AEC RESEARCH AND DEVELOPMENT REPORT

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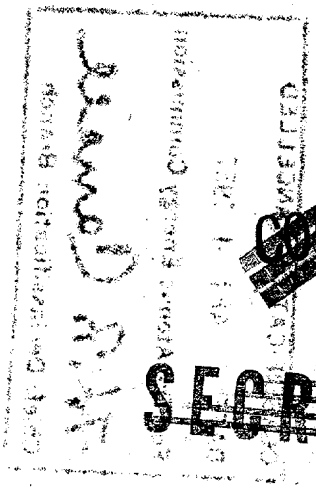

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SUMMARY OF THE ACTIVITIES OF THE EXPERIMENTAL SECTION OF THE NUCLEAR PHYSICS DIVISION IN THE PAST MONTH

E. Fermi

Argonne Pile

Work has been completed on the test of a composite shield of iron and paraffin. The results of this investigation have formed the basis for the design of the shield to be used in the "W" pile.

Measurements have been performed in order to determine the absorption cross section of oxygen and deuterium. Oxygen was introduced into the pile in the form of CO_2, and deuterium in the form of D_2O. Both experiments indicate a considerably smaller cross section for oxygen than had been so far assumed. An attempt to check on the cross section of oxygen by using beryllium oxide has not given constructive results so far due to some impurity introduced into the oxide.

The cross section of O^{18} has been newly measured by determining the activity of O^{19} formed by neutron capture. The result is in substantial agreement with the one obtained in the West Stands.

A test has been made for determining the relative effectiveness of control rods of different cross section: cylinder, cross, and plate.

Some investigation has been conducted on the radioactive gases that emanate from the pile. Most of the activity is due to gas emanating from pressed oxide lumps. Appreciable activity is also directly induced in air, primarily due to the activation of the atmospheric argon.

The usual program of testing of metal lumps has been regularly carried out during the month. The possibility of the use of the pile for testing of graphite has also been investigated with the result that it appears easily possible to determine absorption cross sections of graphite with a sensitivity of the order of magnitude of 1% using samples of the order of 50 or 100 kilograms.

The thermal neutron density across a lattice cell has been determined in order to obtain an experimental measurement of the disadvantage factor.

A series of measurements have been performed using the thermal neutron purification unit on top of the pile. The test has indicated that all epithermal neutrons are removed to a very great extent, so that cadmium ratios of the order of 20,000 have been observed with indium foils. The thermal neutrons escaping from the column have been used to produce a beam for the measurement of cross sections. Certain irregularities in the results obtained in this investigation have led to the observation that neutrons of energy apparently much lower than thermal neutrons can be filtered out of such a beam using a graphite scatterer. These very slow neutrons have in most cases cross sections very substantially different from the cross sections for normal thermal neutrons; in particular the cross section in graphite drops down from the normal value of 4.8×10^{-24} to $.7 \times 10^{-24}$, while the boron cross section

increases by a factor between 3 and 4. It is expected that such large variations of the cross sections for neutrons of very low energy will have a considerable bearing on the discussion of the dependence of the reproduction factor on the temperature of the pile. The details of these investigations are given in the reports of Zinn, Weil, Anderson and Marshall.

Exponential Piles

Mr. Morrison's group has completed the exponential piles for the test of the reproduction factor in the "W" lattice with and without water in the pile. A test has also been conducted to determine the effect of adding some small amount of boron in the water in order to obtain a direct measurement of the migration length of the neutrons in this lattice.

Cyclotron Group

The time of the Cyclotron Group has been primarily taken by irradiations for the Chemistry and Health groups. Besides this work an investigation has been conducted of the absorption cross section of argon and the comparison of the global decay curves of thorium and uranium fission products has been extended to a longer interval of time.

PHYSICS GROUP III - 17

W. H. Zinn - 10

Neutron Absorption of the Argonne Concrete Shield (A. Wattenberg, R. Nobles, H. Lichtenberger)

The neutron intensity throughout the concrete shield surrounding the Argonne pile was measured by placing indium foils on concrete blocks which could be slid into one of the 1' x 1' openings at the center of the east face of the pile. The table gives in the first column the distance of the foil from the outside surface of the dead graphite of the pile. At this point in the pile there are 16-1/2" of dead graphite. The second column gives the saturated activity observed in the indium foils, the higher intensity points being corrected for the long-lived activity. The third column gives the number of neutrons/sec/cm^2/K.W. It is clear from the data that a fast neutron component is present and that it raises appreciably the intensity in the outer points of the shield. For the slow neutrons an exponential relaxation distance of 7.9 cm is indicated. It should be noted that the concrete blocks in which the measurement was made were rather "green" and it is possible that in time some further drying out will take place with a consequent loss in absorbing power. Nevertheless, the number of neutrons escaping from the shield is well below the physiological tolerance amount at the highest power (100 K.W) at which the Argonne pile is ordinarily operated. Gamma-ray measurements on the concrete shield have not as yet been carried out, but measurements of the gamma-ray intensity in the room surrounding the shield indicate that for gamma-rays the shield is also quite adequate. Some typical gamma-ray measurements are the following: 10' from the north face of the pile, .0002 R/K.W.H.; directly in front of the lead shield covering the removable stringer, .0015 R/K.W.H.; on top of the pile midway between the center and side, .001 R/K.W.H. Since the Argonne pile is not operated on the average more than 10 K.W. hours per day, it is seen that these levels are well below the tolerance dose.

Table I

Distance of Indium Foil from Graphite Face

cm.	In Counts/min.	n/sec/cm^2/K.W.
0	2.37×10^8	2.0×10^7
15.2	3.64×10^7	3.1×10^6
30.2	5.06×10^6	4.4×10^5
60.4	1.13×10^5	9.9×10^3
90.6	5.04×10^3	440
120.8	8.91×10^2	78
151	1.88×10^2	16

Tests of the Iron Shield Proposed for "Y" (A. Wattenberg, H. Lichtenberger, R. Nobles, H. A. Fowler & J. M. West)

Experimental shields of iron and mixtures of iron and paraffin were constructed and the neutron and gamma-ray intensities were measured throughout the shield by means of foils, counters, and electroscopes. The iron plates were laid up in a column 5' on the side and thicknesses of iron up to 30" and of iron and paraffin up to 43" were tested. Some of the results

of this measurement and a preliminary analysis are given in report CP-684. A report containing the complete set of measurements will be issued in the future.

The Absorption Cross Section of Oxygen (H. Lichtenberger & H. Fowler)

The oxygen absorption cross section was measured by placing in the Argonne pile a tube containing liquid CO_2. The duraluminum tube had a length of 368 cm and an internal diameter of 6.35 cm; the wall thickness was 6.3 mm. When filled it contained 8150 grams of CO_2. In order that the slowing down of the material in the tube should be canceled out, the measurement consisted of obtaining the shift in the critical position when the tube was filled first with CO_2 and then with an amount of pure graphite which was to have the same slowing down as the carbon and oxygen in the CO_2. This amount of graphite was 5173 grams. The experiment was calibrated by placing cadmium wires of known cross section in the tube with the graphite and remeasuring the critical position. Table II summarizes the results obtained.

Table II

	Critical Position Corrected for Pressure
Tube empty and evacuated	329.94 cm
Tube filled with 8150 grams CO_2	330.66 cm
Tube + 5173 gms. AGOT graphite	330.42 cm
Tube + graphite + 6 Cd. wires evenly distributed along the length	326.66 cm

Each cadmium wire has a cross section for the neutrons in the pile = 1.0 cm^2. The $\sigma_{cd}^{(KT)}$ of each wire is estimated to be 1.25 cm^2 and, therefore, the cross section of the 6 wires added = 7.50 cm^2. The displacement of the rod due to the addition of the cadmium was 3.77 cm and, therefore, 1 cm displacement = 1.99 cm^2. The 5173 grams of AGOT graphite which were used in the tube have $\sigma^{(KT)}$ = 1.299 cm^2. The absorption of neutrons in this graphite caused a shift farther out of the rod = $\frac{1.299}{1.99}$ = .65 cm. Therefore, if there had been no absorption, but only slowing down in the graphite, the position of the rod would have been 330.42 cm + .65 cm = 331.07 cm. The shift in position of the rod due to the absorption of CO_2 is 331.07 - 330.66 = .41 cm. The absorption cross section of the CO_2 in the tube is .41 x 1.99 = .815 cm^2. The carbon in the CO_2 produces part of the absorption and assuming that this carbon has the same absorption cross section as AGOT graphite, we find .56 cm^2 for the cross section. Therefore, the absorption cross section of the oxygen in the tube = .815 - .56 = .25 cm^2 and

$$\sigma_0^{(KT)} = .0011 \times 10^{-24}$$

This measurement is subject to three principal errors. (1) Error in the determination of the critical position. The actual shifts observed are rather small and it is estimated that they could be in error by as much as 20%. In the cross section this amounts to .0004 x 10^{-24} cm^2. (2) Weights of CO_2 and graphite. The error here is entirely negligible. (3) Impurities

in the graphite which are not present in the carbon of CO_2. This would mean than in subtracting .56 cm^2 for the absorption of the carbon in CO_2, too much was subtracted and, therefore, the oxygen cross section is underestimated. If it is supposed that the boron impurity which is known to exist in the ACOT graphite is absent in the CO_2, then the oxygen cross section may be increased by .0005. Thus the final value of $\sigma_O^{(KT)}$ is .0016 $\pm$ .0004 x 10^{-24} cm^2.

The Absorption Cross Section of Aluminum for the Neutrons in the Pile

Ninety-six of the Al cans which are to be used for canning the metal for the "X" pile were placed inside the duraluminum tube used in the CO_2 experiment and the shift in the critical position measured. The shift found was 3.78 cm and, therefore $\sigma^{(KT)}$ of one can = .0785 cm^2. On the average one can weighs 14.8 grams and, therefore, $\sigma^{(KT)}$ for the Al = .24 x 10^{-24} cm^2.

Experiments in Progress

It has been observed that radioactive gases come out of the pile and some work is in progress to measure the source of this gas and the cross section for its formation. Some of this activity has been shown to be due to argon in the air and a far larger fraction of the activity is due to fission gases. Heavy water has been irradiated in the pile for some time and it is hoped to measure the deuterium absorption cross section by comparing quantitatively the amount of H^3 generated in deuterium and also in lithium for which the cross section for the formation of H^3 is known.

Physics Group IV

H. L. Anderson

Capture of Heavy Water: (Anderson, Molloy, Nagle)

A determination of the capture of heavy water was made by observing the change in the critical position of the control rod of the Argonne pile when heavy water was substituted for graphite in 80 cells of the pile. The amount of graphite which was removed was chosen to have the same slowing-down power as heavy water. The results are given in Table I which gives the change in inhours with the various substances which were placed in the cells.

Substance in cell	Inhours
#1 Al cans 19.0 grams	+ .34
#2 Al cans 19.0 grams	+ .35
#2 Al + 307.4 grams AGOT graphite	+ .37
#1 Al + 68.4 grams D_2O	+ 2.82
#1 Al + 11.33 grams Fe + 68.4 gm D_2O	- 6.12
#2 Al + 307.4 grams AGOT graphite	+ .58

The aluminum cans in which the heavy water was placed seem to be equivalent to the aluminum cans which were used in the graphite part of the experiment. The addition of the graphite produced only a small change in the inhours, due to the fact that the amount of graphite in the cell is very nearly optimum. The difference in the inhours between D_2O and graphite was 2.34. To interpret this result in terms of a cross section, an iron bolt was added to each cell. The change in inhours was -8.94. The cross section of an iron bolt for kT neutrons was found to be .278 cm^2 by comparison with Cd wires. These results show that the decrease in the capture cross section when D_2O was substituted was 0.0728 cm^2 per cell. Taking .00493 x 10^{-24} cm^2 for the cross section of AGOT graphite, the cross section of $\frac{1}{2}$ a molecule of D_2O is 0.0008 x 10^{-24} cm^2. These experiments show that heavy water is definitely superior to graphite as a slowing-down medium. On the other hand, it is to be emphasized that the results obtained for the capture of heavy water are subject to considerable error from several causes. Errors of 10% in the value of the cross section of graphite, the estimate of the slowing-down power of heavy water as compared with graphite and in the determination of the inhours are all fairly probable. For these reasons the probable error in the result is several times larger than the result itself. On the other hand, the contamination by ordinary water was about 19%, which would account for all the absorption observed. It may be concluded that while the above measurements do not establish an accurate value for the capture cross section of heavy water, they do indicate that is low enough to affect in only a minor way the design of heavy water plants. If the indication of such a low cross section is borne out, serious consideration should attend the possibility of a homogenous plant.

The Standard Graphite Pile at Argonne: (Leo Seren)

Standardization measurements on a 5' AGNT column were completed. The density of the graphite was 1.6146 grams/cm^2. The diffusion length was taken to be 49.73 cm. The indium foils which were standardized were 4 x 6.5 cm^2 and of weight 2.400 grams. They were measured on our counter set Daleth. Ra + Be sources IV and V were used and their strength was taken to be 11.9 x 10^6 neutrons per second by comparison with sources I and III. The resonance activity was measured and is described by means of the equation

$$A(CdInCd) = 24,672e^{-(z/28)^2} + 11,586e^{-(z/40)^2} - 957e^{-(z/60)^2} \qquad (1)$$

which gives the In resonance activity in counts per minute. The percentage of each range is given in Table II

Table II

Fraction	In Range cm	Thermal Range cm
.3633	28	32.6
.4974	40	43.3
.1393	60	62.2

From this data the thermal neutron density was calculated along the lines given in CPA-6. The results were:

for the slowing-down density -

$$q_{In} = 0.00143\ (CdInCd) \quad \text{neutrons/cm}^3\text{/sec} \qquad (2)$$

and for the thermal neutron flux -

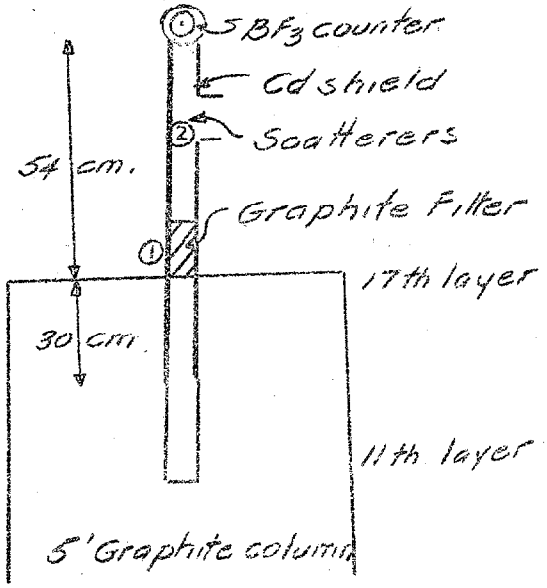
$$nv = 0.102\ (In - 107CdInCd) \quad \text{neutrons/cm}^2\text{/sec} \qquad (3)$$

The quantities of (CdInCd) and (In) represent the saturated activities in counts per minute as recorded on the counter set Daleth. In the equation (3) a mean free path of 2.71 cm was used. A more complete report describing these measurements more in detail is forthcoming.

Interference Effects with Thermal Neutrons: (Anderson, Fermi, and Woods)

On top the Argonne pile there is a thermal purification column made of graphite 5' x 5' and 31 layers high above the lattice. Attempts were made to measure the boron cross section for the neutrons emerging from the top of this column. The results obtained was 522 cm^2/mole, which is considerably larger than the value 464 cm^2/mole previously obtained. This indicated that probably the lower energy neutrons penetrated more readily through large thicknesses of graphite than do the neutrons in the higher energy part of the Maxwell distribution. Further experiments indicated that

interference effects due to the crystal structure of graphite have a considerable effect on the diffusion of neutrons. A good beam geometry was set up in order to study the crystal effects in a more systematic way. The geometry is shown in Figure 1. Measurements were made of the total cross section of various substances placed either at position 2 or 3 in the beam with and without a graphite filter 23 cm long placed at position 1. The results are given in Table III. The first column gives the substances used, the second gives its thickness in grams per cm^2, the third and fourth column give the logarithms of the transmission and the total cross section in units of 10^{-24} cm^2 per atom, respectively, as measured without anything in position 1, while columns five and six give these quantities for neutrons which have been filtered through 23 cm of graphite. With the filter the absorption coefficient in boron (pyrex) increased by a factor of 3.5. This corresponds to a reduction in energy by a factor of 12.4 for the neutrons which emerge from the graphite filter. Such low energy neutrons are transmitted through the filter because their wave length is larger than the lattice spacing in graphite crystals. Destructive interference occurs for all directions except the straight-through direction, and consequently the only scattering which occurs is due to imperfections in the crystals. Since graphite is a polycrystalline material, Bragg reflection scatters all neutrons whose wave length is smaller than the lattice spacing. Thus the scattering cross section for unfiltered neutrons is 4.05B* while for the filtered neutrons the value was 0.70B. A similar effect was observed for Be.



*B = 10^{-24} cm^2.

In the case of lamp black, however, the cross section for the unfiltered neutrons is found to be considerably not only higher than that of graphite, but also its value rose from 11 to 14.8 when filtered neutrons were used. This increase may be explained by supposing that the lamp black atoms are arranged in clusters whose dimensions are small compared to the wave length of the neutrons. Since the atoms are not arranged in a regular way, destructive interference will not take place. Instead, the neutron waves of the scattered radiation will be in phase and the intensity of the scattering will then become proportional to the square of the number of atoms in a cluster rather than to the first power of this number as would be the case for smaller neutron wave lengths. The increase in the scattering cross section observed for paraffin and for D_2O is believed due to the effects of chemical binding. For uranium the increase is due to the increase in the absorption for lower energy neutrons. This increase is smaller than for boron because of the more important role played in uranium by the scattering.

The measurement of the boron cross section was also made using a paraffin filter of 3.8 cm thickness. The result was 368 cm^2/mole, indicating that neutrons which penetrate through paraffin emerge with a higher average energy. From paraffin filtered neutrons to graphite filtered neutrons the energy is decreased by a factor of 25. This should be useful in studying the variation in nuclear cross sections for slow neutrons of different energies. These effects reopen the question of what is the value of the boron cross section for the neutrons of a given energy. It is planned to resolve this difference by measuring boron cross section for indium resonance neutrons, the energy of which has been measured to be 1.44 ev. In addition an attempt will be made to use the monochromatic radiation which may be obtained by Bragg reflection from a crystal.

Table III

Substance	gm/cm^2	No Filter		23 cm Graphite Filter	
		Log T	σ	Log T	σ
Paraffin	.1244	.626	58.4	1.117	104
Paraffin	.2992	1.425	55.3	2.390	92.7
Be	4.52	.977	3.25	.219	.73
Be	9.04	1.693	2.82	.424	.71
Graphite	12.96	2.637	4.05	.453	.70
Lampblack	1.69	.936	11.0	1.260	14.8
Pyrex	.241	.437		1.537	
U	17.5	.697	15.7	1.390	31.4
D_2O	4.352	2.008	7.65	2.475	9.44

Neutron Yields from Polonium Alpha Particles: (Roberts)

Thick targets of several of the light elements have been bombarded with alpha particles from polonium. The neutrons were detected by BF_3 counters in paraffin. The efficiency of detection was determined by a Ra + Be source of known neutron yield. Measurements were made with the counters 7 and 12 cm from the source. The efficiency for counting "C" neutrons was about .0007 per counter for the 7 cm position and .0003 per counter at 12 cm. Range measurements of the α particles indicated that the polonium source was not sufficiently thin for high accuracy. No correction has been made for the effect of the energy of the emitted neutrons upon the efficiency of detection. It is unlikely that this correction would in any case amount to more than twenty percent. However, impurities in the target may have introduced, in some cases, an error of ten or twenty percent. The table gives the neutron yield per 10^6 α particles. In all cases except fluorine the element was used. Fluorine was measured using CF_2 target and connecting for the effect of C. The result was checked using MgF_2 and CaF_2. The boron assayed 80% pure; the impurity was taken to be oxygen, and a correction was made. A complete report will be issued soon.

Element	7 cm η per $10^6 \alpha$	12 cm η per $10^6 \alpha$
A	.29	
Al	.58	.67
B	18.8	23.2
Be	65.9	75.8
C	.085	.12
F	9.5	
Mg	1.1	
N	0	0
Na	1.16	
O	.06	.07
P		.02
Si	.13	

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PHYSICS GROUP V

G. L. Weil

Metal Testing

Calibration - $\frac{\Delta k}{\Delta ih}$

The critical positions of the control rod were determined with and without 29.7 grams of iron wire wrapped around each of the 16 eggs in Lot #1. The results of the measurements follow:

No iron	Critical position	126.29 ih
With iron	" "	121.80
	Δih due to iron poisoning	4.49 ih

The percent change in reproduction factor per cell caused by the introduction of the iron poisoning can be calculated from the following formula:

$$\Delta k\% = 100 \frac{a}{b} D \times f \times \frac{W_i}{W_u}$$

where $\frac{a}{b}$ is the ratio of neutron density at the surface of the metal lump (where the iron was placed) to the average neutron density inside the lumps; D is the danger coefficient of iron, f is the thermal utilization of the cell, W_i is the average weight of iron per cell, and W_u the average weight of the uranium per cell.

The ratio $\frac{a}{b}$ can be calculated for an equivalent spherical lump (radius = 2.94 cm) assuming a neutron density variation inside the lump of the form:

$$\frac{\sinh \mathcal{K} r}{r}$$

The ratio $\frac{a}{b}$ is then given by the following expression:

$$\frac{a}{b} = \frac{3/R^3 \int_0^R \sinh(\mathcal{K}r)\,dr}{\frac{\sinh(\mathcal{K}r)}{R}} = \frac{(\mathcal{K}R)^2 \sinh(\mathcal{K}R)}{3[\mathcal{K}R\cosh(\mathcal{K}R) - \sinh(\mathcal{K}R)]}$$

Using Mr. Wigner's value of $\mathcal{K}$ for metal of density 18.8 gms/cm^3

$$\mathcal{K} = .0424 \times 18.8 = .796$$

and with R = 2.94 cm

We obtain $\frac{a}{b} = 1.32$

with D = 1.32 from measurements with CP #1
f = .83

W_i = 29.7
W_u = 1987

We obtain

$$\Delta k = 100 \times 1.32 \times 1.32 \times .83 \times \frac{29.7}{1987} = 2.2\% \text{ per cell}$$

and

$$\frac{\Delta k}{\Delta ih} = \frac{2.2}{4.5} = 0.49\% \text{ per inhour.}$$

Testing Procedure

The procedure for the testing of billet samples has now been sufficiently standardized to merit a brief description.

The metal testing stringer consists of two sections, each section being a complete stringer for the pile. This affords two advantages; first, when making the change between tests the pile intensity remains constant, and second, while the billet samples in one section are being tested, the other section can be loaded with the next Lot. The double length stringer is moved back and forth by means of 1/8" steel cable which runs through the pile, is attached to wooden blocks at each end of the stringer, and is wound on hand operated winches at each end of the platform outside the pile.

The critical position of the control rod is determined by the galvanometer drift method. The pile is operated at an intensity of about 5 watts, corresponding to a galvanometer reading of 200 divs. If the control rod is .1 inhour off the critical position, the pile has a period

$$\tau = 600 \text{ mins.}$$

and the galvanometer will drift

$$(R-R_o) = R_o \, (e^{t/600}-1) \text{ division in}$$

a time t. The drift is measured for three minutes, therefore,

$$(R-R_o) = 200 \, (e^{3/600}-1)$$

$$\cong 200 \left[1 + \frac{1}{200} - 1\right] = 1 \text{ div.}$$

This corresponds to a drift of 25 divs. on the differential galvanometer which is operated at full sensitivity. Thus a drift measurement of this sort is sufficient to determine the critical position to an accuracy of about .02 inhours, corresponding to approximately 0.4 mm.

The drifts corresponding to two control rod positions are determined for each Lot tested. A complete test, that is from the beginning of one to the beginning of the next, takes 8 to 9 minutes. Since every fourth test is made on the standard Lot, this means that about 5 or 6 Lots of unknown quality can be tested per hour.

In the past month a total of 89 Lots have been tested.

Graphite Testing (E. Montgomery, V. Staebler, & H. Vandersall)

To investigate the sensitivity of the Argonne pile in connection with the testing of graphite purity, the critical positions of the control rod were determined when the three removable dead graphite stringers were loaded with different brands of graphite. The results are given in the following table: Column 1 gives the brand of graphite which filled the three stringers, column 2 the average of two determinations of the critical position, column 3 the change in critical position from that for AGOT, column 4 the atomic cross section as determined from sigma piles, and column 5 the sensitivity.

Brand	Crit.Pos. inhour	Δih	$\sigma \times 10^{27}$	$\frac{\Delta\sigma}{\Delta ih} \times 10^{27}$
AGOT (10,11)	125.59	0	4.84	
Speer 1	124.60	-.99	5.49	.66
U.S.	122.14	- 3.45	6.38	.45
AGX	121.66	-3.93	6.68	.47

The values of $\frac{\Delta\sigma}{\Delta ih}$ are to be taken as indications of the sensitivity of the method, since the cross sections given in column 4 are average values for large amounts of graphite, and not necessarily the true cross section of the relatively small amount of material used in these tests.

From the above results it appeared that substituting the graphite in the central portions of two stringers (total length 264") would give sufficient sensitivity. Such a procedure was calibrated by poisoning each of these bricks with a known cross section of cadmium, and measuring the shift in critical position of the rod. The cadmium, in the form of cylindrical pieces of diameter .101 cm and length 12.6 cm, had a total neutron cross section of 1 cm^2 per piece. This corresponds to a σ_{KT} of

$$\sigma_{KT} = \frac{2}{\sqrt{\pi}} \sqrt{\frac{395}{295}} \times 1 = 1.26 \text{ cm}^2$$

Since this poisoning was added to each graphite brick, the change in cross section per atom amounted to

$$\Delta\sigma = \frac{1.26}{3.29 \times 10^{26}} = 3.83 \times 10^{-27} \text{ cm}^2$$

The observed shift in critical position of the control rod was

$$\Delta ih = 7.45 \text{ inhours}$$

Thus, for the sensitivity we obtain

$$\frac{\Delta\sigma}{\Delta ih} = \frac{3.83 \times 10^{-27}}{7.45} = 0.51 \times 10^{-27} \text{ cm}^2 \text{ (atomic) per inhour}$$

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Reproduction Factor of UC_2

We received from Mr. Spedding 14 cast cylindrical lumps of UC_2 (average weight 2122 grams and density 11.6 gms/cm^3). These were compared in the metal testing stringer with the 16 billet samples (average weight 1796 grams) composing Lot #81, which is the standard used in the metal testing comparisons.

The critical position of the control rod for the two cases was:

UC_2	critical position	107.70 inhours
Lot #81	" "	110.36 inhours

or $(\Delta ih)_{14} = -2.66$ inhours

Since our previously determined calibrations were made for Lots of 16 eggs, and also since the 14 carbide eggs were arranged in the stringer in such a way that their effect should be $\frac{14}{16}$ of a complete stringer, we have

$$(\Delta ih)_{16} = \frac{16}{14}(-2.66) = -3.04 \text{ inhours}$$

Calculating the thermal utilization (CP-372) of the cell containing UC_2 one obtains

$$f = .850$$

which corresponds to that of a cell of similar size containing U metal having a weight of 2400 grams. From the weight correction curve (CP-641) we obtain

$$(\Delta ih)_{weight} = -2.90 \text{ inhours}$$

and, therefore, the total change in critical position of the control rod due to UC_2 compared to a metal cell having an equal thermal utilization is

$$\Delta ih = -3.04 - 2.90 = -5.94 \text{ inhours}$$

From our previous calibration

$$\frac{\Delta k}{\Delta ih} = 0.5\% \text{ per inhour}$$

we get for the carbide:

$$\Delta k = -0.5 \times 5.94 = -3.0\% \text{ compared to U metal.}$$

Safety Rods

During the past month Safety Rod #3 has been put into operation (G. Monk). This rod, designed by Mr. Fermi, makes use of a magnetic clutch in its operations. The construction is extremely simple and its operation has proved to be very reliable. The rod can be removed from the pile in about 7 secs., making it very useful for certain types of measurements. The magnetic clutch feature also makes it adaptable for other uses.

Other Experiments in Progress

Measurements have been made (G. Monk & V. Staebler) on the fine structure of the neutron density through a cell. The results are not yet completely calculated, and will be reported in the monthly report for June.

Humidity calibration of the Argonne pile is in progress. (H. Vandersall)

Preparations for a measurement of the oxygen cross-section (E. Montgomery, V. Staebler & H. Vandersall) through comparison of Be and BeO have been completed. Results should be available shortly.

Preparations have also been made (E. Montgomery) for an experiment to determine the effect of placing Be near the metal lumps.

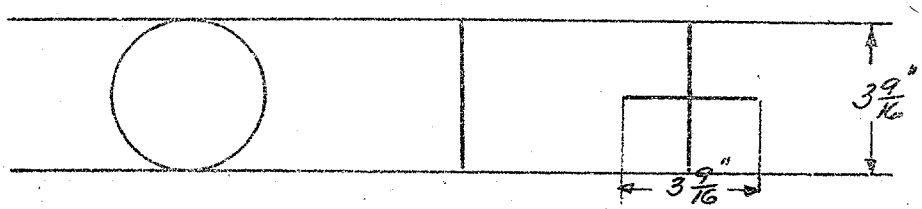
During the past month Mr. George E. Mallinckrodt has joined our group.

PHYSICS GROUP VI

John Marshall dlite

Comparison of Control Rod Shapes

An experiment was performed to determine the efficiency of various control rod shapes. Three shapes were tried, all having the same maximum dimensions. The shapes and dimensions are shown in the figure:



All were made of cadmium sheet and were 60" long. The circular one was wrapped around a steel tube. The rods were inserted to their full length in a 4" x 4" hole in the side of the Argonne pile. The inner end of each rod was placed against the end of the hole. The table gives the results of the experiment.

Shape	Critical Position of Control Rod	Inhours from Pile Calibration Curve	
+	3.5204 meters	87.0	36.9
I	3.5914	90.7	33.2
0	3.4787	84.8	39.1
no Cd	4.2666	123.9	0

Thus it can be seen that the ratio of the effectiveness of the cross shaped rod to the flat rod is: $\frac{+}{I} = 1.11$

and for the circular rod: $\frac{0}{I} = 1.18$.

Cross Section of O^{18}

A rough measurement of the cross section for neutron capture of O^{18} was made. 9 cm^3 of distilled water was placed close to the center of the pile and irradiated for approximately 68.5 sec at an intensity of 2.55×10^6 LI or 6.4×10^4 watts. The water was then placed in a tray under a counter and the decay was followed. It decayed with approximately a 30 second half life and extrapolated to a counting rate of 10560/minute at the end of irradiation. For infinite irradiation it would have been 13500 counts/min. The counter was then calibrated by dissolving UO_2 in HNO_3 and diluting until the equivalent concentration of U_3O_8 would have been 13.9 mg/cm^3. This gave a counting rate of 57.6 counts/sec. Using the value of 10.65 disintegrations/sec mg of U_3O_8, we find that it is necessary to multiply the observed counting rate by 2.57 to get the number of disintegrations/sec in 1 cm^3 of solution. If we assume that the β-rays of UX_2 are like those of O^{19} then there would be 578 disintegrations/sec/cm^3 at the end of an infinite irradiation at this power. At this position in the Argonne pile nv = .969 x 10^4 LI, so that nv was 2.5 x 10^{10}/cm^2/sec. Then the cross section of 1 cm^3 of water for this process is

$$\frac{578}{2.5 \times 10^{10}} = 2.31 \times 10^{-8} \text{ cm}^2.$$

The cross section per oxygen atom then becomes 6.9×10^{-31} cm^2, and since O^{18} has an abundance of .2%, its cross section would be 3.5×10^{-28} cm^2. It must be emphasized that this cross section is based on the assumption that UX_2 and O^{19} β-rays are very similar.

EXPONENTIAL EXPERIMENTS IN THE WEST STANDS

P. Morrison

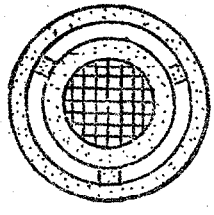
"W" Lattice

An exponential pile simulating the proposed "W" lattice was measured in the last month. The construction of the pile and final measured results are here summarized:

Lattice: 8" square lattice, metal rods in AGOT graphite; L = 50.1 cm.

Cell: ▨ 2S aluminum

▦ Ames metal, mostly with T.D.S. < .1; measured density as used 18.8 g/cm^3.



Metal	1.62 cm radius	
Inner Al	.05 cm thick	
Annular Space	.22 cm thick	Measured vol. of space
Outer Al	.15 cm thick	2.08 cm^3/cm of tube
Al Spacers	.22 x .45 cm	

Results for the Laplacian:

Pile	Laplacian
W_E (air space only)	Δ trans = $-93 \pm 2 \cdot 10^{-6}$ cm^{-2} measured with gradient transverse to rods.
W_F (space filled with tap water)	Δ trans = $-59.8 \pm 3 \cdot 10^{-6}$ cm^{-2} measured

Measured fraction of film space filled with water = $.91 \pm .04$

For 2.08 g H_2O/cm, or 1.86 mm film: Δ corrected = $-56 \pm 3 \cdot 10^{-6}$ cm^{-2}.

A measurement made with sources on the sides of the pile showed a negligible gap correction, giving a value for Δ long about 1 larger than Δ trans.

Program

Measurements have been completed with different concentrations of boron in the water in an effort to measure the migration length. The Al is being removed and the Laplacian for the metal alone will be measured to serve as a reference point for the metal sampling program.

A detailed interpretation of these results will be reported by Mr. Weinberg of the theoretical section. In general, it may be said that there is substantial agreement with the theory on the effect of a water film.

Cyclotron Group - Arthur H. Snell

Table of Contents

General

Most of the operating time of the cyclotron during the past month has been devoted to bombardments for the chemical and health groups. We have had to shut down twice for repairs.

Beta-ray Spectrometers

Mr. Brolley is making a good progress in the design of a magnetic lens spectrometer. Mr. Nedzel has been estimating resolving powers and computing line shapes for the semi-circular focussing spectrometer, with a view toward a good compromise between such parameters as source length and source width, and defining slit width. He has also started investigating the shimming required on the magnet poles to give a sufficiently uniform field at a radius of about 18 cm.

We have borrowed from the Ryerson Laboratory a set of precision Helmholz coils for use as a primary magnetic field standard.

Fission Product Decay Curves for Thorium

Mr. Wilkinson and Mr. Levinger have continued to follow the decay of the lumped fission products of a thorium sample and a uranium sample which were prepared simultaneously in a 120 microampere hour activation carried out on May 11. The thorium was activated with fast neutrons, and the uranium with slow neutrons, Small samples were used (60 mg) and no chemical separations of any kind were made: the natural activities were measured prior to activation and were considered as a constant background. The decay curve of thorium now looks very different from that of the uranium; in particular, the thorium has relatively more long-lived activity than does the uranium. In fact, if one equalizes the activities in the region up to 80 hours after activation (the decay curves are fairly parallel in that interval), then at 500 hours the thorium sample is twice as active as the uranium sample. The possibility that this may be largely due to the 27-day protoactinium 233 is being investigated. Absorption curve data indicate that there may be some difficulty in this explanation.

Neutron Capture Cross Section of argon 40

Mr. Kern has undertaken a measurement of this quality, using the following procedure: A few cc of argon gas (99.6% of which is A^{40}) an activated in a small metal cell buried in paraffin near the cyclotron target, together with some powdered manganese as a monitor. A known fraction of the activated gas is transferred to a thin-walled chamber for counting, and the decay of the 112-minute A^{41} is measured. The monitor is counted in similar geometry. Kern's present value for the capture cross section is $(1.0 \pm 0.3) \times 10^{-24}$ cm^2.

REPORT FOR MONTH ENDING JUNE 15, 1943

Group Leader - Bernard T. Feld

Nuclear Physics - Experimental

The main concern of our group, during the past month, has been with the completion of measurements of "inelastic scattering to below the 28 fission threshold" for a number of elements. In these experiments, the decrease in counting rate of a fast-fission chamber is measured when the source of fast neutrons is surrounded by a sphere of the element in question. This has been done by Mr. Bernstein for three elements - Bi, Pb and Fe - using, for each, three different size spheres.

The results are now being evaluated and compared. Preliminary calculations, neglecting elastic scattering, for the intermediate size spheres yield the following values of cross-section for inelastic scattering:

	σ in (Ra-Be neutrons)	σ in (Ra-B neutrons)
Fe	0.98	0.87
Pb	1.25	0.90
Bi	1.51	1.23

The corrections for the geometry and for elastic scattering are now being computed and more reliable values of the cross-sections should soon be available.

In the meantime, we are repeating the measurement of the fast neutron multiplication factor of υ for Ra-B neutrons. The Ra-B source is being further studied by comparing its activation of various fast neutron reactions with the activation due to Ra-Be neutrons and due to fission neutrons (from the Argonne pile). This comparison is being made by the method of CP-412. The comparison of the relative effectiveness of equal numbers of Ra-Be neutrons and Ra-B neutrons has to-date yielded the following (preliminary) results:

	28 Fission	P(n, p)	Al(n, p)	Al(n, α)	In(n, n)	In(n, γ)	I(n, γ)
Ra-Be / Ra-B	1.04	1.07	4.7	12	0.8	1.04	1.6

In the past week, Mr. Richard Scalettar arrived from Wisconsin to join our group - replacing Mr. Julius Ashkin.

THEORETICAL SECTION

E. P. Wigner

The work of our section in the past month centered around three subjects. The Theoretical Group worked on more general problems of theoretical physics which are only loosely connected with any special project. All the members of this group were added to the section during the last month: S. M. Dancoff, Irving Lowen, and Julian Schwinger. The second group, under Mr. Weinberg's leadership, worked on more general problems of pile design, multiplication constant, pile control, etc. Mr. Young's group is engaged on the design of heavy water piles, particularly on a light water cooled heavy water pile. The groups work, of course, in close collaboration, and in some cases it is impossible to assign a member of the section entirely to a definite group.

Mrs. Monk continues her work for Dr. Wheeler.

THEORETICAL PHYSICS GROUP

Mr. Ibser prepared two tables: one on the cross section of individual isotopes for thermal neutrons, one on the radioactivities, obtainable by (γ - n) reaction, the life time of which is longer than one day.

Mr. Stephenson wrote two reports in collaboration with E. P. Wigner: one on the probable absorption cross section of Cd as function of the energy of neutrons, the other on the multiplication constant of homogeneous mixtures. Unfortunately, in the latter case, the old too high absorption cross section was assumed for D_2O and D_2 so that the corresponding results are incorrect. According to recent measurements of the experimental section, the absorption cross section of D_2O is even lower than our figures were in the case of D_2C so that the corresponding multiplication constant is higher than in that case. The calculation will be repeated as soon as the final cross sections are available.

Continuous γ-ray Spectrum in α Decay - S. M. Dancoff

A calculation has been made of the probability, during the α decay of a heavy nucleus, for the emission of γ radiation through bremstrahlung in the field of the emitting nucleus. The calculation is provisional in that the Coulomb barrier of the nucleus is replaced by a "square" barrier, the constants of which are appropriately chosen. The probability for the α particle to lose most of its energy through radiation proves to be small and of the order of (3×10^{-6}) x energy of the particle in million electron volts. The probability for the emission of a low energy quantum is larger. For example, a 5 Mev α particle has

a probability of about 10^{-4} for radiating a quantum whose energy is 250 kev or higher.

The resultant γ radiation intensity in R units has been estimated for a point removed by one half meter from 1 kilogram of the α decaying substance. Because of absorption in the substance itself, only γ rays of energy above 0.5 Mev contribute appreciably to this intensity. The γ radiation is about 2×10^{-2} R units/hour.

Rigorous Treatment of the Slowing Down of Neutrons - J. Schwinger

A rigorous expression has been obtained for the slowing down range in a pure substance of arbitrary mass, based on the assumption of isotopic scattering in the center of mass system. The formula correctly reduces to that obtained by Fermi for slowing down in hydrogen, and agrees with the usual simplified theory when applied to heavy nuclei. Unfortunately, the labor involved in an accurate numerical evaluation seems quite prohibitive, save possibly in the case of deuterium.

An approximate formula has been developed for the spatial distribution of neutrons slowed down in a medium of high atomic weight. The density near the source is in agreement with that predicted by the age equation, but approaches an exponential behavior at large distances. The transition region can be studied numerically without undue difficulty.

GENERAL LATTICE DESIGN GROUP

A. M. Weinberg

Lattice Calculations

The multiplication constants for various geometries using P-9 as moderator were calculated by Messrs. Williamson and Stephenson. The values quoted below are based on an oxygen cross-section of 8×10^{-27} and a D cross-section of 1.9×10^{-27}; in view of the recent measurements at Argonne, the value for oxygen is extremely pessimistic. This is somewhat balanced by the fact that the P-9 actually available will contain some H_2O contamination.

Geometry	Density of Metal	Moderator	Best η'/ϵ	Radius or Half Thickness of Metal at Optimum (in cm.)	$\left(\frac{\text{Vol. of Moderator}}{\text{Vol. of Metal}}\right)_{\text{optimu}}$
Cylinders	18.9	P-9	~1.111	2 and over	27 at r_o = 2 cm.
Cylinders	9	P-9	1.123	3 and over	
Cylinders	4	P-9	1.129	4 to 5	
Slabs	18.9	P-9	1.1415	0.6	23
Cylinders	18.9	P-9 with 2.5 mm. H_2O film	1.182		
Cylinders	18.9	Graphite soaked in P-9	1.182	1.25 to 1.50	43 at 1.25

The multiplication constant is $k = \eta \epsilon / \eta' \approx 1.305 \ \epsilon / \eta'$. The k loss due to the 2.5 mm. water film is mostly determined by the thermal absorption of the water and much less by the blocking effect and added slowing down in the water. The overall loss for a 2.5 mm. film is about 4% for a 1 cm. rod. The blocking effect is less than in the graphite lattices partly because the diffusion coefficients in P-9 and graphite

are more nearly equal and partly because the absorption in the P-9 is very much smaller to begin with than the absorption in the graphite. The slowing down is less important because, volume for volume, water is only about 5 times as effective as P-9 in slowing (instead of 25 times in the case of graphite).

Mrs. Castle has been calculating the fast effect in hollow cylinders; this result will be useful in connection with some proposals to use empty tubes instead of rods in the P-9 plant.

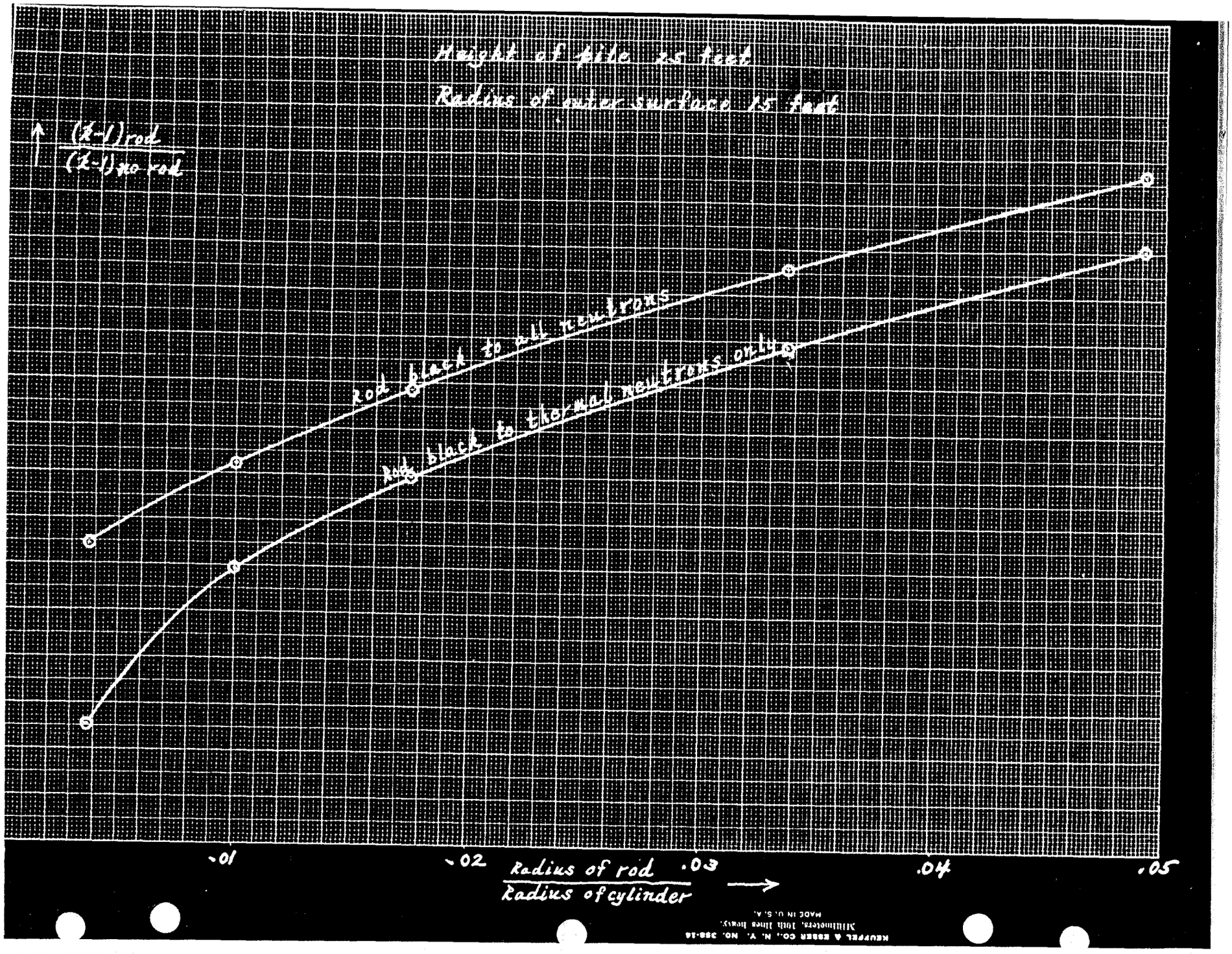
Dr. William Karush has joined the group for half-time work; he will also work with Mr. Wollan and Mrs. Creutz. He is computing the effect of annular shaped longitudinal gaps on the diffusion length of a pile.

The diffusion length in a graphite block containing parallel rods of absorbing material (as in the W reflector) has been computed. It is found that for "water rods" of 2 cm. radius, spaced at intervals of 21.2 cm., the exact diffusion length is 6% longer than computed on the assumption that the water and graphite are intimately mixed.

Efficiency of a Control Rod Which Absorbs Only the Thermal Neutrons - F.H. Murray

The equations for a cylindrical pile with a central control rod black to thermal neutrons only were analyzed for the purpose of determining the critical value of the reproduction factor k.

Because of the difference in form of the equation for fast neutrons during the slowing down process, and that for thermal neutrons with its new boundary condition, it was convenient to represent each density function as an infinite series of functions $J_o(\lambda_m r)$. After setting up the equation expressing the condition that the rate of production of fast neutrons of age zero equals a constant times the thermal


Height of fuel 25 feet
Radius of outer surface 25 feet
↑ (k-1) rod / (k-1) no rod
Rod black to all neutrons
Rod black to thermal neutrons only
.01
.02
.03
.04
.05
Radius of rod / Radius of cylinder →

neutron density, coefficients of the same function $J_c(\lambda_m r)$ on both sides of the equation were set equal, from which an infinite set of equations results. If the determinant of these equations is equated to zero, an equation in k results.

The following table gives the values which the multiplication constant must have in order that the pile just be chain reacting, i.e., that its effective multiplication constant be just 1. Naturally the k must be higher for the pile to be chain reacting if the rod is in than if it is out. The figures refer to a pile of 15' radius and 25' height, which is chain reacting without any control rod for a k = 1.0316. k_1 is the multiplication constant necessary if the control rod is black only to thermal neutrons. k_2 is the multiplication constant necessary if the control rod is black for all neutrons. It is naturally higher than k_1. r is the effective radius of the control rod.

r	.0037	.01	.0175	.0336	.0491
k_1	1.0336	1.0363	1.0379	1.0402	1.0419
k_2	1.0367	1.0381	1.0393	1.0415	1.0432

Migration Length - G. N. Plass

The calculation of the migration length in a lattice structure composed of lumps of a multiplying medium in a moderator has been essentially completed. It can easily be shown that the diffusion length is related to the thermal utilization in a lattice extending to infinity in all directions (P_{20}) and the thermal utilization in a lattice of finite size (P_2 which is defined as the absorption of thermal neutrons in U per thermal neutron produced) according to the formula

$$L^2 = \frac{k}{P_{20}} \frac{P_{20} - P_2}{S^2}$$

k is the multiplication factor and $\vec{S} = \vec{i}\frac{\pi}{S_1} + \vec{j}\frac{\pi}{S_2} + \vec{k}\frac{\pi}{S_3}$ where S_1, S_2, S_3 are the lengths of the three sides of the rectangular pile.

In order to find the difference $P_{20} - P_2$, it is necessary to solve the diffusion equation for a pile with finite dimensions taking into account not only the overall cosine variation, but also the individual variation in each cell. Since one must take into account second harmonic terms of the form $\left[3\,(\vec{S}\cdot\vec{r})^2 - k^2\right] f(r)$ in order to obtain any change in the thermal utilization due to the lattice structure, the actual calculation becomes quite complex. Useful answers have been obtained for certain ranges of r_o, r_1, α_o, α_1, σ_{ao}, σ_{al}.

The migration length for value of r_o and r_1 now of most interest is given by the equation

$$L^2 = \frac{k}{\alpha_1^2 P_{20}} \left(\frac{1}{P_{20}} - 1\right) - \psi$$

where ψ is a correction term that is from 5 to 20% of the main term.

To show the difference between the new formula and the old $\left[L^2 = (1 - P_{20})\, L_1^2\right]$ the following table gives calculated value for spheres with $r_o = 3.00$:

r_1	$L^2 = (1 - P_{20})\, L_1^2$	L^2 according to new formula
7.5	234	244
9	341	388
10.5	466	552
12	604	705

Calculations for other values of r_o have yet to be made. A detailed report will shortly be issued about this calculation.

HEAVY WATER GROUP

G. Young

Design (L. A. Ohlinger) of preliminary exploratory work continues on a light water cooled heavy water pile. Two types of plant design are being considered: one with straight through tubes, the water entering at the top and leaving at the bottom; and the other a U tube arrangement which avoids openings in the bottom of the heavy water tank. A number of arrangements of the metal within the cooling tubes are conceivable, of which the simplest is a small solid rod centered by ribs within the tube, as in the W plant. Another possibility is a metal rod centered within a metal pipe, with water flowing outside the pipe and between the pipe and rod. Mr. Creutz is investigating the extrusion of such pieces. This latter gives a greater distance between tubes and thus eases the structural problems; however, Mr. Ohlinger is working out the construction on the basis of the smaller spacing, to be on the safe side.

In view of the current 70° limitation on aluminum coatings, the whole coating problem is being re-examined since methods had been previously ruled out on the basis of failure at 100°. Mr. Friedman has pointed out the possibility of running the metal uncoated, which simplifies construction and avoids the danger of a loose coating in a high heat flow system.

Our inadequate understanding of heat transfer to flowing liquids is becoming apparent, and estimates of the power output which can be obtained are correspondingly uncertain. It appears that an experiment may have to be made to test each seriously proposed cooling arrangement.

Radiation Hazard from Proposed P-9 Pile at X - F. L. Friedman

Calculations on the contamination produced in cooling water by a P-9 plant with Al coating on the metal have been made. They are appearing in a CP report. These computations are based on the most recent total disintegration energies and include β as well as γ rays to indicate danger in the water itself. The computation in CP-499 is used as a basis and some work of Wollan and Coryell have been generously made available for comparison purposes. Curves of fission product activity on the basis of Borst's data were employed in finding the effect of coating failure. For a 3.5×10^4KW plant at X, the Mg^{27} recoils from the Al may border on the assumed permissible limiting concentration in the water (corresponding to .1 r/day) of the river. A table of permissible coating failure vs. holdup time t is given below for long times of operation (ca 30 - 90 days).

Holdup time	10 m	1 hr.	1 d
Permissible fraction uncoated	.0019	.013	.069

The most recent design constants of a P-9 plant have been employed here (MUC-AMW-#5).

Some problems in X-ray shielding have been written up for presentation in the handbook and further consideration of reflector and shield problems for small piles is in progress. Some formulae for the slowing down of neutrons around a homogeneous spherical pile and the X-ray escape under the same conditions are already available.

DISCLAIMER