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SUBJECT: THE WADC VOID MOCKUP TEST AT THE BULK SHIELDING FACILITY

FROM: E. B. Johnson, K. M. Henry, and J. D. Flynn

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TABLE OF CONTENTS

Introduction	1
Reactor Loading	2
Void and Auxiliary Equipment	3
Experimental Measurements	4
Results	5
Conclusions	7

LIST OF ILLUSTRATIONS

<u>Fig.</u>	<u>Title</u>	<u>Page</u>
1	Bulk Shielding Reactor Loading 41 (WADC Void Mockup Test)	12
2	Underwater View of Reactor and Void Before Coupling	13
3	Underwater View of Reactor Adjacent to Void Ready for Coupling	14
4	View of Void Water Level Indicator and Control Panel	15
5	Schematic Diagram of WADC Void Mockup for the BSF Experiment	16
6	Close-up View of the Void	17
7	Change in Reactivity Resulting from Flooding the Void (No Curtain)	18
8	Change in Reactivity Resulting from Flooding the Void (Boral Curtain)	19

ABSTRACT

A mockup of one of the voids for the proposed WADC reactor was used at the BSR to determine the changes in reactivity which could occur due to the varying of conditions in the void. The void was of sufficient size to completely cover one face of the BSR. Neutron-absorbing curtains (cadmium and boral) were tested to determine their effectiveness in insulating the reactor reactivity-wise from changes inside the void. Equipment to be placed in the WADC void were simulated in the BSR tests by iron slabs located between the neutron-absorbing curtain and the void. The largest reactivity change observed was approximately 3%.

INTRODUCTION

The WADC preliminary reactor design is based on a lattice consisting of a 5 by 7 fuel element array, reflected on the two 5-element sides by graphite and with large beam holes, or voids, adjacent to and completely covering the two 7-element faces. The fuel elements will be of the MTR type. Water will serve as coolant, moderator, and partial reflector. The presence of the large voids will necessitate considerable excess reactivity in addition to that required for operation without voids, and thus represents a potential hazard for a reactor of this type. Since the magnitude of this excess reactivity was uncertain and because it was felt that it could not be determined with sufficient accuracy by calculational procedures, a series of experiments was performed with the Bulk Shielding Reactor (BSR) to determine the magnitude of the reactivities involved.

The mock-up which was installed in the pool of the Bulk Shielding Facility (BSF) consisted of only one void placed against one of the 7-element faces of the lattice. While it was recognized that this would not provide an accurate mock-up of the WADC reactor, constructional difficulties precluded placing voids against opposite faces of the BSR core. Since the mock-up was not an exact duplicate, no attempt was made to reflect the two 5-element sides with graphite.

It is tentatively proposed in the WADC design to permanently attach cadmium to the outer face of the fuel elements which will be placed next to the voids in order to minimize the effect on reactivity

caused by the possible flooding of the voids. In order to simulate the effect of the cadmium in the BSF tests, a cadmium curtain was used to completely cover the face of the void. A similar boral curtain was also tested. These neutron-absorbing curtains were tested to investigate the best means of shielding the reactor against changing conditions within the void.

The reason for the existence of the large voids in the WADC design is for the irradiation of large pieces of equipment. Therefore the effect on reactivity caused by the insertion of such equipment was simulated at the BSF with iron slabs which could be placed between the void and either of the neutron-absorbing curtains.

REACTOR LOADING

The reactor was loaded with a 5 by 7 fuel element array so that the void could be located adjacent to the front 7-element face (Fig. 1). The critical mass of this loading in open water was about 3.9 kg and the amount of U^{235} in the lattice was 4.43 kg. The excess reactivity was about 3.3% $\Delta k/k$ when the reactor was completely reflected by water. Because of the large excess reactivity required for the experiment, two additional boron carbide safety rods were temporarily incorporated in the lattice. These rods were supplied with magnets and magnet amplifiers but did not have mechanical lift mechanisms and position indicators. They were incorporated into the reactor safety circuits.

VOID AND AUXILIARY EQUIPMENT

The void was made of 1/2-in.-thick aluminum plate welded to form an air-tight chamber with outside dimensions 26 in. high by 22-1/2 in. wide by 36 in. deep. Since the fuel section of the lattice against which the void was placed was 24 in. high by 21 in. wide, the void completely covered this face of the lattice. It was assumed that the 36 in. depth would satisfactorily simulate an infinite void. A 1230-pound concrete block and thirty-four 26-pound lead bricks were used to counterbalance the buoyant force of the air-filled void. The entire assembly was rigidly clamped to the reactor frame during each phase of the experiment. Figures 2 and 3 show the void in position in the pool. The water level inside the void was controlled by means of air pressure supplied through an air line. Water level information was transferred through a float and pulley arrangement to an indicating device (Fig. 4) at the side of the pool as shown in Fig. 5.

Figure 6 shows the void after it was removed from the pool.

In addition to the void, two curtains of sufficient size to completely cover the face of the void were provided. One of these was made of 100-mil-thick cadmium and the other of 1/4-in.-thick boral. The effect of the void on reactivity was measured with and without each of these curtains inserted between reactor and void. Three iron slabs (1/2, 1-1/2, and 3 in. thick) were used in conjunction with the neutron-absorbing curtains to simulate experimental equipment placed inside the void. Whenever any of the iron slabs were in place, a neutron-absorbing curtain was adjacent to the reactor.

EXPERIMENTAL MEASUREMENTS

Reactivity was measured in the following situations:

1. The reactor with no void (i.e., completely water-reflected)
2. The reactor against the air-filled void
 - a. With no curtain
 - b. With the cadmium curtain
 - c. With the boral curtain
 - d. With the cadmium curtain and each of the three iron slabs
 - e. With the boral curtain and the 1/2-in.-thick iron slab
3. The reactor against the water-filled tank
 - a. With no curtain
 - b. With the cadmium curtain
 - c. With the boral curtain
 - d. With the cadmium curtain and the 3-in. and the 1/2-in.-thick iron slabs
 - e. With the boral curtain and the 1/2-in.-thick slab
4. Data was also obtained to determine the effect on reactivity of incremental flooding of the initially air-filled void with no curtain and with the boral curtain in position between the reactor and the void.

The differences in reactivity in each experiment were determined from the measured positions of the BSR control rods at criticality. It was necessary to calibrate the regular BSR control rods in terms of

reactivity under several reflector conditions.* It was unnecessary to calibrate the auxiliary rods because both were fully withdrawn during all measurements. Removing the reflector from one face of the loading, either by means of the air-filled void or by means of one of the neutron-absorbing curtains, presumably shifted the peak neutron flux toward the opposite side of the reactor. The effectiveness of the regulating rod was increased by approximately 10% in this location. The change in the effectiveness of the regular BSR safety rods was hardly perceptible ($<1\%$).

RESULTS

Data showing the change of reactivity produced by flooding the initially air-filled void is presented in Table 1. The largest change was observed when there was no curtain between the reactor and the void ($+2.62\% \Delta k/k$). The insertion of the cadmium curtain shielded the reactor sufficiently from the effect of flooding the void to reduce the change in reactivity to $+0.60\% \Delta k/k$, while the presence of the boral curtain reduced this change to $+0.42\% \Delta k/k$. Figure 7 shows graphically the results of incremental flooding of the void with no curtain between it and the reactor, and Fig. 8 shows corresponding data when the boral curtain was between the reactor and the void. It should be pointed out that in the BSF

* For a description of the calibration methods, see ORNL-1682, "Reactivity Measurements with the Bulk Shielding Reactor," R. G. Cochran, J. L. Meem, T. E. Cole, E. B. Johnson (Nov. 30, 1954).

experiment these changes in reactivity occurred very slowly, since it required approximately 50 min. to completely fill the void. Such, of course, would not be the case should the void suddenly collapse or become physically separated from the reactor.

The data which was taken with various possible arrangements of the components yielded results which are summarized in Table 2.

Caution should be exercised in the use of this table. It will be noted that Table 2 attempts to portray concisely the change in reactivity resulting from altering the experimental conditions. For instance, suppose that a reactor which is critical in open water is brought against a water-filled tank with the 100-mil-thick cadmium curtain in place. The reactor will become subcritical -- by $- 2.31\% \Delta k/k$ -- unless the control rods are withdrawn to compensate for the loss of reflector. If the tank is air-filled, the corresponding change in reactivity will be $- 2.91\% \Delta k/k$, while, if the air-filled tank contains an experiment which is equivalent to the 1-1/2-in.-thick iron slab, the change in reactivity will be approximately $- 1.37\% \Delta k/k$. Similarly, if a reactor is critical against the air-filled tank with the 100-mil-thick cadmium curtain in place and an experiment equivalent to the 3-in.-thick iron slab is inserted into the void, the reactor will become supercritical by $+ 1.89\% \Delta k/k$.

When the series of experiments involving reflectors was completed, the void was filled with water with the cadmium curtain in place. The fuel element was then removed from lattice position 5. It was found

that the removal of this element caused a decrease in reactivity of - 0.85%. However, the reactor was still critical with $< 0.2\%$ excess reactivity. Although the measurement was not specifically made, it seems fair to assume that, had the void been air-filled, the reactor would have been subcritical by about - 0.4%. (Table 1 shows that the flooding of the initially air-filled void behind the cadmium curtain increased the reactivity by + 0.60%.) It should be pointed out that the effectiveness of the element in lattice position 5 was measured in the BSR by simply removing the element, while in the WADC reactor the removal of the element will presumably mean the simultaneous removal of the cadmium bonded to that element.

CONCLUSIONS

A lattice composed of 140-g MTR-type elements in a 5 by 7 array will not contain sufficient excess reactivity to support voids covering the two 7-element faces. Some possible design modifications are: (1) the use of only one void, (2) the use of fuel elements containing more U^{235} per element, or (3) the assembly of a larger lattice.

Both the cadmium and the boral curtains which were tested are quite effective in shielding the reactor from changing conditions in the void; the boral curtain is slightly more effective. However, even with a neutron-absorbing curtain between the reactor and the void, an experiment in the void can result in a reactivity change of over + 2%.

If it should be desirable to make reactivity measurements with the WADC reactor, it should be noted that the effectiveness of the control rods will vary as a result of the shift of flux in the reactor caused by changing void conditions.

Table 1

Changes in Reactivity Resulting from Flooding the Initially
Air-filled Void

Experimental Condition	Change in Reactivity Resulting from Flooding the Void with Water ($\% \Delta k/k$)
No curtain	+ 2.62
Cadmium curtain	+ 0.60
Cadmium curtain plus 1/2-in.- thick iron slab	+ 0.49
Cadmium curtain plus 3-in.- thick iron slab	+ 0.15
Boral curtain	+ 0.42
Boral curtain plus 1/2-in.- thick iron slab	+ 0.33

Table 2

Net Change in Reactivity Produced by Altering the Reflector on
One 7-Element Face of the Reactor

Initial Condition	Final Condition	Change in Reactivity* (% $\Delta k/k$)
Reactor completely water-reflected	Water-filled tank	- 0.05
	Water-filled tank plus cadmium curtain	- 2.31
	Water-filled tank plus cadmium curtain plus 3-in.-thick iron slab	- 0.89
	Water-filled tank plus cadmium curtain plus 1/2-in.-thick iron slab	- 1.76
	Water-filled tank plus boral curtain	- 2.59
	Water-filled tank plus boral curtain plus 1/2-in.-thick iron slab	- 2.18
	Air-filled tank	- 2.62
	Air-filled tank plus cadmium curtain	- 2.91
	Air-filled tank plus cadmium curtain plus 3-in.-thick iron slab	- 1.02
	Air-filled tank plus cadmium curtain plus 1-1/2-in.-thick iron slab	- 1.37
	Air-filled tank plus cadmium curtain plus 1/2-in.-thick iron slab	- 2.17

Table 2 (Continued)

Initial Condition	Final Condition	Change in Reactivity* (% $\Delta k/k$)
Water-filled tank	Air-filled tank plus boral curtain	- 3.01
	Air-filled tank plus boral curtain plus 1/2-in.-thick iron slab	- 2.51
	Water-filled tank plus cadmium curtain	- 2.25
	Water-filled tank plus cadmium curtain plus 3-in.-thick iron slab	- 0.84
	Water-filled tank plus cadmium curtain plus 1/2-in.-thick iron slab	- 1.70
	Water-filled tank plus boral curtain	- 2.54
Air-filled tank	Water-filled tank plus boral curtain plus 1/2-in.-thick iron slab	- 2.12
	Air-filled tank plus cadmium curtain	- 0.29
	Air-filled tank plus cadmium curtain plus 3-in.-thick iron slab	+ 1.60
	Air-filled tank plus cadmium curtain plus 1-1/2-in.-thick iron slab	+ 1.24
	Air-filled tank plus cadmium curtain plus 1/2-in.-thick iron slab	+ 0.44

Table 2 (Continued)

Initial Condition	Final Condition	Change in Reactivity* (% $\Delta k/k$)
Air-filled tank	Air-filled tank plus boral curtain	- 0.40
	Air-filled tank plus boral curtain plus 1/2-in.-thick iron slab	+ 0.10
Air-filled tank plus cadmium curtain	Air-filled tank plus cadmium curtain plus 3-in.-thick iron slab	+ 1.89
	Air-filled tank plus cadmium curtain plus 1-1/2-in.-thick iron slab	+ 1.54
	Air-filled tank plus cadmium curtain plus 1/2-in.-thick iron slab	+ 0.74
Water-filled tank plus cadmium curtain	Water-filled tank plus cadmium curtain plus 3-in.-thick iron slab	+ 1.41
	Water-filled tank plus cadmium curtain plus 1/2-in.-thick iron slab	+ 0.55
Air-filled tank plus boral curtain	Air-filled tank plus boral curtain plus 1/2-in.-thick iron slab	+ 0.50
Water-filled tank plus boral curtain	Water-filled tank plus boral curtain plus 1/2-in.-thick iron slab	+ 0.42

*

A positive change in reactivity results when the reactivity is increased over that existing in the reference condition.

Fig. 1. Bulk Shielding Reactor Loading 41 (WADC Void Mockup Test).

Fig. 2. Underwater View of Reactor and Void before Coupling.

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Fig. 3. Underwater View of Reactor Adjacent to Void, Ready for Coupling.

Fig. 4. View of Void Water Level Indicator and Control Panel.

Fig. 5. Schematic Diagram of WADC Void Mockup for the BSF Experiment.

Fig. 6. Close-up View of the Void.

Fig. 7. Change in Reactivity Resulting from Flooding the Void (No Curtain).

Fig. 8. Change in Reactivity Resulting from Flooding the Void (Boral Curtain).