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ANL-4481

Reactors

ARGONNE NATIONAL LABORATORY

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Chicago 80, Illinois

Reactor Engineering Division

QUARTERLY REPORT

MARCH 1, 1950 THROUGH MAY 31, 1950

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Prepared by W. P. Bigler, Assistant to Division Director

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Quarterly Report
REACTOR ENGINEERING DIVISION

PILE OPERATION

W. H. McCorkle, H. T. Goodspeed, H. C. Stevens

CP-2

The graphite-moderated reactor, CP-2, has been used quite extensively since the Laboratory's heavy-water reactor, CP-3, was shut down January 28, 1950. During the interval from March 1, 1950 to May 28, 1950, there were a total of 161 samples irradiated in CP-2 for danger coefficient measurements, activation measurements and other experimental purposes. The kilowatt hours produced during the same period are estimated to be 3800 kwh. Since kwh calculations are made from readings taken on a silver foil at the end of each month, the kwh from May 1, 1950 to May 28, 1950 is estimated.

Plans have been discussed with members of the Laboratory Ventilation Committee for removing radioactive gases from this reactor by sealing the top of the pile and all openings through the shield and then connecting a duct from the large opening at the south pile face to an exhaust fan.

Improved ventilation of the pile room as a whole has been attained by removing the duct work leading to the east blower fan.

CP-3

The removal of fuel rods from this reactor was started February 21, 1950 and was completed on March 14, 1950. Since that time a number of modifications of the reactor have been under development and the Laboratory machine shops have been fabricating parts to be used in the modified version of this reactor. Extruded and threaded fuel rods have been received from ORNL and are now being assembled to form the completed fuel assemblies.

REACTOR DEVELOPMENT

Experimental Breeder Reactor (CP-4) - A. H. Barnes, F. A. Smith,
G. K. Whitham

Electromagnetic Pumps - The d-c electromagnetic pump for use with the Experimental Breeder Reactor is being constructed in the shop. A 25,000 ampere magnesium-copper sulphide rectifier for it has been ordered for delivery in August.

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Thin-walled pumping tubes of nichrome and inconel X, not previously used in these pumps, are being fabricated and will be tested with existing apparatus. The higher resistivity of these materials should provide some improvement in pump efficiency.

Bellows Test - The machine for testing bellows has been in continuous operation during the last quarter. A set of five Chicago Metal Hose Company bellows, 3-ply stainless steel (347), have been flexed at 20 cycles per minute in air at room temperature, and a duplicate set of five bellows have been flexed at the same rate in NaK alloy at 250 C. In each case the total displacement was 14% of the live length, 2/3 being compression and 1/3 extension.

The set which operated in air at room temperature developed leaks in the range 226,000 to 512,000 cycles. The first failure in the set which was run in NaK alloy occurred at 486,000 cycles, but one bellows was still in operation after a million cycles. The average life for the NaK set was nearly twice that of the set which was flexed at room temperature.

In another test, a set of five Cook Electric Company bellows were flexed in air at room temperature. In this group failures occurred between 38,000 and 94,000 cycles. These bellows had a live-length of 2 13/16 inch and were flexed entirely in compression to 24% of live-length.

Nine sets of bellows have now been tested. Table I and Figure 1 summarize the performance of the several types and Table II lists the pertinent information concerning each type.

In nearly all cases failures occurred at a weld.

There has been no evidence that corrosion played a part in the failure of any bellows. The Fulton Sylphon Bellows were operated in NaK alloy at 250 C for a period of three months and subsequent metallurgical examination failed to reveal any corrosion.

As will be evident from Figure 1, the predominant factor determining bellows life is the relative amount of travel. It will be noted that the distribution does not particularly favor any one manufacturer, except perhaps Fulton Sylphon, whose location on the chart is in doubt because no failures had occurred up to 10^6 cycles at which point the test was stopped. There is a considerable variation in this spread of values over which failure occurred. Here, as might be expected, the bellows with the least number of welds are favored.

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Table I

NUMBER OF CYCLES FOR BELLOWS FAILURE(Pressure across bellows was 20 lb/in² in all cases.)

<u>Manufacturer</u>	<u>Number of Cycles to Failure</u>	<u>Average</u>	<u>Conditions</u>
(a) Cook Electric	800, 1170, 3600, 3990, 4150, 4485, 5100, 5500, 6500	3,900 $\pm$ 36%	Operated in air at room temperature.
(b) Chicago Metal Hose	6800, 7000, 7500, 8700, 8750, 8000, 9000, 11000, 11900	8,800 $\pm$ 13%	Operated in NaK at 250 C.
(c) Cook Electric	11800, 13000, 202000, 21000, 24000, 34000, 70500, 82000, 91000, 103000	47,000 $\pm$ 66%	Operated in NaK at 250 C.
(d) Cook Electric	38000, 42000, 52500, 58000, 94000	57,000 $\pm$ 27%	Operated in air at room temperature.
(e) Chicago Metal Hose	17000, 23000, 25000, 28000, 34000	25,400 $\pm$ 17.3%	Operated in NaK at 250 C.
(f) Chicago Metal Hose	30000, 34000, 38000, 41000, 42000	37,000 $\pm$ 11%	Operated in NaK at 250 C.
(g) Chicago Metal Hose	226000, 314000, 362000, 400000, 512000	363,000 $\pm$ 20%	Operated in air at room temperature.
(h) Chicago Metal Hose	486000, 549000, 780000, 1000000 +	704,000 $\pm$ 26%	Operated in NaK at 250 C.
(i) Fulton Sylphon	No failures up to 1,000,000	>1,000,000	Operated in NaK at 250 C.

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No RDG-20
 DRAFTS G.G.
 FOR BARNES
 DATE 6-7-50

FIGURE 1

7

Table IIBELLOWS DATA

(All bellows were 347 stainless steel.)

<u>Manufacturer</u>	<u>No. of Ply</u>	<u>Live Length</u>	<u>No. of Convolutions</u>	<u>Total Travel</u>	<u>Travel in Compression</u>	<u>Travel in Expansion</u>
(a) Cook Electric *	1	2 1/8 "	11 1/2	11/16 "	2/3	1/3
(b) Chicago Metal Hose **	3	2 3/4 "	20	3/4 "	1/2	1/2
(c) Cook Electric *	1	3 1/4 "	24 1/2	3/4 "	1/2	1/2
(d) Cook Electric *	1	2 13/16 "	20 1/2	11/16 "	1	0
(e) Chicago Metal Hose **	3	3 3/4 "	30	3/4 "	1/2	1/2
(f) Chicago Metal Hose **	1	3 3/4 "	38	3/4 "	1/2	1/2
(g) Chicago Metal Hose **	3	3 3/4 "	30	1/2 "	2/3	1/3
(h) Chicago Metal Hose **	3	3 3/4 "	30	1/2 "	2/3	1/3
(i) Fulton Sylphon **	1	3 3/4 "	30	1/2 "	2/3	1/3

*Fabricated from 0.010 " thick stock.

**Fabricated from 0.005 " thick stock.

239-007

Other factors affecting bellows life are temperature and the relative distribution of the travel between compression and extension. In the single controlled test, increasing the temperature from 25 C to 250 C nearly doubled the average life. This result is in accord with other tests made previously on double-bellows-sealed valves, where it was found that the outer bellows failed before the inner bellows, which operated at a higher temperature. Although there is no definite evidence from these tests, there is some indication that bellows life is improved when the travel is such that the bellows is flexed mostly in compression.

NaK Level Indicator - Although considerable effort has been made, it has not been found possible to eliminate the effect of temperature on the calibration of the electromagnetic level indicator. (ANL-4238) The variation with temperature is largely due to the magnetic core material, and the core can be dispensed with only at a large sacrifice in sensitivity. However, if the temperature of the liquid metal in the tank is known, the level can be determined accurately either by using calibration curves for various temperatures or by adjusting the current to the temperature.

Since the level indicator must be calibrated against the known liquid level in the tank, an electromagnetic probe has been designed which permits the level to be found without breaking a seal on the tank. To accomplish this, a small coil is lowered into a closed tube which extends down into the tank. As the coil passes a point inside the tube which is at the same level as the liquid surface outside, a small change in impedance occurs. This provides a signal which may be read on a suitable meter.

Fuel Element Pressure Indicator - A possible means of detecting a rise in pressure in the Experimental Breeder Reactor fuel elements is by measuring the breakdown potential difference across a small spark gap, located in the upper end of the fuel element handle. Tests of such an arrangement indicate that over the pressure range contemplated (0.5 to 1.0 atmosphere) there is a 50% change in breakdown voltage which varies linearly with pressure. The effect of γ radiation is to stabilize the readings.

Argonne Reactor (CP-5) - J. M. West, J. T. Weills, S. Untermyer

Status - A Report to the Atomic Energy Commission on the Proposed Argonne Research Reactor (ANL-WHZ-252) has just been issued giving characteristics of the machine which are pertinent for evaluation by the Reactor Safeguard Committee.

The latest design drawings for the reactor are shown in Figures 2, 3, and 4. A number of small changes have been made but most of the major features are unaltered. The quick drain line has been relocated to drain the D₂O directly from the plenum chamber. The drain rate will be very rapid until the D₂O level reaches the bottoms of the openings in the upper

FIGURE 3

TOLERANCES:		APPROVED FOR CONSTR.		ARGONNE NATIONAL LABORATORY		BY: _____	
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DECIMAL TOL.	$\pm .005$	CHIEF DRAFTSMAN				BY: _____	
ANGLE	$\pm \frac{1}{4}^\circ$	CHECKED				DATE _____	
ALL SURFACES TO HAVE VEEBEE (1/8" ROUNDED) OR AS DIRECTED HEREIN, UNLESS OTHERWISE NOTED				DRAWN	E.H. 1/3/50	SCALE	1/2" = 1'-0"
				GROUP	KOLB	MATL.	—
				REPRESENTATIVE	WEST	NO. RECD.	—
						SHEET	—
						DRWG. NO.	RR-2
						ITEM NO.	—

B GENERAL REVISION 6-8-50	
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REVISION	
52450 DQ

FIGURE 2

TOLERANCES:		APPROVED FOR CONSTRUCTION		ARGONNE NATIONAL LABORATORY		REVISIONS	
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DECIMAL TOL. $\pm .005$	CHIEF DRAFTSMAN					6-8-50	WZC
ANGLE $\pm 1^\circ$	CHECKED					MICROFILMED	
ALL SURFACES TO HAVE FINISHES (SEE SPEC 1000 OR AS RECEIVED) UNLESS OTHERWISE NOTED	DRAWN	DQ 2-10-50				MAY 1 1950	
	GROUP	KOLB	WEST			ARGONNE NATIONAL LABORATORY	
						REVISION	
						5-23-50	WZC
				SCALE		DATE	
				1" = 1'-0"		BY	
						PART	
						HORIZONTAL SECTION	
						ASSEMBLY	
						CP-5	
						SHEET	
						DRWG. NO.	
						RR-1	
						ITEM NO.

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FIGURE 4

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DECIMAL TOL. $\pm .005$	CHIEF DRAFTSMAN		SCALE 1" = 1"		PART	
ANGLE $\pm 1^\circ$	CHECKED		NO. RECD.		ASSEMBLY	
ALL SURFACES TO HAVE FINISH UNLESS OTHERWISE NOTED	DRAWN	G.G. 6-20-54	MATERIAL		LARGE BEAM HOLE	
	GROUP	KOLB	REPRESENTATIVE		SHEET	
		WEST			OF RR-42	
					ITEM NO.	

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sections of fuel assemblies. A loss of $10\% \frac{\Delta k}{k}$ in about 15 seconds can be accomplished in this way. The velocity of the D_2O will be adequate for cooling while the pile is shutting down. The remaining D_2O keeps the fuel assemblies cool after shutdown. It can be removed only at a very slow rate through a 2 inch-diameter drain line.

Considerable thought has been devoted to the design of the reactor building. Preliminary drawings have been made for the purpose of establishing space requirements, floor loadings, and optimum arrangements of experimental and utility equipment. The actual designing of the building will be done under subcontract by an architect-engineering firm. Negotiations with prospective architect-engineers have progressed to a point where the actual selection can be made and the design work started in the very near future. It is anticipated that several alternate building schemes will be developed during the coming quarterly period.

Pile Physics - Additional calculations have been made on reactivity effects. These are:

1. If all the D_2O is removed from inside the fuel assemblies, the reduction in $\frac{\Delta k}{k}$ is 38%.
2. A steam bubble 5 cm in radius causes a reduction in $\frac{\Delta k}{k}$ of 0.88%.
3. The $13.8\% \frac{\Delta k}{k}$ reported in the last quarterly report (ANL-4428) is for a 3 inch central cadmium cylinder full of D_2O . Without the D_2O core, the effect is calculated to be $11.7\% \frac{\Delta k}{k}$.
4. The variation of control versus angle of the rod with the horizontal is given on Figure 5. This curve is appropriate for the two rods just off center.
5. The temperature coefficient of the reactor is calculated to be $-0.066\% \frac{\Delta k}{k}$ per degree centigrade.

Control Rods - It is planned to operate two rods exclusively as safety units. These will be crossed and at an angle of about 25 degrees with the horizontal. The two other rods are to be operated as shims and safeties. As shims, they are to move alternately so as to be at nearly the same angle. For startup, they are to be moved out stepwise in $\frac{\Delta k}{k}$ increments just under the $0.6\% \frac{\Delta k}{k}$ managed by the regulating rod. This latter rod is to move slowly to search for criticality within each step after the instruments indicate that criticality is being approached.

The rod width has been increased to $5 \frac{1}{2}$ inches for the 4 shim and safety rods.

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STRENGTH OF SHIM - SAFETY ROD
(BORON ROD $5\frac{1}{2}$ " X 1" X 60")

FIGURE 5

RDG 31
FT
1000 HPSI
10 10 20

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Safety Rod Tests - Functional tests have been made on model control rods and auxiliary equipment, such as shafts and bearings, under conditions similar to those under which rods will operate in CP-5. A photograph of the two rods tested is shown in Figure 6. The rectangular rod (called rod A) has dimensions of $1" \times 4 \frac{1}{2}" \times 52 \frac{1}{2}"$. Three $1 \frac{1}{4}" \times 4 \frac{1}{4}"$ sheets of aluminum (in the real rod these would be Boral sheets) are encased in a tight-fitting aluminum can $\frac{1}{8}$ inch thick. The rod is attached to a stainless steel bearing and splineway. The combined weight of the rod, bearings, and splineway is 21 pounds. A splined stainless steel shaft $1 \frac{1}{4}$ inch in diameter and 10 feet long passes through the splineway. The rod and one end of the shaft were supported vertically by oil hardened stainless steel bearings. For the mockup test, the shaft was supported near its center and at the other end by steel sleeve bearings attached to an I beam. The rod was allowed to swing vertically inside a 6-ft. diameter steel tank which had been provided for other mockup studies. A sketch of the experimental setup is shown in Figure 7.

The other model rod (rod B) tested was made by shaping an aluminum tube to an elliptical cross section and tapering it from one end to the other. The portion of the tube within 17 inches of the bearings was filled with lead. The lead gave a high ratio of torque to moment of inertia and served as a binding agent for attaching the tube to a steel rod, which in turn was fitted with the bearings and splineway from rod A. Rod B weighed 49 pounds.

Rod A required 0.56 seconds to rotate 90 degrees in air as compared with 0.44 seconds for rod B. For 90 degrees rotation in water the times were 0.97 and 0.56 seconds for A and B, respectively. The first 15 degree rotation occurred in the same time in water as in air, showing that water resistance is negligible at the velocities reached during the first 15 degrees of rotation. Graphs giving the free fall of rods A and B in water are shown in Figure 8.

The effects of springs and weights as driving forces for rod A are shown in Figure 9. In the case of an initial spring force of 300 pounds (decreasing to zero at 18 degree rotation) and a moment arm of 18 inches, the rod rotated 15 degrees in 0.08 seconds. A fast rod such as this would be an extremely effective safety device. A plot of the amount of reactivity controlled as a function of the amount of rotation is shown in Figure 5. The starting point of the rod would normally be about 30 degrees below the horizontal. An additional 15 degrees rotation would destroy about $4\% \frac{\Delta k}{k}$. Even with an allowance for the neutron flight time, instrument response time, and hysteresis of the holding magnet, the $4\% \frac{\Delta k}{k}$ could be controlled within 0.12 seconds. Since four such rods are planned for the reactor, the combined effect should be at least $8\% \frac{\Delta k}{k}$ in 0.12 seconds.

The ability of the $1 \frac{1}{4}$ inch diameter stainless steel rod to withstand the shearing stress, due to sudden stopping of the rod when there is

FIGURE 6

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CONTROL ROD DROP TEST

FIGURE 7

No: RRG-15
 DRAFTS: M.A.H.
 AUTHOR: WEST
 DATE: 5/17/50

20

FIGURE 8

No: RQG-14
 DRAFTS: MAM.
 AUTHOR: WEST
 DATE: 5-17-59

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FIGURE 9

239 018

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no water in the tank; was tested by releasing rod A 100 times in air and stopping it suddenly after 60 degree rotation. No damage to splines or to the shaft was observed. As a more severe test, two lead bricks were attached to the side of the rod and 10 more drops were made. There was still no sign of damage. Since no damage occurred in these tests and since the tank will always contain D_2O (unless drained by mistake) when the rods are dropped, the shaft and splines are considered entirely adequate.

Shutdown Heating Mockup Test - In a normal shutdown, the D_2O will never be drained lower than 4 inches below the top of fuel plates. Situations could conceivably arise in which all the D_2O is lost, however, and in that case fission product heating of fuel plates would be considerable. A mock-up test has been performed to determine the temperature of the fuel plates under these conditions.

The apparatus for the mockup test is shown in Figure 10. Fuel plates were simulated by nichrome sheets insulated with mica, sandwiched between aluminum plates, and heated electrically. Power and temperature measurements were made on each of the 15 assemblies used. The results are plotted in Figure 11.

The amount of heat generated in the hottest fuel assembly of CP-5 was calculated for various operational shutdown schedules. The results are plotted in Figure 12. The data in Figure 11 and 12 were used to make a stepwise calculation of the temperature of the hottest fuel assembly as a function of time following shutdown from 2000 kw, without D_2O or helium in the tank. The power value was taken from Figure 12 and the heat loss value appropriate for each interval was taken from Figure 11. The resulting temperature versus time curve is shown in Figure 13. Since the highest temperature in the mockup experiment was 500 C, it was necessary to estimate the curve (Figure 11) beyond this point. This was done very pessimistically by making the curve linear in the high temperature region, with the same slope as the last part of the experimental curve. Convection and radiation losses are known to increase in proportion to temperature, raised to the 1.25 and 4.0 powers respectively, so the curve would certainly continue to decrease in slope. The portion of the curve actually determined experimentally illustrates this trend. The maximum temperature of 560 C, shown in Figure 13, already includes a safety margin because of this pessimistic assumption. The curve beyond 500 C will be determined at a later date, when the mockup fuel assemblies can be sacrificed.

The tank temperature for the mockup experiments averaged about 35 C. The reactor tank temperature is expected to be about 55 C. When this 20 degree temperature correction is applied, the maximum shutdown temperature becomes 580 C, reached in about 16 minutes after shutdown.

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FIGURE 10

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ELECTRICAL HEATING OF FUEL ASSEMBLIES

FIGURE 11

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FIGURE 12

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FIGURE 13

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The mockup experiment indicates that the fuel assemblies would not melt even if both the water and helium were lost immediately and completely from the tank. A repetition of the experiment with helium in the tank showed that one-third more heat was removed at this temperature than when the tank was filled with air.

As additional insurance against shutdown melting of fuel plates, pressed aluminum powder discs (described in the preceding quarterly report, ANL-4428) mounted in the bases of hollow stems above the fuel assemblies will allow D₂O to drain down on the fuel plates. The stems will retain enough D₂O to prevent the fuel plates from melting for several hours. By the time the D₂O is all evaporated, the rate of heat generation will have decreased far below the danger point.

D₂O Coolant Flow Tests - The mockup apparatus shown in Figure 10 was also used to study the water surface irregularities produced by water flowing in one pass and two pass systems. The largest ripples found in any of these tests were only 1/4 inch high. The effect of surface ripples on CP-5 reactivity will be negligible.

NP-MTR Project - A. H. Barnes

In connection with the design of a proposed NP reactor, several measurements have been made to determine the power which can be dissipated, both in air and in helium, by aluminum-jacketed fuel elements. The fission product heat was simulated electrically, and the equilibrium temperatures were determined for various power inputs.

REACTOR RESEARCH

Irradiation Damage - A. H. Barnes

The hardness and tensile strength specimens of stainless steel and nickel, which had been found to increase in hardness and tensile strength during irradiation at Hanford (ANL-4428), have been further studied to determine the effect of heat treatment in restoring their original properties. A test conducted by the ANL Metallurgy Division showed that 400 C for 24 hours did not produce any appreciable softening of the nickel specimens, but that after 8 days at this temperature, the hardness dropped from 97 to 78 (Rockwell B). Twenty-four hours at 600 C returned the metal almost to its original annealed softness.

In the case of the stainless steel specimens, 24 hours at 400 C had only a slight effect. After 8 days at this temperature the hardness had changed from 98 to 86 (Rockwell B). At 600 C, 24 hours returned the stainless steel almost to its original hardness. A further 7 day treatment had little, if any, additional effect.

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Conductivity and Heat Capacity Measurements of Molten Li - S. Untermeyer

The conductivity of molten Li in the neighborhood of 250 C was found to be 63 percent of that of Na. The specific heat of molten Li was found to increase slightly with temperature.

<u>Temperature (°C)</u>	<u>Specific Heat (cal/gm °C)</u>
200.	0.804
300	1.03
400	1.11
500	1.14

A report was written covering this work (ANL-4458).

Reduction in Reactivity of Heterogeneous Reactor by Expulsion of Coolant - S. Untermeyer

Work reported in a previous memorandum (ANL-WPB-50) has been expanded.

A 10 kva lighting transformer has been modified to provide low voltage a-c current (up to 100 kw for short periods). Tests have been made with water-filled Al tubes at heat inputs up to 300 cal/sq cm sec and preliminary tests have been made with "rods" of Al tube, externally cooled, to simulate CP-3 prime design (see Figure 14).

ZP REACTOR PROGRAM

C. A. Benz, F. H. Martens, A. H. Toepfer

In preparation for the zero power reactor experiment a counting room has been equipped and tests made to establish plateau voltages, backgrounds, counting rate errors and reproducibility. Counters and associated scalers for obtaining data from irradiated foils have been checked for backgrounds and with a standard source over many days. The results are reproducible within statistical fluctuations (about 1%). Losses at high counting rates have been experimentally determined and the geometric corrections for various counting positions have been evaluated.

Indium foils have been cut and weighed and are available in 5 mil thickness with 1 sq cm and 5.06 sq cm area. All foils will be intercalibrated in the same flux. Aluminum and cadmium containers are available for foils.

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FIGURE 14

3a

A control desk has been built in the control room and most of the major instruments mounted. The control desk contains eight panels and a desk height shelf. There is space for all the instruments needed to build the reactor up to critical size and operate it at low power levels. Special attention was given to placing the most needed devices where they can be most easily observed and manipulated by the operator.

Sufficient instruments are on order or under construction at ANL so that the first assembly may be taken up to power.

To provide flexibility and safety, eleven circuits (seven P circuits and four M circuits) have been planned and no limit has been set on other experimental circuits that may become necessary for fast flux determinations and the testing of various chambers, pile-period meters and other detectors. Circuits PI through PVII (reactor power indicating circuits) are outlined below:

P Circuits - Circuits PI, II, III, V, and VI are necessary for startup and have been delivered and calibrated. Plateaus on the current chambers and drift rates of the amplifiers and chambers have been determined. Checks on the pulse counters have been made.

P-I: A $B^{10}F_3$ filled current chamber (neutron detector) connected to an Applied Physics Corporation Vibrating Reed Electrometer and Brown Recorder.

P-II: This circuit is the same as P-I, but has in addition a trip circuit with both preset and rate rise tripping arrangements.

P-III: This circuit is identical to P-I, but operates on the emergency power supply.

P-IV: An anthracene crystal (gamma sensitive) is connected to a photomultiplier tube, amplifier and trip circuit.

P-V: An argon filled pressure chamber (gamma sensitive) connected to an Applied Physics Corporation Vibrating Reed Electrometer and Brown Recorder.

P-VI: A $B^{10}F_3$ filled current chamber connected to a d-c amplifier and a Brown Recorder. This circuit is also connected to a trip circuit.

P-VII: A $B^{10}F_3$ filled current chamber connected to a logarithmic amplifier and pile period meter with trip circuit.

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M Circuits - Circuits M-I to M-IV are for measuring multiplication as fuel is added. These four circuits are used to supplement one another in that four separate graphs can be plotted as criticality is approached.

M-I: A B^{10} coated proportional counter to a preamplifier and scaler with a noisemaker.

M-II: Circuit M-II is similar to M-I.

M-III: A $B^{10}F_3$ filled pulse counter, with no gas amplification, to furnish long life and fast counting rates.

M-IV: M-IV is identical to M-III.