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Reactors - Research and Power

ARGONNE NATIONAL LABORATORY

CRITICAL STUDIES WITH G. E. TYPE FUEL ELEMENTS

by

ZPR-I Group

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PHYSICS DIVISION

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CRITICAL STUDIES WITH G. E. TYPE FUEL ELEMENTS

Preface

This brief study of critical assemblies was undertaken by Argonne National Laboratory at the request of Dr. Lewi Tonks of Knolls Atomic Power Laboratory. The fuel and control rods under investigation were supplied by KAPL. Dr. Robert Luce of that organization was present during the time the experiment was carried out to assist with the many technical questions that arose. In addition, several other technical personnel from KAPL were present at different times while the experiment was being performed. They were Robert Arthur, Edward Bean, Raymond Ostrowski, H. B. Stewart, J. A. Bistline, and M. J. Martone. The rod-drop data were obtained by the General Electric personnel, chiefly, Mr. Bean and Mr. Arthur.

The experimental work on the reactor was carried out by the ZPR-I group. This group includes the following personnel:

1. Merle Burgy	8. Robert Springer
2. Gerard Helfrich	9. Kenneth Weberg
3. Frederick Martens	
4. Robert Nobles	
5. Paul Roggenkamp	
6. Edmund Sowa	
7. Alan B. Smith	

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Description of the Reactor

The ZPR-I is a facility to study low power critical assemblies using enriched uranium as fuel, having a light water moderator and an essentially infinite water reflector on all sides. The fuel is held in elements 43" long with a 1" square cross section. Any of these elements may be placed in or removed from any position in the reactor tank. Thus, any desired core configuration may be easily obtained.

The fuel is composed of 93.15% enriched uranium metal foil, 0.003" thick, 20" long, and 0.75" wide. The fuel was supplied in two batches in which the average weight of U²³⁵ in the first was 13.0 grams, and in the second, 13.7 grams. This difference is taken into account in calculating the critical masses. The uranium strip was encased in polyethylene sheet, 0.030" thick, to prevent any chemical reaction with the water. Four of these strips are placed in the lower end of the assemblies to give them weights of 52.0 or 54.8 grams. A detailed drawing of the assemblies is shown in Figure 1.

The fractional volume of water in the core is 0.4813; of polyethylene, 0.2184; of steel, 0.3003. The hydrogen density of water, assuming the temperature to be 20° C, is 0.1111 grams per cc. The density in the polyethylene is 0.1314. This raises the effective hydrogen density in the core to 0.1164. The metal to water volume ratio, counting the plastic as water, is 1:2.33.

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Facilities for raising the water which forms the moderator and reflector are provided. The water level is maintained automatically at any predetermined height within the limit of the tank. In all of the work reported here, the water level was held 8" above the active core. This upper reflector was not a complete water reflector, as every stainless steel strip used in the fuel assemblies extended through it. An 8" lower water reflector was maintained by using a Lucite lattice structure, the effect of the Lucite being essentially the same as water. On the sides of the active core, the reflector was always greater than 8".

Control rod drive units located above the core allow placing control rods at any location in the core. These can then be driven from the control room to any height and positioned to within 0.2 mm. They may also be dropped rapidly, falling in approximately 0.4 seconds.

Safety features to prevent any hazardous condition from occurring, or for correcting such a condition if it did occur, are also provided. A more detailed description of this facility may be found in ANL-4684, by R. O. Brittan. The fuel used in this experiment, however, was different from that described in that report.

Clean Critical Experiment

The first experiment consisted of finding the minimum critical mass with no voids or control rods in the core. A configuration approximating a cylinder was built up in steps until the reactor became critical. At this time

there were 155 elements loaded in the configuration shown in Figure 2. The mass of U^{235} was 8152 grams, and a circle of equal area has a radius of 6.99". This core had an excess reactivity of 52 inhours (one inhour equals $0.00254\% \Delta k/k$). Another fuel element was added and the excess reactivity again found. This gave the worth of one element, so an extrapolation to the minimum critical mass could be made. This was 8.087 kg.

A flux plot of this core was made using iron-manganese wires as thermal neutron detectors. These wires are 0.032" in diameter and long enough to run the length of the fuel element and extend above the top so it may be reached for removal after irradiation. These wires are composed of an alloy of 14% manganese, 84% iron, and 2% molybdenum. They were taped securely to the fuel or dummy elements in the desired position and then placed in the reactor, where they were irradiated for 30 minutes. The resulting beta activity of the manganese was detected, using a proportional counter. A 1" section of each of the wires was counted. Activity from the iron and molybdenum is negligible.

A series of these wires were located at points running radially from the center of the core into the reflector, as shown in Figure 3. The relative flux of each of these wires was measured at the midplane of the reactor. Table I and Figure 4 show these results. Also shown are the results from cadmium-covered wires whose locations are shown in Figure 3. The cadmium covers were 2" lengths of tubing with 0.035" inside diameter and

0.030" wall thickness. From these two curves, we can obtain the cadmium ratio which is shown in Figure 5.

Axial flux plots were made in a similar manner, but different sections of the same wire were counted for the plot. Three wires were counted, one at the center, one at 2.5", and the last at 3.9" from the center of the reactor. For these last two plots, cadmium-covered wires were located in symmetric positions so the epithermal flux and cadmium ratios could be obtained. The thermal flux plot at the center is shown in Figure 6. The other two plots, with the results from the cadmium-covered wires, are shown in Figure 7. Figure 8 shows the cadmium ratios for these two runs. The numerical data are all contained in Table I.

Control Rod Studies

Four elements in the center of the core were removed and replaced by a control rod channel. Fuel was added on the periphery until the reactor was again critical. This core configuration is shown in Figure 9. With this arrangement, the worths of several different type control rods were found by rod-drop methods. The following rods were tested:

Rod A -- A stainless steel rod of 1-1/2" diameter covered with 1/32" cadmium.

Rod B -- A steel tube filled with boron carbide powder. The inside diameter of the tube was 1.25".

Rod C -- A similar tube, but with a 1.73" diameter.

Rod D -- A 1-1/2" pure aluminum (2 S) rod.

The cadmium-covered rod was hung on the central rod drive unit, and fuel was added. This made the pile critical with the rod below the top of the core. The rod was then raised a few centimeters, putting the pile into a reasonable positive period, which was measured. From this, the worth of the rod in the interval was determined. Fuel was added again and the process repeated until the pile was critical with the rod completely inserted. The data are shown graphically in Figure 10. The core outline with the rod down is shown in Figure 11. By graphical methods, this differential worth curve was integrated, and the integral curve is shown in the same figure. The total worth of the rod is also given in Table II in the column headed "Positive Period."

With the same amount of fuel in the reactor, the cadmium rod was replaced by the boron rod. Being a greater poison, this rod had to be withdrawn 23.1 cm to obtain criticality. The same procedure was repeated until the pile was critical with the rod completely inserted. The total worth of that rod was also found and is listed in Table II.

Fuel was removed again, so that the pile was critical with the central rod removed, and the 1-1/2" solid aluminum rod hung on the drive unit. It was found that this rod added 30 inhours reactivity when dropped full length into the pile.

The aluminum rod and guide channel were removed and replaced by a 2" x 2" aluminum bar, so that there would be no water space around the metal. The result of this was to decrease the reactivity of the reactor by 60 inhours. This was done with the pile shown in Figure 9.

Iron Reflector Study

A slab pile, whose cross section is shown in Figure 14, was set up to study the effect of various thicknesses of iron reflectors. This was as near critical as possible with all control rods removed. Iron bars, 1" x 1", were added on the long side of the slab. Fuel was added until the pile was again critical. The worth of this fuel and, consequently, the worth of the reflector were found. Figure 15 shows the condition of the reactor at this time. Then another layer of iron was added, and criticality was again found, this time, by removing fuel. The reactor under these conditions is shown in Figure 16, which also lists the deviation of reactivity from the water-reflected pile.

The pile configurations and reactivity differences due to adding the third and fourth inches of steel reflector are given in Figures 17 and 18, respectively. Two layers of iron were then added to make the reflector six inches thick, as shown in Figure 19, which also gives the reactivity differences. These data are summarized in Figure 20, which is a plot of the reactivity change vs the thickness of the iron reflector.

The reactor was then set up to have an iron reflector on each of the long sides, as shown in Figure 21. The fuel loading was adjusted to obtain criticality with the control rods almost removed. The effect of the second reflector was found.

A horizontal flux plot was made passing through the center of the core perpendicular to the plane of the iron reflectors. Table III gives the value

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of the bare and cadmium-covered wires and the cadmium ratio through the iron reflector and into the water reflector. These values are also shown graphically in Figures 22, 23, and 24. An axial flux plot was made using the central wire, and the results from this are shown in Figure 25.

There was approximately 2% water, by volume, in the iron reflector, as the 1" iron pieces forming the reflector did not align with each other properly, so it required 18-1/2" of space to hold 18 iron pieces.

Finally, the three center layers of each of the reflectors was moved so that the layers were separated by 1/4" of water, giving about 23% water in the reflector. This setup is shown in Figure 27 along with the reflector worth, as a difference in reactivity from the water-reflected pile.

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TABLE I

Flux Plot Data - Cylinder

Radial				Axial			
Distance from Center (inches)	Bare	Cd-covered	Cd-Ratio	Distance from Center (inches)	Bare	Cd-covered	Cd-Ratio
0	109			(2.5" off center)			
0.5	105	23.3	4.49	6	72.6	15.0	4.84
1.5	106			7	64.4	13.1	4.92
2.5	101			8	54.3	10.6	5.12
3.5	90.2	19.4	4.65	9	44.5	8.45	5.27
4.5	76.6			10	41.9	6.06	6.91
5.5	60.0	13.2	4.55	11	45.4	3.82	11.9
6.5	61.5	9.40	6.54	12	32.2	2.32	13.9
7.5	161	7.51	21.4	13	20.1	1.37	14.7
8.5	169			14	11.9	.76	15.6
9.5	121	2.67	45.4	(3.91" off center)			
Wire 1	52.4			6	62.7	13.0	4.82
Wire 2	58.8			7	54.5	11.1	4.91
				8	43.9	9.42	4.66
				9	33.5	6.93	4.83
				10	33.5	5.03	6.66
				11	35.8	3.27	10.9
				12	26.3	1.98	13.3
				13	17.3	1.11	15.6
				14	9.96	.64	15.6
				(through center)			
				-8	57.6		
				-7	69.3		
				-5	89.8		
				-2	109		
				0	109		
				2	110		
				5	89.2		
				8	58.7		
				9	48.1		
				10	43.8		
				11	47.7		
				12	34.9		
				13	21.9		
				14	12.8		

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TABLE II

Control Rod Worth

<u>Rod</u>	<u>Description</u>	<u>Worth</u>	
		<u>Rod Drop</u>	<u>Positive Period</u>
A	1-1/2" SST, 1/32" Cd	720 ih	675 ih
B	1-1/4" Boron carbide	1320	1235
C	1-3/4" Boron carbide	1575	--
D	1-1/2" Al	--	-30
E	2" sq Al	--	+60

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Table III

Flux Plot - Slab Core

Distance from Center of Core (inches)	<u>Horizontal</u>			<u>Vertical</u>	
	<u>Bare</u>	<u>Cd-Covered</u>	<u>Cd-ratio</u>	Distance from Bottom (inches)	<u>Bare</u>
0.5	144	36.6	3.93	1	69.5
1.5	159	34.5	4.61	2	87.3
2.5	146	31.4	4.65	3	103
3.5	130	28.2	4.61	4	114
4.5	89.4	22.0	4.06	5	124
5.5	31.8	14.4	2.21	6	135
6.5	18.2	10.5	1.73	7	143
7.5	15.5	7.12	2.18	8	150
8.5	22.0	5.16	4.26	9	145
9.5	86.2	4.31	20.0	10	146
10.5	106	3.26	32.5	11	150
11.5	77.0	1.81	42.5	12	156
12.5	49.0	.88	55.7	13	154
				14	143
				15	134
				16	124
				17	101
				18	81.7
				19	65.8
				20	42.6
				21	69.0
				22	52.5
				23	34.4
				24	20.8
				25	12.6

G.E. TYPE FUEL ASSEMBLY

FIGURE 1

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Figure 2

Core Outline for Clean Critical

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Figure 7

Axial Manganese-Activating Flux - Cylinder
(Bare and Cd-covered)

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Figure 11

Core Outline with Cadmium Rod Inserted

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Figure 16

Core Outline with 2" Steel Reflector

Total number of fuel elements	170
Total weight of U-235	9.044 kg
Excess Reactivity	16 inhours
Worth of steel	-6 inhours

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Figure 17

Core Outline with 3" Steel Reflector

Total number of fuel elements:	165
Total weight of U-235:	8.778 kg
Excess reactivity:	7.4 inhours
Worth of steel:	8.11 inhours

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Figure 18

Core Outline with 4" Steel Reflector

Total number of fuel elements:	163
Total weight of U-235:	8.672 kg
Excess reactivity:	22.4 inhours
Worth of steel:	+214 inhours

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Figure 19

Core Outline with 6" Steel Reflector

Total number of fuel elements:	160
Total weight of U-235:	8.512 kg
Excess reactivity:	0.6 inhours
Worth of steel:	1321 inhours

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Figure 21

Core Outline with 4" Steel Reflector on Two Sides

Total number of fuel elements:	157
Total weight of U-235:	8.352 kg
Excess reactivity:	9.3 inhours
Worth of steel:	424 inhours

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Figure 26

Cores Outline with 1/4" Water Spaces in Steel Reflector

Total number of fuel elements:	165
Total weight of U-235:	8.778 kg
Excess reactivity:	4 inhours
Weight of steel:	113 inhours