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PHYSICS DIVISION

PROGRESS REPORT FOR THE QUARTER SEPTEMBER, OCTOBER, NOVEMBER 1948

A.M. WEINBERG, DIRECTOR

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PHYSICS DIVISION

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A. M. Weinberg, Director

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PHYSICS DIVISION

QUARTERLY REPORT

SUMMARY

A. M. Weinberg, Director

Personnel Changes

The following have left the Division during the past quarter:

John R. Barnes	
Sergio DeBenedetti	
Hubert M. James	(Purdue University—summer loan)
Paul W. Levy	
Phyllis O. Levy	
Milton C. Marney	
Thomas W. Mulliken	
Henry W. Newson	
Eric Rodgers	(University of Alabama—summer loan)
Thomas A. Read	
Harold C. Schweinler	
Mabel P. Greever	
Vernon T. Underwood	(Transferred to Health Physics Division)
Jerald E. Hill	

The following have joined the Division during the past quarter:

Lorraine S. Abbott	
Neal F. Lansing	(Transferred from Power Pile Division)
Jay C. Pigg	
Marguerite M. Rogers	
Morris F. Phillips	(Transferred from Personnel Section)
H. E. Robertson	(Transferred from Power Pile Division)
Robert R. Hall	(Transferred from Instrument Division)
James Schenck	

Reactor Physics and Reactor Design

Critical experiments with H_2O-Al core and Al and Pb reflectors have been performed. The critical mass with Pb reflector is sufficiently low (2.6 Kg) to make it not unattractive as a possibility in a moderate flux research reactor.

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The high-flux pile project has been re-activated as a joint Argonne National Laboratory and Oak Ridge National Laboratory enterprise. The Oak Ridge project engineer is M. M. Mann, and the chairman of the three-man Steering Committee is S. McLain.

Work continues on the N. N. E. S., Volume III, Reactor Theory, at a slow but steady pace. At present about half of the contemplated 12 chapters have been completed.

Considerable effort is being devoted by the shielding group to improvement of methods for measuring γ-ray attenuations in a shield; emphasis is being placed on the possible use of scintillation counters for γ-ray spectrum determinations. Evidence has been obtained for the fact that the captures in Pb are an extremely important source of γ-rays in Pb containing thermal shields.

Neutron Physics

Efforts to detect coincidences between electrons and protons in the neutron decay experiment are continuing. The coincidence circuit is being rebuilt and should be working soon.

The total cross section of Ni^{60} has been measured on the neutron spectrometer; the thermal neutron scattering cross section is only 2 barns compared to the 26 barn scattering cross section of Ni^{58}.

The Xe^{135} cross section measurement has gotten under way; results will be given in the next quarterly report.

Neutron Diffraction

In cooperation with R. E. Rundle of Iowa State College, the crystal structure of ThD_2 has been determined to be tetrahedral. These measurements represent the start of a systematic study of hydrides, deuterides and carbides of heavy elements. The hydride studies should lead to an accurate value for the n-p range in the triplet state.

The coherent scattering cross section of vanadium has been found to be less than 1/50 of the total scattering cross section—this indicates a very strong spin dependence of the scattering.

Physical Electronics

Some success has been achieved in using an anthracene crystal as a crude spectrometer for measurement of Co^{60} and Na^{24} γ-rays. By using the

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crystal counter in conjunction with a pulse height analyzer, it is possible to determine roughly the shape of the β-ray spectrum from long lived Ru. The corresponding Kurie plot is surprisingly straight near the end-points. The measurement of Cd capture γ-rays with these counters continues.

Much effort was expended toward developing a continuous tape recorder for monitoring the particle density in the air cooling stram of the pile.

Low Temperatures

The division has embarked on a low temperature program which it is hoped ultimately will lead to the achievement of nuclear paramagnetism, i.e., the lining up of an appreciable fraction of nuclear spin. A Collins He liquefier has been ordered and is due to arrive by January 2. The adiabatic demagnetization magnet (25,000 gauss) is under construction. This program is being carried out with the cooperation of Professor J. G. Daunt of Ohio State University.

Van de Graaff Program

A joint Physics-Chemistry Van de Graaf program is well under way. The 2 Mev electron machine which has been on the laboratory grounds for the past two years will be converted into a proton machine—it is hoped that after conversion it will be possible to use it for either electrons or protons. The machine will be housed in the old power house.

Physics of Solids

Experiments on release of fission gas during annealling of irradiated Al-U alloys show that at 700°C all the 10 yr. Kr^{85} comes out of the metallic matrix

Attempts to produce single crystals of uranium have been only partially successful, the largest such crystal being only 1 mm. in diameter.

Experiments on relaxation of strain in U, directed toward understanding of Hanford blistering, indicate that any sudden increase or decrease of length of a slug (resulting from a sudden temperature change) is followed by a slow further decrease or increase of length.

The increase of electric resistance of graphite on pile irradiation on graphite at -78°C (dry ice) is found to be twice as rapid as at room temperature. This indicates that the low temperature exposure tube should be very useful for further studies of this sort.

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Measurements on the effect of radiation on hardness, resistance, and X-ray line width in various metals continue to show that measurable changes in metals following pile bombardment are not at all uncommon.

The semi-conductor work has been devoted to investigation of the behavior of silicon and cuprous oxide rectifiers under pile irradiations. In all cases the rectifying action disappears on bombardment.

Theoretical and Mathematical Physics

The Monte Carlo method continues to show promise as a means for computing neutron distributions in complicated systems. The agreement between Monte Carlo and transport theory computed ages in H_2O is excellent. On the other hand, it appears as though the Monte Carlo method will not be of general usefulness for obtaining the complete solution of partial differential equations.

The theory of bremstrahlung from thick targets has been worked out.

The internal conversion calculation (K shell) is being carried out on the Harvard Mk I machine.

[redacted]

SECTION I—NEUTRON AND NUCLEAR PHYSICS AND VANDEGRAAF

A. H. Snell, Section Chief
S. Bernstein, Associate Section Chief

T. E. Stephenson
J. B. Dial
W. M. Good
C. D. Moak
F. Pleasonton
C. P. Stanford

Neutron Decay Experiment (A. H. Snell, F. Pleasonton)

As noted in the last quarterly report, the search for coincidences between the beta particles and the protons resulting from neutron decay has led to somewhat inconclusive results. The betas are detected in a double Geiger counter and the protons were accelerated and focused upon a secondary electron multiplier. Many fewer coincidences were observed than would be expected from the single counting rate attributable to protons falling upon the multiplier. Two possibilities then arose: (1) the circuits were not functioning correctly, or (2) the neutron has an unexpectedly long half-life, and the counts registered on the multiplier are for the most part not caused by decay protons.

During the past quarter, the coincidence circuits have been studied rather extensively. They were found not to be ideal, in that thyratrons used as pulse shapers in the Geiger channels had firing times which introduced delays of as much as several microseconds into these channels. These delays were sufficient to cause the loss of some coincidence counts.

The delay time depended upon the size of the pulse arriving at the thyratron from the counter. The background counting rate was so high that a considerable number of undersized Geiger pulses could be expected, and therefore the possibility was apparent that such pulses would be delayed too much to give coincidences. Considerable time was spent in efforts to offset these delays in the Geiger channels by introducing compensating delay lines in the multiplier channel. Although runs were taken with delay lines covering the whole interval in which it was expected that the coincidences would be found, any effects which were found were so small that their reality was questionable. Thus in spite of these particular shortcomings of the apparatus, the effect was given a chance to show itself, and it failed to do so.

In our reluctance to accept this as a final answer, we have asked W. H. Jordan to design a new coincidence circuit. This circuit has now been built (through the efforts of R. Hall) and is at present under test. Meanwhile we are trying to improve the performance of the multiplier by installing a radiofrequency heating coil such that the plates can be activated in place in

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the vacuum tank, instead of being evacuated individually in a separate system and then assembled in air. It is hoped that this will effect a better discrimination between proton pulses and the pile background pulses.

Total Cross Section of Ni^{60} (T. E. Stephenson, J. B. Dial, C. P. Stanford, S. Bernstein)

The transmission of a 218.9 milligram sample of NiO containing 97.7% Ni^{60}, 1.9% Ni^{58} and 0.4% of the remaining stable isotopes of nickel has been measured in the energy interval 0.03 ev to 0.5 ev. The total cross section vs energy for the $Ni^{60}O$ is given in Fig. I-1, uncorrected for the water present in the sample. The cross section of $Ni^{60}O$ corrected for the water and Ni^{58} impurities is shown in Fig. I-2. The water content of the sample was 1.17% by weight. This amount corresponds to a ratio of 0.05 H_2O molecules per NiO molecule. Because of the high cross section of water in the energy region covered, the correction for the presence of this small amount of water impurity comes to 40 to 50% of the uncorrected cross section. Consequently, any conclusions with regard to the cross sections of NiO depend strongly upon the accuracy of the water content determination. This measurement was made by Messrs. D. LaValle and P. Westerdahl of the Chemistry Division. They actually weighed a mass of several grams of dessicant material, the weight of which was increased by about 200 micrograms by absorption of the water from the NiO sample. They believe their measurement to be good to ± 20 micrograms, or 10%.

The number of points in the energy region .03 ev to 0.5 ev at which measurements were taken for $Ni^{60}O$ is considerably less than the corresponding number taken for $Ni^{58}O$, reported in ORNL 159. Consequently the details of the fluctuations of the cross section due to crystal interference are not as marked as for $Ni^{58}O$. However, they are present in the data, especially on the water-corrected curve, Fig. I-2, in spite of the much lower scattering cross section of Ni^{60}. The fluctuations in the case of $Ni^{60}O$ appear at roughly the same energy values as for Ni^{58}.

An attempt was made to arrive at a figure for the scattering cross section of Ni^{60} by subtracting the capture cross section of Ni^{60} and the scattering cross section of O. Values of the capture cross section of Ni^{60} were calculated from Pomerance's pile oscillator value of 2.7 barns at 0.025 ev, assuming 1/v variation. Values of the scattering cross section of O were taken from Feld and Goldsmith, R.M.P. Oct., 1947. After making these subtractions it was found that there was very little, if any, cross section

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FIG. I-1

TOTAL CROSS SECTION OF $Ni^{60}O$

UNCORRECTED FOR WATER IMPURITY

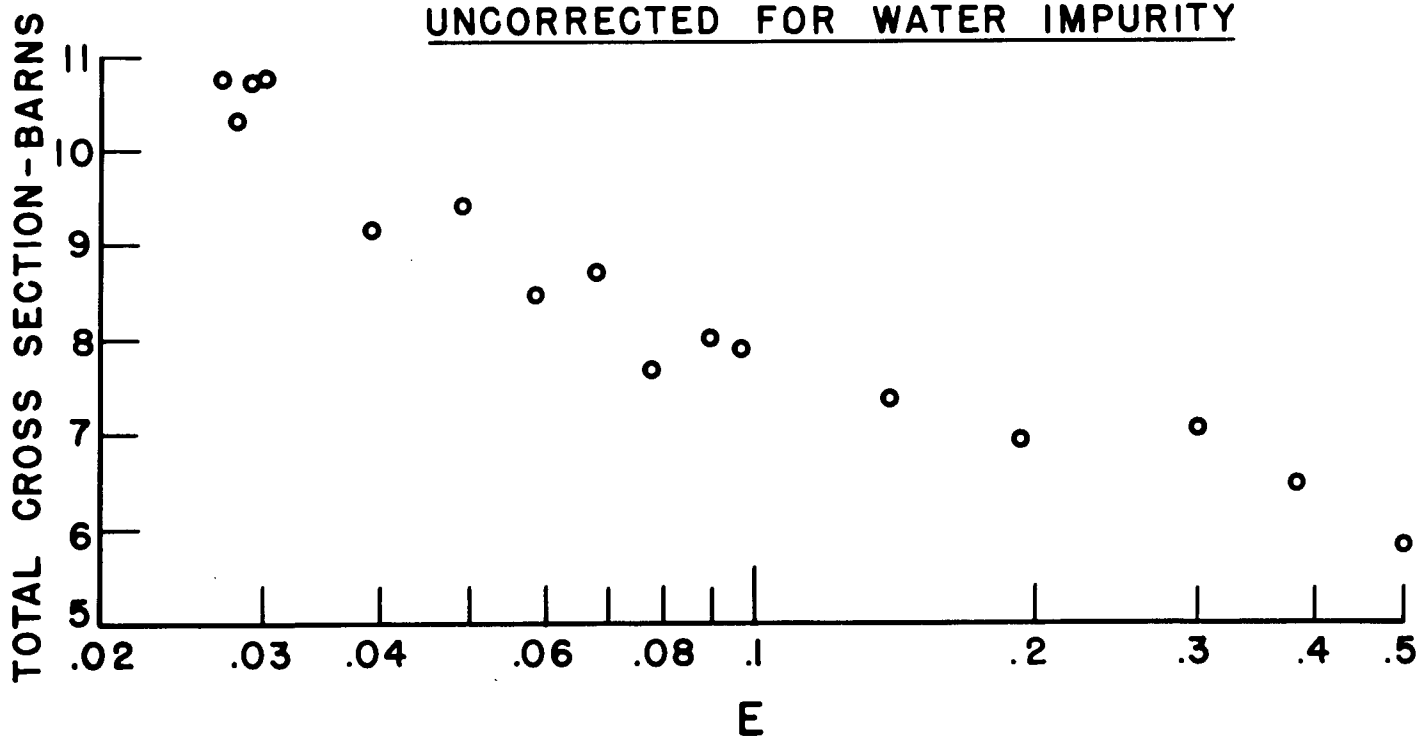

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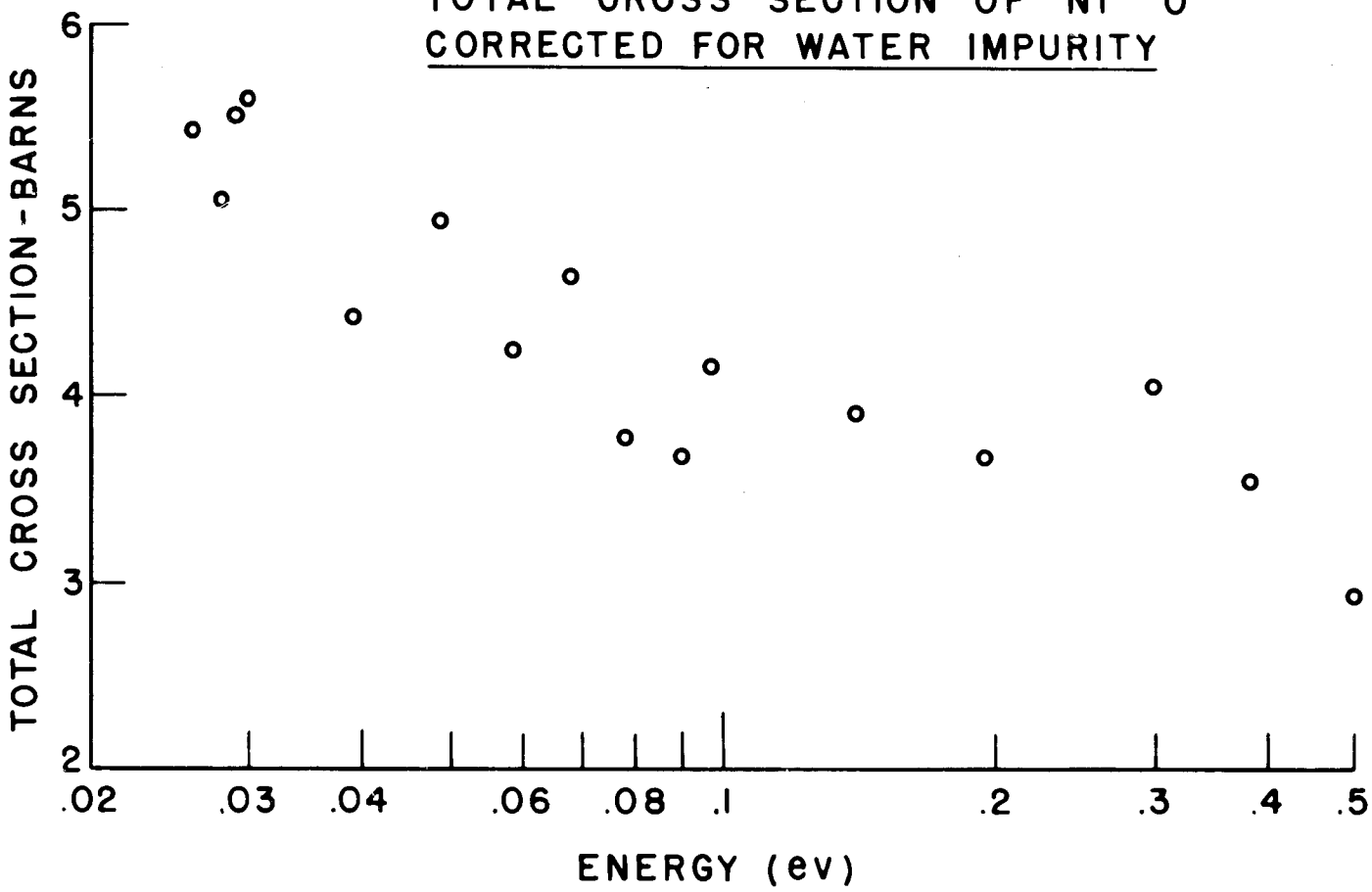
FIG. I-2

TOTAL CROSS SECTION OF $Ni^{60}O$
CORRECTED FOR WATER IMPURITY



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left for scattering by Ni^{60}. This result is obviously in error, however, because the crystal interference peaks are present. Although exact figures for the Ni^{60} scattering cross section cannot be given, because of the great importance of the water impurity correction, it seems fairly certain that Ni^{60} does have an unusually low scattering cross section. These results therefore are substantially in agreement with the preliminary value of 2.0 barns obtained by C. Shull for the coherent scattering cross section of Ni^{60}. In order to obtain more precise measurements of the scattering cross section by this method, a sample of Ni^{60} completely free of any water would be necessary. These results corroborate the conclusion made from the Ni^{58} is the isotope responsible for the anomalously high scattering cross section of normal nickel.

VandeGraaf Program (W. M. Good)

Since the initiation of a VandeGraaf program at ORNL early in September, the major progress that has been made has been in laying the ground work for such a program.

Considerable thought and discussion has been devoted to what equipment would be desirable in a high voltage laboratory in order to carry on investigations with charged particles and with neutrons. It has been decided that a proton accelerator capable of furnishing as large proton currents as possible would be necessary for the contemplated neutron studies. In addition, a 5 Mev accelerator is desired. A survey of the best known p-n reaction with regard to differential cross section, Q values, etc., has led to the conclusion that a VandeGraaf generator is the most desirable instrument for the neutron studies. This conclusion rests very largely on the fact that up to 3 Mev proton energy the D, D reaction gives a rising neutron yield.

The question, how to best start out on the proposed program with the limited past experience available, seemed partially answered with the presence in the Chemistry department of a 2.35 Mev VandeGraaf generator fitted as an electron accelerator. This machine required a building and erection before it could be used by the chemists. A realistic program that could be achieved in something like a year, and that would at the same time provide basic experience for a VandeGraaf group, appeared to be the erection of the 2.35 Mev machine as both a proton and an electron accelerator. The chemists have cooperated in such a program. The immediate objective, the erection of the 2.35 Mev machine as an electron machine is being achieved with their aid. The ultimate objec-

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tive of the Physics Division is the conversion of the instrument to a positive ion or alternatively an electron accelerator.

The generator has been assembled without the pressure tank in a shack behind the physics building and the electron tube will shortly be installed. Electrons will then be available up to a few tenths of a Mev and at currents as high as can be tolerated with limited shielding possibilities. The problem of suitable housing for the machine has been largely solved and suitable quarters have been promised by Feb. 1. Other details on the building and on the erection of the machine as an electron accelerator will be found in the quarterly report of the Chemistry Division. A group in the Physics Division has undertaken the conversion of the machine to a positive ion accelerator. Since the machine was originally designed for rather large currents, the conversion program envisages getting as large currents of positive ions as possible—100 μa. or more.

The difficulties encountered in applying high voltages to an accelerating tube for either electrons or protons are well known. We are not aware that a great deal is known about the nature of the problems encountered with large currents. What is known is that positive ion currents are generally small and there seems general agreement that this is partly due to the gas pressure encountered in accelerating tubes with positive ion sources. The question of low pressures is all the more important with positive ions because of the high rate of ionization associated with masses a few thousand times greater than the electron mass. The most important matter seems to be that of pumping. In machines of recent design, the problem of more efficient pumping has been solved by multiple pumping tubes alongside the accelerator tube. The present 2.35 Mev machine cannot be so treated without a complete redesign. This is due to the M. I. T. construction which makes use of equipotential planes to distribute the voltage down the column thereby getting the maximum possible electrical gradient. It therefore seemed necessary to tackle the pumping problem by pumping the accelerator tube from both ends, one system ofpumps being located under the high voltage terminal.

To incorporate a pumping system under the high voltage terminal, the system taking its power from the charging belt, raises many problems. Some of those that have so far been considered are : (a) Cooling in the high voltage terminal. Part of the heat dissipated by pumps and ion sources is taken care of by windage from the belt. However, for really efficient pumping, even with oil diffusion pumps a cold trap is important. Of course, the periodic introduction of some refrigerant such as liquid nitrogen is distinctly feasible. However, it appears that a glass capillargy of 1 mm diameter could carry enough liquid CO_2

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to maintain temperatures down to -25C by merely allowing it to expand into the pressure tank. This assumes that the insulating medium in the pressure tank is CO_2. The feasibility of this scheme depends first of all on the conductivity of liquid CO_2. Since no figures are available on this, such measurements are about to be made. (b) Power at high voltage terminal. The power for operating pumps, ion source, etc., will be obtained from a permanent magnet, 400 cycle alternator driven from the upper pulley. (c) Space under the high voltage terminal. To accommodate the extra gear of ion source and pumps, the present high voltage dome will be replaced by one which will likely be about five feet high. The pressure tank will be extended a like amount.

Because of the relatively large potential gradient, about 420 KEV/ft in the present machine, it seemed advisable to go along with the M. I. T. people in the choice of materials for the positive ion tube. They employ 707 Corning glass with stainless steel electrodes. The tube is cemented together with vinyl cement at about 200°C. At the same time, Herb and Company have demonstrated the superiority of a re-entrant type of accelerating electrode. We have therefore chosen to build a tube after the design of Herb but of 707 Corning glass with stainless steel electrodes bonded together with vinyl seal cement.

An ion source is presently under construction and when completed will permit a study of some of the problems associated with the pumping. The materials for the accelerating tube are on order.

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SECTION II—NUCLEAR PHYSICS, NEUTRON DIFFRACTION, LOW TEMPERATURES

E. O. Wollan, Section Chief
C. G. Shull, Associate Section Chief

E. C. Campbell
T. E. Fitch
J. W. T. Dabbs
J. Schenck
K. L. Robertson
H. Pomerance
L. D. Roberts
C. D. Moak
W. A. Strauser

Neutron Diffraction (C. G. Shull, E. O. Wollan, R. E. Rundle*, W. A. Strauser)

A. Diffraction Studies of VC and V

A sample of VC was received from Argonne and the neutron diffraction pattern was obtained for this. The pattern is the characteristic NaCl-type of pattern, but the intensities are such as to indicate a very small scattering amplitude for vanadium. From the intensities of the (111) and (200) reflections one obtains

$$\alpha\ (f_C - f_V) = 0.615 \times 10^{-12}\ \text{cm}$$

$$\alpha\ (f_C + f_V) = 0.628 \times 10^{-12}\ \text{cm}$$

where α is a temperature correction factor essentially constant for these two reflections. Solution of these equations, coupled with the fact that f_C should be about 0.64×10^{-12} cm, indicates that the vanadium amplitude is extremely small so that

$$\sigma_V^{coh} < 0.1\ \text{barn}.$$

The algebraic sign of the vanadium scattering amplitude, or phase of scattering, is uncertain because of its very low numerical value. Since the total scattering cross section for vanadium is about 5 barns and since this element is monoisotopic, the very low coherent scattering cross section indicates a very pronounced spin dependence in the scattering of neutrons by this nucleus.

As a check on this cross section a sample of vanadium metal was examined and found to produce no observable neutron diffraction peaks. On the other hand, X-ray diffraction studies showed a normal vanadium pattern with some oxide impurity. An upper limit to the cross section was evaluated from the neutron pattern and this agreed with the value established in the VC study.

* Iowa State College

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B. Diffraction Studies on Deuterides and Carbides of Uranium and Thorium

A start has been made on the neutron diffraction study of various hydrides, deuterides and carbides of heavy metal elements in collaboration with the crystallographic group at the Iowa State Atomic Research Institute. X-ray diffraction analysis of such compounds is generally incomplete because of the great difference in scattering power for the heavy element and the lighter centers so it was hoped that the neutron study would resolve some of the ambiguities. Aside from the crystallographic interest in these compounds, additional data on the coherent scattering properties of hydrogen and deuterium are to be welcomed because of their nuclear physics implications.

The Iowa State group has prepared to date samples of Th, ThO_2, ThD_2, ThC_2, UC, UC_2 and UD_3. Neutron diffraction data for all of these have been obtained but the data interpretation for the ThC_2, UC_2 and UD_3 is not considered complete at this writing and a discussion of these will be given in a later report.

(1) Th and ThO_2 - These materials were used for determining the coherent scattering cross section and the relative phase of scattering of thorium. From the diffraction peak intensities, the coherent scattering cross section for thorium was determined to be 12.8 barns and this agrees excellently with the total scattering cross section of 12.8 barns as determined from a transmission measurement through a solid block of metal. One would not expect a difference between these two values since there can be no isotopic or spin incoherence in thorium scattering. The pattern obtained for ThO_2 confirmed the CaF_2-type structure and showed the phases of scattering of thorium and oxygen to be the same. Thus the thorium scattering amplitude is of positive sign.

(2) ThD_2 - X-ray diffraction examination of this material shows the metal atoms to be located on a body centered tetragonal structure, but no information on the deuterium (or hydrogen in ThH_2) positions is available. The neutron diffraction pattern obtained over the angular region from 15° to 60° is shown in Fig. II-1. This interval contains 17 possible reflections for neutrons of our wavelength (1.06 angstroms) and these should suffice to establish the structure.

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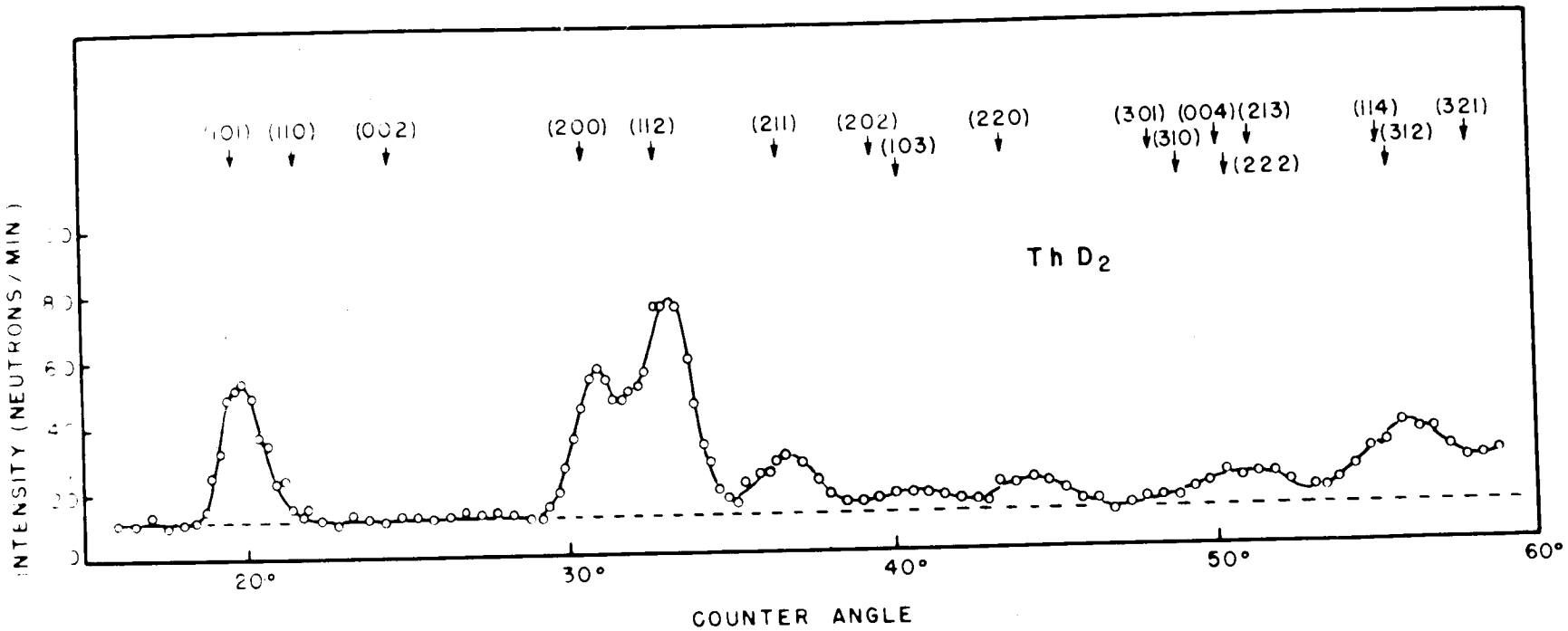

FIG. II-1

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Three plausible structures for describing the deuterium locations have been suggested by considerations of the available space between the already established thorium positions. The coordinates for the atoms in these three structures are given as:

(a) "Bridge Structure"

Th: $000;\ \frac{1}{2}\frac{1}{2}\frac{1}{2}$

D: $\frac{1}{2}00;\ 0\frac{1}{2}0;\ 0\frac{1}{2}\frac{1}{2};\ \frac{1}{2}0\frac{1}{2}$

(b) "Tetrahedral Structure"

Th: $000;\ \frac{1}{2}\frac{1}{2}\frac{1}{2}$

D: $\frac{1}{2}0\frac{1}{4};\ 0\frac{1}{2}\frac{1}{4};\ 0\frac{1}{2}\frac{3}{4};\ \frac{1}{2}0\frac{3}{4}$

and (c) "Octahedral H_2-Groups"

Th: $000;\ \frac{1}{2}\frac{1}{2}\frac{1}{2}$

D: $x\bar{x}\frac{1}{2};\ \bar{x}x\frac{1}{2};\ \frac{1}{2} + x,\ \frac{1}{2} + x, 0;\ \frac{1}{2} - x,\ \frac{1}{2} - x, 0$

with $x \sim 0.1$

Structure factors have been calculated for these three models and, using earlier obtained cross section data for thorium and deuterium, the powder pattern intensities to be expected for each model have been calculated. These calculated intensities along with the experimental ones are summarized in Table I. It is seen that some of the peaks are not resolved and in these cases the total intensity in the resolved group has been used for comparison with the sum of the calculated intensities for the individual peaks.

A comparison of the experimental and calculated intensities for the three models shows definitely that the "Tetrahedral Structure" is the correct one. The wide variation in the calculated and experimental intensities permits an easy selection of this model. The calculated intensities have been derived without the use of temperature correction factors since these are unknown for this compound. Application of the temperature correction factors would decrease the calculated values only slightly for the low index reflections and somewhat more for the higher index reflections. This descrepancy between the experimental and the calculated intensities of the tetrahedral model is to be noted in Table I where application of the

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temperature corrections would improve the agreement. Thus it is established that each deuterium atom is located at the center of a tetrahedron having four thorium atoms at its corners.

Once the structure of the crystal has been established, the above procedure can be reversed and the pattern intensities can be used to evaluate the thorium and deuterium coherent scattering cross sections. All of the pattern peaks for this structure possess structure factors (which are proportional to the square root of the intensities) of either f_{Th}, $f_{Th} + 2 f_D$ or $f_{Th} - 2 f_D$. The last named peaks are too weak for measurement. From the measured intensities, the structure factors for the other reflections have been evaluated numerically and these are graphed in Fig. II-2 as a function of $\sin^2\theta$ where θ is one-half of the scattering angle. The temperature corrections are of the form $e^{-K \sin^2 \theta}$ and hence a semi-logarithmic graph should show to a first approximation a linear relationship between these variables. By extrapolation to zero scattering angle (no temperature correction) the true scattering amplitudes are obtained. The intensity in the (220) peak is smaller than the others and it has not been weighted as heavily as the others in drawing in the line for the $f_{Th} + 2 f_D$ amplitudes. Further justification for such a procedure is evidenced in that the slopes of the two lines should be the same to a first approximation according to X-ray studies on thermal oscillation amplitudes.

The extrapolated amplitudes yield

$$f_{Th} = 1.015 \times 10^{-12} \text{ cm}, \quad \sigma_{Th}^{coh} = 12.9 \text{ barns}$$

$$f_D = 0.64 \times 10^{-12} \text{ cm}, \quad \sigma_D^{coh} = 5.1 \text{ barns}.$$

This thorium cross section agrees well with that obtained from the above studies on Th and ThO_2 whereas the deuterium cross section is about 20 percent higher than that obtained with NaD. The latter sample was known to possess considerable impurity so that the present deuterium cross section value is probably to be preferred. Further study on this is indicated and will be carried out with other materials as they become available.

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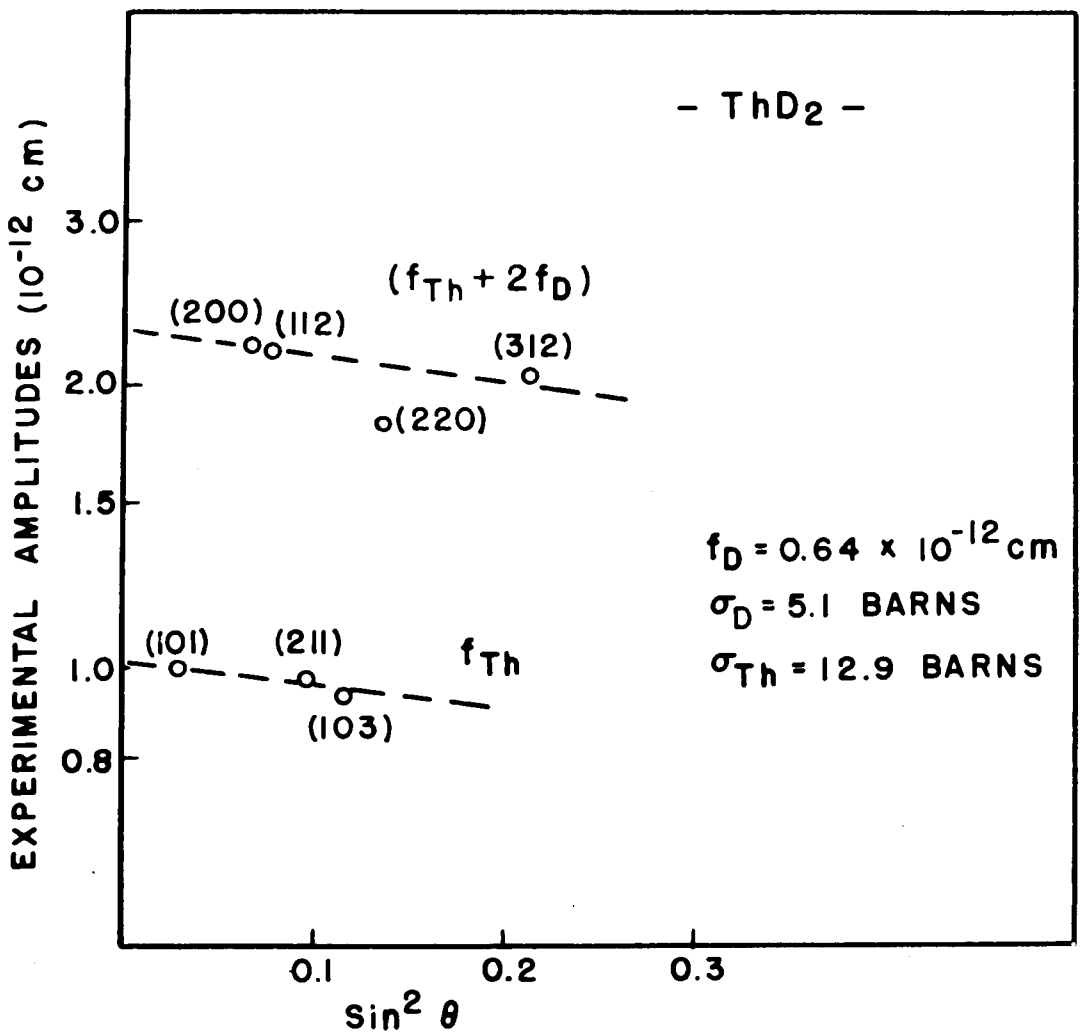
FIG. II-2


- ThD2 -
EXPERIMENTAL AMPLITUDES (10-12 cm)
3.0
2.0
1.5
1.0
0.8
(fTh + 2fD)
(200)
(112)
(312)
o(220)
(101)
(211)
fTh
(103)
fD = 0.64 x 10-12 cm
σD = 5.1 BARNS
σTh = 12.9 BARNS
0.1
0.2
0.3
sin2 θ

[redacted]

TABLE I

NEUTRON DIFFRACTION DATA FOR ThD_2

Reflection	Experimental Intensity	Calculated Intensities		
		Tetrahedral	H-Bridge	H_2-Molecule
101	322n/4min	332	332	3
110	10	2	2	421
002	10	1	245	244
200	344	325	325	130
112	586	571	2	382
211	191	207	207	108
202	74	2	410	164
103		87	87	1
		89	497	165
220	125	173	174	47
301	181	65	65	118
310		1	1	33
004		69	69	69
222		1	273	48
213		117	117	61
		253	525	329
114	429	1	1	159
312		474	2	55
		475	3	214

using $f_{Th} = 1.01 \times 10^{-12}$ cm

$f_D = 0.57 \times 10^{-12}$ cm

[redacted]

[redacted]

C. Note on Structure of Ice

In the May quarterly report we discussed our measurements of the diffraction of neutrons by heavy ice and we compared these measurements with a number of possible structures. The data were found to agree best with what we referred to as the half hydrogen model in which half the scattering amplitude of each deuterium nucleus was taken at a distance of 0.96 Å along each tetrahedral line joining an oxygen to its nearest neighbors. It was suggested that this half hydrogen model might be considered as approximating the Bragg scattering which would be given by the Pauling model in which the hydrogens would spend half their time at each of these sites with two hydrogens always located near a given oxygen. It has since been pointed out to us by H. M. James that the half hydrogen model which we had considered as an approximate solution to the Pauling dynamic model is indeed the exact solution for the Bragg reflected part of the total scattering. This can be seen if one considers the lattice as possessing a substitution disorder in which half of the sites are unoccupied and hence have zero scattering amplitude associated with them. The average scattering amplitude per hydrogen will then be

$$\frac{f_H + 0}{2} = \frac{f_H}{2}$$

or just the half hydrogen model considered. The contribution to the Bragg scattering cross section by a molecule will be $4[\ 4\pi(f_H/2)^2\ ] = 4\pi f_H^2$, while the total scattering must be $2[\ 4\pi f_H^2\ ]$. The difference between the total and Bragg scattering cross sections will equal $4\pi f_H^2$ and this will then appear as diffusely scattered radiation. The distribution of this diffuse scattering has not been studied in our experiments.

Our results, in which the Bragg scattering is found to agree well with the half hydrogen model, can then be taken as strong evidence for the correctness of the Pauling dynamic structure of ice. The entropy arguments of Pauling also support this structure. A complete publication of this work will be made in the near future.

Cloud Chamber Studies of Capture γ-Rays (C. D. Moak, J. W. T. Dabbs)

About 50,000 photographs have been made on the capture gamma rays from Cl and a short series of photographs has been made on the gamma from fission and capture in U^{235}. The photographs have not yet been analyzed.

[redacted]

[redacted]

Pile Oscillator (H. S. Pomerance)

Some additional measurements of thermal neutron capture cross sections are reported.

Element	Capture Cross Section	Sample
Al	.22 barns	2S
	.22	spectroscopic standard
As	4.06	elemental
	4.23	oxide
Br	6.95	sodium bromide
	6.45	bromine liquid
Cl	31.8	potassium chloride
	34.3	lead chloride
Cr	2.84	metal
	2.82	oxide
Hg	328	mercuric iodide
	337	mercuric oxide
	358	mercuric oxide + diluent
Mo	2.40	metal
	2.40	oxide
	2.58	from isotope measurements
Sb	5.16	oxide
	5.37	metal
Yb	35.7	oxide
Zr	1.01	metal

Low Temperature Program (L. D. Roberts, J. W. T. Dabbs)

Notice has been received that the Collins liquefier has been completed and tested at Cambridge. Preparations are being made for its installation and we expect it to arrive before December 20th. The adiabatic demagnetization magnet and coils are in the shop; completion is scheduled for February 1, 1949.

We have grown a number of large single crystals of Chromium Potassium Alum for use in the demagnetization experiments.

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[redacted]

SECTION III—MATHEMATICS AND COMPUTING

A. S. Householder, Section Chief

M. R. Arnette	E. A. Forbes
R. R. Coveyou	M. K. Hullings
R. Crook	K. M. Martin
N. M. Dismuke	B. I. Spinrad

The major activities of the Section for the past quarter fall under four main headings.

The computation of internal conversion coefficients for the K shell has been coded for the Mark I Computing machine at Harvard University, and is now almost finished. This coding has been done by John Harr and Peter Strong of the Harvard Computation Laboratory in consultation with B. I. Spinrad of O.R.N.L. Important suggestions concerning the coding have been made by R. R. Coveyou and Nancy Dismuke.

In preparing the problem for the machine, it was decided that series expansions of the Γ- functions of real and complex arguments would be required. The following expansions were therefore obtained by Nancy Dismuke and B. I. Spinrad.

1. z real. $z - 1.5 \equiv x \qquad |x| \leq \frac{1}{2}$

$$\Gamma(z) = .886227 + .032341\,x + .414808\,x^2 - .107453\,x^3 + .14483\,x^4 - .07529\,x^5 + .05664\,x^6 - .0494\,x^7 + .0344\,x^8$$

The maximum error in this expansion is less than 2×10^{-6}

2. z complex. $z - 1 - .9i \equiv x \qquad |x|^2 \leq .45$

$$\Gamma(z) = .552328 - .175146\,i + [\,.187179 + .564485\,i\,]\,x + [-.209734 - .177030\,i\,]\,x^2 + [\,.306209 + .055265\,i\,]\,x^3$$

[redacted]

[redacted]

$$
\begin{aligned}
&+ [-.182805 + .138412\, i]\, x^4 \\
&+ [\ .045734 - .162156\, i]\, x^5 \\
&+ [\ .054905 + .115887\, i]\, x^6 \\
&+ [\ .086813 - .037404\, i]\, x^7 \\
&+ [\ .066567 - .021762\, i]\, x^8 \\
&+ [\ .026013 + .044876\, i]\, x^9 \\
&+ [-.007855 - .037629\, i]\, x^{10} \\
&+ [\ .007822 + .037553\, i]\, \frac{x^{11}}{z}
\end{aligned}
$$

For most of the region, the error in this expansion is less than 2×10^{-6}. There are regions on the border of the region of expansion (generally, those points for which $|z|$ is smallest) where, however, the error is 2×10^{-5}.

Theoretical studies and applications of the method of stochastic estimates ("Monte Carlo") have been carried on by Householder, Coveyou, and others. M. K. Hullings and M. R. Arnette have spent most of this time at Y-12 helping to run the computations on the IBM there, and incidentally, gaining familiarity with the machines themselves.

Spinrad, assisted by Buford Carter at K-25, has worked out efficient techniques for numerical solution of certain partial differential equations, in particular, two-group critical calculations, on IBM equipment.

A sample one group problem has been completed to test the method, and a two group problem of interest to the critical experiments group is now being computed. This problem is that of determining the fluxes and critical conditions of a square core in a square reflector.

Householder has been working with the Health Department and with members of C. C. Hurd's statistical group at K-25 on two rather extensive statistical analyses for the Health Department at ORNL. One of these is a correlation analysis of dispensary visits; the other is a study of leucocyte counts. The latter problem reduces to a series of analyses of variance. The other problem is fairly straightforward as a statistical problem, but derives its complexity from the large number of independent variables, requiring the inversion of a laxge matrix.

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Stochastic Estimates (R. R. Coveyou, K. M. Martin, R. Crook, E. A. Forbes, A. S. Householder)

Calculation of the space and energy distributions in H_2O from 25 Kev have been completed. Distributions in graphite are now being calculated. This is the work being done at Y-12.

The method had been suggested as suitable for an attack on partial differential equations. Further consideration, however, indicates that this is true in a very limited sense only. If a solution of a partial differential equation is required in numerical form, then one must somehow construct a table of functional values against selected points within the region over which the function is defined. The number of points at which the tabulation must be made is essentially an exponential function of the number of independent variables. This is intrinsic to the equation and not characteristic of the method of solution.

The case is somewhat different with such problems as the age problem. Here there enter certain variables which are of no interest to the result (the direction cosines, the variables characterizing the types of scatterers, and the initial energy in the case of a spectrum), though they do affect this result. When classical numerical methods are employed, each additional variable multiplies the labor by a substantial factor, whether or not the variable appears in the result. This is not so, however, when stochastic estimates are made. In effect, an auxiliary variable which does not occur in the solution merely enters into the distribution function characterizing the population from which the random selections are to be made. It adds to the labor but does not multiply it by a factor. Thus the most useful range of application for the method appears to be in the realm of integral equations and of integro-differential equations.

However, von Neumann has pointed out a useful application of the method to differential equations. In principle the method generally provides a sample of any size which may be regarded as having been selected at random from a population whose distribution is the function being sought. If the sample is of sufficient size, then its histogram, approximately smoothed, may be taken as approximating to the distribution of the unknown, infinite population. It may be, however, that one does not need the entire distribution, but is interested only in making a random selection, or a finite number of random selections, from this distribution. Such selections may be required as a step in building up some other distribution.

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A case in point is the random selection of a number from an exponential distribution. This is required for the determination of a free path in the age problem, and it can be effected by making an appropriate sequence of drawings of random numbers uniformly distributed on the unit interval. We proceed as follows:

The number y which is to be drawn from an exponential distribution we write in the form k + x, where k is an integer, and x a decimal. We draw in succession the numbers $x_0, x_1, \ldots\ldots x_n, x_{n+1}$ from the uniform distribution and stop when for the first time it is true that $x_{n+1} > x_n$ (if $x_1 > x_0$, then n=0, and we stop there). If it happens that n is an even number, then k = 0 and $x = x_0$. If n is odd we form a new sequence $x'_0, \ldots\ldots x'_{n'+1}$, where, again n′ is the smallest integer for which $x'_{n'+1} > x'_{n'}$. If n′ is even, then k = 1 and $x = x'_0$. If n′ is odd, we form another sequence. Ultimately we shall have k + 1 sequences, possibly k = 0, of which the first k are such that each n is odd whereas in the next the n is even. Then $y = k + x_0^{(k)}$ where $x_0^{(k)}$ is the first term in the first sequence with an even n. The y thus found is a random selection from a population whose distribution satisfies the differential equation d u/d y + u = 0. In this sense we may say the equation is "solved." Similar processes yield the "solutions" of other equations. Such processes and the associated distributions are being studied.

On the application of the process to integral equations, some relatively simple ones are being used as test problems for an assessment of the results and comparison with standard methods. In particular about 4000 Δz's have been accumulated for collision densities of thermal neutrons in a slab. These can be accumulated without regard to the source or to the slab dimension. For an isotropic source at a boundary the collisions are located by a simple summation of successive Δz's, continued to transgression of the boundary. For non-isotropic sources the first collision has to be located by a separate operation, subsequent collisions being located by similar summations.

Statistical Analyses for the Health Division (M. K. Hulling, A. S. Householder)

The first of these is an attempt to determine to what extent, if any, the frequency and type of dispensary visit is correlated with a number of variables such as job classification, race, sex, education, etc. In order to handle the qualitative variables it is necessary to introduce a formal variable, taking on the values 0 and 1 only, for each category. This gives a total of about 50 independent variables to be correlated. The numerical operations are being performed on IBM by C. C. Hurd's group at K-25, but even with the IBM the operations are quite formidable

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with such a large matrix. The matrix is therefore being normalized to reduce each diagonal element to unity. It is hoped that by simple inspection one can then eliminate a substantial number of the variables. However, even that matrix which remains is apt to be quite large. Several possible attacks have suggested themselves, and the selection must await the examination of the matrix. Fortunately the inversion of large matrices is a subject that has received much study recently along with technical advances in the construction of computing machinery.

[redacted]

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Age Calculations (M. R. Arnette, M. K. Hullings, E. A. Forbes, K. M. Martin, Phyllis Johnson (Y-12), A. S. Householder)

In the previous Quarterly Report is an outline of results of a stochastic study of 100 neutrons starting at 10 Mev from a plane source in water. A more detailed discussion is contained in the report ORNL-142. For this small sample the age to 1 Mev was too small whereas the age to lower energies was too large, the curve showing an upward concavity near the source energy when age was plotted against the lethargy u.

Using IBM equipment at Y-12, 1000 neutrons were started at 25 Kev and traced to 1.3 ev. The routine of calculation, and the table of cross sections were the same as for the 100 neutrons. This particular study was undertaken for the purpose of comparing computed distributions with experimental measurements being made by P. R. Bell. In this case the variation of age with energy showed no anomaly and was, in fact, almost strictly rectilinear in lethargy. Moreover the age extrapolated at thermal agrees very closely with that calculated by Nancy Dismuke and M. Ruth Arnette (Mon P-219) using an approximate analytic formula. Nevertheless the age at 1.44 ev was substantially lower (by about 40%) than that measured by P. R. Bell. This discrepancy could be due to faulty cross section measurements, or it would be due to an underestimate of the true source energy. It appears that agreement might be obtained by assuming a source at about 35 Kev, and it is proposed to repeat the calculation on this basis.

The accompanying tables summarize the results of the calculations. The σ's are all estimated from the distributions themselves. The u-distributions at higher collisions are truncated, since the neutrons were followed only to 1.3 ev. This accounts in part for the fluctuation in the third moment. All moments were about the mean.

Age measurements in graphite made by J. E. Hill and L. D. Roberts fail to agree at near-source energies with computations made from Placyek's analytic expressions. Consequently 1000 neutrons, slowed down to 1/100 of initial energy in graphite, are being calculated, also at Y-12. This machine work is almost complete and moments of the energy distributions are now being calculated. Since the graphite scattering cross section is constant it is not necessary to specify the initial energy, nor even the length of the mean free path, in the machine work.

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The formulae are essentially the same as those used in the water calculation, but some steps are not needed. In particular, there being only one scattering medium, and no absorption, a single random number is sufficient for the energy drop at any collision, and this, together with another random number for the azimuth, gives the new direction cosine. Simple quadratic interpolation formulae make it possible to get the increment in lethargy from the random number, and the value of κ required for the angle of scattering, without resort to tables of logarithms or to a square-rooting.

A suggestion of Spinrad's concerning analysis of water distributions from Monte-Carlo techniques is now being investigated by M. K. Hullings. Briefly, it consists of estimating flux rather than collision density from the results of the stochastic processes. To do this, one prepares a chart listing the region in z traversed by a neutron whose energy is in a pre-assigned "detector range," together with the reciprocal cosine of the angle the path of flight made with the source plane. This latter is assumed to be proportional to the "detection probability" of the neutron. Then, one adds up all the reciprocal cosines corresponding to flights which cross any given z. This is taken to be proportional to the flux. It is hoped that this analysis will throw some light on the correct interpretation of Monte-Carlo data in water.

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TABLE I

Statistics of z-distribution in H_2O from 25 Kev (in cm^2)

E	μ_2	$\sigma\mu_2$	Kurtosis
10^4	1.19	.09	3.93
3×10^3	1.99	.13	2.19
10^3	2.72	.15	1.24
3×10^2	3.56	.20	1.28
10^2	4.25	.23	1.05
30	5.05	.28	.98
10	5.80	.30	.64
3	6.76	.33	.43
1.3	7.39	.37	.48

TABLE II

Statistics of u-distribution in H_2O from 25 Kev

Collision	N	$\bar{u}$	σ_u	μ_2	$\sigma\mu_2$	μ_3	$\sigma\mu_3$
1	1000	.93	.03	.868	.07	1.65	.23
2	1000	1.86	.05	2.08	.14	4.25	.60
3	1000	2.75	.06	3.07	.19	6.46	.87
4	995	3.67	.06	3.93	.19	6.33	.74
5	992	4.56	.07	4.79	.25	8.36	1.35
6	976	5.33	.07	4.98	.21	5.06	.81
7	946	6.10	.07	5.15	.23	4.15	1.00
8	901	6.74	.07	4.83	.20	.94	.90
9	830	7.30	.07	4.43	.19	-.42	.94
10	735	7.82	.08	4.58	.28	2.3	1.75

$u = \ln (25000/E)$

[redacted]

[redacted]

Fission Spectrum

In view of the new fission spectrum data and the fitted curve representing these data presented by Watt at the Chicago information meeting, a curve obtained last year by Spinrad on the basis of older experimental data might be of interest. The expression is

$f(z) = \sinh[6.85\sqrt{E}] \cdot e^{-(5.02 + 2.52E)}$, where E is measured in Mev.

In addition to the work outlined above, members of the Section have worked on the following problems.

Compilation and analysis of nuclear cross section and fission data (N. Dismuke).

Numerical evaluation of an improper definite integral (R. Crook) for M. E. Rose.

Computations relating to the slowing down of neutrons in graphite (R. Crook) for L. D. Roberts and J. E. Hill.

Shielding calculations (R. Crook) for F. H. Murray.

Calculation of energy spread in a reflected beam from a bent crystal spectometer (E. A. Forbes) for M. M. Shapiro.

Integration of neutron distributions from a point source to obtain distributions from a plane source (E. A. Forbes) for L. D. Roberts.

Calculation of critical masses of lead and beryllium reflected reactors (E. A. Forbes) for B. Spinrad and A. B. Martin.

Calculation of structure factor in ice (E. A. Forbes) for E. O. Wollan.

Numerical evaluation of a definite integral (K. M. Martin) for D. Nicoll of the Technical Division.

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[redacted]

SECTION IV—PHYSICAL ELECTRONICS

W. H. Jordan, Section Chief
P. R. Bell, Associate Section Chief

T. E. Cole	J. E. Francis
R. C. Davis	G. G. Kelley
E. P. Epler	J. C. Gundlach
W. E. Jones	F. K. McGowan

A sizable fraction of the efforts of the entire group during the past quarter has been devoted to the particle problem. Early estimates of the total activity of particles going up the pile stack were made by exposure of sticky patches in the air ducts. From this evolved a device for continuous monitoring of the particle activity. It consists in part of a long tube protruding into the air duct. A reel of waxed tape is threaded down the tube, over a roller in the air stream, and back up the tube. It then passes by a thin window Geiger counter which is connected through a counting rate meter to a Brown recorder. One of these instruments has been in use for the past month; another is under construction. A more detailed description of this work will be found in ORNL 197.

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Three-Fold Coincidence Counter (W. H. Jordan, J. C. Gundlach)

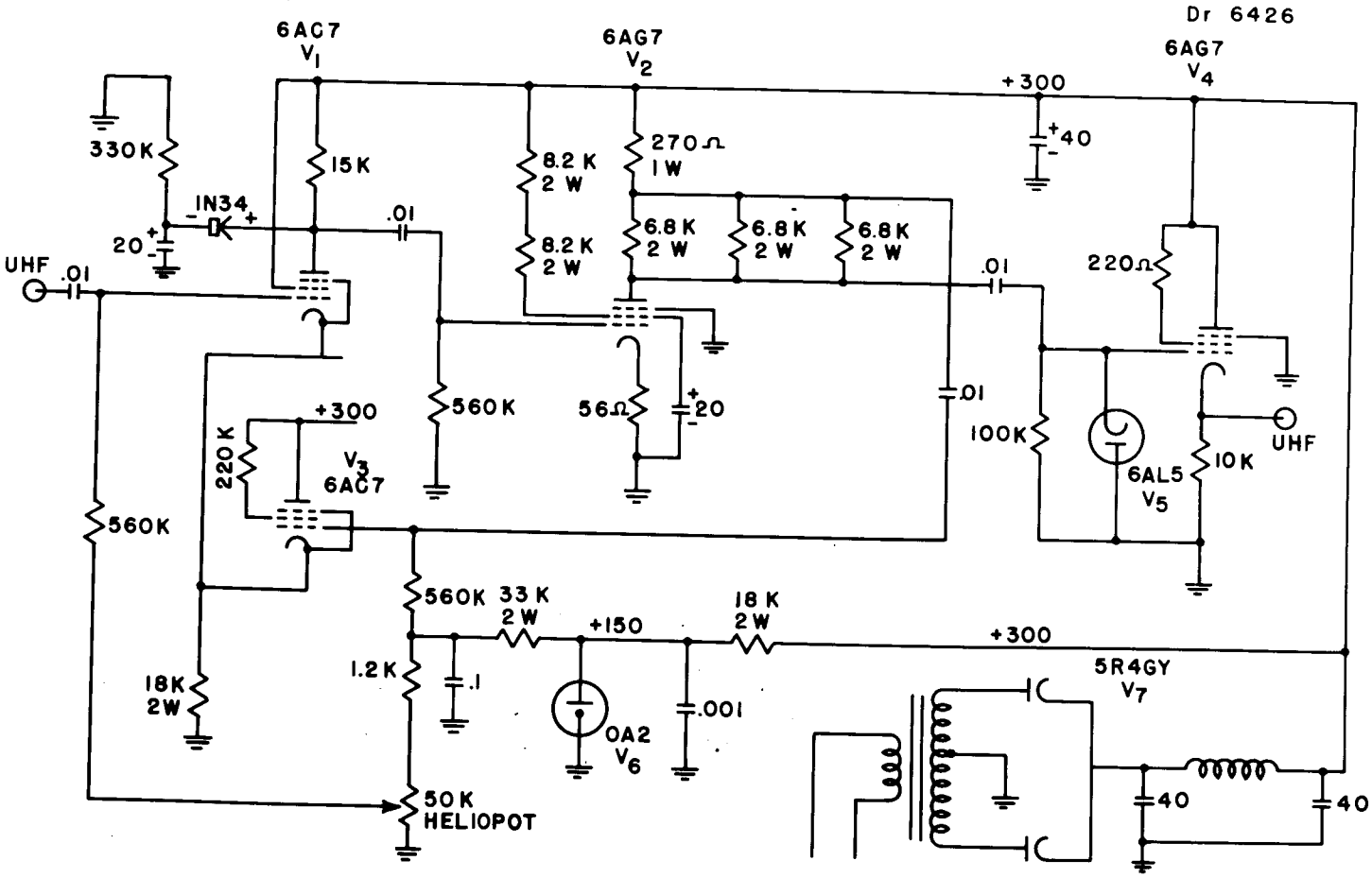
Some months ago a circuit was designed and constructed for Snell's use in measuring the neutron half-life. It was designed to measure coincidences between the protons observed by the multiplier tube and electrons which traverse two Geiger tubes. Experience with this circuit indicated several desirable modifications, so that a completely new circuit has been constructed. The delay between the primary electron and the coincidence pulse has been reduced to one or two tenths of a microsecond. This was accomplished by replacing the 2D21 pulse shaper by a multivibrator, and providing sufficient gain between the Geiger tube and the multivibrator so that it will be triggered at the beginning of the Geiger discharge. (See ORNL-159, p. 36.)

In order to search for coincidence counting rates that are only a fraction of the random rate, it is necessary that the random rate be accurately measured and held as nearly constant as possible. As an aid in accomplishing these objectives two things have been done. First, the resolving time has been held very nearly constant by using delay-line controlled multivibrators to produce pulses of constant length. Second, the random rate is measured at the same time as the true rate. This is done by splitting the pulse from the Geiger tube into two channels, delaying the pulse in one channel by ten microseconds, and then observing the coincidences from each channel with the undelayed pulses from the multiplier. Coincidences from the delayed channel are random coincidences; from the other channel one should count random plus true coincidences.

Capture γ-Rays with Scintillation Counter (J. E. Francis, W. H. Jordan, P. R. Bell)

The work reported by DeBenedetti and Rogers in the last quarterly report is being continued. The curves shown there are integral curves of pulse height versus amplitude; these can be used for end point determination, but the derivative is required for information as to the complexity of the gamma ray spectrum. While one can get a differential curve from the integral curve, the data can be obtained much more quickly by use of a single or multi-channel analyzer. A simple single channel amplifier has been built and is shown in Fig. IV-1. Stages V_1, V_2, and V_3 make up a feedback amplifier with a gain of 10. It does not amplify until the incoming pulses reach

[redacted]



PULSE HEIGHT SELECTOR
FOR DRIVING 2 SCALERS
AMPLIFIER GAIN ≅ 10

FIG. IX-1

[redacted]

a certain peak level, which may be varied between zero and 85 volts by the 50K heliopot. Pulses which exceed this level by as much as 85 volts will still not draw grid current. The amplified pulses are connected to two scalers. One scaler is set to count all pulses larger than say two volts. If the other scaler is then set to count pulses that are 22 volts high, then only pulses that lie in a channel of two volts width will be counted on the lower scaler but not on the upper.

Calibration runs have been made on Co^{60} and Na^{24}. Fig. IV-2 shows the differential counting rate from Na^{24} with three different channel widths. The lower scaler was set at 7 volts, the upper at the values indicated for each curve. In spite of the statistical fluctuations of the multiplier tube, the narrow channel shows more detail. It is known that Na^{24} emits two gamma rays of equal numbers and of energies 1.38 and 2.76 Mev. The energy spectrum of the Compton recoil electron to be expected from these two gamma rays has been calculated and is plotted to an arbitrary scale. The difference between the observed and computed shapes is ascribed to wall effects and statistical fluctuations.

We are now trying to get a differential curve for cadmium capture gammas, but are seriously handicapped by low counting rates at high energies.

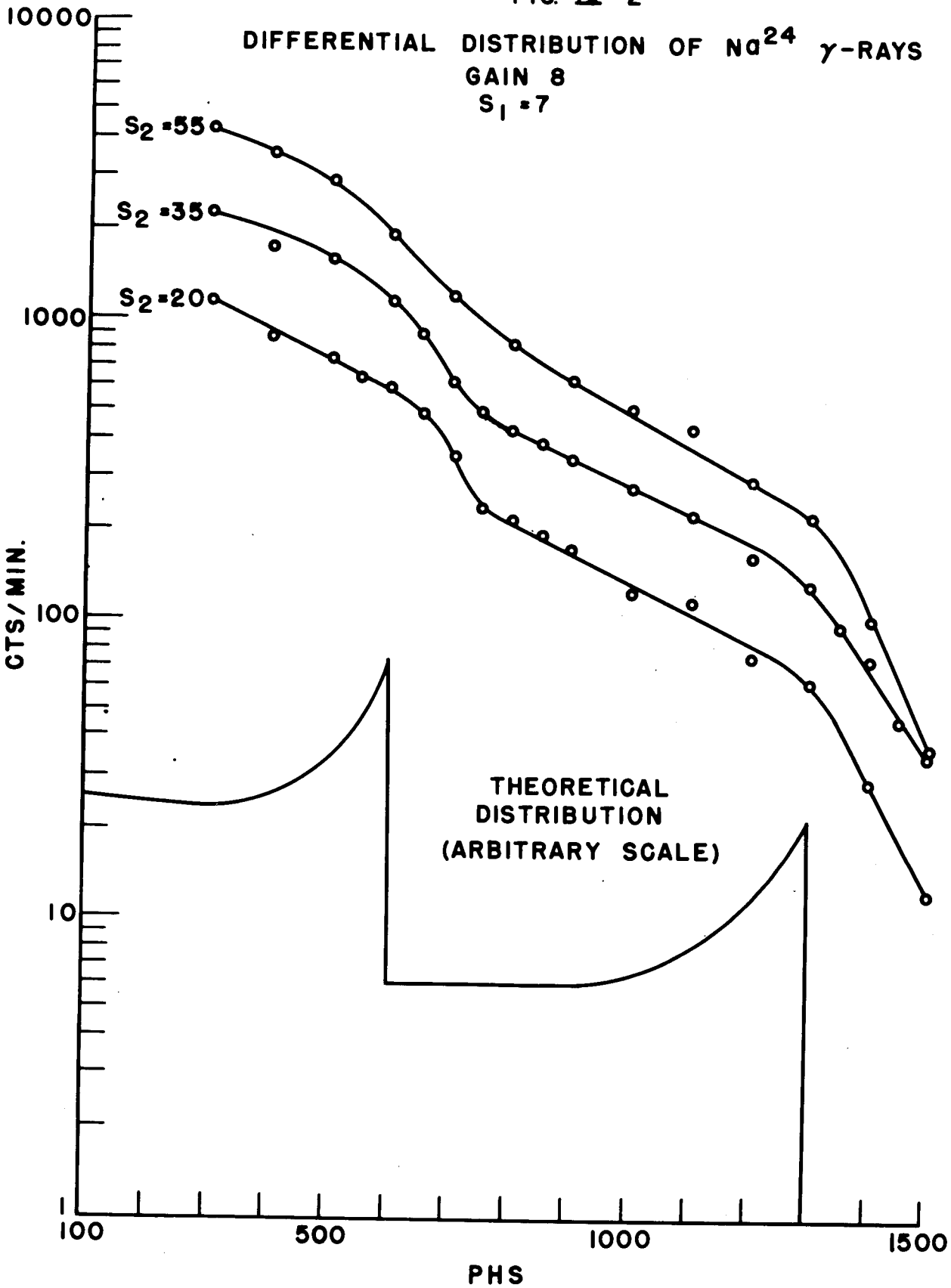
Geiger Counter Delays (G. G. Kelley, P. R. Bell)

A fast coincidence apparatus has been developed to measure the relative delay between two Geiger counters excited by the same initial ionizing event. The equipment has a resolving time of $\sim 3 \times 10^{-8}$ second and preliminary results show delays between one counter and another to average as small as 10^{-7} second. More complete information is to be obtained.

[redacted]

FIG. IV-2

DIFFERENTIAL DISTRIBUTION OF Na^{24} γ-RAYS
GAIN 8
$S_1 = 7$



[redacted]

Scintillation Counter (P. R. Bell, R. C. Davis, W. E. Jones, J. C. Gundlach)

Comparison of various materials as scintillation phosphors has continued. Table I shows a comparison of some materials investigated recently.

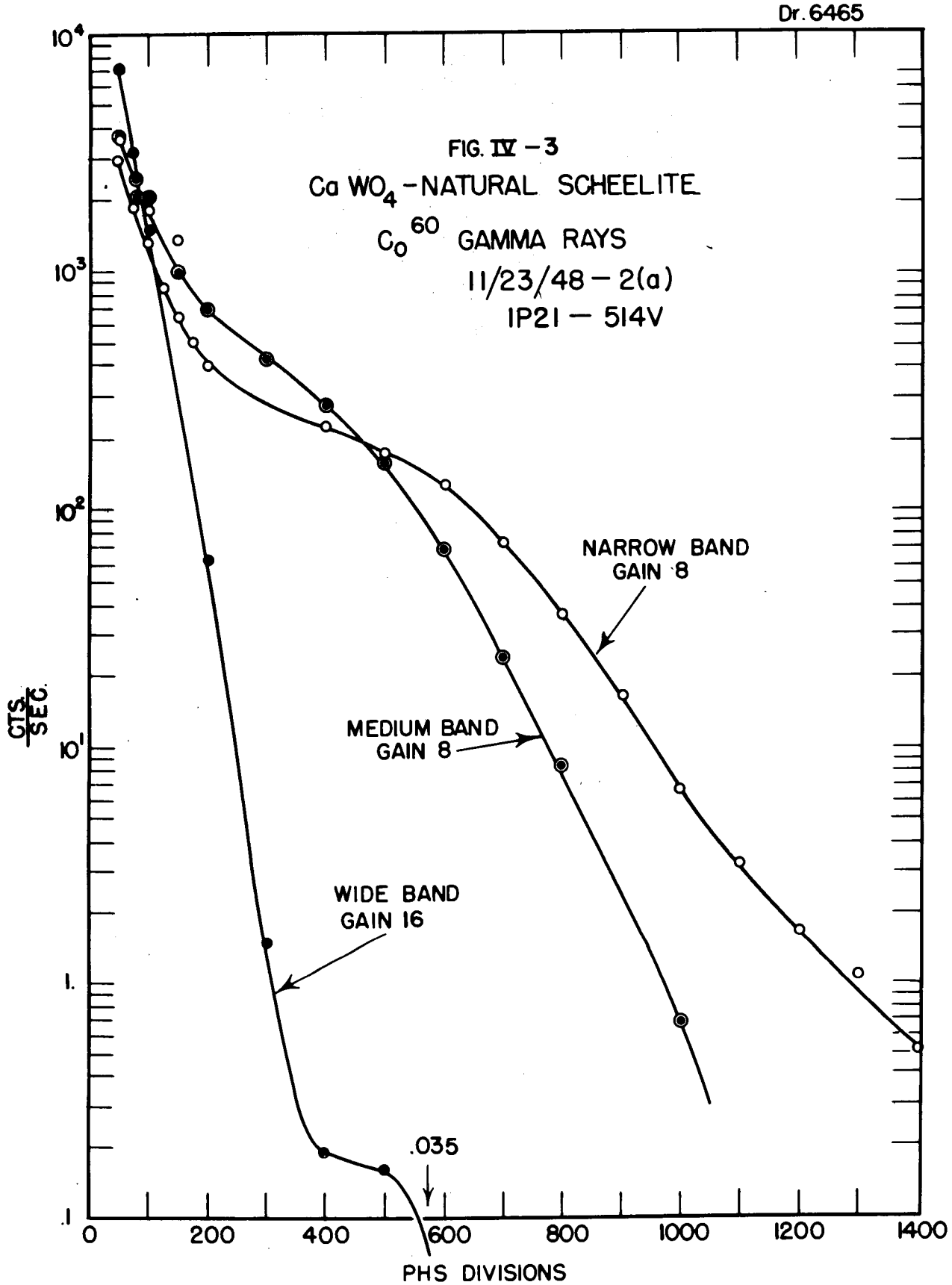
TABLE I

Substance	Material form	Pulse height for electrons compared to anthracene	Scintillation time	Remarks
$CaWO_4$	natural scheelite	.26	~5μ sec	Performance about same on 1P21-1P28 See Fig. IV-3
$CaWO_4$	synthetic from Linde Air	.26	~5μ sec	
Fluorite CaF_2	natural crystal	0.62	short	1P28 used, most of the scintillation light between 2000-3000Å
Synthetic white sapphire "counting type"	Linde Air	0.11		
NaI + TlI	clear single crystal	2 measured on med. band Al amplifier	~½μ sec room temp. ~1μ sec dry ice temp.	Large scintillation pulses but too slow for best results
anthracene	single crystal	1	0.013μ sec[1]	Best material to date

(continued on next page)

[1] George B. Collins, Phys. Rev. 74, 1543, 1947

[redacted]


Dr. 6465
FIG. IV - 3
Ca WO4 - NATURAL SCHEELITE
Co60 GAMMA RAYS
11/23/48 - 2(a)
1P21 - 514V
NARROW BAND
GAIN 8
MEDIUM BAND
GAIN 8
WIDE BAND
GAIN 16
.035
CTS./SEC.
10^4
10^3
10^2
10^1
1.
.1
0
200
400
600
800
1000
1200
1400
PHS DIVISIONS

[redacted]

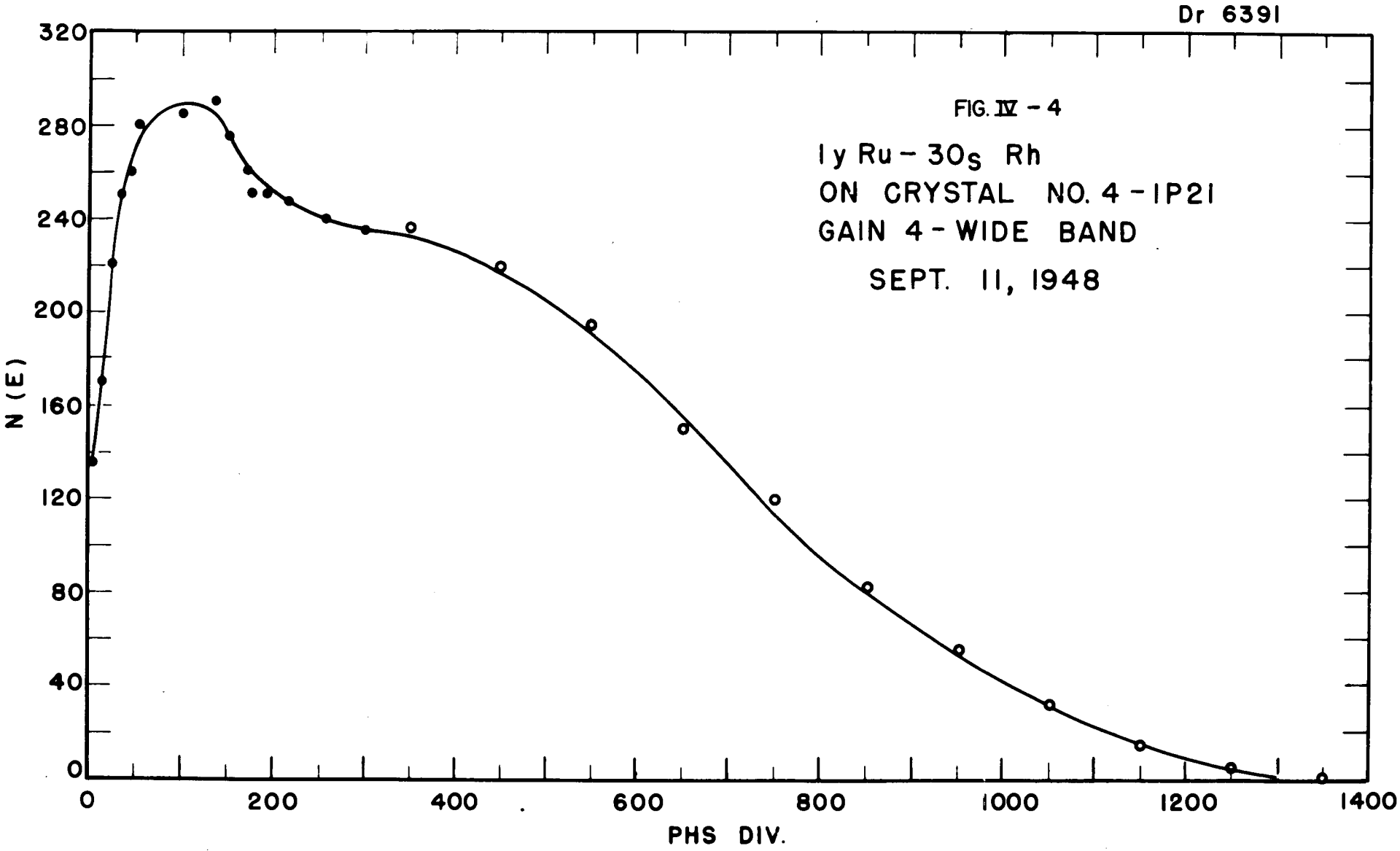
TABLE I (cont.)

Substance	Material form	Pulse height for electrons compared to anthracene	Scintil-lation time	Remarks
naphthalene	single crystal	0.3	0.057μ sec[1]	Pulses small, evaporates slowly
phenanthrene	poor crystal	small	0.009μ sec[1]	Very hard to grow crystals, smaller pulses
fluorene	translucent mass	0.35	short	
fluoran-thene	translucent mass	0.65		
Trans-Stilbene	clear single crystal	0.5 - 1.	very short	Next to anthra-cene in pulse size, variation of pulse size with purity is very bad
diphenyl	clear crystal	0.19	short	
lithium fluoride	single crystal Harshaw	negligible pulses		No pulses pro-duced by a Po-Be neutron source also

Analysis of the pulses from the photomultiplier has shown that the pulse height is quite proportional to the energy lost in the phosphor, particularly for anthracene. Fig. IV-4 shows the pulse height versus number curve for 1 y Ru - 30 s Rh. The β energies given by a beta spectrometer are 3.55 mev, 2.30 mev[2]. Fig. IV-5 shows a Kurie plot of the data of Fig. IV-4 and the two beta rays can be separated satisfactorily. Fig. IV-6 shows the pulse height vs. number curve of the beta rays from a sample of 33 year Cs^{137}.

[2] W. C. Peacock, Phys. Rev. 72, 1049 (1947).

[redacted]


Dr 6391
FIG. IV - 4
1y Ru - 30s Rh
ON CRYSTAL NO. 4 - 1P21
GAIN 4 - WIDE BAND
SEPT. 11, 1948
N (E)
PHS DIV.
0
40
80
120
160
200
240
280
320
0
200
400
600
800
1000
1200
1400

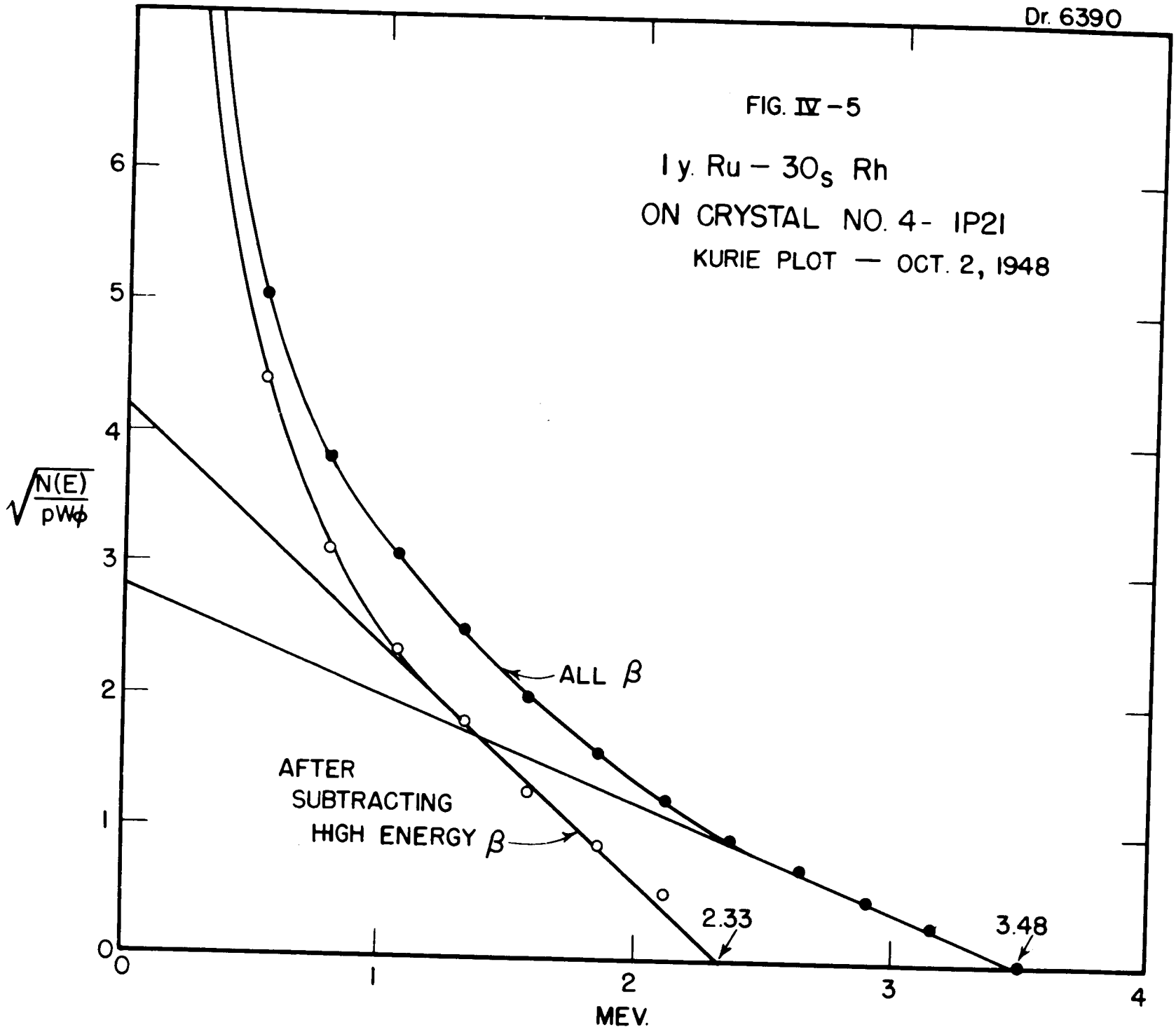
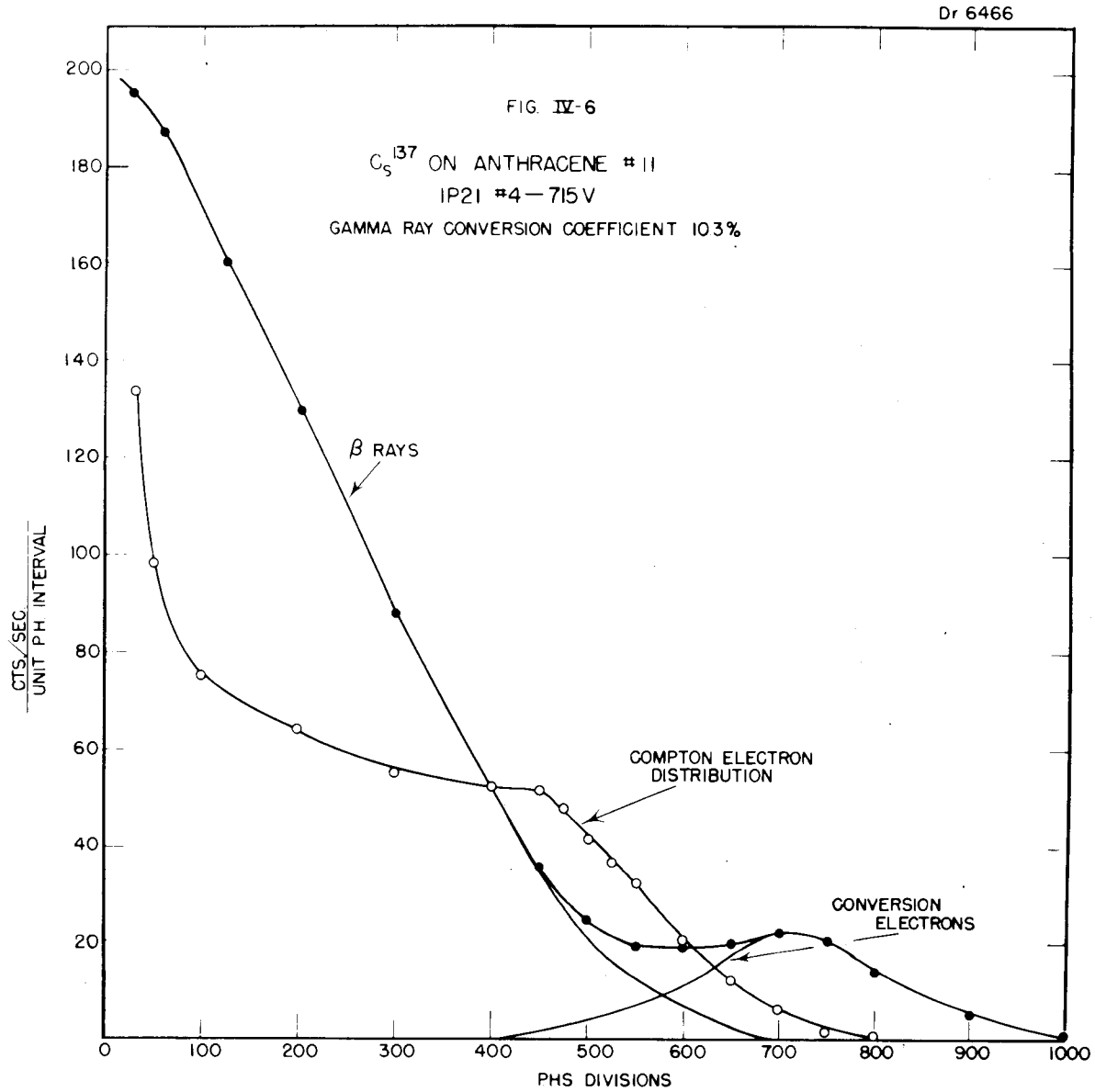


FIG. IV-5
1 y. Ru – 30s Rh
ON CRYSTAL NO. 4- 1P21
KURIE PLOT — OCT. 2, 1948
ALL β
AFTER
SUBTRACTING
HIGH ENERGY β
2.33
3.48
$\sqrt{\frac{N(E)}{pW\phi}}$
0
1
2
3
4
5
6
MEV.


Dr 6466
FIG. IV-6
C_S^{137} ON ANTHRACENE #11
1P21 #4—715 V
GAMMA RAY CONVERSION COEFFICIENT 10.3%
β RAYS
COMPTON ELECTRON DISTRIBUTION
CONVERSION ELECTRONS
CTS./SEC. / UNIT PH INTERVAL
PHS DIVISIONS
0
100
200
300
400
500
600
700
800
900
1000
20
40
60
80
100
120
140
160
180
200

[redacted]

This substance has a 0.550 mev β ray and 12% internally converted gamma ray of 0.663 mev[3]. Also on this curve is the Compton distribution produced in the crystal by the gamma rays. From these curves the internal conversion factor for 33y Cs^{137} seems to be ~ 10.3%. The gamma ray efficiency of this particular anthracene crystal (.5 cm thick) is 7%. It should be possible to estimate the energy of a gamma ray in this energy range to about 2%. The fact that a usable Kurie plot can be obtained permits the measurement of β emitters of low specific activity since $\frac{1}{2}$ of all the emitted β rays enter the crystal to be counted. By using two crystals, or a split crystal and a thin transparent source and source mounting all beta rays leaving the source can be measured. The high gamma ray efficiency obtainable will allow the measurement of weak gamma emitters.

3 Townsend et al, Phys. Rev. 74, 99 (1948).

[redacted]

[redacted]

SECTION V—PHYSICS OF SOLIDS

S. Siegel, Section Chief
W. E. Johnson, Associate Section Chief

R. H. Kernohan (NEPA)	R. P. Metcalf
R. W. Coyle (NEPA)	J. C. Pigg
S. E. Dismuke	F. T. Rogers
M. R. Goodman	M. M. Rogers
F. A. Sherrill	L. C. Templeton

K. Lark-Horovitz*

Al-U Alloys (S. Siegel, E. B. Roth)

The experiments on the release of 10-year Kr^{85} (not 9.5 days as erroneously given in ORNL 159) during annealing of irradiated Al-U alloy samples have been concluded. The temperature range covered was 200° C. to 700° C.; the samples were held at each temperature, differing by 50° C., for 20 hours. The computed amount of activity contained in the sample is 35 mc. Up to 550° C. about 0.2% of this was released, with a maximum near 250° C. At 625° C. 25 mc was released, and at 700° C. 13 mc was released; these amounts give an experimental total of 38 mc. The agreement between observed and computed totals may be fortuitous however, since doubt remains as to the validity of the sample-dilution method at 625° C. and 700° C.

The effect of these anneals on the electrical resistance and hardness of the irradiated sample was also determined and the results are plotted in Fig. V-1.

Uranium Single Crystals (F. A. Sherrill, M. M. Rogers)

More than fifty back-reflection Laue photographs have been made of regions of uranium wires 3/32 inch in diameter which had been slowly cycled and recycled through the α-β transformation temperature in a steep temperature gradient. To the eye these wires appeared to be single crystals for almost their full lengths, but on close examination there were exhibited definite "striations." The pattern on each x-ray photograph consisted of clusters of definite spots, each cluster being a string of spots lying on a segment of circular arc up to 30°, concentric with the center of the pattern.

Further attempts were made to produce single crystals by the strain-anneal method. Of a dozen 3/32 inch wires given the strain-anneal treatment, two developed areas which appeared to be good crystals having diameters of about 1 mm. The back-reflection Laue photograph of one of these areas showed an excellent pattern of single (not clustered) spots, in which

* Consultant from Purdue University

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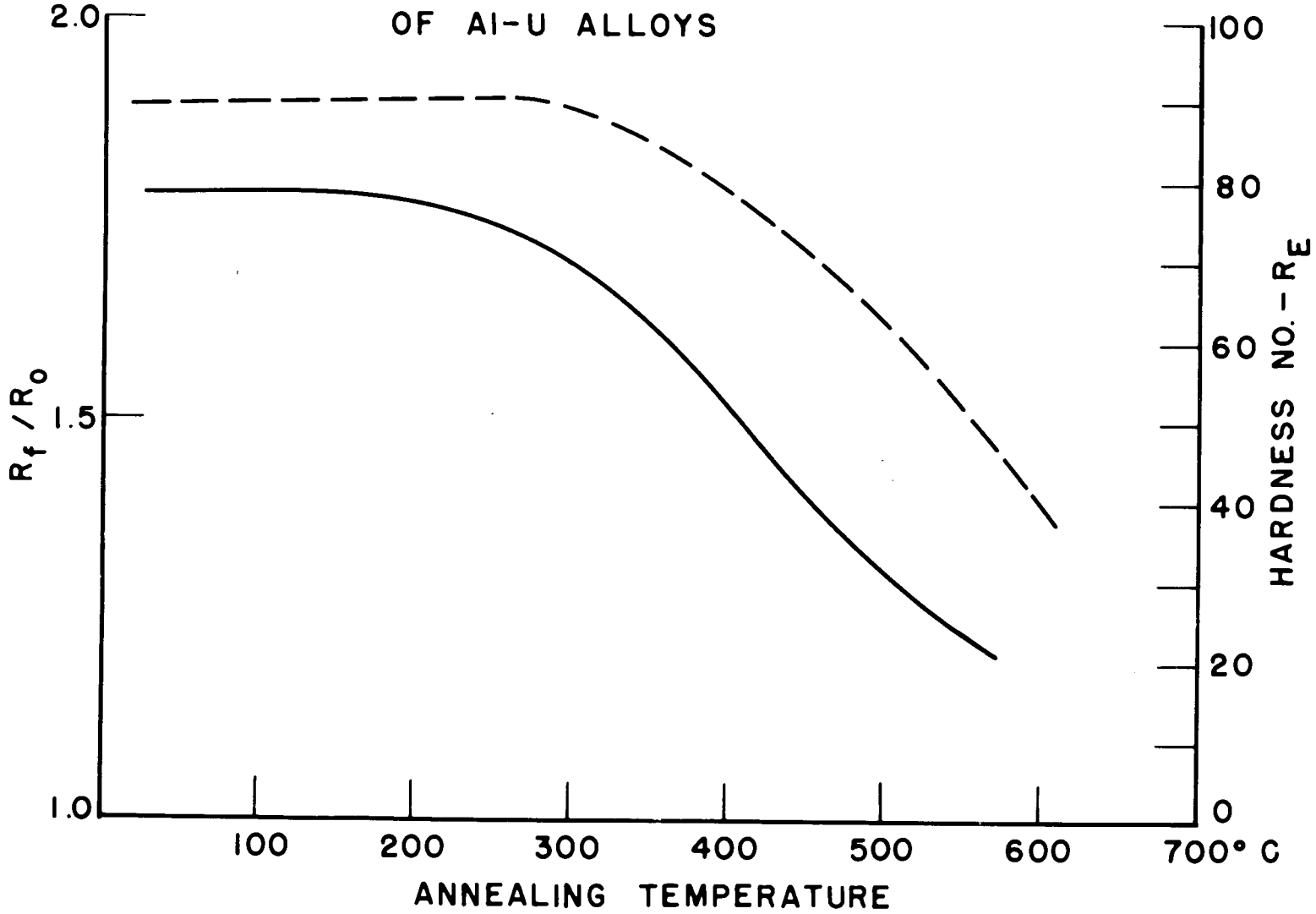
FIG. V-1

Dr 6268

ANNEALING OF RADIATION PRODUCED CHANGES
IN ELECTRICAL RESISTANCE RATIO ——
IN HARDNESS ON R_E SCALE — — —
OF Al-U ALLOYS



[redacted]

the 001-plane spot was only slightly off the center of the pattern. Efforts have been made to cut these small crystals out of the wires, but have not been uniformly successful to date.

Relaxation of Strains in Uranium (M. R. Goodman, M. M. Rogers, F. T. Rogers)

In continuation of the investigations reported in ORNL 159, further observations have been made of the thermal expansion and contraction of uranium slugs, by means of strain-gauges. The gauge-resistances exhibited abrupt changes corresponding to abrupt temperature changes, followed by the previouly-reported "relaxations." The following results can be reported:

(a) An 8-inch gamma-extruded Hanford slug was held for 12 days at 32.7° C., and then in 25 minutes its temperature was increased to 41.1° C.; after 21 days at 41.1° C., the temperature was increased to 60.0° C. The coefficient of thermal expansion (α) along the longitudinal axis of the slug appears from the following Table I to be somewhat dependent upon the temperature in this particular cycle.

Table I

Gauge	Temp. range (°C)	α (1/°C)
#8	32.7—41.1	27×10^{-6}
#9	32.7—41.1	30×10^{-6}
#8	41.1—60.0	22×10^{-6}
#9	41.1—60.0	25×10^{-6}

After repeated temperature changes (ΔT) having no cyclical character, there was no apparent correlation of the corresponding values or signs of $\Delta\alpha$ with ΔT.

(b) The following Table II shows α-values obtained from 4-inch Hanford slugs after eight cyclical changes of temperature from 32.5° C. to 60.0° C.

[redacted]

[redacted]

Table II

Gauge	Type of Slug	α (1/°C)
#1	γ-extruded	16.7×10^{-6}
#2	" "	13.5×10^{-6}
#3	" "	14.4×10^{-6}
#4	" "	17.1×10^{-6}
#5	α rolled	15.1×10^{-6}
#6	" "	18.0×10^{-6}
#7	" "	14.4×10^{-6}

Here the gauges were cemented to the 0.001" - 0.002" thickness of aluminum which remained on the slugs after machining to remove most of the can-material. These results appear to indicate gross inhomogeneities in the expansion of a slug.

(c) Whereas the abrupt changes in gauge-resistance can be attributed to the α-values quoted above, the cause of the subsequent relaxations are not so clear. Strain-gauges on the aluminum bar exhibited relatively short-period relaxations (~20 hours), and the amounts of relaxation significantly decreased as the cycling-process continued. These relaxations appear to be interpretable as stress-relief in the gauges themselves.

(d) The relaxations observed by gauges on uranium slugs were of the same general character as those observed in the case of aluminum but were larger and of longer period; they did not decrease in magnitude as cycling continued. On the average, α-rolled uranium produced greater relaxation than γ-extruded; but inhomogeneities in relaxation were quite marked, the maximum for either slug being four to six times as great as the minimum. If these relaxations are characteristic of the uranium rather than of the gauges, they indicate that any sudden increase or decrease of length of a slug (resulting from a sudden increase or decrease of temperature) would be followed by a slow decrease or increase of length; further independent measurements on this point are desirable.

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Effect of Pile Radiation on Electrical Resistance of Graphite at -78° C (R. P. Metcalf)

It is well known that the rate of increase of the electrical resistance of graphite when exposed to pile radiation, is greater at lower temperatures, at least for temperatures above room temperature. An experiment has been carried out to explore the behavior below room temperature. It was found that at the temperature of dry ice (-78°C) the rate of increase of resistance is approximately twice as great as at room temperature.

The graphite specimen measured 3" × ¼" × ¼", with the long axis perpendicular to the direction of extrusion. Current and potential leads and a thermocouple were attached; the resistance of the specimen at various temperatures was measured before irradiation. The specimen was enclosed in a silica glass tube which was packed in dry ice in an aluminum can. The assembly was lowered into Hole 12, the vertical water-jacketed hole in the ORNL pile, while the pile was operating at full power. The resistance of the graphite was measured from time to time with a potentiometer. The temperature of the graphite remained constant to within 1°C for over 4 hours, during which time the resistance increased about 0.8%. After the dry ice had evaporated, the graphite warmed up to the temperature of the water-jacket, about 25°C, and was left in the pile for about 5 days in order to allow determination of the rate of increase of resistance at room temperature.

The results may be expressed as follows:

$$\frac{\Delta R(-78)}{\Delta R(25)} = 2.3; \qquad \frac{\Delta R(-78)}{\Delta R(25)} \times \frac{Ro(25)}{Ro(-78)} = 1.9.$$

Here $\Delta R(t)$ is the increase in resistance per megawatt hour at temperature t, and $Ro(t)$ is the initial resistance at temperature t.

Low Temperature Exposure Tube (R. P. Metcalf, S. Siegel)

Developmental work has continued on the apparatus for keeping materials at a temperature in the neighborhood of 100°K while being irradiated in the ORNL pile.

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Modifications have been completed in the auxiliary equipment, permitting the use of liquid nitrogen as the primary coolant, and tests of the apparatus are now being made.

It is expected that the job of designing and building an improved cryostat may be started in the near future.

The water-jacketed slow-to-fast neutron converter tube is progressing toward completion. The Al-U alloy cylinder has been fabricated and contains 110 gm of U-235. Final steps toward inserting this in the pile are under way, principally concerned with instrumentation, monitoring, and interconnection with the pile shut-off.

Effects of Radiation on the Lattice Constants of Uranium (F. T. Rogers)

Preliminary observations of x-ray diffraction from thin uranium foils have been made by Dr. Max Bredig of the Chemistry Division, using Geiger-counter detection, to assure that adequate precision can be got in determinations of the lattice constants of uranium with that Division's apparatus. Plans are under way for constructing, or otherwise procuring, a bent-crystal focusing attachment for this apparatus; this attachment is required to allow shielding of the counting-tube from the activity of irradiated uranium specimens.

Plans for New "Hot" Laboratory (F. T. Rogers)

Preliminary, definitive designs are being prepared by the Engineering Division for additional laboratory facilities for researches involving "hot" specimens. Specifications call for a heavily shielded experimental space about 6' × 60' in area and about 15' in height, subdivided into five (or less) areas by movable internal shields. This is to be contained in a laboratory building having a usable area of about 5000 square feet. A water pit for storing highly active specimens is to be included in the building.

Effects of Radiation on Various Metals (S. Siegel, D. Billington, L. C. Templeton, R. H. Kernohan)

Progress on this activity continues, with the accumulation of further data. Two reports, ORNL 115 and ORNL 138 have been issued, and a paper has been completed for the AEC Journal of Metallurgy and Ceramics.

[redacted]

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A specimen of Ni_3Mn, annealed for 100 hours at 420° C, is being irradiated in the ORNL pile. In 75 days its resistance has increased 4.5%, and it continues to increase at an apparently uniform rate. Measurements have been made of the resistance of Cu_3Au before and after irradiation, but have not yet been interpreted.

Measurements of hardness, resistance, and x-ray line width were made on samples of Be-Cu which had been irradiated for four weeks in the ORNL pile. Prior to irradiation the Be-Cu specimens had been subjected to a precipitation hardening treatment at 300° C for times varying from 5 minutes to 60 minutes. After irradiation increases in both resistance and hardness were most in evidence for those specimens which had had short-time precipitation haxdening treatment. The percentage increase in resistance was on the order of 10-15% for the 5 minute treatment and amounted to 1% or less for the 60 minute treatment. Measurements of x-ray line widths sometimes gave anomalous results by comparison with the hardness and resistance measurements although the general trend was a broadening of the lines for irradiated samples.

Samples of brass containing varying percentages of zinc have been irradiated in the ORNL pile in order to investigate changes in resistance and hardness. Results are not yet complete although a considerable increase in hardness has been noted in previously annealed brass specimens containing a low (5-10%) percentage of zinc. These same specimens exhibit a slight decrease in electrical resistance on the order of 1%.

Arrangements have been made for the exposure of samples in the Chalk River reactor. Samples of Cu_3Au for further study of effects on order, and of kovar for study of effects on phase transformations, have been submitted.

Effects of Radiation on Creep of Metals (R. H. Kernohan)

Two separate devices have been considered for measuring creep. Both are in the process of development and should soon be ready for preliminary testing.

The first device is designed to fit into a stringer hole in the ORNL pile. The device is intended for the measurement of creep in wire specimens three inches long and no larger than .064 inches (#14 B & S gauge) in diameter. Stress is applied to the wire specimens by means of a lever system and a lead weight. Deformation is measured by means of a differential transformer (microformer coil) coupled to an automatic recorder. Deformations in specimens

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length of about 1.5% can be made. Stresses very near the plastic range of the specimens tested will be applied in order to study the first stages of creep and to make short-time tests. The temperature can be maintained constant at 150° C by meams of an auxiliary heater built into the apparatus. The original microformer coil deteriorated at this temperature and a new heat-resistant coil is on order.

The second creep testing device designed for a "doughnut" hole is in the process of assembly and calibration. Stress is applied by means of a triple steel spring to a strip specimen 2 inches long. The deformation will be measured by an electric strain gage bonded to the specimen. Auxiliary heaters to maintain a constant temperature of 50° C are also included in the apparatus.

Annealed samples of soft pure materials such as copper and aluminum are being prepared for specimens in both creep testing devices.

Effect of Neutron Bombardment on Internal Friction (S. E. Dismuke)

Internal friction measurements on Al single crystals mounted in front of a pile beam hole gave no indication of change due to neutron bombardment.

Plans have been made to make internal friction measurements while the metal single crystals are inside the pile. Several designs for the necessary equipment have been tested.

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Semi-Conductors (W. E. Johnson, K. Lark-Horovitz, J. C. Pigg)

The name of Dr. K. Lark-Horovitz as one of the senior investigators in the semi-conductor work was inadvertently omitted from the list of authors in the report on semi-conductors in ORNL 159, and in a reference in ORNL 115 by S. Siegel entitled "The Effects of Nuclear Radiations on Solids." The preparation of samples of germanium and silicon, and the Hall-effect measurements on these samples, were carried out at Purdue University under the supervision of Dr. Lark-Horovitz.

Data have now been obtained on the effect of pile radiation on various commercial P type silicon rectifiers. These types include the 1N21A, 1N21, 1N23 and CV 113. Fig. V-2 indicates the typical behavior of all these rectifiers. Both the forward and back resistance increase continuously with time eventually becoming essentially equal. This behavior would be expected on the basis of the previously reported effects of pile radiation on P type and N type silicon plates. The resistivity of both P type and N type silicon increased upon pile exposure.

P type cuprous oxide plates of various resistivities and cuprous oxide rectifiers, prepared by Dr. S. J. Angello of Westinghouse Research Laboratories, show a behavior similar to silicon. The resistivity of the plates increases continuously with pile exposure. Both the forward and back resistance of the cuprous oxide rectifier increase with pile exposure effectively destroying the rectifying action. The resistance of this type rectifier, however, is so temperature sensitive that it is not possible to separate the effects of temperature and irradiation during the early part of the exposure.

The Hall-effect equipment referred to in the previous Quarterly Report, ORNL 159, has now been tested. Measurements on low resistivity samples can be made accurately. However, it has not been possible to make measurements of suitable accuracy on high resistivity samples such as cuprous oxide. The equipment for making Hall-effect measurements on samples while in the pile is now being constructed in the shops.

Apparatus

The conversion of an analytical chemical balance for remote control operation has been completed and is now in use. In addition to the

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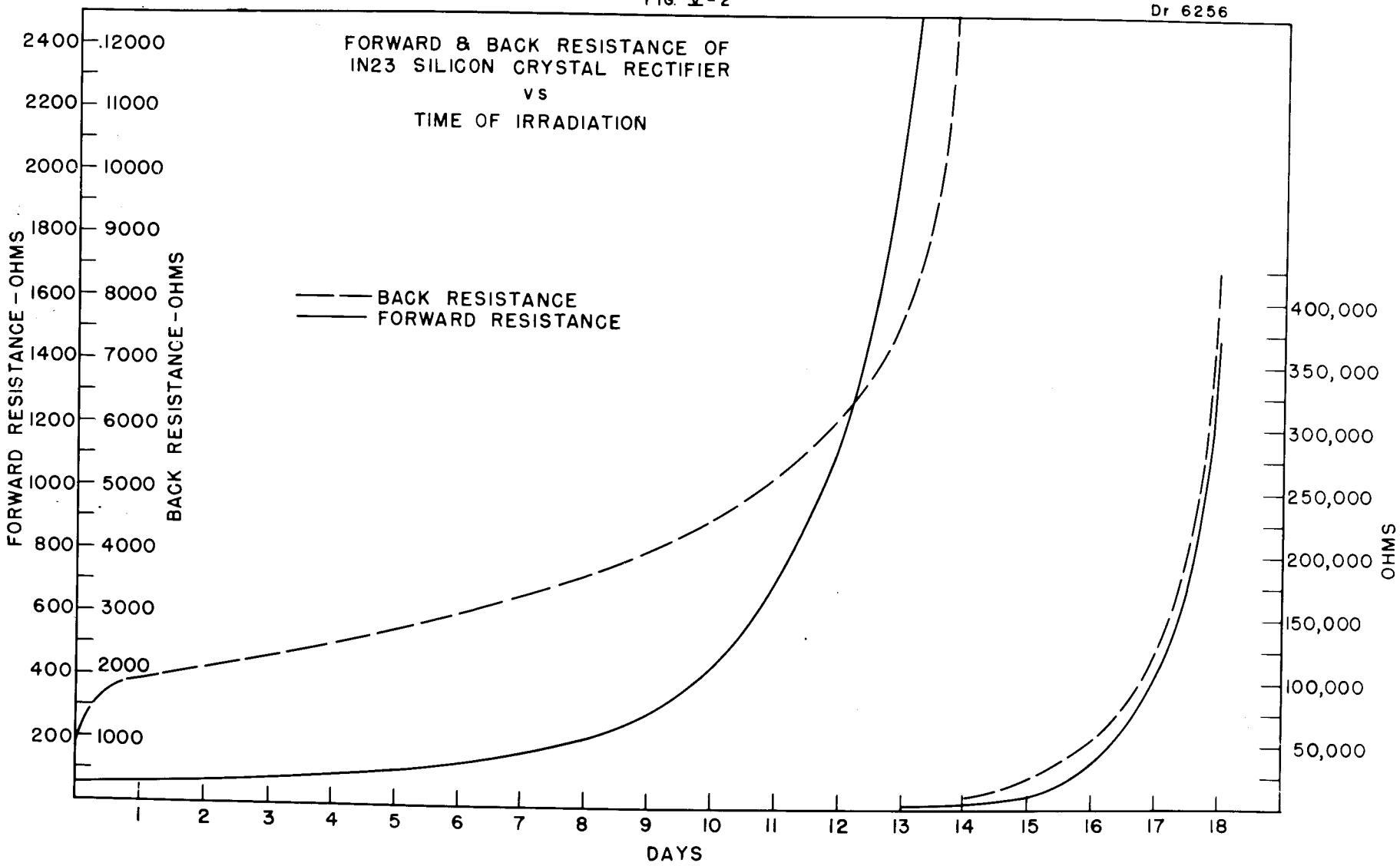
FIG. V-2

Dr 6256



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normal operations performed by a chemical balance, the converted balance permits hydrostatic weighing for density determinations. All operations such as opening and closing doors, lowering the beam, moving 0.1 gm rider, and moving the chain weight are accomplished by using small electric motors attached permanently to the balance. However, placing weights over 1 gm on the pans, and placing objects to be weighed on the pans must be done with the aid of the regular remote control manipulator.

[redacted]

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SECTION VI—CRITICAL EXPERIMENTS AND REACTOR DESIGN

M. M. Mann, Section Chief

J. K. Bair (Nepa) R. V. McCord
A. B. Martin G. McCammon
N. M. Smith

During the past quarter the critical experiments group has been engaged in carrying forward the general program of studying the physical properties of small thermal reactors consisting of the high flux reactor core material and various reflector materials.

Spinrad continues to use the results of these experiments as a basis for an investigation of the usefulness of the 2-group diffusion theory in predicting the critical mass and neutron flux distributions in small thermal assemblies of this type.

Graphite Reflector

Greuling has carried out 2-group calculations for the thermal neutron flux distribution in the graphite reflected assembly described in the last quarterly report. The thermal flux predicted by 2-group theory for cylindrical geometry and for slab geometry are shown in Fig. VI-1, together with the thermal flux measured experimentally.

Aluminum Reflector

A critical assembly has been built with reflector on four sides made up of aluminum containing 2% lucite by volume to simulate cooling water. This 31 cm thick primary reflector was backed by a 30 cm layer of graphite which acted as a secondary reflector. The active core in this case was 34.6 × 43 cm in cross section and 66 cm high. There was no reflector on the top or the bottom of the core. The minimum critical mass of this assembly was found by experiment to be 3.4 kg. The volume ratio of Al to H_2O in the core was 0.65.

Fig. VI-2 shows the thermal and cadmium covered saturated activities of Indium foils exposed at various distances from the center of the core of the aluminum reflected assembly. The foils were placed along a line bisecting one side of the core, at the mid-height of the assembly.

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FIG. VI-1

THERMAL NEUTRON FLUX

GRAPHITE REFLECTOR

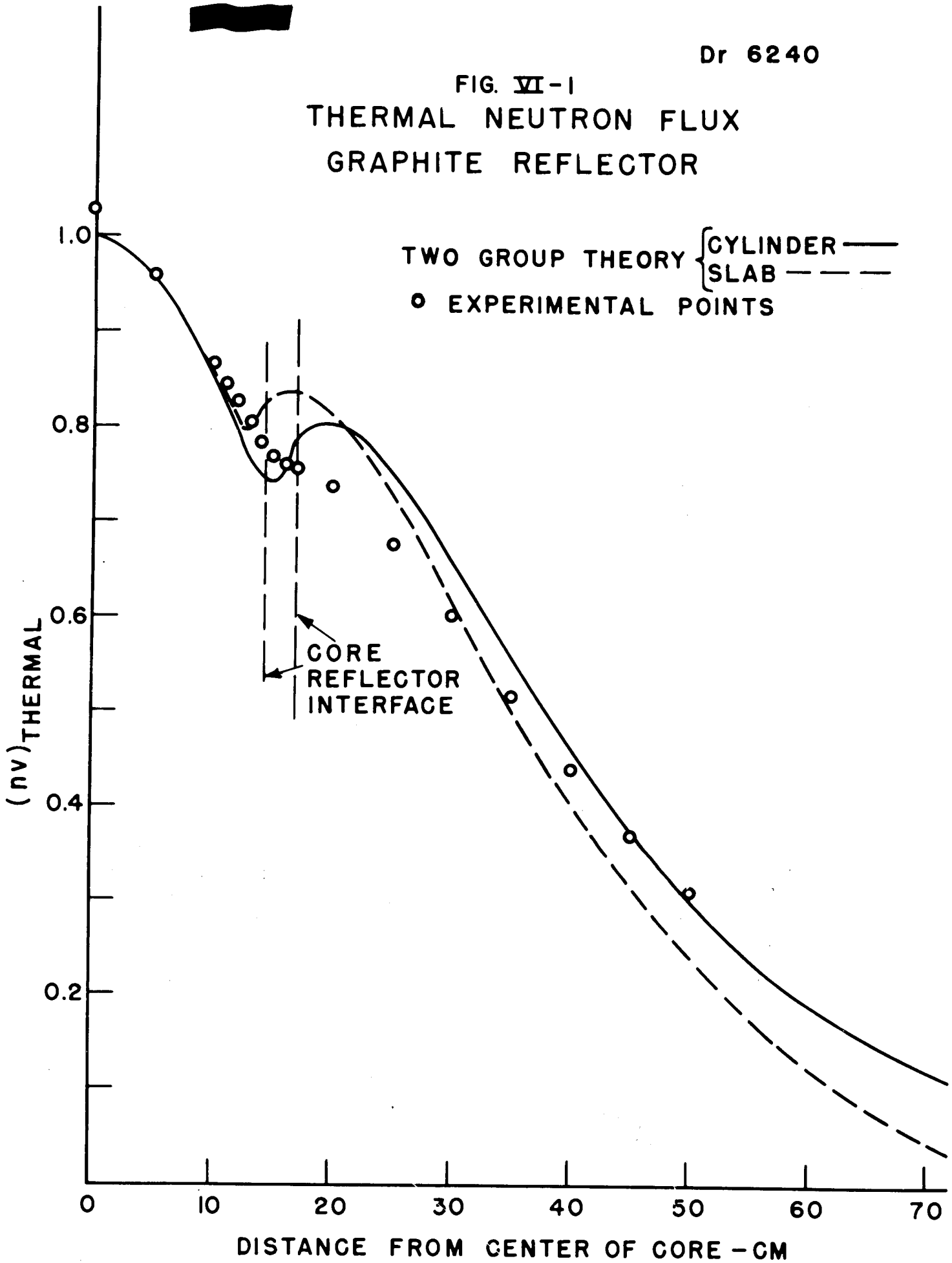

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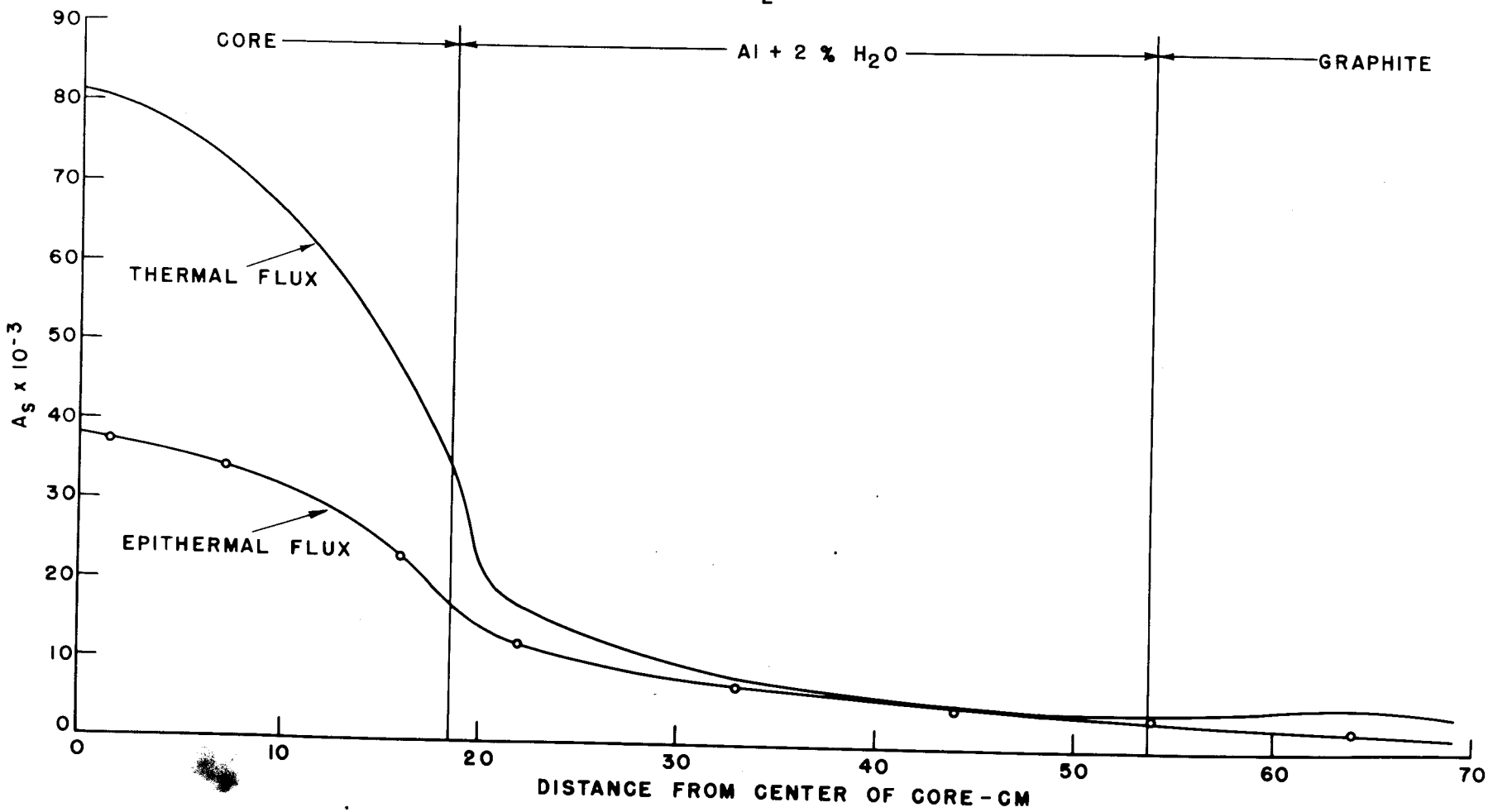
FIG. VI-2
NEUTRON FLUX DISTRIBUTIONS
(Al + 2 % H_2O) REFLECTOR

Dr 6414



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In Fig. VI-3 we show the comparison between the thermal neutron flux determined experimentally and that predicted by 2-group theory. The calculations in this case took account of the water in the aluminum, but the presence of the graphite secondary reflector was neglected.

Fig. VI-4 shows a similar comparison between theory and experiment for epi-thermal neutron flux in this assembly. The uncommonly good agreement in this case is probably due to the fact that the age is used in these calculations in a manner not entirely consistent with a 2-group slowing down theory and leads to incorrect flux distributions when the reciprocal age makes an appreciable contribution to the relaxation distance for slowing down. In the case of this Al-H_2O mixture the age is so large that the contribution of the reciprocal age is negligible compared to the leakage term. The fact that the experimental points do not fall off as rapidly in the aluminum as does the theoretical curve is probably due to the presence of the secondary reflector of graphite which was not taken into account in the calculations.

In Fig. VI-5 we have plotted the distribution of Indium resonance neutron flux (nv) and the fast ($E > 1$ Mev) neutron distribution. The fast neutron flux is measured with a U-238 threshold type fission chamber.

Lead Reflector

An assembly having a 31 cm thick reflector of lead became critical at a loading of approximately 2.6 kg. The corrected minimum critical mass is 2.3 kg. The core dimensions in this case are 31.6 × 34 × 66 cm and the aluminum to water volume ratio is 0.65. The thermal and Indium resonance neutron flux distributions in this assembly are shown in Fig. VI-6.

In Fig. VI-7 we show a comparison between the experimental thermal flux (solid curve) and the thermal flux predicted by a 2-group theory calculation carried out by Spinrad. It appears that both the critical mass and the thermal neutron flux distribution predicted by 2-group theory for the lead reflector are in excellent agreement with experiment.

In Fig. VI-8 we show a similar comparison between the experimental Indium resonance flux and the distribution predicted by 2-group theory.

Fig. VI-9 shows the distribution of neutron flux for energies greater than 1 Mev. The Indium resonance flux distribution is plotted for purposes of comparison.

From the shapes of the thermal and very fast flux curves, it appears that the diffusion lengths in lead of these two groups of neutrons are very

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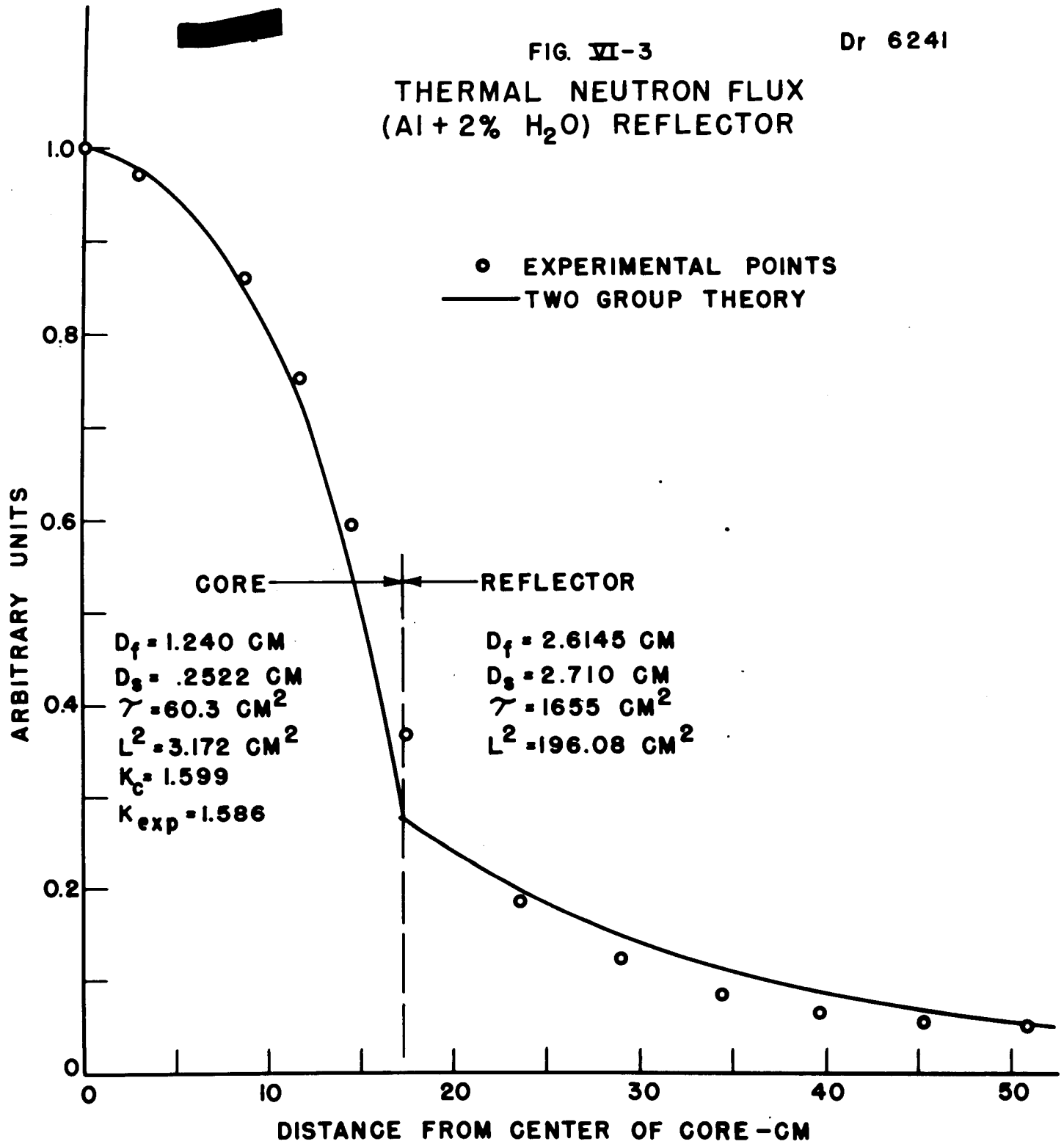
Dr 6241

FIG. VI-3

THERMAL NEUTRON FLUX
(Al + 2% H_2O) REFLECTOR



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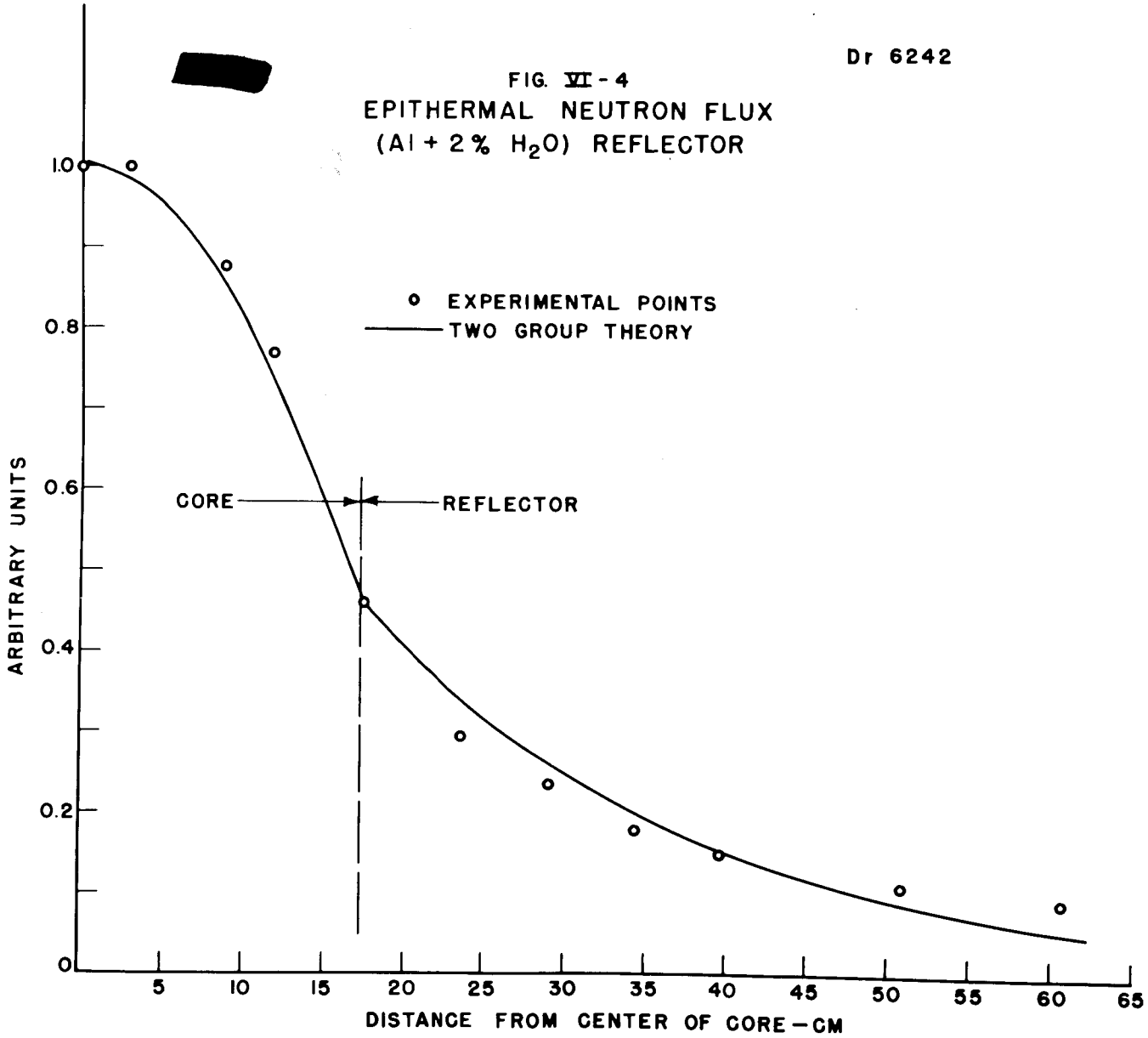
Dr 6242

FIG. VI - 4

EPITHERMAL NEUTRON FLUX

(Al + 2% H_2O) REFLECTOR



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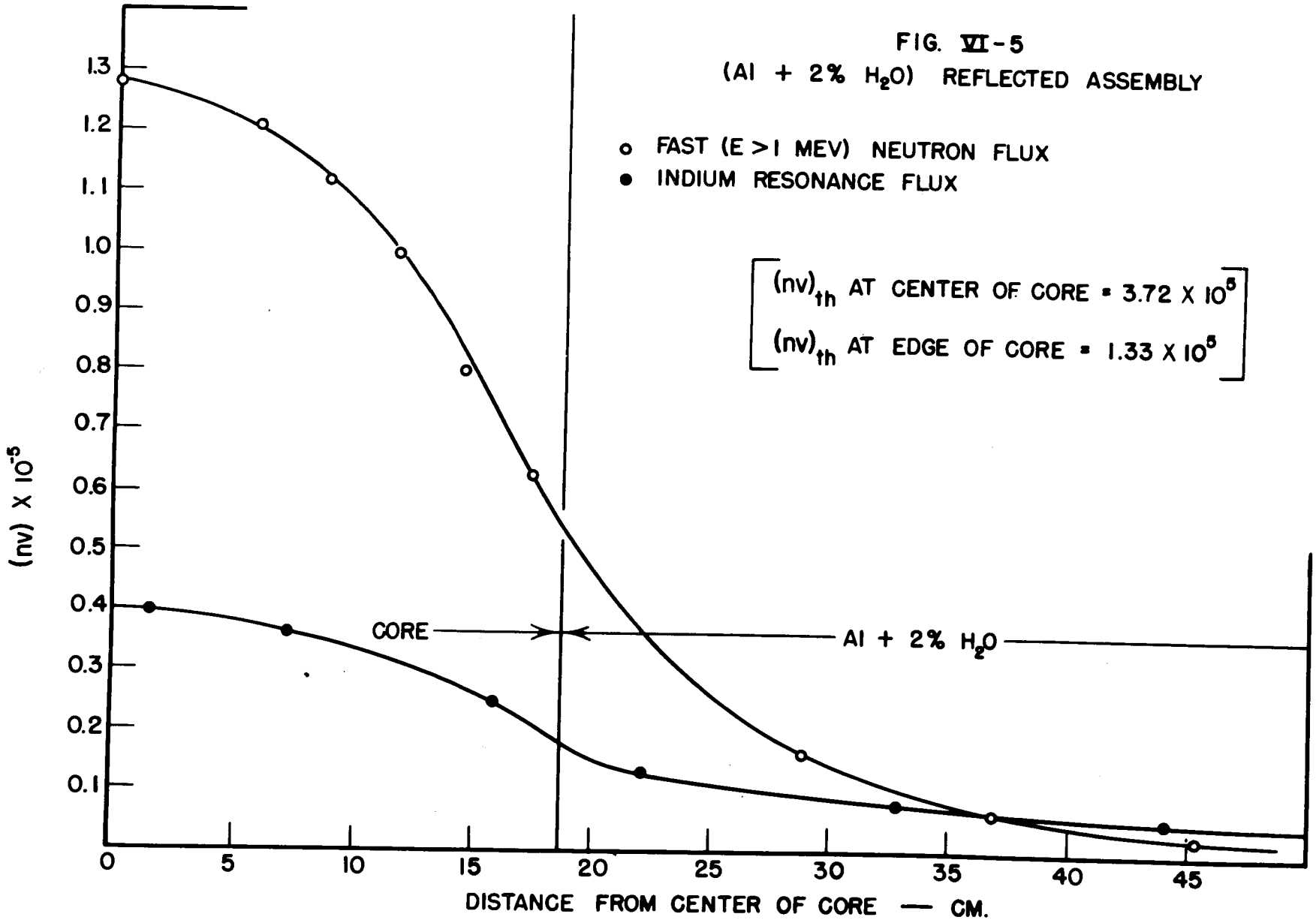
Dr 6413

FIG. VI-5
(Al + 2% H_2O) REFLECTED ASSEMBLY



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Dr 6411

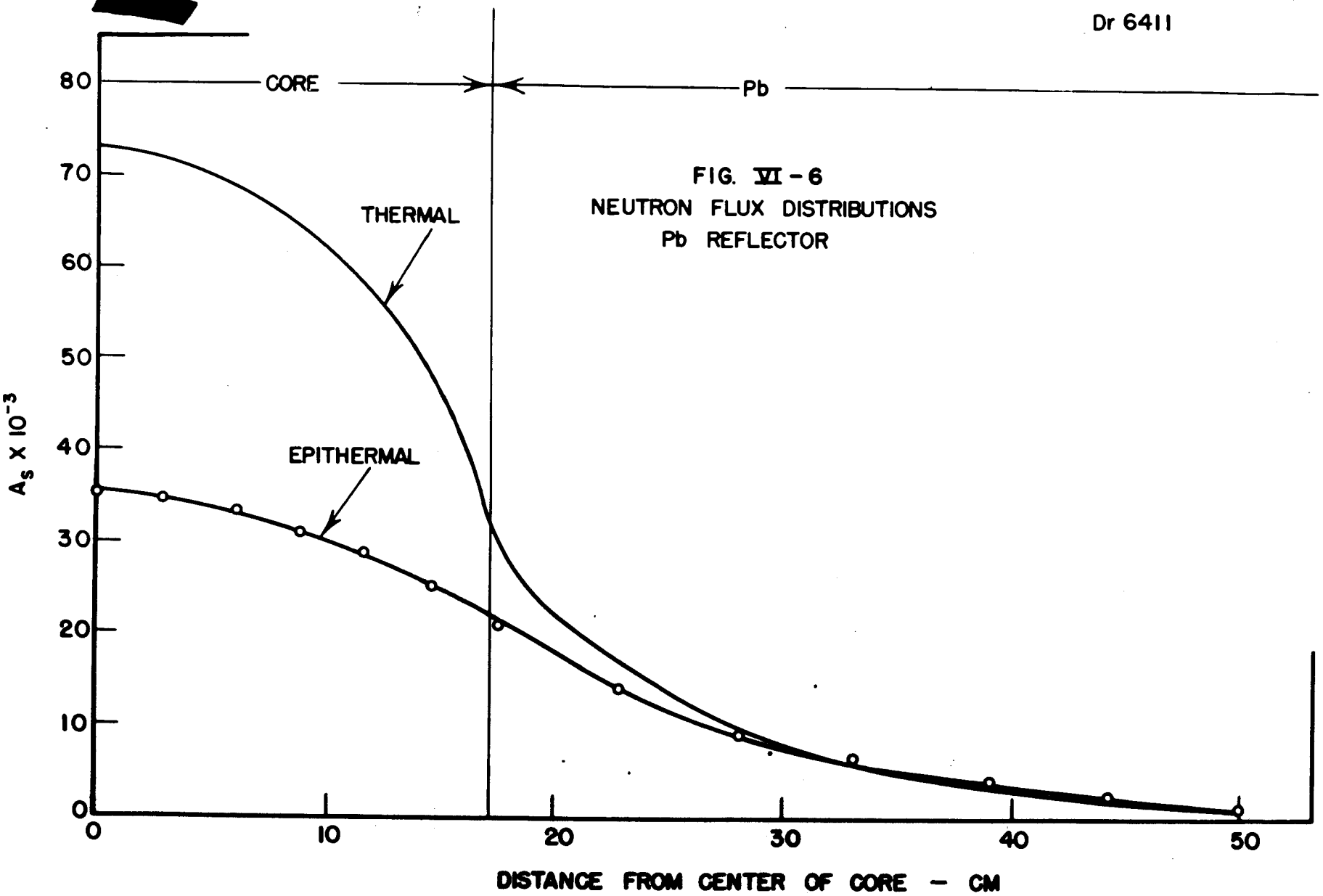

FIG. VI – 6
NEUTRON FLUX DISTRIBUTIONS
Pb REFLECTOR

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Dr 6417

FIG. VI - 7
THERMAL NEUTRON FLUX DISTRIBUTION
Pb REFLECTED ASSEMBLY

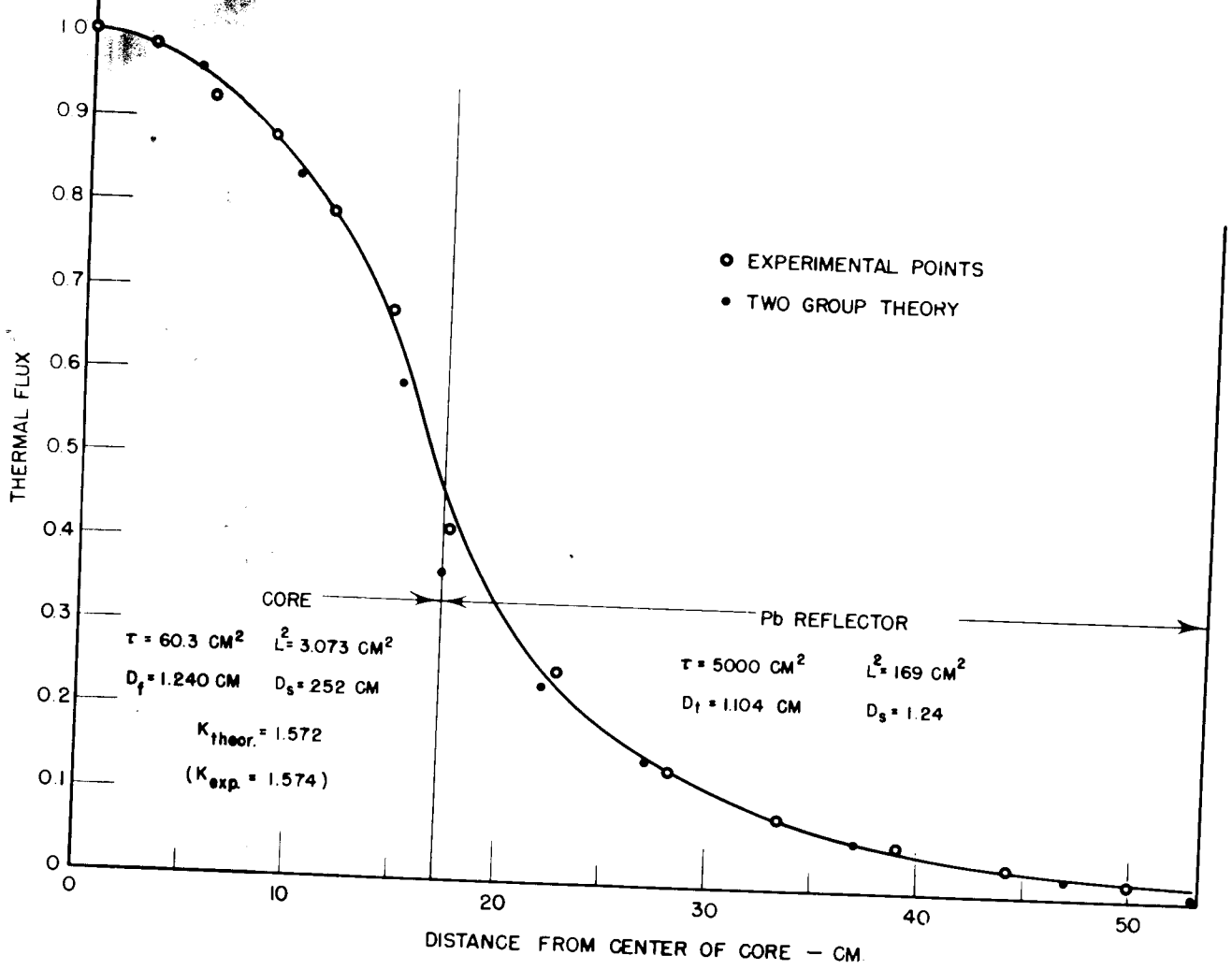

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FIG. VI-8
INDIUM RESONANCE FLUX DISTRIBUTION
Pb REFLECTED ASSEMBLY

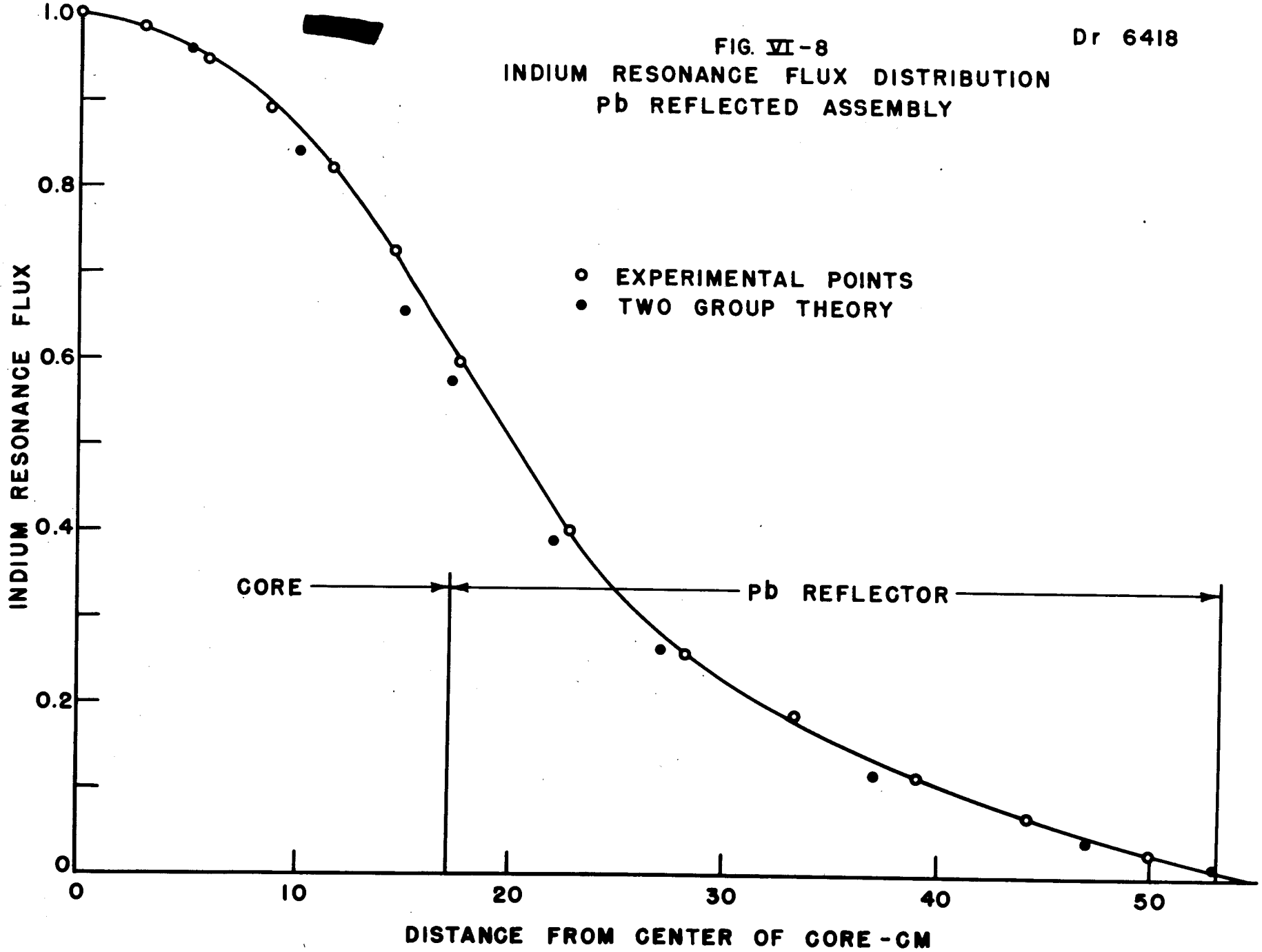

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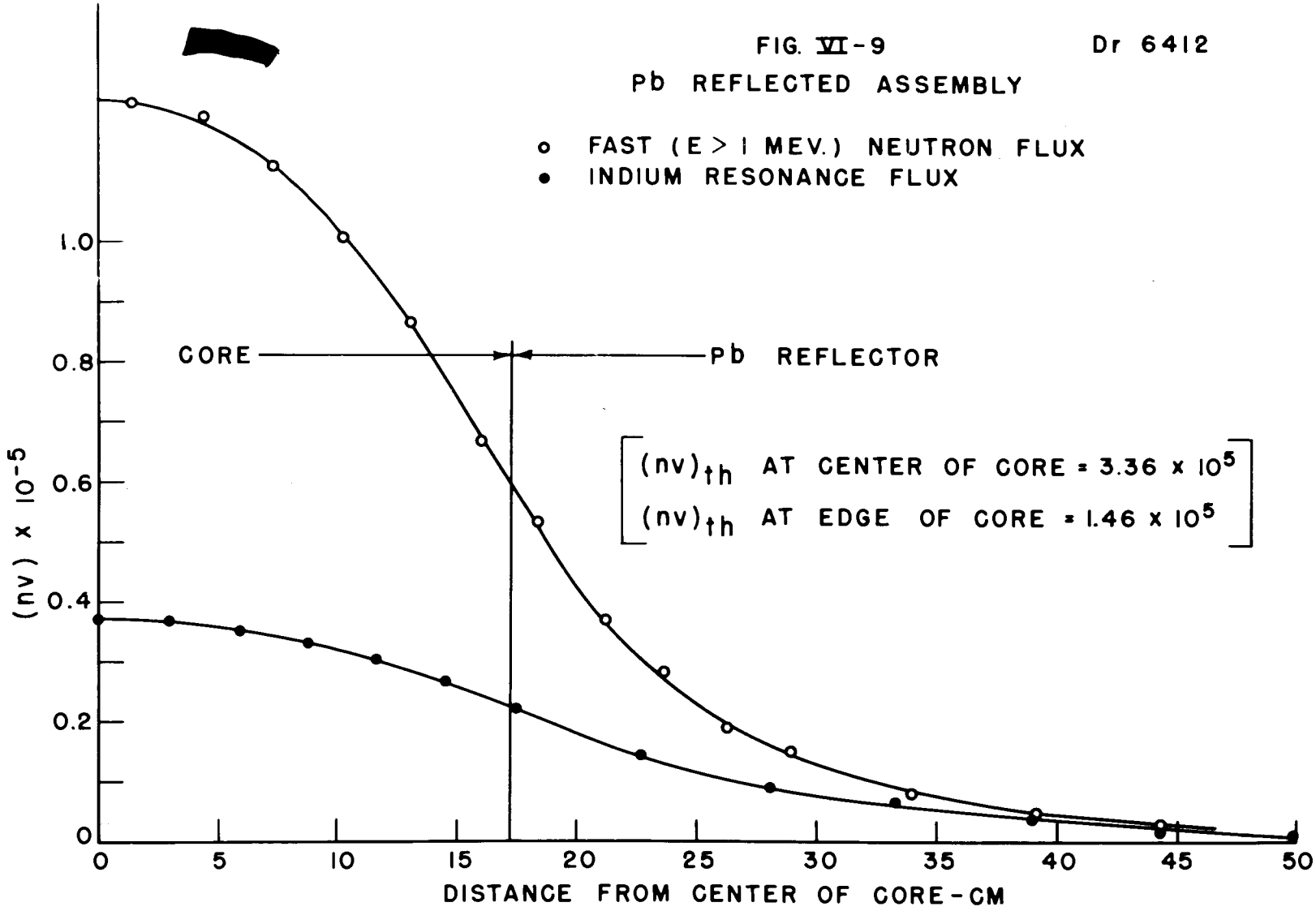
FIG. VI-9 Dr 6412

Pb REFLECTED ASSEMBLY



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closely the same. Spinrad has pointed out that, for very fast neutrons, inelastic scattering is an equivalent process to absorption in the thermal case. With this assumption we can infer from the experimental data a value for the inelastic scattering cross sections. We take κ^2 as a measured value, corrected for geometrical leakage factor, to be .00592. Using a σ_t of 6.1 barns, we solve to get an inelastic scattering cross section of 0.32 barns for neutrons above the 28 fission threshold.

A check on the validity of the leakage corrections is afforded by the thermal flux curve, which solves to a σ_a of 0.23 barns, in excellent agreement with the accepted 0.25 ± .03 barns.

It is probable that the inelastic cross section obtained from this experiment represents a combination of two types of events: single large-energy-loss inelastic scatterings for neutrons in the lower end of the fission spectrum; and multiple inelastic scatterings for the high energy neutrons. Hence, this cross section is expected to be lower than the measured experimental values, for this experiment has in principle a 1 Mev bias.

However this value is obviously of interest in practical reactor studies on the effects of lead on fast neutrons.

The rate of gamma ray energy absorption in the lead reflector has been measured by means of an ionization chamber having lead walls. The volume of the chamber was approximately 10 cc and the filling gas was air at atmospheric pressure. The results of these measurements are shown in Fig. VI-10. We are now trying to determine the relative contributions of neutron capture and inelastic scattering to the gamma ray flux in the lead reflector.

Study of Methods for Measuring Fast Neutron Energies (J. K. Bair, G. McCammon)

For some time we have been investigating experimentally the possibility of measuring the energy of randomly directed neutrons by using lithium loaded photographic plates. An analysis of this technique has recently been published[1] by Roberts. The reaction of interest is Li^6 (n,α) H^3. Cadmium coverings are necessary since the reaction has a high thermal cross section. The method is considered only for neutron energies of over a few hundred kilovolts. While the experimental work is as yet incomplete, it is thought that some comment on results obtained to date may be of value.

At present, the main problems are those of gamma ray fog and of reading the desired lithium tracks through a heavy background of recoil protons. Since it is intended to use such plates in work with critical experi-

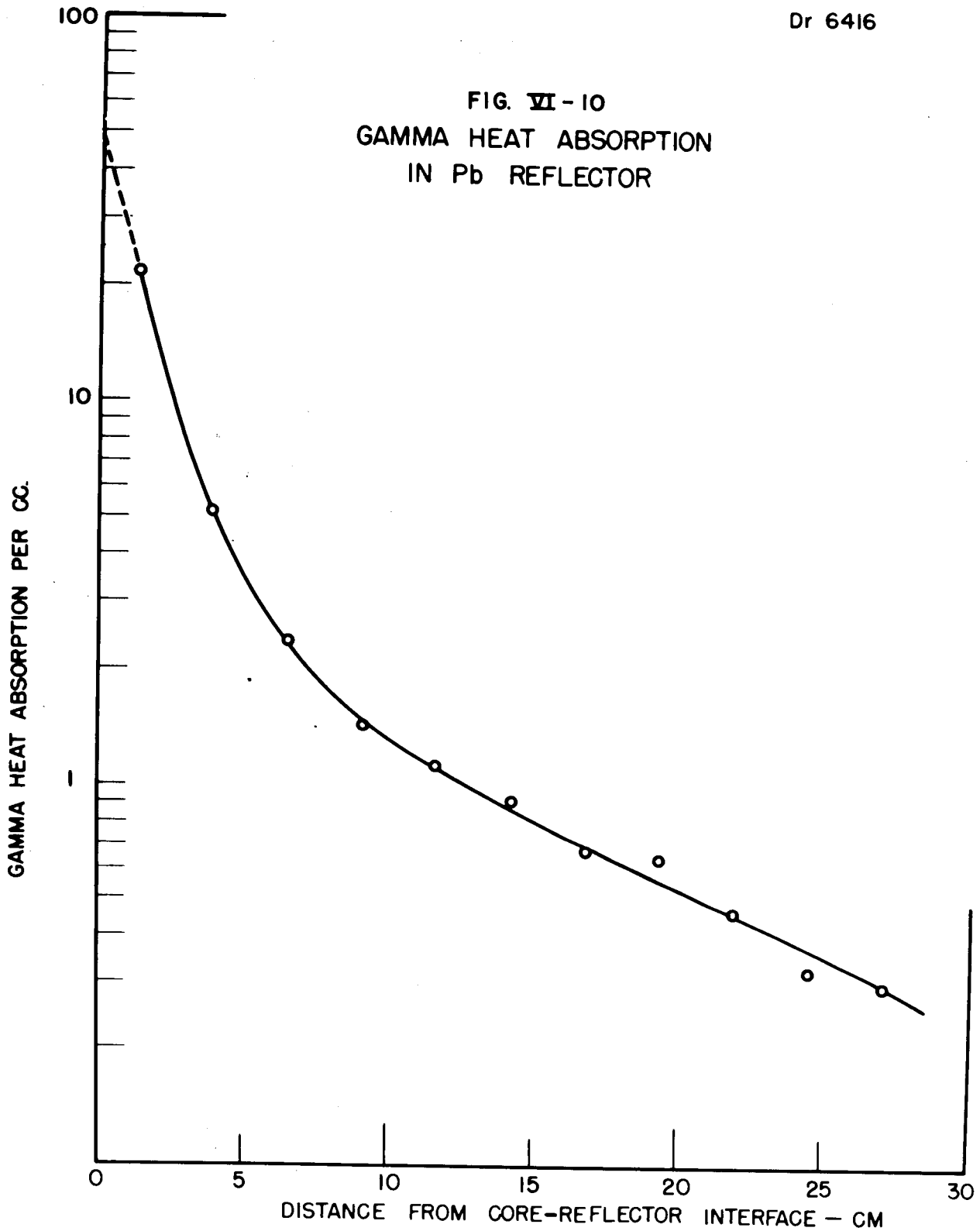
[redacted]

[1] Roberts, LAMS 779.

[redacted]

Dr 6416

FIG. VI - 10
GAMMA HEAT ABSORPTION
IN Pb REFLECTOR



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ments it is necessary to process them in such a way as to minimize background gamma ray fog. Such processing is not necessarily that which gives maximum differentiation between tracks of similar range but produced by different particles. It has not been found possible to reliably distinguish the alpha track from that of the triton, and thus the location of the disintegrating nucleus, when the particles are ejected at angles near 180°. Protons of range equal to the sum of the ranges of the lithium disintegration particles are easily confused with the desired event, particularly when the proton suffers a scattering near the end of its range.

Eastman has informed us that they are unable to reduce the hydrogen content of the plates although it would not seem impossible to develop a non-hydrogenous emulsion. After preliminary tests with emulsions containing the usual amount of 0.1 mg lithium per cm^2 of 50 micron emulsion, E. K. furnished some special plates in which they attempted to load a factor of ten more lithium. These plates, as received, were marked as containing 0.8 mg/cm^2. However, a chemical analysis shows about 0.38 mg/cm^2 while a nuclear determination showed the presence of a lesser amount. Since these plates were considerably thicker than the original ones with 0.1 mg/cm^2, the actual lithium to hydrogen ratio has not been markedly changed. Attempts to load large amounts of lithium into emulsions at this location have been unsuccessful. Further attempts will be made to obtain suitable plates both from Ilford and Eastman despite earlier information that Ilford could load only to 0.1 mg per square centimeter of 50 micron emulsion. If tests of these plates are encouraging, an attempt will be made to obtain plates loaded with the separated isotope.

Other methods of measuring neutron energy are being considered. Crystal counters, both of the electrical and optical pulse type, appear to be worth investigating. Conductivity pulses have been reported by Ahearn[2] in impure natural Sphalerite similar to those observed in diamonds. It would be of interest to use lithium as an impurity in such a crystal and observe any resulting pulses under neutron bombardment. Ahearn has been contacted on this subject.

Hofstadter[3] has reported scintillations in alkali halide crystals using sodium and potassium iodide. While lithium iodide is probably not available as a crystal since it decomposes just above the melting point, lithium fluoride, cloride and bromide are obtainable. Further, Moon[4] reports "excel-

[2] A. J. Ahearn, Phys Rev 73 524 (1948)
[3] Robert Hofstadter, Phys Rev 74 100 (1948)
[4] R. J. Moon, Physical Rev 73 1210 (1948)

[redacted]

[redacted]

lent" response from $LiAlSi_2O_6$ and LiF, presumably to gamma rays. A lithium fluoride crystal is now available and will be checked with the cooperation of P. R. Bell.

The fact that data on pulse heights produced by alpha particles indicate a wide variation in size, together with the fact that they are generally smaller than gamma produced pulses, is discouraging. However, no data seems to be available for pulses from alphas produced inside the crystal. A check of this type is planned.

Some search of the literature has been made for a gas compound of lithium for possible use in a proportional counter or ion chamber.

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SHIELDING PROJECT

E. P. Blizard, Physics Division, Leader
T. Rockwell, Technical Division, Associate Leader

H. P. Sleeper (KAPL) C. E. Clifford
W. K. Ergen (NEPA) N. F. Lansing
W. E. White (NEPA) T. I. Arnette
M. S. Johnson (NEPA) J. M. Cassidy
F. H. Murray

Experiments on Non-Uniform Shields (H. P. Sleeper, W. K. Ergen, W. E. White, M. S. Johnson, C. E. Clifford, T. I. Arnette, J. M. Cassidy, E. P. Blizard)

Attention has finally been turned to a study of non-uniform shields. A preliminary study has been made, using lead and boron cement in one experiment, and tungsten-carbide and boron-carbide in another. The WC-B_4C experiments are part of the NEPA test program, and are reported in the Oak Ridge Shielding Symposium Supplement. A report on the lead-boron cement shields will be issued shortly, ORNL-208.

The boron cement (BC) moderator was discussed in the previous monthly report. It has a density of 2 gm/cc, and contains 0.7 gm/cc of water and 0.09 gm/cc boron. The lead has a density of 11.3, tungsten carbide 7.9, and boron carbide 1.9 gm/cc. These are the densities as used; the theoretical densities are 15.7 for WC and 2.5 for B_4C.

In runs 33 and 34, results were compared for two inches and ten inches of lead in front of the BC, which was followed by more lead. The overall attenuation for fast neutrons was a factor of 10^6 in 30 inches of shield in both cases. This shows that the inelastic scattering in lead made a significant contribution to the attenuation of fast neutrons. Similar results were obtained for tungsten carbide and boron carbide shields, except that here the total attenuation was about 10^4 for 30" of shield. The neutron data for the NEPA samples are plotted in Fig. 1. The above mentioned 30" of NEPA shield, and abscissa in Fig. 1, refer to the samples of the density actually used. Compression of the samples to theoretical density would, of course, yield about 10^5 attenuation for 30" of shield. 1/4" thick masonite boards were used as foil holders, and an independent run was made to show that the effect of the masonite was negligible.

On the other hand, samples containing about equal thicknesses of B_4C and hydrogenous material (paraffin) were investigated. Here the large amount of hydrogen had a considerable effect, but the data are not evaluated in detail as yet.

The most interesting results were obtained for the gamma ray attenuation. Moving the heavy material from the front to the rear of the shield re-

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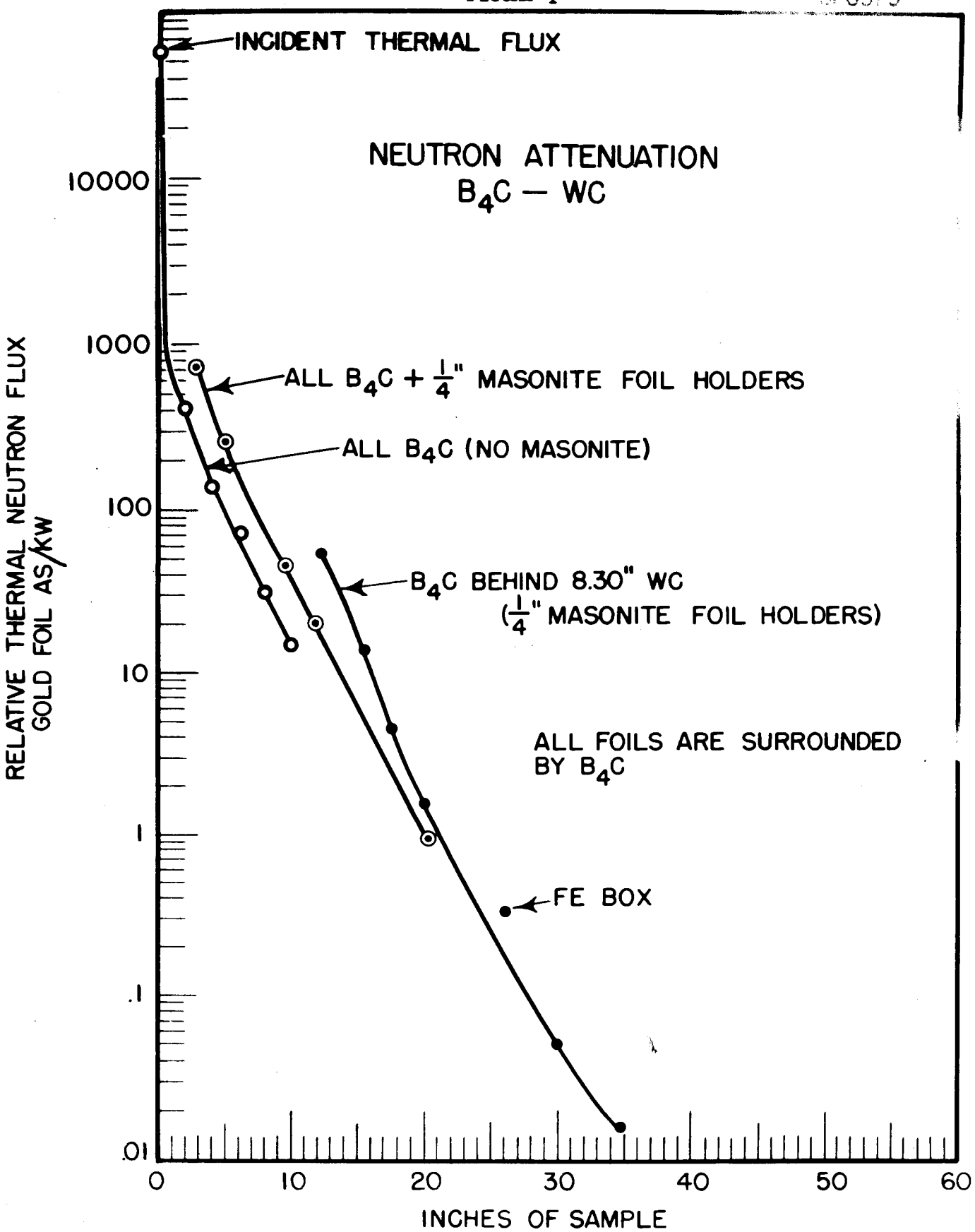
FIGURE 1

Dr 6375



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moves it from a high neutron flux to a much lower one. This affords a method of distinguishing between the primary gamma radiation and the secondary radiation due to capture and inelastic scattering of the neutrons in the heavy material. A thin coat of boron paint was used to reduce the capture in the lead, and 2" of B_4C served the same function for WC. Of course, some thermals were generated in the WC because of the carbon present.

The gamma data for lead and boron cement are plotted in Fig. 2. The results for runs 33 and 34 show a remarkable difference. At a point corresponding to 10" of lead and 33" of BC there is a ratio of about 600 in the gamma intensities. Evidently the effect of the secondaries from neutron interaction with the lead in front is overwhelming.

Run 35 was a rapid test to see whether the lead could be introduced half way in the moderator without producing a significant number of secondaries. The results confirmed the premise. It remains to be seen how much further forward the heavy metal can be moved, what is the optimum weight distribution, and whether the predominant secondaries are due to capture or inelastic scattering.

Similar gamma data are shown for the NEPA samples in Fig. 3. Evidently the effect of the secondaries is less serious, since the corresponding ratio is only about 6 in this case. The 8.3" layer of tungsten was protected in front against slow neutrons by 2" of B_4C, but there may have been significant neutron leakage into the sides from the X shield. A new boron-walled box will be used to repeat the experiment.

Application of Scintillation Counters to Gamma Measurements (C. E. Clifford)

Because the scintillation counter pulse height is a function of the gamma energy per photon, this instrument should afford at least an approximate method of measuring gamma spectra at various shield depths.

A counter of the type developed by Bell and Davis has been obtained and set up in conjunction with four Atomic scalers. As each scaler has its own pulse height discriminator, it is possible to take simultaneous counts at four different pulse heights.

A separate circuit was built for supplying uniform voltages to the pulse height discriminators, but at present there still seems to be individual drifting of the bias voltages. Measurements on a cobalt source have not been very satisfactory, due also in part to poor performance of 1P51 photomultiplier tube. Modifications are contemplated to remove these difficulties.

The counter does not exhibit very great sensitivity compared to a Geiger tube. Although this is a disadvantage in the present core hole tests,

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FIG. 2 Dr 6192

GAMMA ATTENUATION
BORON CEMENT-LEAD SHIELDS
(M.O. COMPARISONS)
G.M. MEASUREMENTS

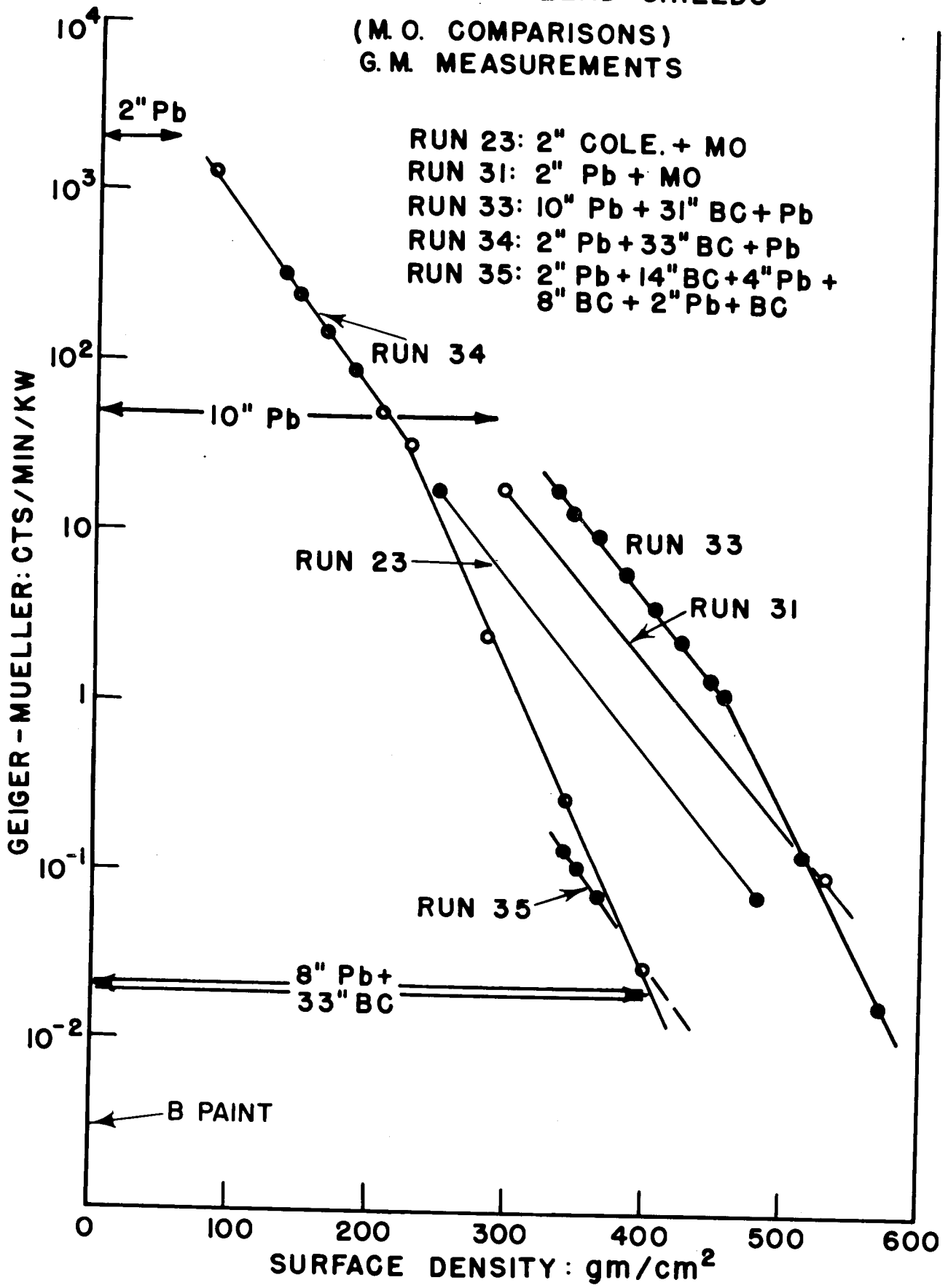

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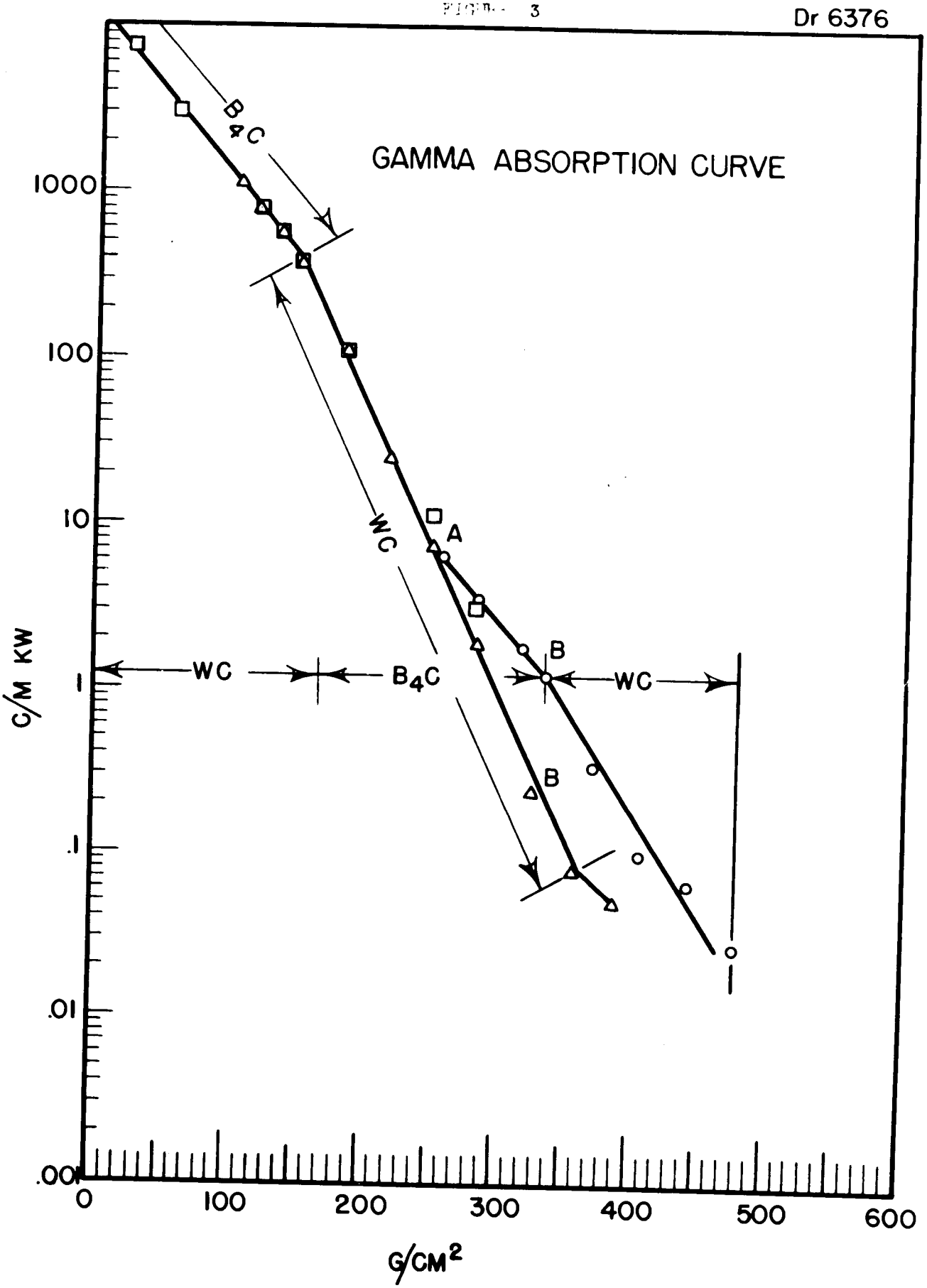
FIGURE 3

Dr 6376



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it will not be serious when the lid tank is installed and long counting times are permissible.

Scintillation counters can cover a wide range of intensities because their pulse time is so short that very fast counting rates are possible. Thus the piling up of counts at high counting rates in a Geiger tube is avoided with scintillation counters. This is very important in shielding measurements where large γ attenuation factors are the rule.

Evaluation of Gamma Measurement Technique (H. P. Sleeper, T. I. Arnette, E. P. Blizard)

The collimation characteristics of the lead shielded G. M. tube used in core hole measurements have been investigated further. The method using the point radium gamma source was described in the previous quarterly report, ORNL-159. The range has been extended to include measurements in planes from 6 to 14 feet from the G. M. tube. Core hole measurements are made over a range of 7 to 12 feet. The characteristics are given in Fig. 4, where the fraction,

$$\frac{\text{counts from source of radius R}}{\text{counts from infinite plane source}}$$

, is plotted against the radius of the source. It will be seen that 95% or more of the counts will be registered from the shield sample for distances up to 10 feet, and only somewhat less for 12 feet. Thus the contribution to the measurements from the Clinton X shield is shown to be very small, except for the 12 foot measurement. For an efficient shield, measurements are never made in this position, since the samples are moved near the rear of the X shield to reduce streaming effects at the edges.

Further confirmation of the reliability of the gamma data was obtained in run 26 for ordinary concrete. Here the data was taken in the standard position, and compared with measurements made directly behind the samples. We obtained attenuation curves exactly parallel, except for a small difference for the 12 foot measurement. These results show that we are measuring the characteristics of the shield sample, rather than extraneous effect due to gamma streaming from the edge cracks or from the surrounding shield.

Additional data were obtained in runs 33 and 34 to compare results for G. M. tube and ion chamber measurements, Fig. 5. The agreement is good for lead in run 34 with the electroscope, and fair for the cutie pie in run 33. The cutie pie data varies in the opposite direction to explain the difference between Zinn's* and our data. The agreement has not been checked for the light element portion of the shield.

* CP-684

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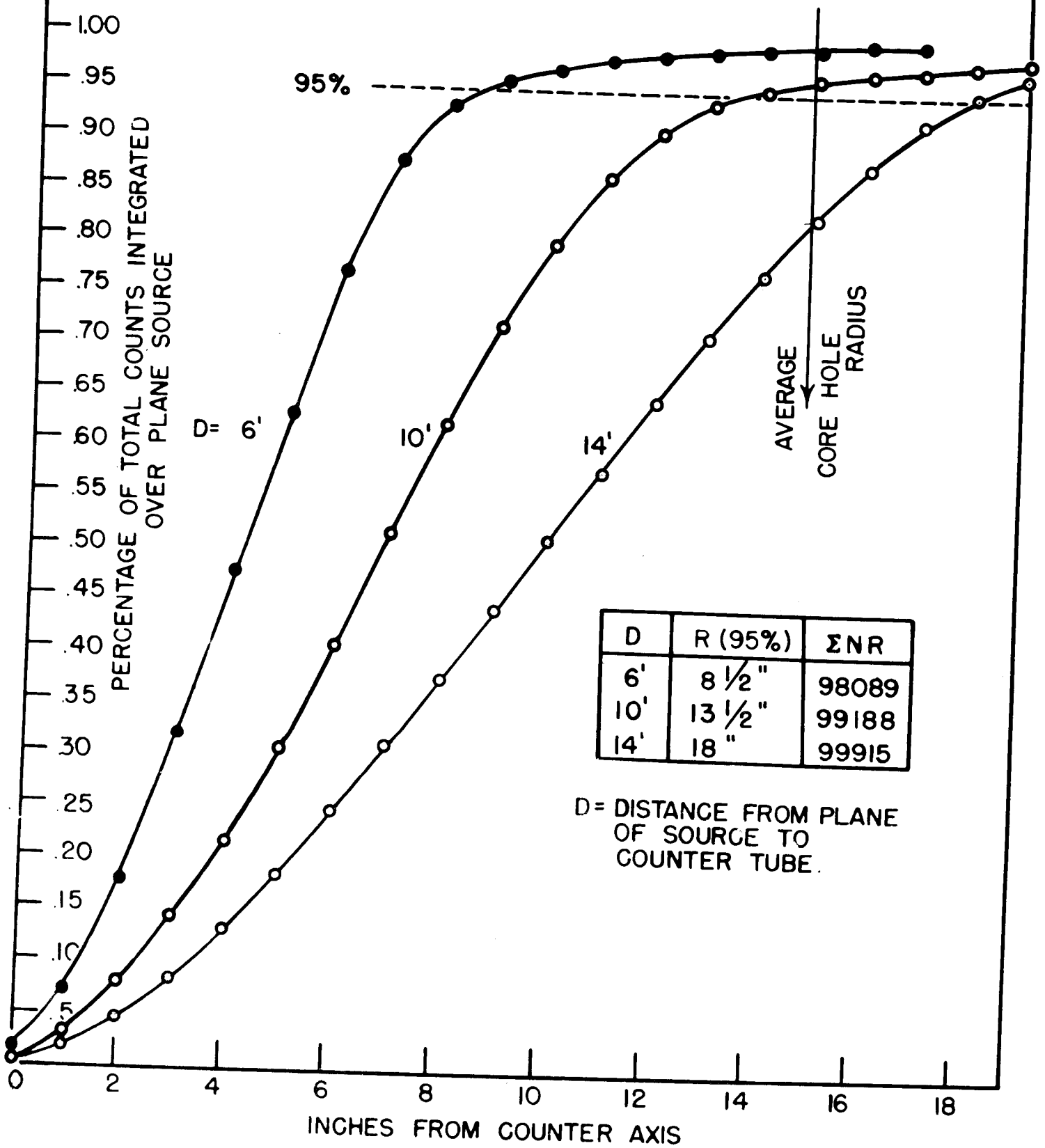
Dr. 6194

FIG. 4

—GEIGER COUNTER COLLIMATION CHARACTERISTICS



D	R (95%)	ΣNR
6'	8 1/2"	98089
10'	13 1/2"	99188
14'	18"	99915

D= DISTANCE FROM PLANE OF SOURCE TO COUNTER TUBE.

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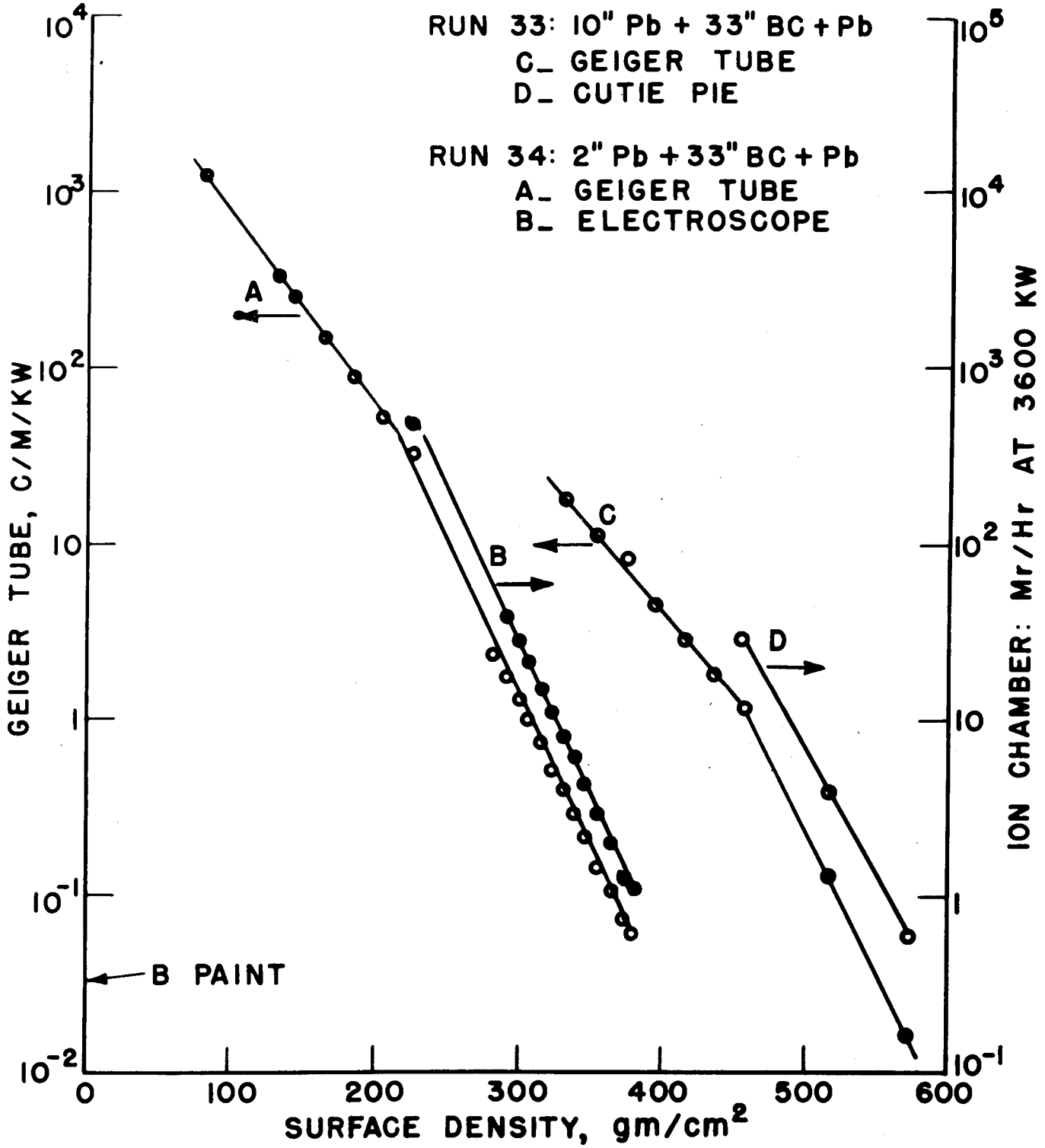
FIG. 5 Dr 6196

GAMMA ATTENUATION

COMPARISONS OF G.M. & ION CHAMBER MEASUREMENTS

BORON CEMENT-LEAD SHIELDS



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A summary of the gamma data taken to date shows that the observed relaxation masses seem to fall in three principal regions, 25, 35, and 45 gm/cm^2. The first region includes the heavy elements lead and tungsten, and agrees well with theoretical values expected by Friedman et al (Lex. P-1). The second region includes ordinary concrete, and Portland cement-iron mixtures. The third region includes iron-magnesium oxychloride mixtures, and the Hanford iron-masonite combination. Occasionally some materials like boron cement (4% B by wt.) fall between the second and third groups. There is no obvious explanation for the difference between the last two groups, although, it may have to do with the production and energy of secondary gammas.

Lid Tank (E. P. Blizard, C. E. Clifford)

The construction of the external core hole water tank to be used for lid tests is scheduled for completion February 15th. An ion chamber to monitor the thermal neutron flux incident upon the source as well as ion chambers to measure gamma flux throughout the tank over a range from 10 mr/Hr to 10,000 r/Hr are being designed and constructed by the Instrument Department.

A cost estimate on a method for handling samples up to 1500 lbs. in weight is being prepared by the Engineering Department. It is planned to use two $1\frac{1}{2}$ ton electric hoists available at Y-12. This will provide facilities for bringing heavy samples from outside the building into the area immediately behind the lid tank and also for placing the samples in the tank.

Reports

A report has been issued on the lead-acid battery damage tests, ORNL-106, by C. E. Clifford and T. I. Arnette.

The attenuation tests on wetted concrete have been reported by S. W. W. Shor and J. M. Cassidy, ORNL-203.

Early data on reactor shielding with iron aggregate portland concretes are reported by Blizard, Cassidy, Clifford and T. Arnette in ORNL-209.

Neutron Source Calibration for M.I.T. (T. Arnette)

Indium and gold foils have been exposed in this laboratory's standard pile and counted. The same foils will be exposed to a 1 gm. Ra-α-Be neutron source at M.I.T. Laboratory for Nuclear Science and Engineering. Calibration of the two sources will then be made by the M.I.T. group.

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Shielding Symposium Papers Presented

A short paper was presented by A. M. Weinberg to open the question of whether the heavy gamma-absorbing thermal shield is desirable. Some cost estimates made by N. F. Lansing of alternate designs were presented.

Another short talk by Blizard was designed to orient the audience with respect to shield testing. The large-scale tests were described briefly and justified.

The shielding program at Oak Ridge was described in two talks, the Physics Section being presented by Blizard and the Technical Section by Rockwell. In the former, the large-scale tests were evaluated and improvements proposed.

A third talk by Blizard described recent experiments on a non-homogeneous shield, presenting recent data in support of the premise that gamma shielding should be located at a place where neutron flux is already low, so that secondary gamma production is minimized.

Reference: Shielding Symposium, Central Files 48-10-44 and forthcoming supplement, C. F. 48-10-44.

Tests on MO Concrete with Fission Source (E. P. Blizard, C. E. Clifford, H. P. Sleeper, J. M. Cassidy, T. I. Arnette)

These tests on MO concrete were described in the last quarterly report, ORNL-159, p. 106 ff. Briefly, two tests were run, one of them with an array of natural uranium slugs at the inner face, the other without. Differences in flux presumably arise from the virgin fission neutrons. Neutron data are shown in Fig. 6. Gamma data were not very complete and are not reported here.

Attenuation Through Oak Ridge Pile Shield (S. W. W. Shor, J. M. Cassidy)

A complete report is being issued as ORNL-203. The report includes information on using the $Al^{28}(n,p)$ reaction as a threshold detector, including a calibration by means of the same activity induced by thermal neutrons in Mg.

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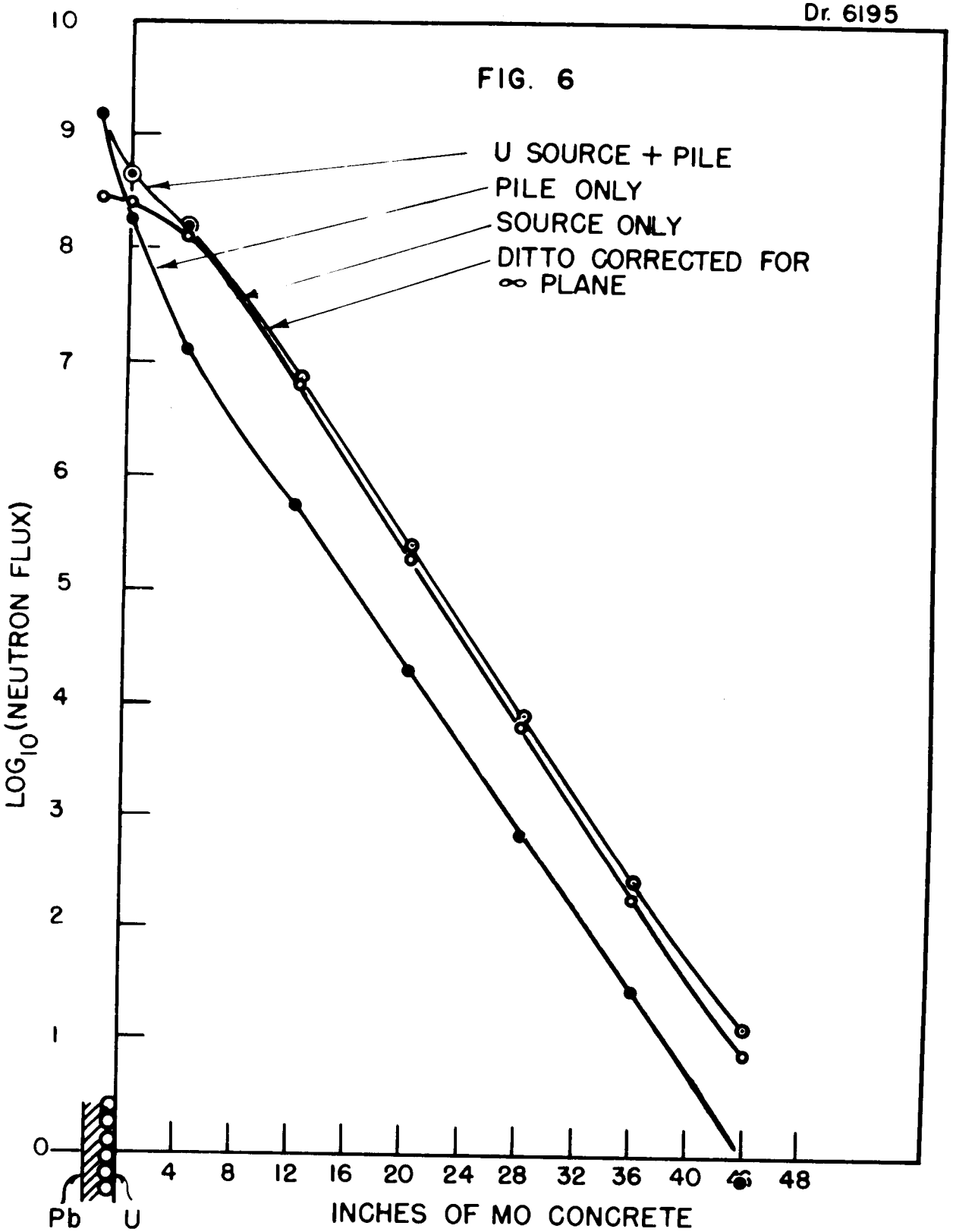
Dr. 6195

FIG. 6



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TECHNICAL DIVISION WORK

Shielding Symposium (T. Rockwell)

A four-day symposium was arranged for the period September 27-30, at which about 50 papers were presented on all aspects of shielding.

Thermal and Stress Properties of Oxychloride Concretes (T. Rockwell, W. K. Stromquist, J. B. Ruch, V. L. McKinney, D. Kirby)

At the request of the Knolls Atomic Power Laboratory, extensive tests are being carried out to determine thermal conductivity, allowable thermal stress thermal stability, etc. for MO concrete as well as M1. MO is an oxychloride cement iron aggregate concrete, of density 5.8, while M1 varies in that sufficient colemanite is added to afford 1% boron by weight. The density of the latter is decreased by the addition of the colemanite to about 4.9 gms./cm^3.

THEORETICAL WORK (F. H. Murray)

Continuing earlier work on the Boltzmann equation for neutron scattering, we have developed a method of solution by successive approximations for mixtures with variable cross sections which can be described as follows. When the flux nv is expressed in terms of an expansion in Legendre coefficients $F_n(z,u)$, z the distance from a plane source and $u = ln(E_0/E)$, scattering by a nucleus of mass M is represented in the Boltzmann equation with the aid of integrals

$$I_n^M = \int_{u-a_M}^{u} \sigma_M(u')g_M(u,u')P_n(Z_M)F_n(z,u')du'$$

$$a_M = 2 \ln (M+1)/(M-1)$$

where $\sigma(u')g_M(u,u')$ is the differential cross section for the transition (u',u), Z_M the scattering angle expressed in terms of u,u', and P_n is the nth Legendre function. In the Boltzmann equation one substitutes for I_n the product $h_{Mn}(z,u)\sigma_M(u)F_n(z,u)$ with the result that the integro-differential equation is reduced to a differential equation in z, which can be transformed into a system of linear differential equations in z, and solved by any convenient method.

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While the calculation of the coefficients h_{rs} by successive approximations is equivalent to the solution of the original equation containing a plane source, approximate solutions for mixtures containing hydrogen can be obtained easily by fairly simple considerations in some cases, as for H_2O. Where it appears likely that for a mixture containing hydrogen the solution will contain a factor $\exp(-az/E)$ due to the variable H cross section, in addition to a source distribution of the form $\exp(-bE)$, the product $\exp(-az/E-bE)$ can have a maximum at E_1 in the high energy region. Near this maximum one can assume the variation of F_0, F_1 with energy to be small, and assume that the factors h_{Mn} $(M > 1)$ vanish for all $n > N$. With $N = 0$ and a slight change in the analysis, one arrives at an approximate formula for H_2O similar to that of Wigner and Young, assuming no change in angle in the scattering of a neutron by a hydrogen displacement (about 17cm) in the forward direction due to aging down to indium resonance energy, the computed relaxation lengths are slightly greater than the observed, as expected theoretically.

For a single element at energies for which inelastic scattering is important, if $C_0 = \sigma_e/\sigma$, $C_1 = 3(\sigma-\sigma_{tr})/\sigma$, in the high energy region one obtains the approximate formula $nv = C\exp(-p\sigma z)$, where p satisfies the equation

$$\frac{C_1}{p^2} + \frac{1}{\frac{1}{C_1} - 1} = \frac{1}{\frac{\tanh^{-1}p}{p} - 1}$$

Here σ is the total cross section, σ_e the elastic, and σ_{tr} the transport cross section, and it is assumed that neutrons which have been inelastically scattered are prevented in some manner from penetrating to large distances.

This work is reported in fuller detail in ORNL 218.

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THEORETICAL PHYSICS

M. E. Rose

Since the last quarterly report the following work has been done:

1. Bremstrahlung spectrum for thick targets. The spectral distribution of radiation emitted when a fast electron passes through a target sufficiently thick to bring the electron to rest has been calculated. The results are easily interpreted physically. No numerical calculations have as yet been carried out. This work is of interest to the Health-Physics Division and is being turned over to Mr. J. Neufeld.

2. A survey article entitled "Nuclear Physics and Low Temperatures" has been written for Nucleonics magazine and will appear in the December issue. Two Letters to the Editor have been sent to the Physical Review. These are: "On the Production of Nuclear Polarization" and "The Scattering and Absorption of Polarized Neutrons by Polarized Nuclei."

3. Work is being done in collaboration with Mr. Neufeld of Health Physics on the problem of electron-neutrino correlation in heavy elements.

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