812903010E 04	92
.4060106240E 06	.9241846270E 04	2
.1013727810E 07	.1583756370E 05	91
.1008136950E 07	.1616384680E 05	1

RUN NUMBER IS 60
LOCATION NUMBER IS 10.1 M

ACTIVITY	S.D.	FOILNO
.1024859930E 07	.1329082860E 05	4
.9432592910E 06	.1303187440E 05	94
.3824669150E 06	.8128399990E 04	3
.3694981150E 06	.8144970980E 04	93
.3868556910E 06	.8558838060E 04	92
.3980001800E 06	.8890668300E 04	2
.9569398830E 06	.1480295670E 05	91
.9623980590E 06	.1520355170E 05	1

RUN NUMBER IS 61
LOCATION NUMBER IS 10.2 M

ACTIVITY	S.D.	FOILNO
.9797198390E 06	.1226471690E 05	4
.9528883540E 06	.1238039470E 05	94
.3744966050E 06	.7583016150E 04	3
.3894348810E 06	.7926221560E 04	93
.3846885990E 06	.8059960300E 04	92
.3617728500E 06	.7943860210E 04	2
.8972249320E 06	.1349706460E 05	91
.9534705720E 06	.1428029760E 05	1

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Thesis
G524 Goebel 79465
Return coefficient measurements for the MIT enriched uranium-D_2O lattice.