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THE NEUTRON ENERGY DISTRIBUTION IN THE CENTER OF THE LOS ALAMOS PLUTONIUM REACTOR

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The Neutron Energy Distribution in the Center of the Los Alamos Plutonium Reactor

Introduction

The neutron energy distribution in the center of the reactor has been examined by 1) use of proton recoil, and fission photographic plates and Be, B, and Li impregnated plates, 2) a fission counter which has interchangeable 28, 25, and 37 foils, and 3) by activation of S and Al detectors using the (n,p) threshold reactions. This report will be concerned with only the fission counter, fission plates and activation results. The proton-recoil plate method will be reported as a separate LAMS and it is expected that the results will be more accurate than the ones reported here.

Experimental Arrangement

Fig. 1A shows the active material loading of the reactor when this set of experiments was performed. The reactor pot was filled with mercury and in order to insert detectors into the region shown in Fig 1B a steel tube closed on the bottom was put through the top tamper in the mercury exit pipe into the active material cage. A canned uranium rod, shown in Fig. 1C, was inserted in this tube with detectors being placed in the available gap in the center of the uranium. When the fission chamber was used the steel tube was removed and the chamber placed in the mercury in the center hole.

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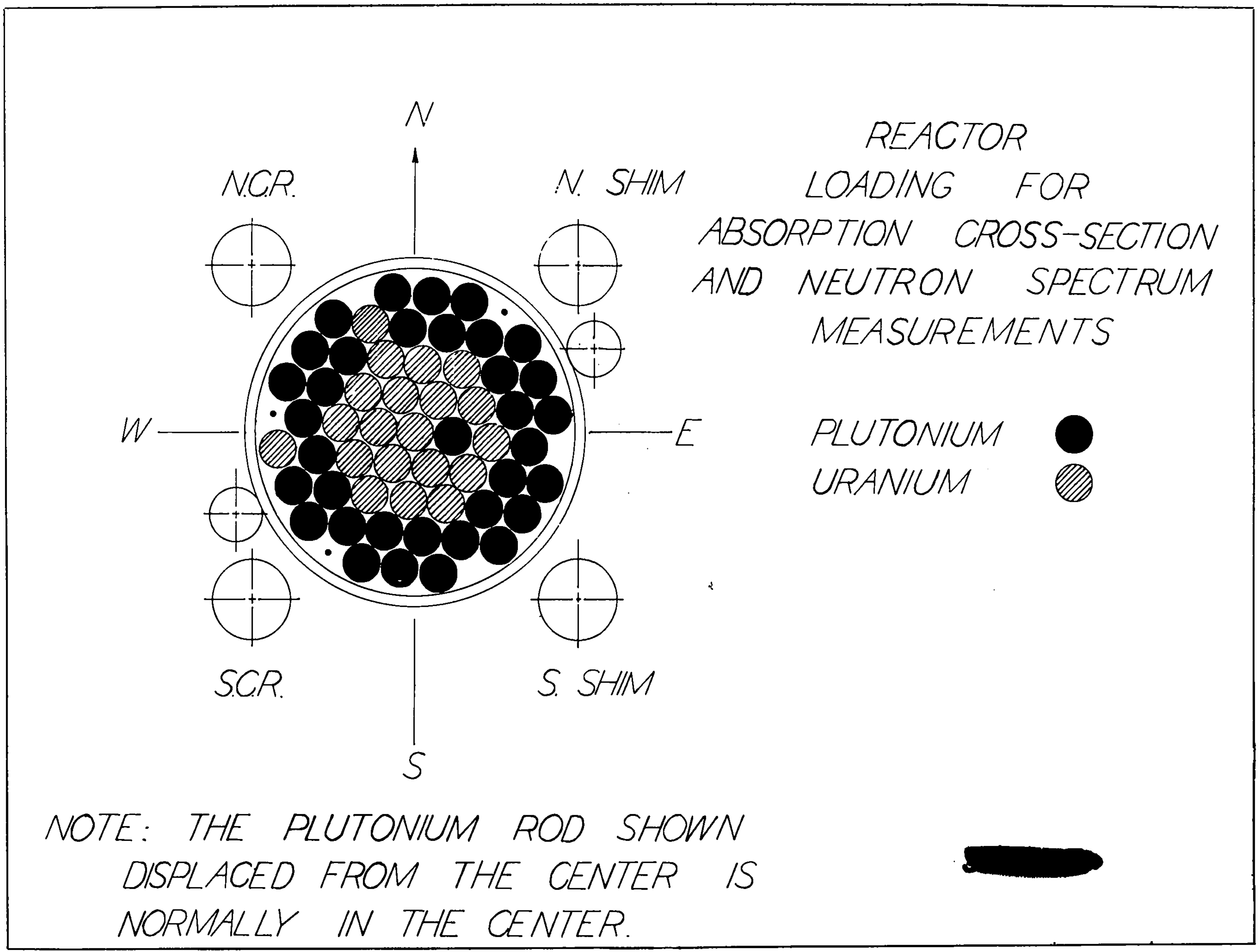

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FIG 1A

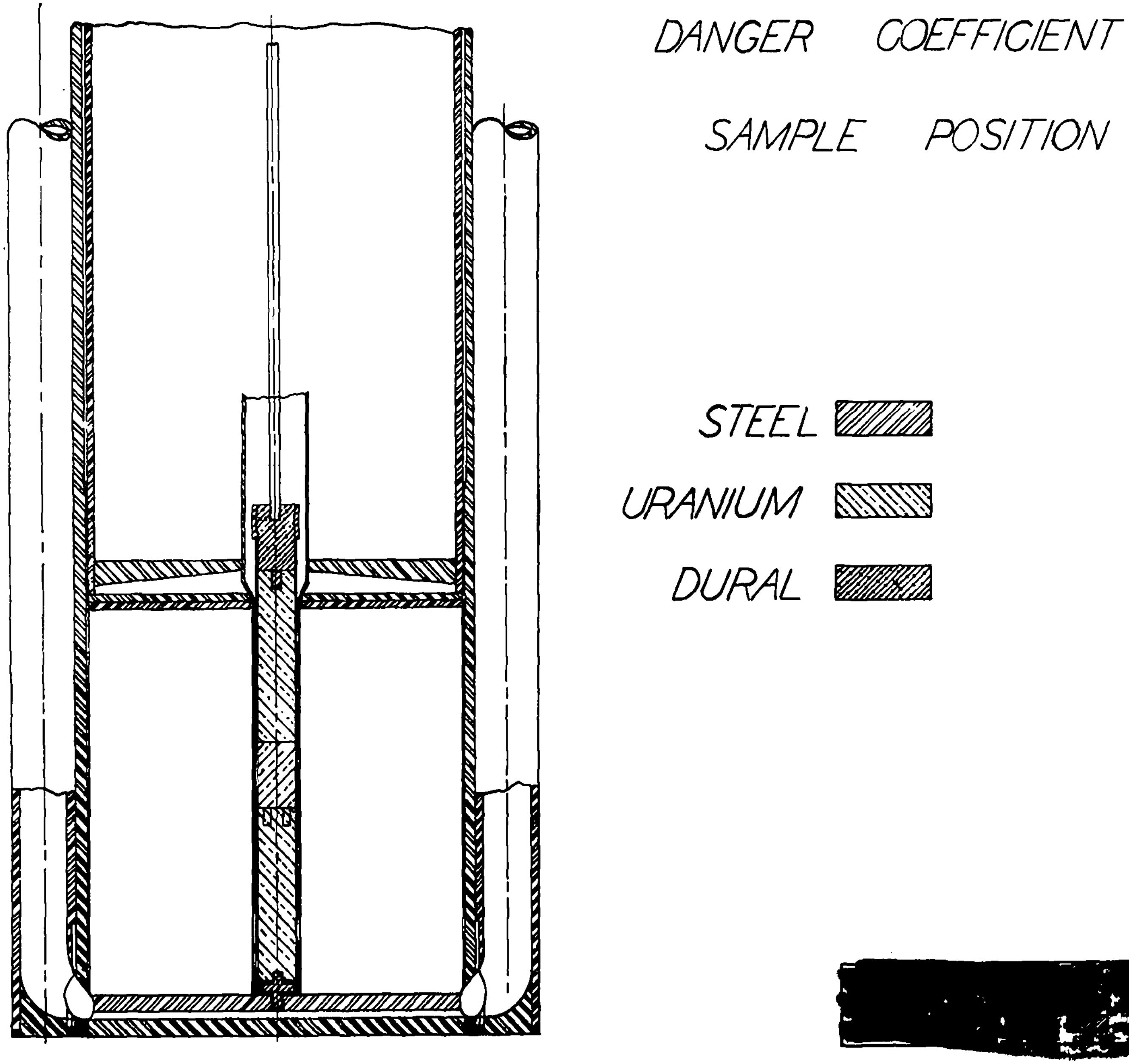

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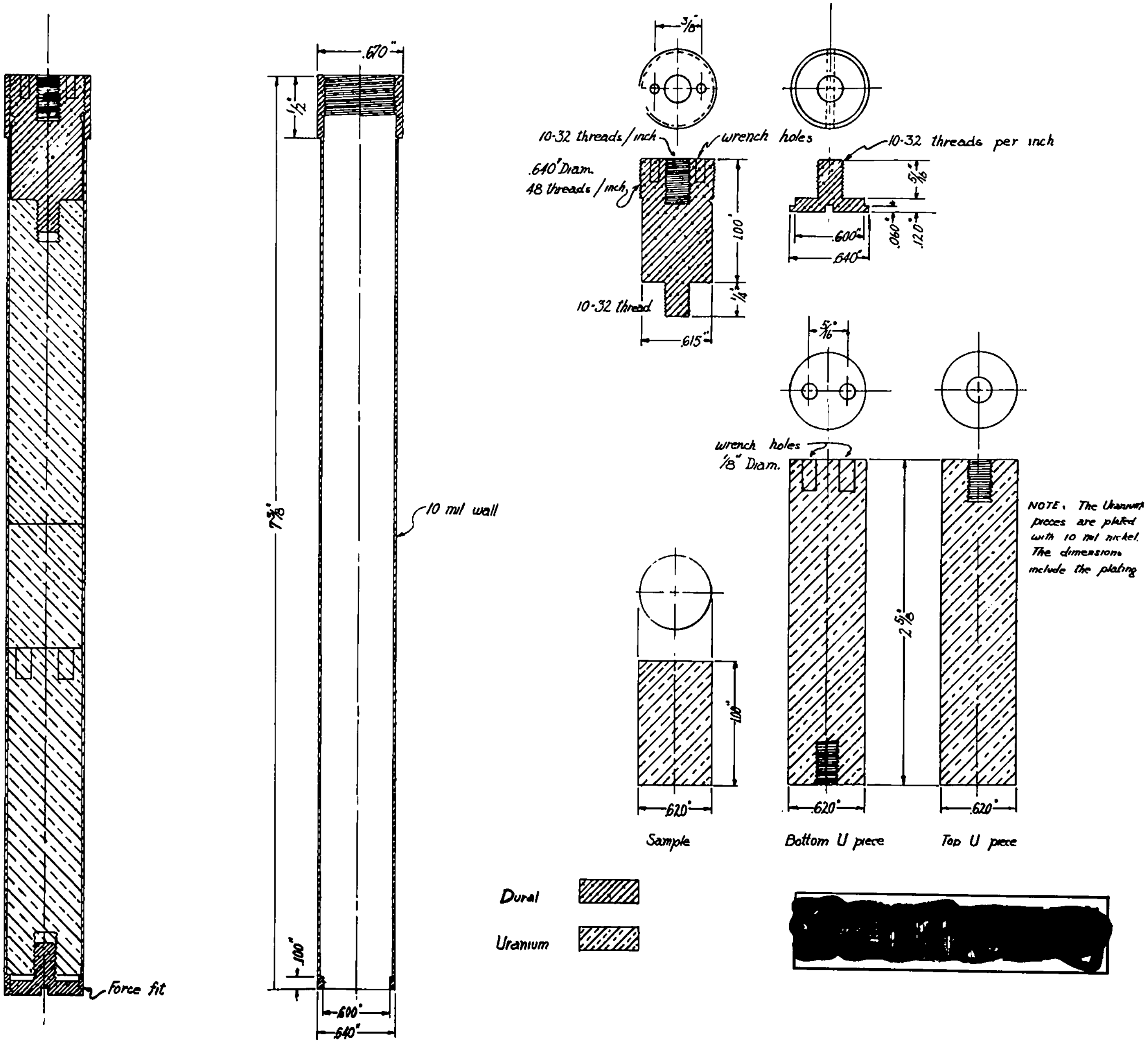
FIG IB

-C-



NOTE: The Uranium pieces are plated with 10 mil nickel. The dimensions include the plating.

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FIG 1C

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I. Fission counter method:

Fig. 2 shows the fission counter used. It is possible to easily interchange the fission foil and retain the same geometrical conditions. The counter was filled with 600 mm of argon plus 1.5 percent CO_2. The foil weights as determined by alpha-counting were U^{238} = 0.347 mg, Np^{237} = 0.054 mg, U^{235} = 0.340 mg. Since the mean range of fission fragments is approximately equal to 10 mg per cm^2, self-absorption corrections of a few percent were made for the foil masses. An efficiency correction of 0.90 was made to the observed counting rates. Table I gives the alpha-counting data, and Table II the fission-counting data from the reactor with the final results.

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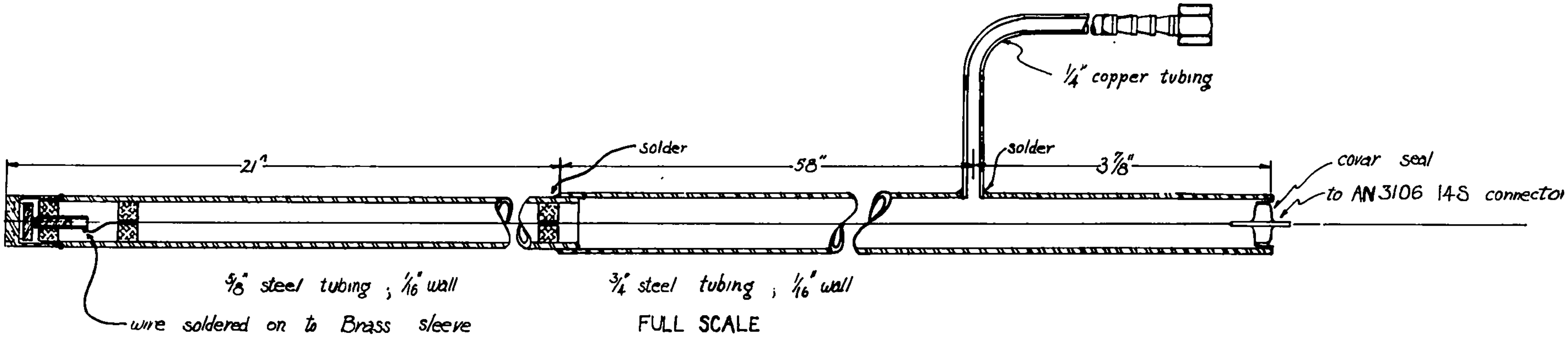
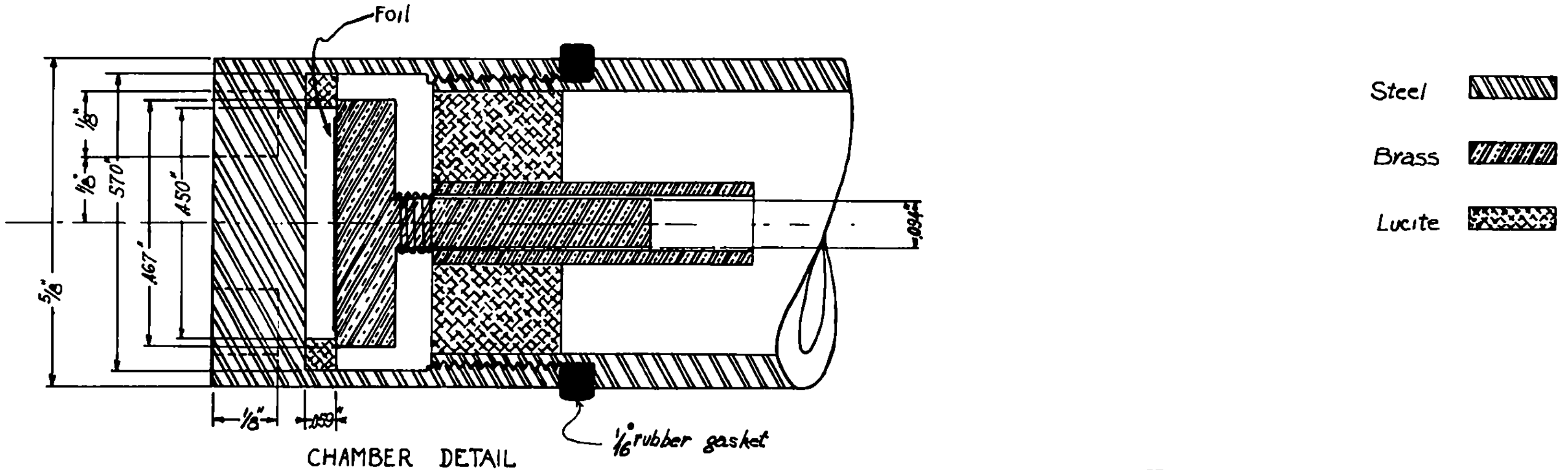


FULL SCALE



CHAMBER DETAIL

SCALE 6"=1"

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FIG 2

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TABLE I

Determination of Fission Foil Masses

Foil	Weight (mg)	Observed cpm	Correction for 10 channel discriminator	Correction for abs. of alphas in foil	Corrected cpm	Specific activity in geometry (cpm/mg)	Weight of fissile material (mg)
25	0.5	15,950	1.005	1.004	16,100	45,400 (95.7% U^{235})	0.340
28	0.4	1,390	1.005	1.003	140	405	0.347
37	0.11	40,500	1.005	1.001	40,700	750×10^3	0.054

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The activation of the fission foils in terms of disintegrations per second per watt per atom is equal to $\int n v \sigma \frac{dE}{E}$ integrated over the neutron spectrum. It has been assumed that few, if any, neutrons of energy less than 100 ev exist in the center of the active material because of the large fission cross section of plutonium for low energy neutrons. The integration for U^{235} is therefore taken from 100 ev to 10 Mev and

$$\int_{100\text{ ev}}^{10\text{ Mev}} \sigma v \frac{dE}{E} \quad \text{for } U^{235} = \frac{144 \text{ meter barns}}{\mu\text{sec}}$$

Similarly, the fission threshold for Np^{237}, 0.4 Mev, was used as the lower limit of integration and for U^{238}, 1.0 Mev. The values of these integrals are

$$Np^{237} \int_{100\text{ ev}}^{10\text{ Mev}} \sigma v \frac{dE}{E} = 97.3 \frac{\text{meter barns}}{\mu\text{ sec}}$$

$$U^{238} \int_{1.0\text{ Mev}}^{10\text{ Mev}} \sigma v \frac{dE}{E} = 38.6 \frac{\text{meter barns}}{\mu\text{ sec}}$$

Hence n, which is the number of neutrons per cm^3 per watt in the energy intervals, is equal to the disintegration per second per watt per atom divided by the value of $\int \sigma v \frac{dE}{E}$. Table II tabulates the number of neutrons in the three ranges.

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TABLE II

Fission Counting Rate in Reactor

Foil	Mass (mg)	Counting Rate	Power (watts)	Fission prod. abs. correct.	$\frac{\text{Counts}}{\text{sec-watt-atom}}$	Counter Efficiency	$\frac{\text{dis}}{\text{sec-watt-atom}}$	$\int \sigma v \frac{dE}{E}$	$\frac{n}{cm^3\text{-watt}}$
25	0.340	8,030	0.275	1.025	5.74×10^{-16}	0.90	6.3×10^{-16}	144×10^{-16}	0.044 (100ev-10
	0.340	5,800	0.20	1.025	5.67×10^{-16}	0.90			
37	0.054	5,020	1.50	1.005	4.07×10^{-16}	0.90	4.5×10^{-16}	97.3×10^{-16}	0.046* (0.4 Mev -
28	0.347	4,530	1.50	1.020	5.85×10^{-17}	0.90	6.5×10^{-17}	38.6×10^{-16}	0.017 (1.0 - 10

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*The data appear to indicate that there are more neutrons between 0.4 Mev and 10 Mev than there are between 100 ev and 10 Mev. The 37 data was discarded because of some uncertainty in Mass and lack of agreement with the fission plates.

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II. (n,p) activation:

Two (n,p) reactions were used:

1) $S^{32}(n,p)P^{32}$ which has a 1.5 Mev threshold, a half-life of 14.7 days, and emits a 1.7 Mev beta. Using values of sigma from LA-515 the $\int_{1.5}^{10} \sigma v \frac{dE}{E}$ was calculated to be 17.2 meter barns per microsecond.

2) $Al^{27}(n,p)Mg^{27}$ which has a 2.3 Mev threshold, a half-life of 9.6 min and emits a 1.8 Mev beta. The value of

$$\int_{2.3}^{10} \sigma v \frac{dE}{E} \text{ is equal to } 0.8 \frac{\text{meter barns}}{\mu\text{sec}} .$$

The detectors were discs 0.50 inch in diameter. One thickness of aluminum was used and two of sulfur. The detectors were placed in the sample can shown in Fig. 1C and irradiated in the reactor. Beta-counting was done in a flat geometry using an aluminum G-M tube of 0.004 inch wall thickness. Corrections were calculated for the self-absorption of the betas in the detector and in the counter wall. A geometry efficiency was found by calibrations described below.

<u>Geometry efficiency of beta-counting</u>

Aluminum foil and disc; sulfur disc.

Two standard indium foils and a 0.50 inch diameter indium disc were irradiated in a known thermal flux in the G Building standard pile, and the disc counted in the same geometry that the aluminum and sulphur discs were counted in. The foils were wrapped around the counter tube. The following data were obtained.

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A saturated	mass (gms)	cm^2	gm/cm^2	E_a(1)	nv	$E = E_a E_g$(2)	E_g
Foil 1×10^3 c/sec	2.4	24	0.10	0.64	6350	0.067	0.105
							0.107
Foil 7.5×10^2 c/sec	2.4	24	0.10	0.64	4500	0.070	0.109
Disc 21.1 c/sec	0.08_3	1.27	0.065	0.74	4350	0.059	0.080

The values of E_g obtained were used as the over-all geometry factors for the Al foil and disc activations and for the S discs.

Al and S Irradiations in the Reactor

A disc of aluminum 0.50 inch in diameter and a foil of aluminum 24 cm^2 of same dimensions as the standard indium foil were irradiated in the reactor and the (nv σ) causing the aluminum activity found. From this value and the value of $\int \sigma v \frac{dE}{E}$, n, the number of neutrons per cm^3 watt in the range 2.3 Mev to 10 Mev was determined.

Two discs of sulfur 0.50 inch in diameter were likewise irradiated and the number of neutrons per cm^3 per watt in range 1.5 to 10 Mev found. The data also was used to calculate the average absorption cross section of the two elements for the reactor neutron spectrum. The data is compiled in Table III.

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(1) Percent of betas from In^{116} (End point = 0.85 Mev) transmitted through half thickness of foil plus the aluminum wall of G-M tube (0.027 gm/cm^2). Calculated by Range-Energy relations and Fermi distribution curve of In^{116} betas.

(2) $\frac{A_{Sat}}{\sigma} = E(nv\ N)$ where N = number of atoms in detector. σ was taken as 200 barns.

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TABLE III

	Mass	cm^2	gm/cm^2	E_a (calc)	E_g (from In calib)	E	A_{sat} (cps)	A_{corr}	Irradiations	$\frac{\text{dis}}{\text{sec-watt-atom}}$	$\int \sigma v \frac{dE}{E}$	Neut/cm^3watt	$\overline{\sigma}$ (assing nv 4x1 per wa
Al foil	0.339	24	0.014	0.976	0.107	0.104	1,000	$9.6 x 10^3$ c/sec	18.4 watts 30 min	6.9×10^{-20}	$0.8 x 10^{-16}$	$8.6 x 10^{-4}$	0.2 mil bar
disc	0.018	1.24	0.014	0.976	0.080	0.078	50.7	650	18.4 watts 30 min	8.7×10^{-20}	$0.8 x 10^{-16}$	$10.9 x 10^{-4}$ Av=$9.8 x 10^{-4}$ =0.001	
S disc	0.268	1.27	0.210	0.845	0.080	0.068	1.39×10^5	$2.06 x 10^6$	50 watts 83 min	$0.81 x 10^{-17}$	$17.2 x 10^{-16}$	4.7×10^{-3}	20* mil bar
disc	0.916	1.27	0.722	0.340	0.080	0.027	1.73×10^5	$6.4 x 10^6$	50 watts 83 min	$0.74 x 10^{-17}$	$17.2 x 10^{-16}$	4.3×10^{-3} Av=0.0045	

* MonP-405

For U^{235} fission neutrons a value of 2.8 mb is given for Al(n,p); a value of 12 mb for S(n,p) for U^{23} fission neutrons, but 0.23 barns for "fast" pile neutrons.

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III. Fission photographic plate method:

Foils of 28, 37 and 25 were placed in contact with Eastman NTC plates of emulsion thickness 25 μ and irradiated in the reactor. The following observations were made.

Foil	Alpha-counting mass	Area	mg/cm^2	Irradiation (watt-min)	Total Tracks and No. of Fields*	$\frac{\text{Tracks}}{\text{field-watt-min - (atom/cm}^2)}$
25	0.292 gm	3.24 cm^2	0.090	92	16,706; 379 fields	2.07×10^{-18}
	0.292	3.24	0.090	46	4,372; 210 fields	$>2.02\times10^{-18}$ 1.96×10^{-18}
37	0.018	3.19	0.0056_5	184	263; 100 fields	0.995×10^{-18}
	0.018	3.19	0.00565	368	271; 50 fields	$>1.01\times10^{-18}$ 1.03×10^{-18}
28	0.330	3.25	0.101_5	184	1,179; 150 fields	0.165×10^{-18}
				368	871; 50 fields	$>0.18\times10^{-18}$ 0.184×10^{-18}

Using the values of the integrals $\int \sigma v \frac{dE}{E}$ in terms of $\frac{\text{cm - cm}^2}{\text{sec}}$,

	$\frac{\text{Tracks}}{\text{field-etc.}}$	$\int \sigma v \frac{dE}{E}$	Energy Interval	kn (n = no. of neutrons/cm^3 watt; k = constant**)
25	2×10^{-18}	144×10^{-16}	100 ev - 10 Mev	1.39
37	1×10^{-18}	97.3×10^{-16}	0.4 Mev - 10 Mev	1.03
28	0.18×10^{-18}	38.6×10^{-16}	1 Mev - 10 Mev	0.47

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* The field in each case was 6,500 μ^2.

** The constant k includes the efficiency of the photographic plate. The number kn will be normalized to the fission chamber data for comparison.

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The ratio of 37/28 in the center is 2.2. Fission plates placed in an experimental hole which is separated from the edge of the pot by 1" of uranium and is thus 4" from the center position indicated a ratio of 37/28 at 4.6. Thus at this position the spectrum has about five times as many neutrons in range from 0.4 to 10 Mev as from 1 Mev to 10, indicating a rather large degradation of the energy in passing through the active material and uranium.

Summary

Combining the data from the fission chamber and from the activation measurements and normalizing the fission plate data to this data the following is obtained. The 37 data from the fission chamber was not used because of the discrepancy between 25 and 37.

Foil	Energy Band	Method	$\frac{n}{cm^3 - watt}$	
25	100 ev - 10 Mev	Fission Chamber	0.044	
25	100 ev - 10 Mev	Photographic Plate	0.044 (normalized to 25 fission chamber)	
37	0.4 - 10 Mev	Photographic Plate	0.033	
28	1.0 - 10 Mev	Photographic Plate	0.015	> Av = 0.016
28	1.0 - 10 Mev	Fission Chamber	0.017	
S	1.5 - 10 Mev	Activation	0.004	
Al	2.5 - 10 Mev	Activation	0.001	

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Foil	Energy Band Difference	Method	$\frac{n}{cm^3 - watt}$	Fraction	Range (Mev)	Normalized Height of Block
25-37	100-0.4	P.P.	0.011	0.24	0.4	635
37-28	0.4-1.0	P.P.&F.C.	0.017	0.39	0.6	660
25-28	100-1.0	P.P.	0.029 } 0.028	0.66 } 0.63_5	1.0	640
25-28		F.C.	0.027	0.61	1.0	
28-S	1.0-1.5	F.C.&A.	0.012	0.27	0.5	545
S-Al	1.5-2.5	A.	0.003	0.068	1.0	69
Al	2.5-10	A.	0.001	0.023	7.5	3
28	1 - 10	F.C.	0.016	0.36	9.0	40
28-Al	1 - 25	P.P.	0.015	0.34	1.5	230

The block diagram of this data is plotted in Fig. 3 and the resulting neutron spectrum drawn. Note that blocks are indicated for the bands 1 - 1.5 and 1.5 to 2.5 and also for the band 1 - 2.5 for comparison. This was done because the band 1 - 1.5 depends very markedly on the efficiency assigned to the S foil counting. For comparison the plutonium fission spectrum is plotted in dashed lines and then broken into block diagrams for the same energy intervals that were used in the reactor neutron spectrum. The areas have been normalized.

The normal fission spectrum appears to have been degraded to lower energies with the result that the maximum occurs at about 0.5 Mev and with about 65 percent of the neutrons lying below 1 Mev. The average energy is about

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0.8 Mev as contrasted with an average energy of about 1.8 Mev for the 49 fission spectrum.

The observed activation cross section for Al (n,p) of 0.2 millibarns is reasonable because of the fact that only two percent of the neutrons in the spectrum lie above the aluminum threshold, whereas for the 25 fission 32 percent lie above the threshold in which spectrum the Al cross section is 2.8 millibarns.

In the case of the S(n,p) reaction the number of neutrons above 1.5 Mev in the reactor spectrum is about 9 percent. The average energy of the number of neutrons above 1.5 Mev in the reactor spectrum is about 2 Mev -- a region in which the S(n,p) cross section is changing rapidly. At 2 Mev the cross section is given in LA-515 as about 30 millibarns. The observed value of 20 millibarns for the reactor spectrum is in fair agreement with this.

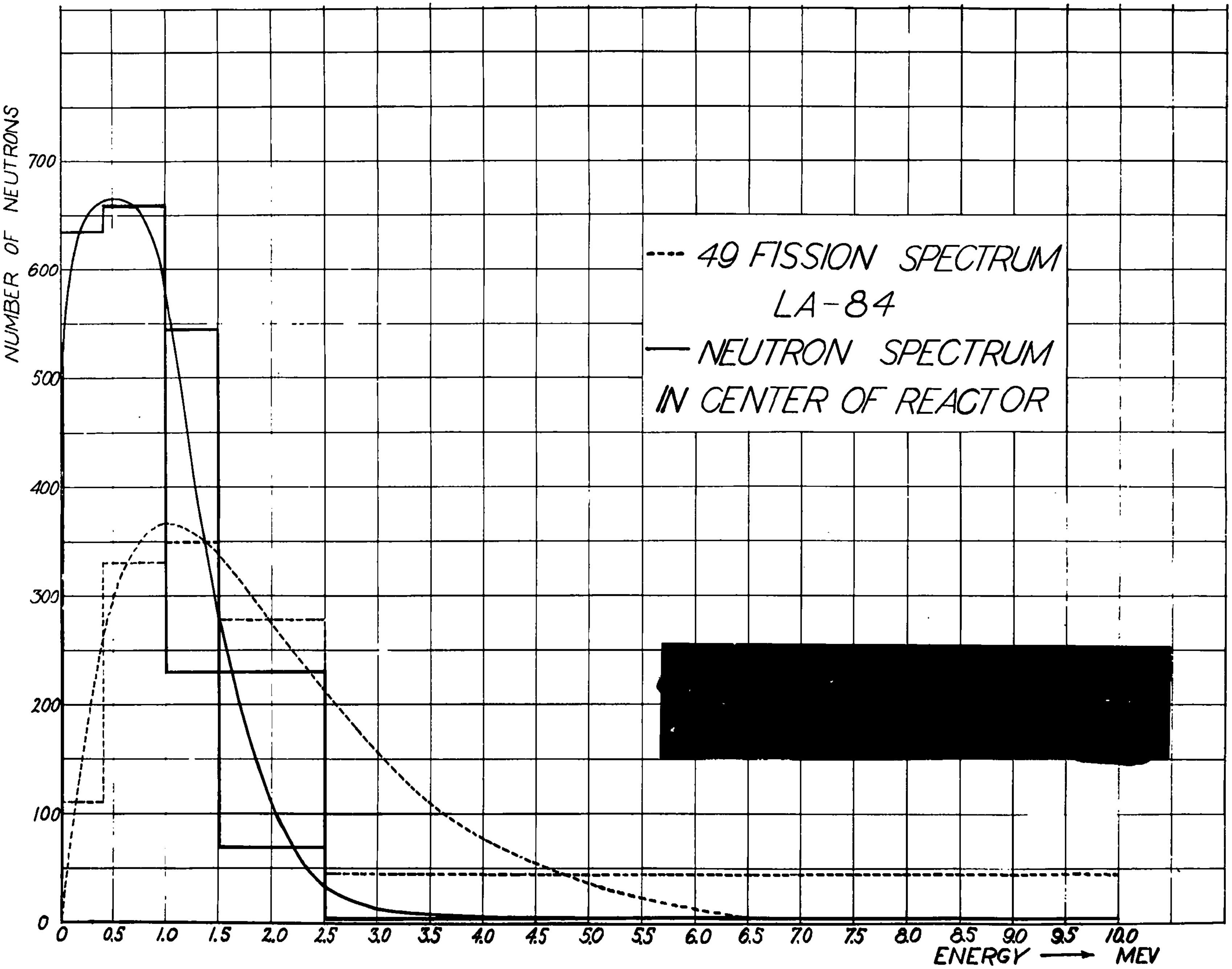

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FIG 3

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