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THE SLOWING DOWN DISTRIBUTION FROM A POINT SOURCE
OF FISSION NEUTRONS IN LIGHT WATER

BY
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THE SLOWING DOWN DISTRIBUTION FROM A POINT SOURCE
OF FISSION NEUTRONS IN LIGHT WATER

INTRODUCTION

Because of the effectiveness of water in slowing down neutrons, and because it is good as a heat transfer fluid, it is probable that this medium will be of increasing importance in reactor design. Previous measurements of the age of fission neutrons from a point source in water have been made by Fermi, Anderson and Nagle, CP-1531 (A2209). In this earlier work, the neutron distribution was measured only to a distance of ~30 cm. from a point source. In this earlier work, the neutron sources were rather large, making geometry corrections somewhat uncertain; and the water tank used was perhaps smaller than the optimum size. In the measurements reported here, the indium resonance neutron distribution has been measured out to 92.20 cm. from a point fission source. At the expense of using a rather large number of neutron source sizes, the geometry corrections were kept small. The water tank which we used held a five foot cube of water, which is certainly equivalent to an infinite body of water in this experiment.

In some measurements of the neutron slowing down distribution in graphite we found that indium foils were appreciably activated at $\epsilon = 1.44$ ev. neutron energies. As will be discussed later, it was found through the use of B^{10} covered indium foils that this higher energy activation does not appreciably affect the ~1.44 ev. neutron distribution, and that the moments calculated from the neutron

distribution measured with cadmium covered indium foils are probably very close to the correct ones for neutrons of energy ~ 1.44 ev. Since the neutron distribution was measured to 92.20 cm. from the source, it was possible to calculate r^2 , r^4 , r^6 and r^8 . Between 0 cm. and 92.20 cm. from the point source the indium resonance neutron flux was found to decrease by a factor of 4.27×10^{-8} .

PROCEDURE AND EQUIPMENT

Briefly, the technique of the experiment was to place a large tank of water on the thermal column of the Oak Ridge National Laboratory pile. Thermal neutrons coming up from the pile entered the tank through the bottom. A fast neutron source plate of U^{235} -Al alloy was suitably located relative to the bottom of the tank. Some of the entering thermals were captured by this source plate thus generating fission neutrons. The slowing down distribution of these neutrons was measured with cadmium covered or with B^{10} covered indium foils.

DETAIL OF THE APPARATUS

The large tank mentioned above was 5' x 5' x 6' high and was fabricated from $\frac{1}{2}$ " thick aluminum plate. An "I" beam with a 3" web was mounted across the top and center of the tank and on this was mounted a set of guides. The neutron source plate and the foils in suitable boxes were supported in a 2-S aluminum frame, Fig. 2 - Fig. 6, which was in turn supported at the end of a 1" O.D. aluminum tube, Fig. 4.

When this tube was inserted in the above mentioned guides, the neutron source plate and foils lay in a plane parallel to the bottom of the tank and on the central vertical axis of the tank. Due to the precision construction of this guide and of the framework holding the source plate and the foils, all distances relative to the spacing of the source and foils from each other or from the bottom of the tank are good to better than 0.03 cm.

Two sizes of cadmium boxes, "A" + "B", Fig. 1, were used in these measurements. Box "A" was rectangular in shape and sufficiently large to hold a foil 4 cm. x 6.35 cm. The wall thickness of this box was 2.74 gr/cm² of cadmium. The other cadmium box "B" was of pill box shape with an internal diameter of 1.52 cm., sufficient to accept foils 1 cm. square. The wall thickness was 3.07 gm/cm². The boxes were clamped shut with a small amount of grease around the edges to keep water out during a foil activation when the box was immersed in the water tank. To make measurements at large distances from the neutron source, the foil was covered with 0.020" thick aluminum sheet rather than the cadmium box.

In addition to the cadmium foil covers discussed above, two boxes were also made to cover foils with B¹⁰ powder. It was felt that the B¹⁰ should be used without any binder, so, in one set up an aluminum box, "C", Fig. 1, with a steel cover was made. This box was large enough to accept a 4 cm. x 6.35 cm. foil plus a layer of B¹⁰. The top was attached to the box by a number of screws and the assembly sealed against water by a

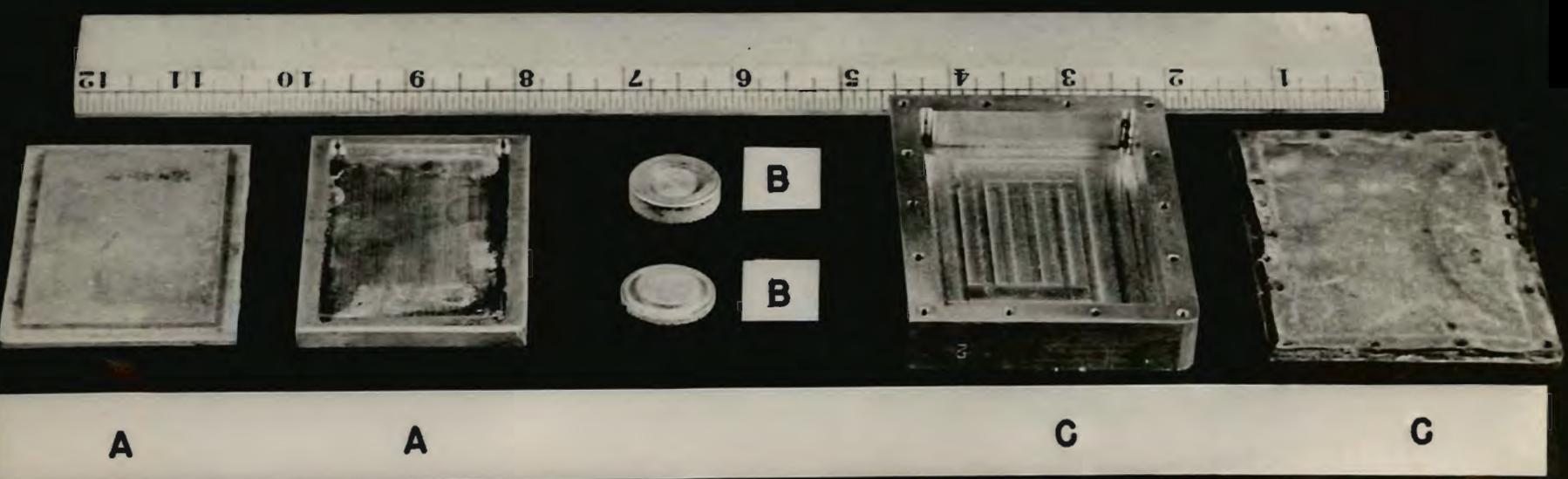


FIG. I

rubber gasket glued to the top. To use this box, B^{10} powder was weighed into the box on an analytical balance to a prescribed amount. The B^{10} was then spread over the bottom of the box uniformly, and the foil carefully laid on the B^{10} powder. A second layer of B^{10} equal in weight to the first was then weighed into the box, and spread out uniformly over the foil. The top of the box was then screwed on. No difficulty was found in obtaining reproducible results using this technique. The other B^{10} box consisted of a set of brass shells of pill box proportions. In appearance they were very similar to cadmium box "B", Fig. 1. However, they were made of brass and both the top and bottom were hollowed out and filled with boron 10. In box "C", there was 0.245 gr/cm^2 of boron and in the pill box, there was 0.337 gr/cm^2 . This boron was 88% boron ten by weight.

The indium foils used were approximately 0.10 g/cm^2 thick but within the measurement of a given section of the distribution, the foil weights were within 0.5% of the average weight. For different sections of the curve where the average weight of the foils differed, the sections were normalized together, usually by one or more common points. The area of the foils used is given in Table I.

The different size sources of the fission neutrons were plates of aluminum-uranium 235 alloy. The uranium was 96% U^{235} and the alloy 18% uranium by weight (eutectic composition). The alloy plate neutron sources were $0.080" \pm 0.004"$ thick and of various areas as specified in Table I and as described below. This thickness of uranium, with the surrounding water reflector, was sufficient to absorb about 95% of the incident thermal neutrons from the thermal column.

TABLE I

SUMMARY OF SOURCE SIZE AND LOCATION, FOIL SIZE AND FOIL BOX MATERIAL,
ALUMINUM SUPPORTING FRAME WORK USED, AND RANGE OF "r" OVER WHICH
THE GIVEN EXPERIMENTAL CONDITION APPLIED

Range of Distances from Source "r"	Neutron Source Geometry	Neutron Foil Size and Foil Box	Aluminum Frame Used
2.35 cm. to 15.02 cm.	Disk 5.08 cm. Diameter, 10 cm. from bottom of water tank	Disk foil 1.43 cm. diameter in Cd box "B", Fig. 1	As shown in Fig. 2
12.06 cm. to 22.00 cm.	Disk 1 cm. dia. in contact with bottom of water tank	1 cm. square foil in Cd box "B", Fig. 1	As shown in Fig. 2
15.32 cm. to 41.99 cm.	Disk 2 cm. dia. in contact with bottom of water tank	Rectangular foil 4 cm. x 6.35 cm. in Cd box "A", Fig. 1	As shown in Fig. 3
34.54 cm. to 61.21 cm.	Square 10 cm. x 10 cm. in contact with bottom of water tank	Rectangular foil 4 cm. x 6.35 cm. in Cd Box A, Fig. 1	As shown in Fig. 3
54.10 cm. to 79.96 cm.	Square 30.5 cm. x 30.5 cm. in contact with bottom of tank	Rectangular foil 4 cm. x 6.35 cm. in Cd box A, Fig. 1	As shown in Fig. 5
69.34 cm. to 92.20 cm.	Square 30.5 cm. x 30.5 cm. in contact with the bottom of water tank	Rectangular foil 4 cm x 6.35 cm in Aluminum cover (not shown)	As shown in Fig. 5
2.28 cm. to 7.54 cm.	Disk 5.08 cm. Dia. 10 cm. from bottom of tank	1 cm. square foil covered with 0.337 g/cm ² boron	As shown in Fig. 2
7.54 cm. to 17.60 cm.	Disk 5.08 cm. Dia. on bottom of tank	1 cm. square foil covered with 0.337 g/cm ² boron	As shown in Fig. 2
17.60 cm. to 35.59 cm.	Square 10 cm x 10 cm on bottom of tank	Rectangular foil 4 cm x 6.35 cm in boron cover 0.245 g/cm ²	As shown in Fig. 6

Figures 2 - 6 show the aluminum structures used to hold the foil boxes and indium foils.

The view in Figure 2 shows the lower end of a tube 8' long. The upper end is inserted in a guide, previously mentioned, which is used to locate the whole mechanism in the water tank. The lower end holds the foils in cadmium boxes as follows. The foils were placed in boxes "B" which nicely fit in the tube. Then the spacers A and the boxes "B" were inserted alternately into the tube. Eight boxes were put in for each run, the foils being 3.00" apart, and the first foil being either approximately 3" or $\sim 1.5"$ from the neutron source. The elongated holes shown in the tube and the notches at each end of the spacers were cut to permit water to freely fill the tube. The assembly of boxes and spacers were held in place in the tube by suitable stops. The fission neutron source plate was attached by screws to the lower end of the tube in an accurately reproducible fashion.

The view in Fig. 3 shows the aluminum holder used for the large size cadmium box "A", Figure 1. One of the three long slotted aluminum tubes was removable to facilitate the loading and unloading of the cadmium boxes from the aluminum frame. The measurements were made using sets of four foils per run. In a given run the foils were always 3.00" apart, as shown in the photograph. When the 2 cm. or 5 cm. diameter disk sources were used with this frame, they were attached to the bottom of plate "B" by a screw. When the 10 cm. square source plate was used, it was inserted into the slot at the left side of holder

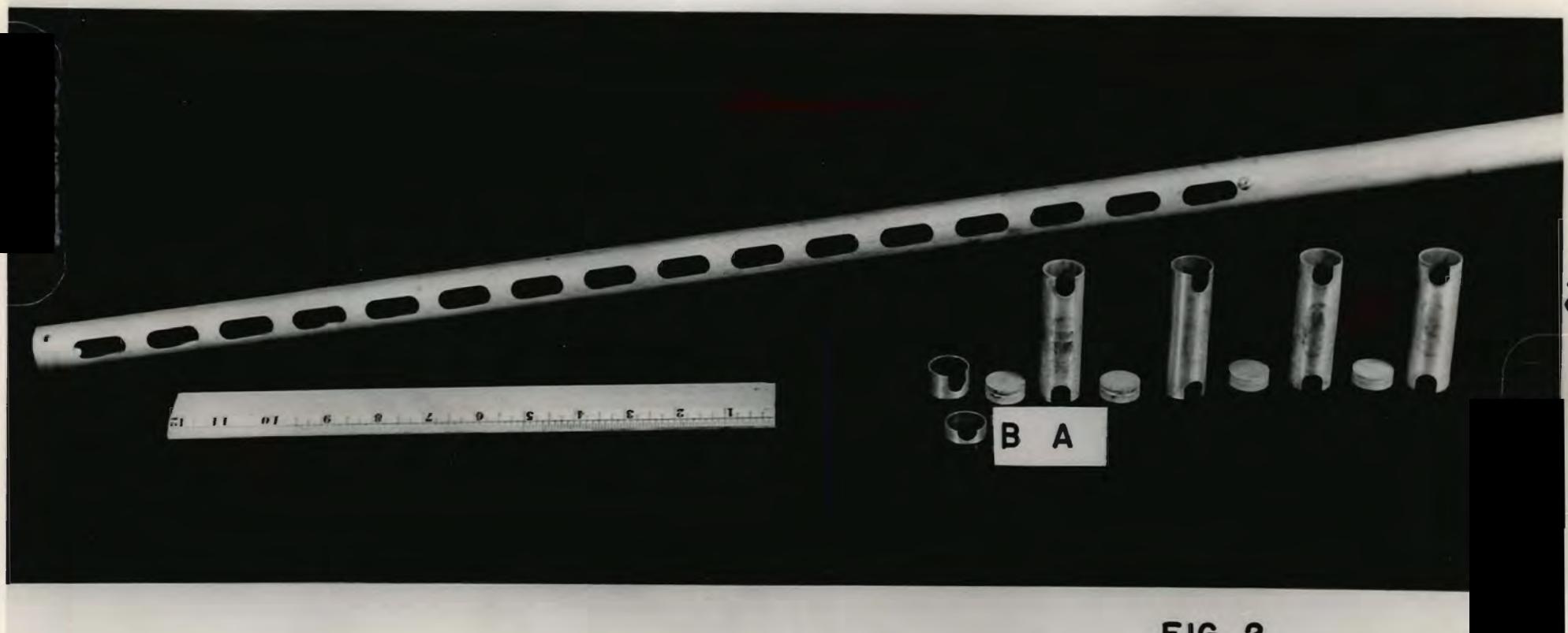
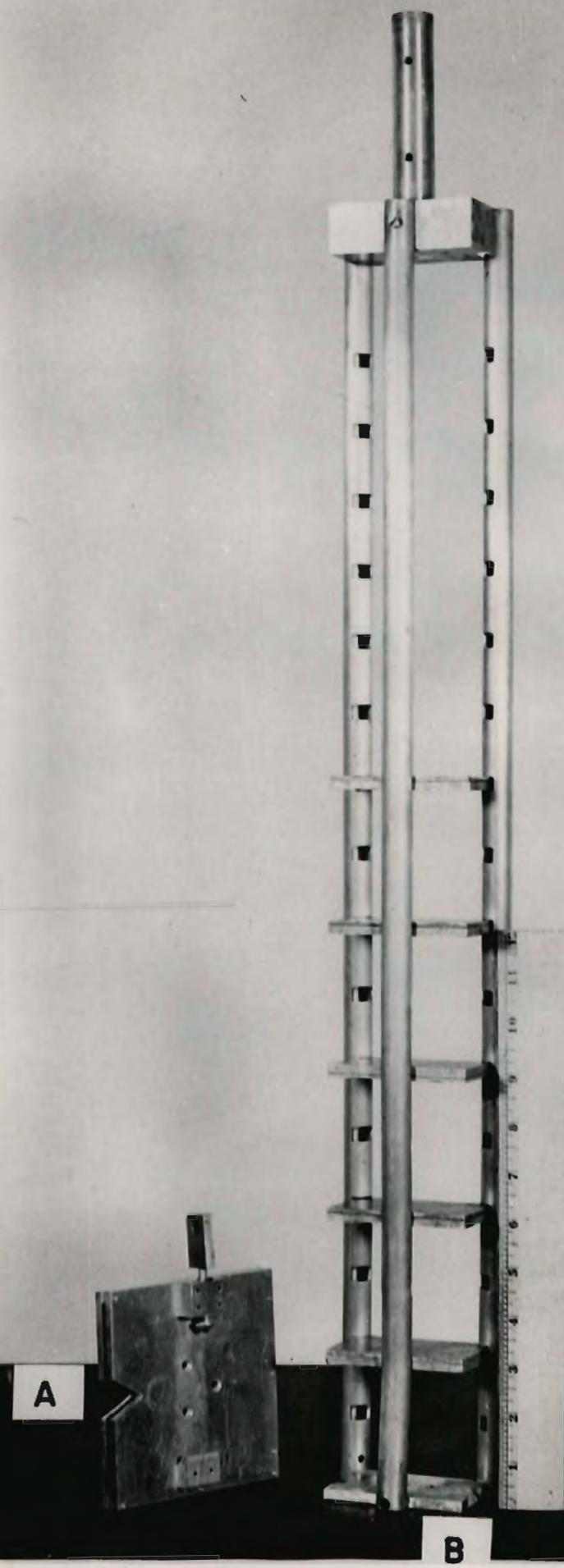


FIG. 2

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FIG. 3



A, and the whole was snapped onto plate "B" using a spring latch mechanism shown on A. This spring latch mechanism enabled one to remove the U²³⁵ source from the frame holding the foils quickly, and was necessary to reduce the γ -ray exposure of the operator, this larger size fission source plate being quite hot immediately after removal from the water tank.

The photograph, Fig. 4, shows the unit discussed above, Fig. 3, completely assembled and ready to be inserted in the water tank.

The view in Fig. 5 shows the frame, Fig. 3, discussed above, attached by a spring latch mechanism and through an extension post one foot long to a fission source plate 30.5 cm. square. The uranium alloy was encased in an aluminum sheath. Again, it was important to have the spring latch to be able to remove quickly the very "hot" neutron source.

The photograph, Fig. 6, shows the frame work used to hold the large boron boxes "B", Fig. 6 and "C", Fig. 1. The box at "A", Fig. 6 is one of the cadmium boxes. The activity of the foil in this box was used to normalize together the points obtained with boron covered foils, and to obtain the relative magnitudes of the saturated activities for boron covered and cadmium covered foils. When the smaller pill box shaped boron covers were used with the frame work, Fig. 2, a cadmium covered foil was always simultaneously activated for the same purpose as mentioned above.

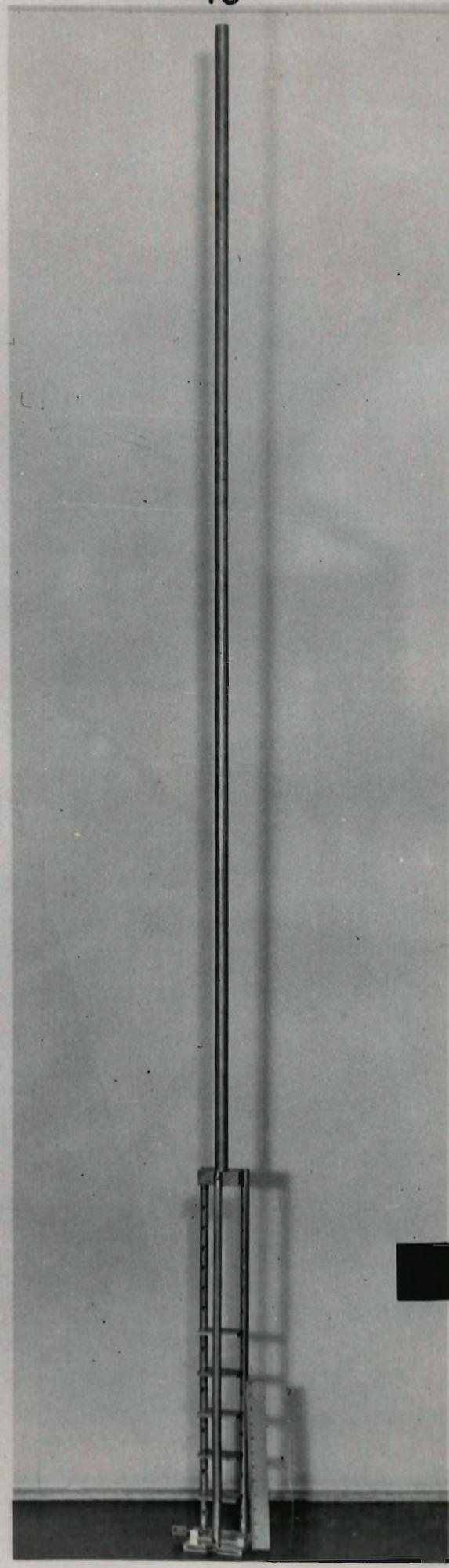


FIG. 4

FIG. 5

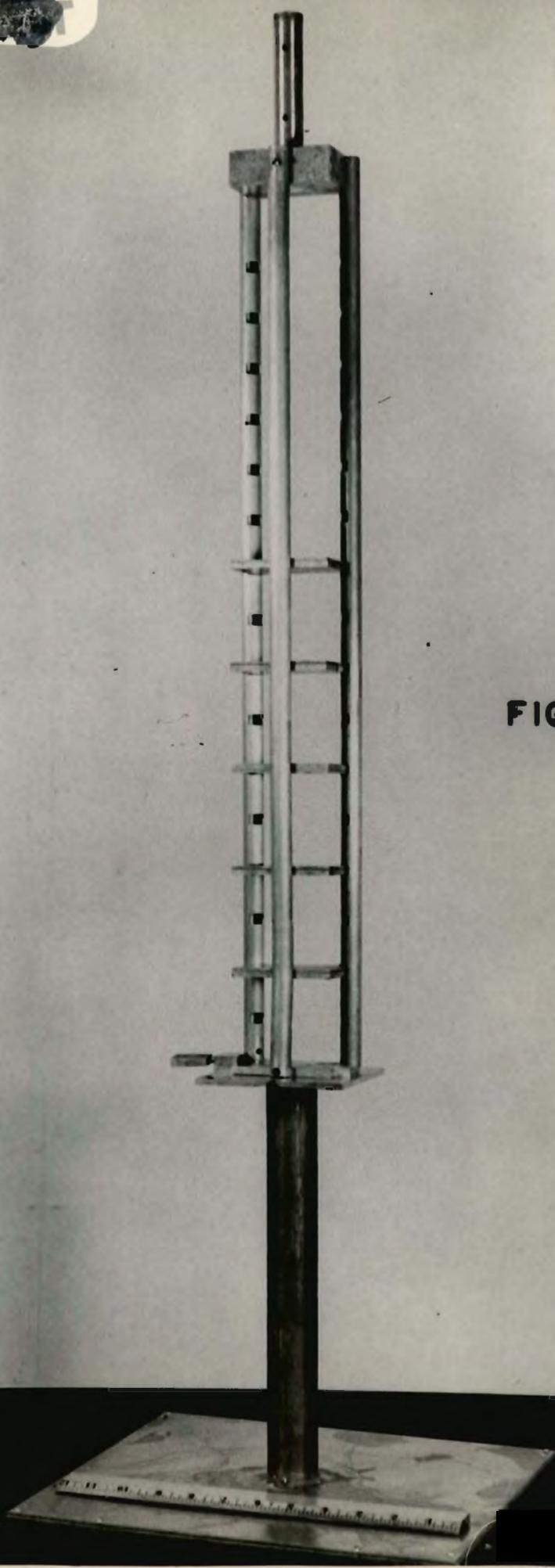
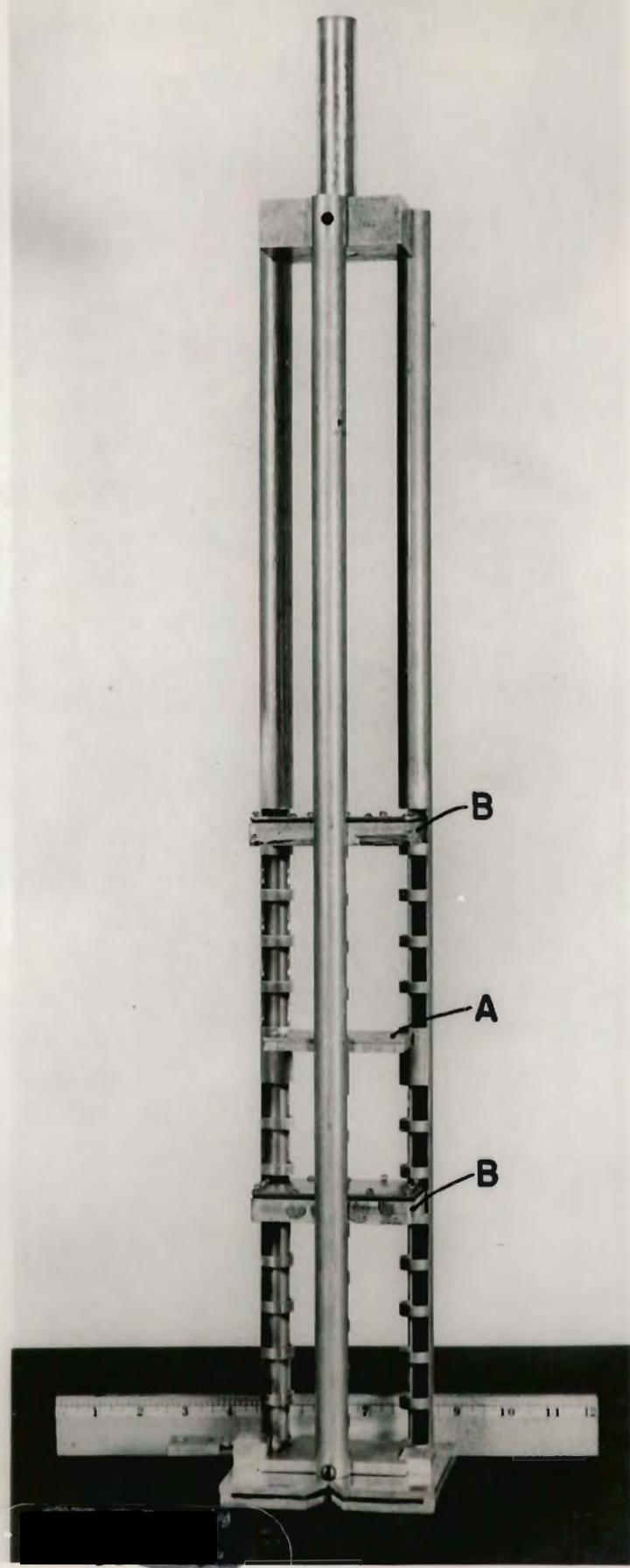


FIG. 6



MEASUREMENT PROCEDURE

In general, the foils were activated for an hour and counted for an hour. Two counters were used and two foils were counted simultaneously. Usually, only four foils were activated in a given run. The ratio between the two counters was obtained using a single hot indium foil and this ratio was used in all of the calculations. In addition, the ratio between the two counters was obtained using a uranium oxide standard. The counters were checked daily for constancy using this standard.

The side of the foil nearest to the neutron source was counted in all cases. In addition, the ratio of the activities of the two sides of the foil was measured at a number of selected positions and this ratio was plotted as a function of the distance from the neutron source. Then, using this graph, all of the measured points were corrected to give the average activity of the two sides. In all of the foil activities reported here, it is this average activity which is given. The activity which one would like to measure would be that for neutrons coming from a point source and being detected by a small detector. Actually the source and detector size must be fairly large to have a measurable foil activity, and as a result, one must correct this measured activity for geometry. In practice this correction rarely exceeded ten percent and was usually much less. The formulas used are straightforward and only the general method of derivation will be outlined. This derivation and the results for the various cases used in reducing the data are given in the appendix.

BOUNDARY CONDITIONS

The best boundary conditions for a neutron slowing down measurement would be to have the neutron source located at the center of a very large volume of the slowing down medium. When a fission neutron source is used, however, the thermal neutrons from the thermal column which are used to produce the fissions have to diffuse through this slowing down medium. If the neutrons have to diffuse very far, their number will be greatly attenuated, thus weakening the fission source. In water, the thermal neutron relaxation length is roughly one inch and a fission source placed four inches in from the water boundary will give less than 2% of the number of fission neutrons that the same source would give at the water surface. For measurements at large distances from the source, this decrease of source strength would be a serious handicap. A scheme to overcome this difficulty which seemed reasonable was to make measurements close to the neutron source with the source 4" or ~ 10 cm. in from the water boundary, and to make the measurements at large distances from the source with the source at the water boundary, or, at the bottom of the tank, Table I. To check up on this procedure, we measured two distributions, in the range, zero to twenty centimeters from the source. (1) with the source at the water boundary and (2) with the source four inches into the water. Close to the source the curves differed in shape as one would expect, but beyond ten cm. the two curves were proportional. This indicated that it would be satisfactory to make measurements at

distances greater than ten cm. from the source with the source at the water boundary. Since ten cm. is many transport mean free paths for indium resonance neutrons, on the basis of the above experiment, we felt that correct results would be obtained in the region from zero to ten cm. if the neutron source were ten cm. from the water boundary.

Even with the largest neutron source, 30.5 cm. x 30.5 cm. square and with the larger size foils, the foil counting rate became unacceptably small at ~ 70 cm. for cadmium covered foils. To obtain the distribution between ~ 70 cm. and 92.20 cm. measurements were made using indium foils in aluminum covers, Table I. The aluminum covers were used to provide mechanical support for the foils and to prevent contamination.

The justification for this procedure rests on the work of Rush, P.R. 73, 271 (1948), and on some of our measurements in which it was found that, at large distances from the neutron source, a distribution measured with cadmium covered indium foils and a second one measured with aluminum covered foils were proportional within experimental error. The range of r over which we checked this proportionality was ~ 60 cm. to ~ 76 cm. and in the work of Rush, 10 cm. to 40 cm. This proportionality over a moderated range of r is not so surprising when one remembers that, due to the very large scattering cross section of hydrogen, the age from 1.44 ev to thermal is only of the order of one cm^2 while the age from fission energies to 1.44 ev is 30.8 cm^2 . Thus the first moment of the neutron slowing down distribution from fission

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energies to thermal is only about 3% greater than to 1.44 ev, leading one to anticipate that the distributions will be very similar. This may be visualized physically in the following simplified picture. At the high initial source energies of a neutron, the hydrogen cross section is small and the neutron may move out far from the source before it makes a collision in which a great deal of energy is lost. After this collision, if the neutron energy is below, say 200,000 ev, the corresponding hydrogen cross section will be relatively quite large and the neutron will not be able to diffuse far from this point of first collision. Thus, to a first approximation the slowing down distribution in water far from the source will be given by a distribution of first collisions, independent of the energy at which the distribution is measured as long as the measuring energy is less than, say, 1000 ev. To our knowledge, this first collision treatment was first used by Fermi.

DATA, CALCULATIONS AND DISCUSSION

Using the equipment and methods described above, the distribution in water of indium resonance neutrons originating at a point fission source was measured in the range of distances from the source, $0 \leq r \leq 92.20$ cm. This distribution is given in Table II. When this work was completed, we were not sure to what neutron energy the curve corresponded because we knew from other experiments that the indium foils were activated to some extent by neutrons in the kilovolt region.

TABLE II

DISTRIBUTION OF INDIUM RESONANCE ACTIVITY FROM A FISSION SOURCE
IN LIGHT WATER (WITH TRANSPORT AND GEOMETRY CORRECTIONS)

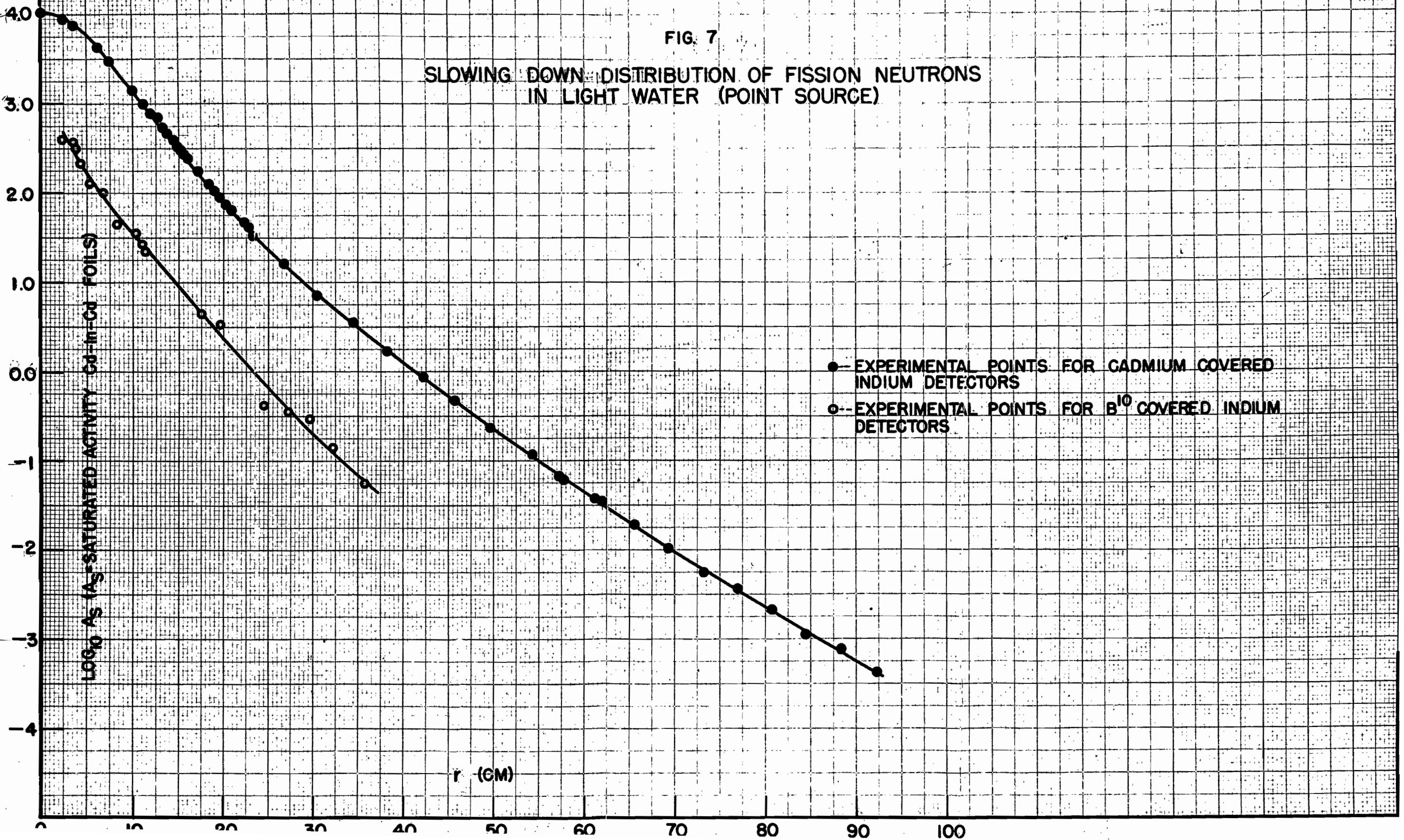
r (cm)	A _s
2.35	9167.82
3.62	7274.64
6.15	4281.38
7.42	2994.17
9.95	1445.58
11.22	1008.26
12.07	775.84
12.70	614.59
13.33	521.57
13.75	460.48
14.61	354.36
15.02	318.63
15.24	292.87
15.49	273.70
15.88	255.98
17.15	176.99
18.42	126.26
19.05	107.00
19.69	88.17
20.32	77.10
20.96	65.90
22.23	46.83
22.94	40.32
23.11	37.77
26.75	16.64
30.56	7.126
30.73	7.036
34.54	3.616
38.38	1.727
42.16	872.3 x 10 ⁻³
45.72	445.4 x 10 ⁻³
45.97	484.4 x 10 ⁻³
49.78	227.8 x 10 ⁻³
53.59	116.6 x 10 ⁻³
54.10	108.4 x 10 ⁻³
57.40	661.2 x 10 ⁻⁴
57.91	610.4 x 10 ⁻⁴
61.21	381.6 x 10 ⁻⁴
61.72	354.3 x 10 ⁻⁴
65.55	184.3 x 10 ⁻⁴
69.34	100.4 x 10 ⁻⁴
73.15	59.19 x 10 ⁻⁴
76.96	35.91 x 10 ⁻⁴
80.77	20.28 x 10 ⁻⁴
84.58	11.27 x 10 ⁻⁴
88.39	7.529 x 10 ⁻⁴
92.20	4.439 x 10 ⁻⁴

To determine the extent of this higher energy neutron activation and to correct for it, measurements were made using B^{10} covered foils, Table I. The amount of boron used was sufficient to essentially completely remove neutrons in the energy range below 10 ev. The results of these measurements are given in Table III and in the graph, Fig. 7 of $\log_{10} A_s$ vs. r. From Fig. 7, it is seen that the boron covered curve is about 3% of the cadmium covered curve, and also that the two curves are almost proportional over a considerable region, though the statistics of the boron covered curve are rather poor.

TABLE III
CURVE OF A_s VS. r FOR INDIUM COVERED WITH BORON

r (cm)	A_s (counts/min)	r (cm)	A_s (counts/min)
2.28	399.7	10.93	27.1
2.37	397.1	11.35	22.4
3.65	377.3	17.60	4.56
3.78	303.6	19.56	3.42
4.43	210.2	24.64	0.412
5.29	129.4	27.17	0.357
6.73	98.7	29.71	0.292
8.24	44.9	32.25	0.141
10.23	36.3	35.59	0.0592

This proportionality of the distribution measured under boron to that measured under cadmium may be explained in much the same way as we explained the proportionality of the thermal to cadmium covered distribution, page 10. This means that the second moment $\overline{r^2}$ of the two curves will be almost the same, within $\sim 10\%$. Because of the small magnitude of the boron covered indium foil activity and because of the proportionality



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of the two curves, the correct moments for a ~ 1.44 ev detection energy will be obtained within a minute error directly from the cadmium covered indium distribution without a correction for a contribution by higher neutron energies. To calculate these moments, the experimental data were plotted on a $\log A_s r^2$ vs. r plot and the best smooth curve was drawn through the data. Then points were read from this curve every cm. and these smoothed points were used in all of the numerical integrations used to obtain the moments. The smoothed points are given in Table IV. The portions of the " I_n " integrals from $r = 92$ cm. to $r = \infty$ were obtained analytically by using the extrapolating function

$$(1) \quad A_s = k \frac{e^{-r/\lambda}}{r^2},$$

with

$$\lambda = 8.786 \text{ cm. and } k = 1.324 \times 10^5$$

which are the values obtained from the experimental curve near 92 cm.

The general form of these integrals is

$$(2) \quad k \int_{r_0}^{\infty} e^{-r/\lambda} r^n dr = k \lambda e^{-\frac{r_0}{\lambda}} \sum_{i=0}^n [i! n_i c_i r_0^{(n-i)} \cdot \lambda^i]$$

where

$$n = 0, 2, 4, \dots \text{ and } n_i c_i = \frac{n!}{i! (n-i)!}$$

TABLE IV

SLOWING DOWN DISTRIBUTION OF FISSION NEUTRONS
TO INDIUM RESONANCE r in (cm) A_s is saturated activity in indium under cadmium values in () were extrapolated.

r	A_s	r	A_s	r	A_s	r	A_s
(0)	(10,400)						
(1)	(10,190)	25	24.27	49	0.2661	73	0.6026
(2)	(9,441)	26	19.28	50	0.2265	74	0.5248
3	8497	27	15.49	51	0.1905	75	0.4571
4	7162	28	12.59	52	0.1622	76	0.3981
5	5755	29	10.23	53	0.1380	77	0.3507
6	4519	30	8.318	54	0.1161	78	0.3020
					x 100		
7	3350	31	6.839	55	9.886	79	0.2630
8	2512	32	5.625	56	8.414	80	0.2291
9	1862	33	4.624	57	7.161	81	0.2022
10	1396	34	3.856	58	6.095	82	0.1748
11	1047	35	3.199	59	5.188	83	0.1514
12	776.2	36	2.661	60	4.416	84	0.1318
13	582.1	37	2.213	61	3.758	85	0.1150
14	431.5	38	1.841	62	3.199	86	0.1000
					x 1000		
15	323.6	39	1.531	63	2.754	87	0.8710
16	242.7	40	1.303	64	2.344	88	0.7586
17	132.0	41	1.048	65	1.995	89	0.6683
18	138.0	42	0.9120	66	1.718	90	0.5821
19	105.9	43	0.7586	67	1.479	91	0.5070
20	81.28	44	0.6383	68	1.274	92	0.4416
21	63.10	45	0.5270	69	1.096		
22	49.55	46	0.4519	70	0.9441		
23	38.90	47	0.3758	71	0.8128		
24	30.55	48	0.3162	72	0.6998		

The values of "In" and the moments, r^n , calculated from the distribution are given in Table V. Table V also gives the fraction of each "In" integral contributed by the extrapolated part from $r = 92$ cm. to $r = \infty$.

TABLE V

THE MOMENTS r^n OF THE DISTRIBUTION OF ~ 1.44 ev. NEUTRONS
FROM A POINT FISSION SOURCE IN WATER

n	$I_n = \int_0^\infty A_s r^n dr$	Fraction of I Extrapolated	$r^n = \frac{\int_0^\infty A_s r^n dr}{\int_0^\infty A_s r^{n-2} dr}$
2	2.092×10^6	1.40×10^{-5}	$\overline{r^2} = 184.7 \text{ cm}^2$
4	3.863×10^8	7.95×10^{-4}	$\overline{r^4} = 1.222 \times 10^5 \text{ cm}^4$
6	2.556×10^{11}	0.0130	$\overline{r^6} = 2.270 \times 10^8 \text{ cm}^6$
8	4.375×10^{14}	0.0857	$\overline{r^8} = 8.642 \times 10^{11} \text{ cm}^8$
10	1.357×10^{18}	0.333	

In comparing our results with the earlier work of Fermi et al it is seen that our value of $\overline{r^2} = 184.7 \text{ cm}^2$ is rather less than the earlier value of 194 cm^2 . The source of this difference may be seen in a comparison of the earlier distribution with ours. It is found that in the region from 10 cm. to 24 cm., the earlier work and our measurements are in excellent agreement. At smaller and at large r , however, the earlier measurements fall higher than ours, probably due to geometry close to the source and statistics for cut. The effect of this was that much too large a relaxation length, λ , was used in extrapolating the earlier distribution.

to infinity. Since the 194 cm^2 was $\sim 30\%$ extrapolated, the difference between the earlier work and our results can readily be explained in this way.

Reference to Table V shows that an appreciable part of r^6 and r^8 is extrapolated. This means that the values given are probably underestimates. The reason for this lies in the fact that the extrapolating function used is that of a distribution of first collisions with constant relaxation length, λ , whereas it is clear that λ is not a constant but gradually increases with r , due to the hardening of the neutrons. If λ , as a suitable increasing function of r had been used, the extrapolated areas would have been larger.

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APPENDIX

FORMULAE FOR GEOMETRY CORRECTIONS

In this experiment all of the sources and detecting foils were thin plane configurations and were arranged with their planes accurately perpendicular to and with their geometrical centers on the axis of the distribution. Let r_o be the distance between these centers for a given measurement and r the variable distance between arbitrarily placed elements of area dS and dS' on the source and detecting foil with total areas S and S' , respectively. Let $\frac{A(r)}{S S'}$ be the activity induced in the detecting foil per unit area from a unit area of source when their separation is r . If $A_m(r_o)$ is the measured activity then,

$$(3) \quad A_m(r_o) = \iint_{S S'} \frac{A(r)}{S S'} dS' dS$$

If the dimensions of the foil and source are small compared to r_o then one may approximate the expression for r in terms of r_o and the coordinates of the area elements dS and dS' by the first two terms of a binomial series expansion, i.e.

$$(4) \quad r \approx r_o \left[1 + \frac{h(x_1, x_2, x'_1, x'_2)}{2 r_o^2} \right],$$

where h is a function of the coordinates x_1, x_2, x'_1, x'_2 of dS and dS' appropriate to the geometries of any given case.

Substituting (4) in (3), expanding $A\left\{r_o \left[1 + \frac{h(x_1, x_2, x'_1, x'_2)}{2 r_o^2} \right]\right\}$ in Taylor's series and neglecting all except the first two terms one obtains

$$(5) \quad A_m(r_o) = \frac{1}{S S'} \iint_{S S'} \left[A(r_o) + \frac{h(x_1, x_2, x'_1, x'_2)}{2 r_o} A'(r_o) \right] dS' dS$$

where $A(r_o)$ is the desired activity for a point source and point detector. In all the specific geometries used, these integrals are standard forms and one can evaluate (5) and solve for $A(r_o)$ in terms of $A_m(r_o)$, $A'(r_o)$ and the dimensions of the source and detecting foils. Since the corrections are small one may in every case substitute $A'_m(r_o)$ for $A'(r_o)$ with an error much smaller than the experimental uncertainty and hence all the quantities necessary to calculate $A(r_o)$ are known.

The cases, used in the course of these experiments and the resulting correction formulae are listed below.

Case I:

Circular Source of Radius, a' , and Circular Detector of Radius, a .

$$(6) \quad A(r_o) = A_m(r_o) - \frac{(a'^2 + a^2)}{4 r_o} A'(r_o)$$

Case II:

Rectangular Source of Dimensions $2 a' \times 2 b'$ and Rectangular Detector $2 a \times 2 b$.

$$(7) \quad A(r_o) = A_m(r_o) - \frac{[a'^2 + b'^2 + a^2 + b^2]}{6 r_o} A'(r_o)$$

Case III:

Circular Source of Radius a' and Rectangular Detector of Dimensions $2 a \times 2 b$

$$(8) \quad A(r_o) = A_m(r_o) - \frac{[4(a^2 + b^2 + 6 a'^2)]}{24 r_o} A'(r_o)$$

Other combinations used such as point source and circular detector, point source and rectangular detector, square source and square detector and square source and circular detector are obvious trivial simplifications of the above formulae and will not be listed here.

It should be pointed out that in this work $A'(r_o)$ is always negative

and therefore the corrections always make $A(r_o) > A_m(r_o)$.

Since the experiments with different source and detector configurations were always arranged so that several points overlapped in r values for purposes of normalization, a very good experimental check on the above formulae for geometry corrections was obtained in that portions of the distribution obtained with a geometry which required negligible geometry corrections agreed well within experimental error with the same portions taken with a different geometry which required corrections up to 10 percent. In a few instances even larger geometry corrections up to 20 percent gave excellent agreement with the same points taken under conditions of geometry where the correction was small.

The general method of making geometry corrections, outlined above, has been used by Fermi and other workers but the explicit forms given are not, to the author's knowledge, available in the literature and are given here for ready reference.

