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THE REACTIVITY EFFECT OF AN AIR TANK AGAINST ONE FACE OF THE BULK SHIELDING REACTOR

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ABSTRACT

A large air-filled tank was placed against one face of the Bulk Shielding Reactor in order to observe the effect on reactivity as the reflector was changed from water to air. The interest in this type of measurement arises from the use of large air-filled irradiation chambers adjacent to pool-type reactors. The possible sudden flooding of such chambers presents a reactor hazard which could not be adequately treated by existing calculational techniques. Neutron-absorbing curtains (cadmium and boral) were tested to determine their effectiveness in insulating the reactor reactivity-wise from changes inside the void. Experimental equipment that might be placed in the chamber and would give fast-neutron backscattering was simulated in the BSR tests by iron slabs located between the neutron-absorbing curtain and the tank. The largest net reactivity change observed was approximately 3%, which occurred when the reflector on one face of the reactor was changed from water to boral and air.

INTRODUCTION

Several pool-type reactor installations are being designed, most of which incorporate irradition test facilities extending through the reflector to the reactor core. These proposed beam tubes range in size from a few inches in diameter to facilities covering one or more faces of the reactor. The presence of the large voids will necessitate considerable excess reactivity in addition to that required for operation without voids, and the possible flooding of such chambers represents a potential hazard for a reactor of this type. Since the magnitude of this reactivity was uncertain, and because it was felt that it could not be adequately treated by existing calculational techniques, a series of experiments was performed with the Bulk Shielding Reactor to determine the magnitude of the reactivities involved.

The particular configuration chosen for installation in the pool of the BSF consisted of a large air-filled tank placed against one of the faces of the reactor lattice. While it was recognized that this might not provide an accurate mockup of any proposed design, constructional difficulties precluded placing voids against any other faces of the core simultaneously.

A suggestion which has been made for at least one reactor design is to permanently attach cadmium to the outer face of the fuel elements which will be placed adjacent 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 such neutron-absorbing curtains in the BSF tests, a cadmium sheet was placed in this position. A boral curtain was also tested. These neutron-absorbing curtains were tested also to investigate the best means of shielding the reactor against changing conditions within the void, e.g., the insertion of experimental equipment within the void.

Since the primary purpose of incorporating large voids in reactor designs is to provide for the irradiation of large pieces of equipment, the change in reactivity caused by fast-neutron backscattering from such equipment was also investigated. Iron slabs which could be placed between the void and the neutron-absorbing curtain simulated the equipment.

REACTOR LOADING

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

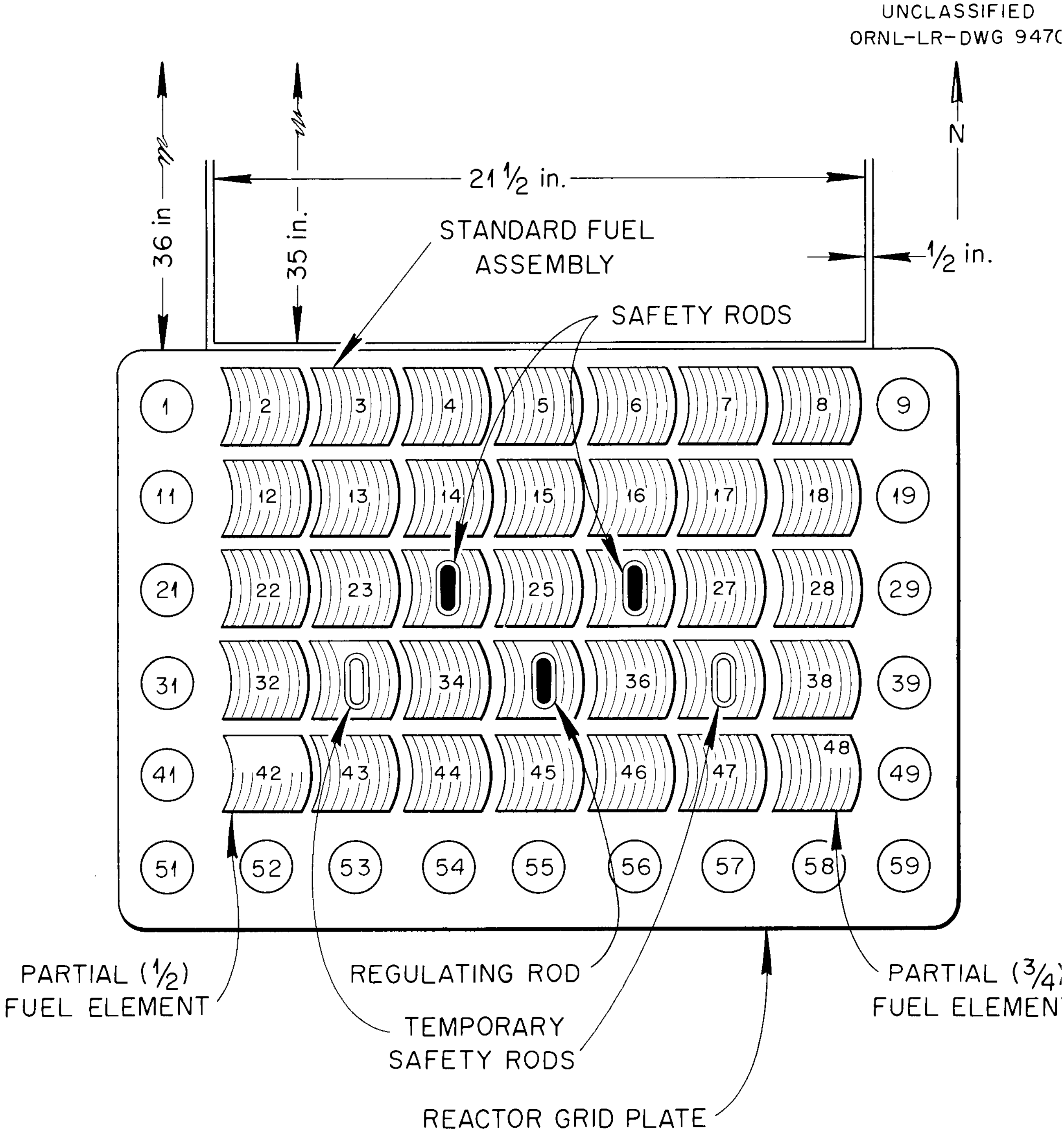

Fig. 1. Bulk Shielding Reactor Loading 41 Used in Void Mockup Test.

TANK AND AUXILIARY EQUIPMENT

The tank was constructed of 0.5-in.-thick aluminum plate welded to form an air-tight chamber with outside dimensions 26 in. high by 22.5 in. wide by 36 in. deep. Since the fuel section of the lattice against which the tank was placed was approximately 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.[1] A 1230-lb. concrete block and 34 26-lb. lead bricks were used to counterbalance the buoyant force of the air-filled tank. The entire assembly was rigidly clamped to the reactor frame during each phase of the experiment. Figures 2 and 3 show the tank in position in the pool. The water level inside the tank 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 at the side of the pool, as shown in Fig. 4.

In addition to the void, two curtains of sufficient size to completely cover the face of the tank were provided. One of these was made of 100-mil-thick cadmium and the other of 0.25-in.-thick boral. The effect of the void on reactivity was measured with and without each of these curtains inserted between reactor and tank. Three iron slabs (0.5, 1.5, and 3 in. thick) were used in conjunction with the neutron-absorbing curtains to simulate experimental equipment

1. "Research Reactors", Chap. 2, TID-5275, p. 114, Tables 2-3.

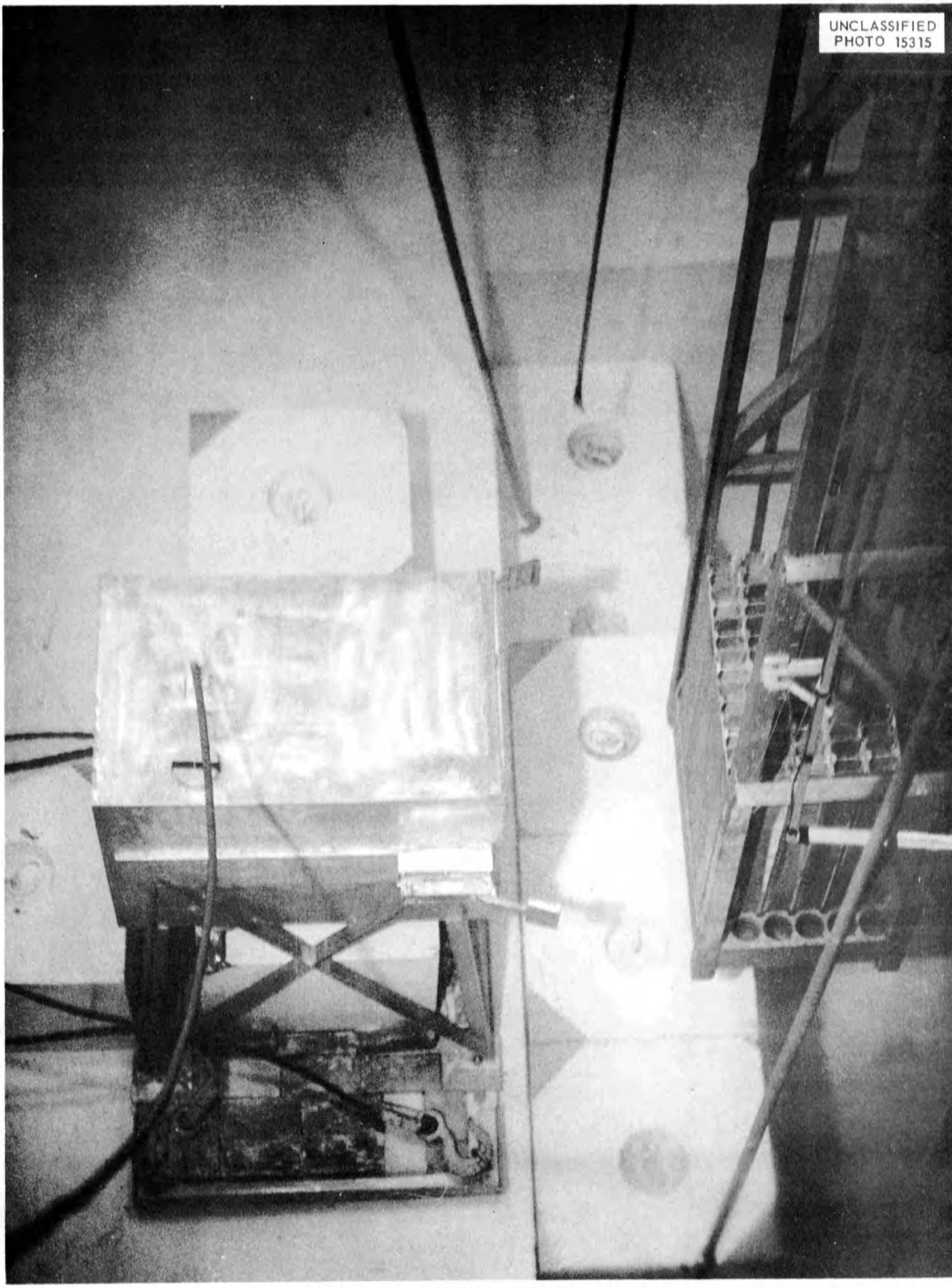

Fig. 2. Underwater View of Reactor and Void before Coupling.

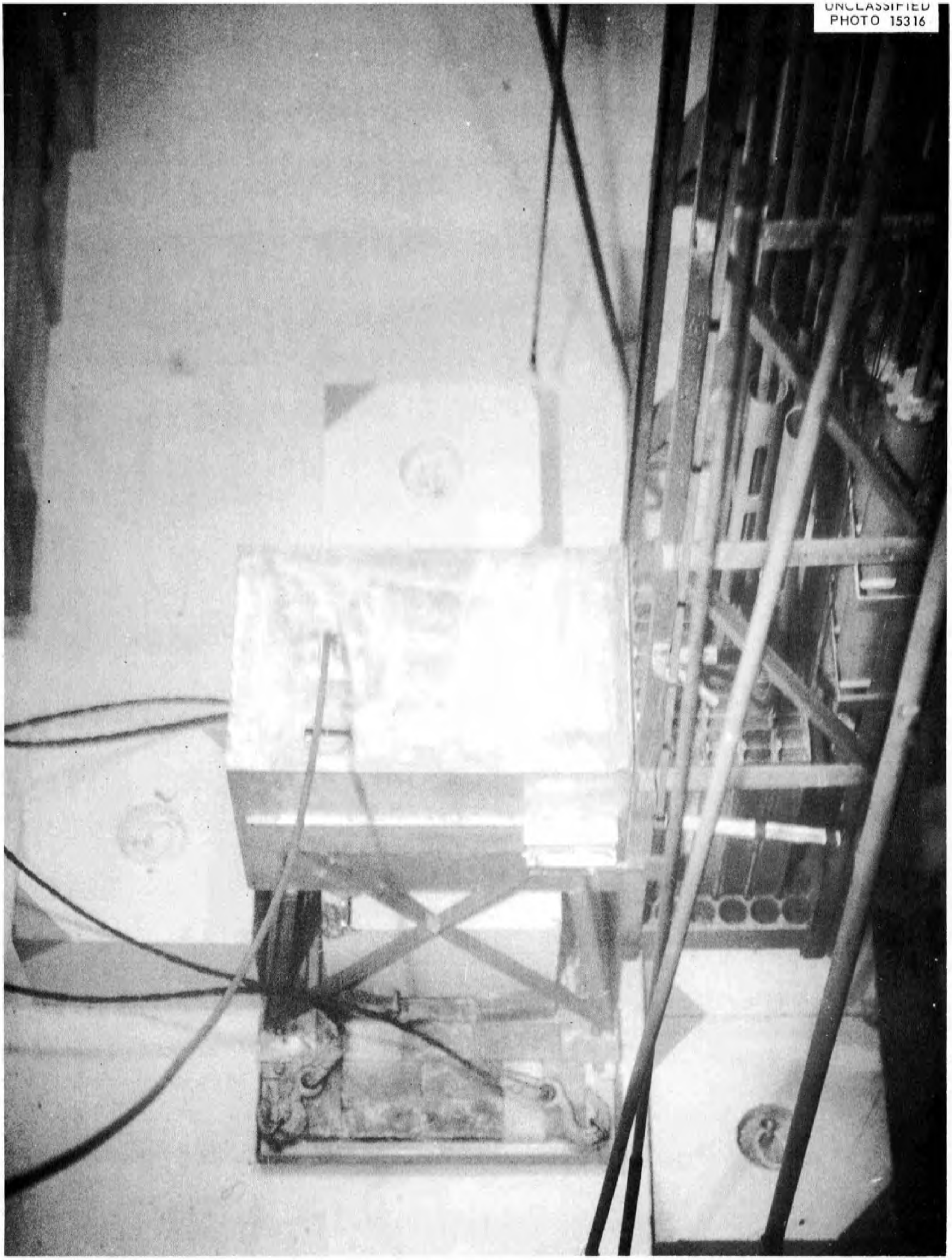

Fig. 3. Underwater View of Reactor Adjacent to Void, Ready for Coupling.

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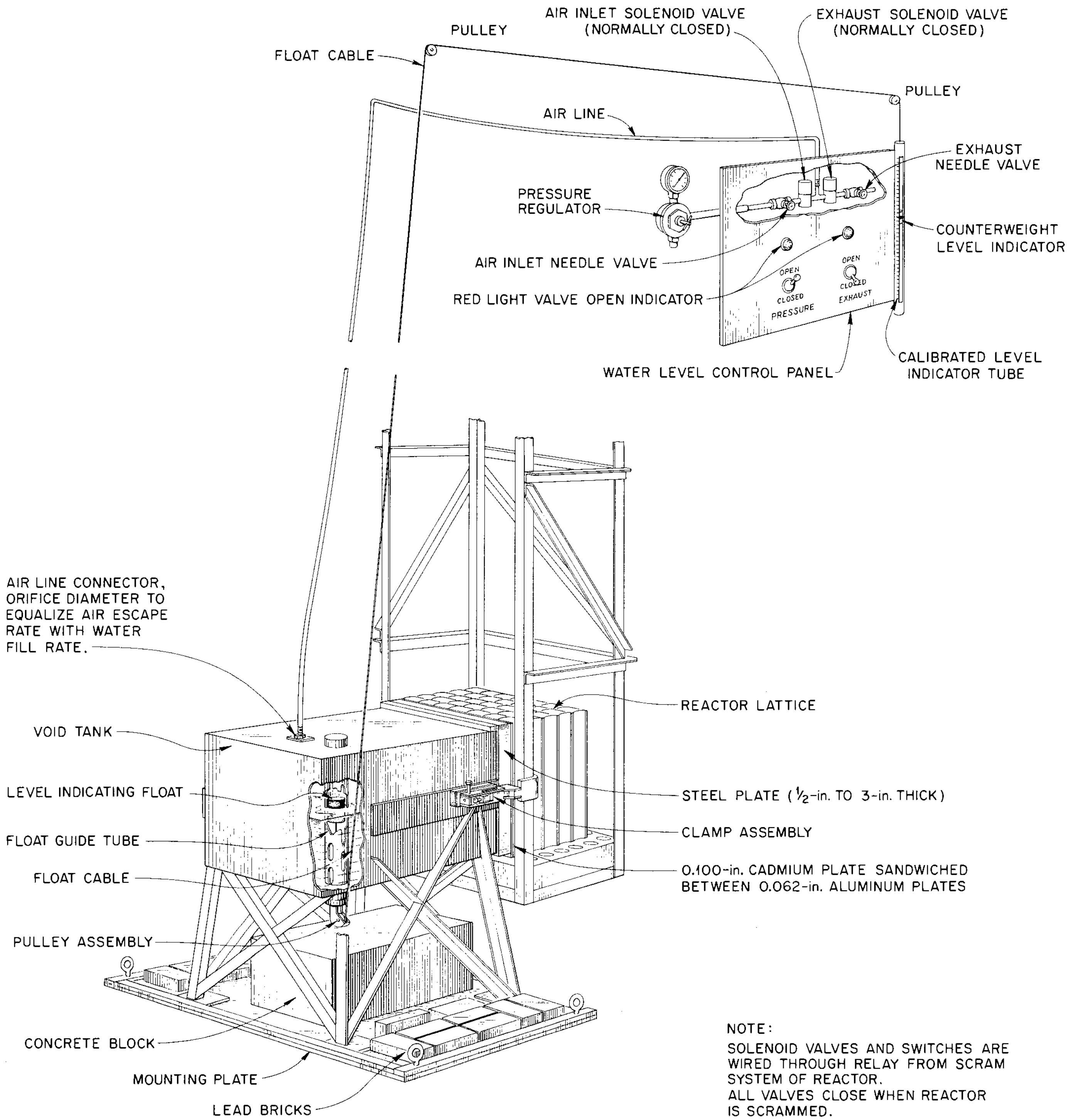

NOTE:
SOLENOID VALVES AND SWITCHES ARE WIRED THROUGH RELAY FROM SCRAM SYSTEM OF REACTOR.
ALL VALVES CLOSE WHEN REACTOR IS SCRAMMED.

Fig. 4. Schematic Diagram of Void Mockup for the BSF Experiment.

placed inside the tank. Whenever any of the iron slabs was in place, a neutron-absorbing curtain was adjacent to the reactor.

EXPERIMENTAL MEASUREMENTS

The change in reactivity of the BSR was measured for the following situations:

1. The reactor with no void (i.e., completely water-reflected).
2. The reactor against the air-filled tank
   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 0.5-in.-thick iron slabs.
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 0.5-in.-thick iron slabs.
   e. With the boral curtain and the 0.5-in.-thick iron slab.
4. The reactor against the initially air-filled tank which was incrementally flooded
   a. With no curtain.
   b. With the boral curtain.

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.[2] 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% by this asymmetrical flux distribution.[3]

EXPERIMENTAL RESULTS

Data showing the change of reactivity produced by flooding the initially air-filled tank 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 tank 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% $\Delta k/k$. Curve A of Fig. 5 shows graphically the results of incremental flooding of the tank with no curtain between it and the reactor, while Curve B shows corresponding data when the boral curtain was between the reactor and the tank. It should be pointed out that in the BSF experiment these changes in reactivity occurred very slowly, since

2. 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).
3. The calibration curves for the pertinent rods may be found in Appendix A.

Table 1

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

Experimental Condition	Changes in Reactivity (% $\Delta k/k$)
No curtain	+2.62
Cadmium curtain	+0.60
Cadmium curtain plus 0.5-in.-thick iron slab	+0.49
Cadmium curtain plus 3-in.-thick iron slab	+0.15
Boral curtain	+0.42
Boral curtain plus 0.5-in.-thick iron slab	+0.33

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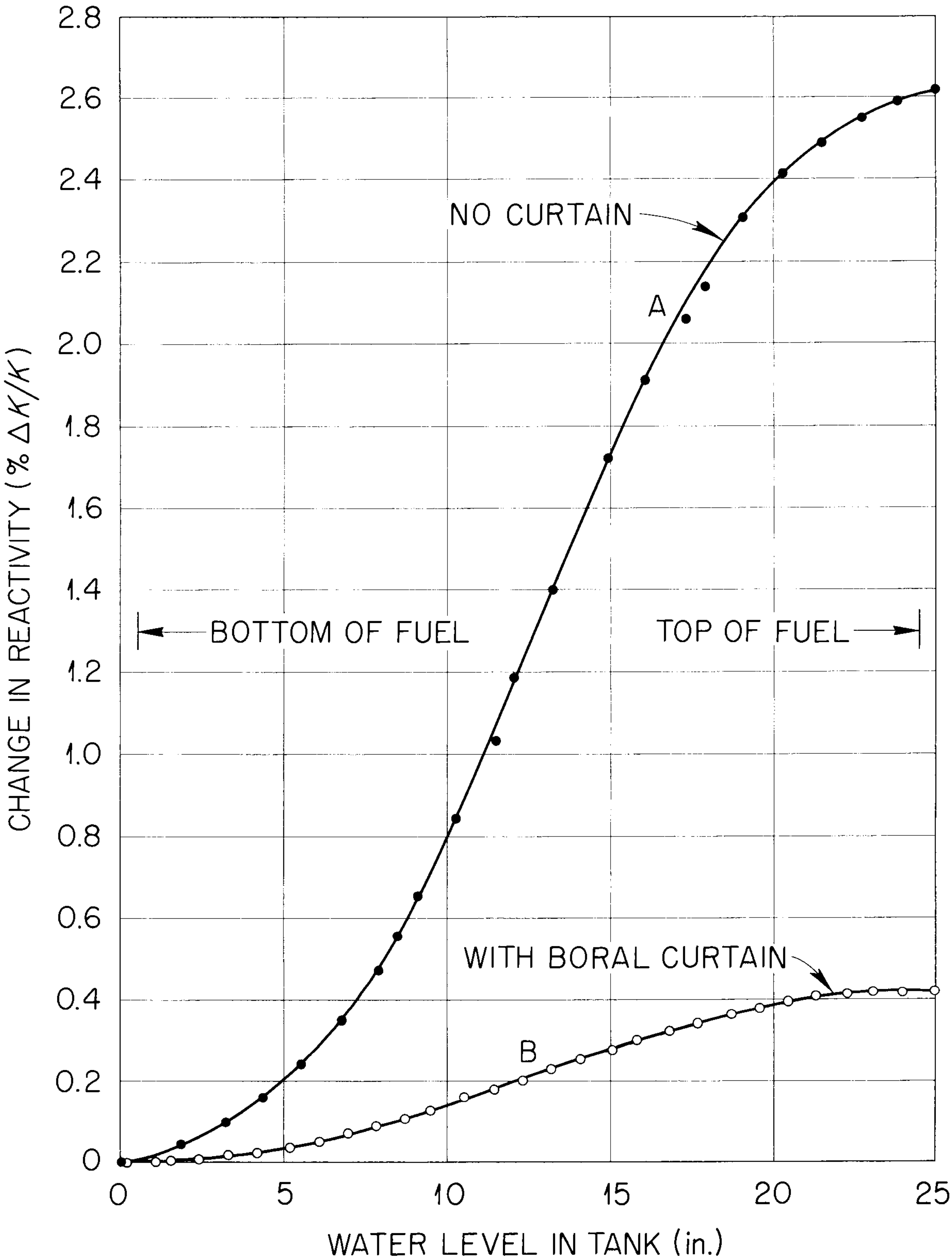

Fig. 5. Change in Reactivity Resulting from Flooding the Void.

it required approximately 50 min to completely fill the tank. 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 initial 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 1.5-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 tank 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

Table 2

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

Reflector		Change in Reactivity* (% Δk/k)
Initial Condition	Final Condition	
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 0.5-in.-thick iron slab	-1.76
	Water-filled tank plus boral curtain	-2.59
	Water-filled tank plus boral curtain plus 0.5-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 1.5-in.-thick iron slab	-1.37
	Air-filled tank plus cadmium curtain plus 0.5-in.-thick iron slab	-2.17

Table 2 (Continued)

Reflector		Change in Reactivity* (% $\Delta k/k$)
Initial Condition	Final Condition	
Reactor completely water-reflected	Air-filled tank plus boral curtain	-3.01
	Air-filled tank plus boral curtain plus 0.5-in.-thick iron slab	-2.51
Water-filled tank	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 0.5-in.-thick iron slab	-1.70
	Water-filled tank plus boral curtain	-2.54
	Water-filled tank plus boral curtain plus 0.5-in.-thick iron slab	-2.12
Air-filled tank	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 1.5-in.-thick iron slab	+1.24
	Air-filled tank plus cadmium curtain plus 0.5-in.-thick iron slab	+0.44

Table 2 (Continued)

Reflector		Change in Reactivity* (% Δk/k)
Initial Condition	Final Condition	
Air-filled tank	Air-filled tank plus boral curtain	-0.40
	Air-filled tank plus boral curtain plus 0.5-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 1.5-in.-thick iron slab	+1.54
	Air-filled tank plus cadmium curtain plus 0.5-in.-thick iron slab	+0.74
Air-filled tank plus cadmium curtain	Water-filled tank plus cadmium curtain	+0.60
	Water-filled tank plus cadmium curtain plus 3-in.-thick iron slab	+2.02
	Water-filled tank plus cadmium curtain plus 0.5-in.-thick iron slab	+1.15
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 0.5-in.-thick iron slab	+0.55

Table 2 (Continued)

Reflector		Change in Reactivity* (% Δk/k)
Initial Condition	Final Condition	
Water-filled tank plus cadmium curtain	Air-filled tank plus cadmium curtain	-0.60
	Air-filled tank plus cadmium curtain plus 3-in.-thick iron slab	+1.29
	Air-filled tank plus cadmium curtain plus 1.5-in.-thick iron slab	+0.93
	Air-filled tank plus cadmium curtain plus 0.5-in.-thick iron slab	+0.13
Air-filled tank plus boral curtain	Air-filled tank plus boral curtain plus 0.5-in.-thick iron slab	+0.50
Water-filled tank plus boral curtain	Water-filled tank plus boral curtain plus 0.5-in.-thick iron slab	+0.42

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

reactivity. Although the measurement was not specifically made, it seems fair to assume that, had the tank been air-filled, the reactor would have been subcritical by about -0.4%. (Table 1 shows that the flooding of the initially air-filled tank behind the cadmium curtain increase the reactivity by +0.60%.)

CONCLUSIONS

1. 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, extreme conditions of fast-neutron backscattering from equipment within the void could result in a positive reactivity change of more than +2%.

2. Some experiments would absorb rather than reflect neutrons, and the change in reactivity resulting from the insertion of such experiments into an irradiation facility would be negative or zero, depending on the effectiveness of the neutron-absorbing curtain and the energies of the neutrons involved.

3. 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 seven-element faces. In order to achieve a two-void reactor design it would therefore be necessary either to use fuel elements containing more U^{235} per element or to assemble a larger lattice.

4. When making reactivity measurements with a reactor which incorporates irradiation test facilities against its core faces, 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.

APPENDIX A

CONTROL ROD CALIBRATIONS

The control rods used for this void experiment consisted of four boron carbide safety rods and one stainless steel regulating rod. Two of the safety rods were the regular BSR rods and the other two were spare rods (auxiliaries) located as shown in Fig. 1 of the foregoing text. The regulating rod was a shell of type 347 stainless steel with an 87-mil-thick wall. These rods were described in earlier reports.[4]

The regular BSR control rods were calibrated under several reflector conditions during the course of this experiment. In each case the regulating rod was calibrated by applying the inhour equation and the safety rods were calibrated by comparison with the regulating rod. Both of these procedures have been described in detail in earlier reports.[4]

It had been expected that the shape of the calibration curve and the total worth of a specific rod would change with different reflector conditions, but the magnitude of the change was not known. Figure A-1 shows the calibration curves for the regulating rod when the reactor was completely water-reflected and when the air-filled tank was located against the north face of the lattice. The total worths of the rod under these two conditions were 0.53% and 0.66% $\Delta k/k$, respectively. The higher value under the latter condition

4. ORNL-1682, op. cit.; see also E. B. Johnson, F. C. Maienschein, K. M. Henry, R. G. Cochran and J. D. Flynn, "Reactivity Measurements with the Bulk Shielding Reactor: Control Rod Calibrations; Beam Hole Coefficients; Partial Reflector Coefficients," ORNL-1871 (Sept. 6, 1955).

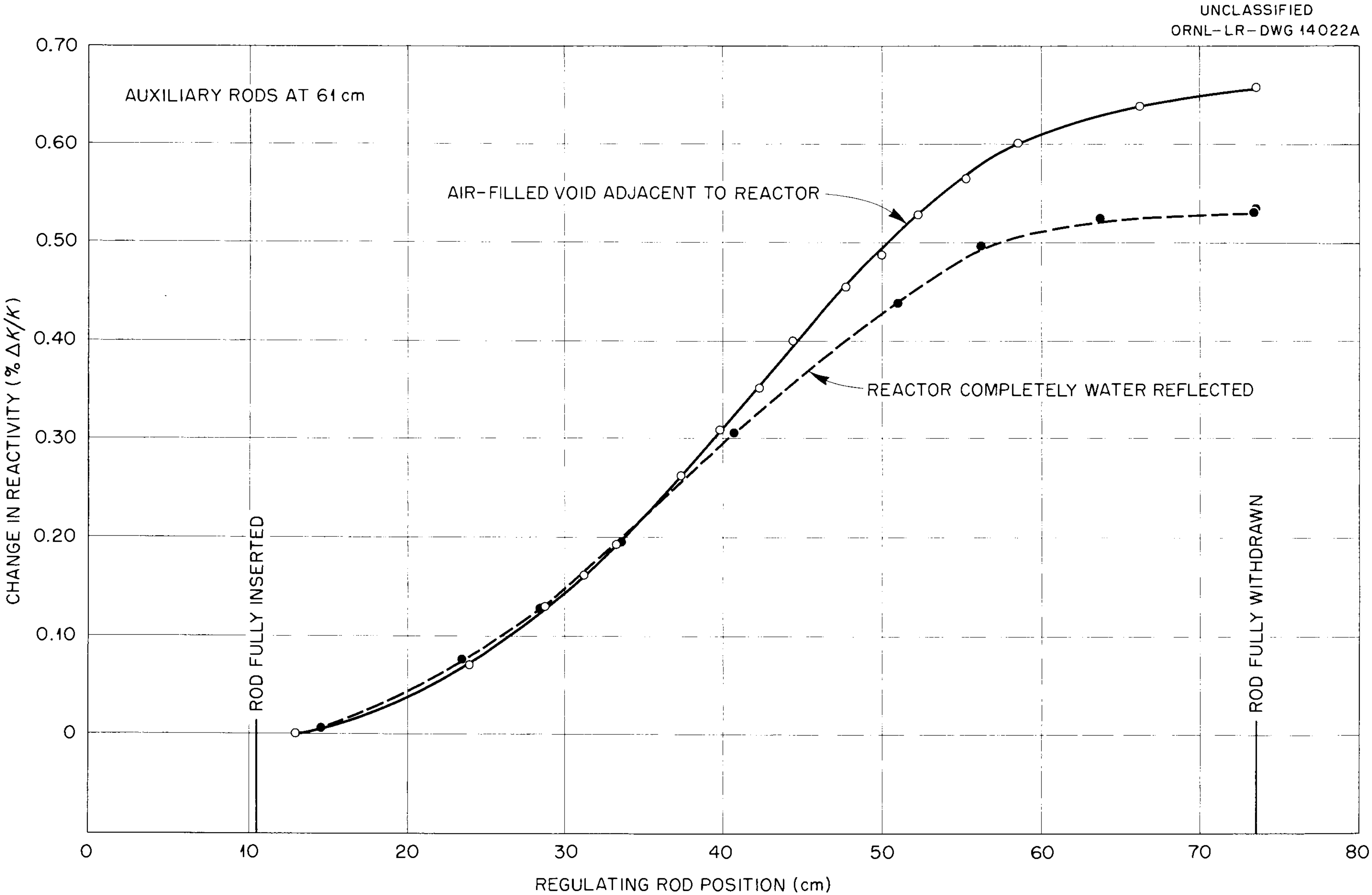

Fig. A-1. Integral Curves for the Stainless Steel Regulating Rod in BSR Loading 41.

lends support to the hypothesis that the removal of the reflector from one side of the reactor results in a shift of the peak neutron flux toward the opposite side of the lattice, thus increasing the effect of poison (a rod) in this region. The insertion of the cadmium curtain between the reactor and the tank resulted in no change in the total worth of the regulating rod from that with the air-filled tank in position, but the shape of the calibration curve changed.

It has long been recognized that the presence and positions of the rods in a given lattice results in the "shadowing" of one rod by another, and that a true determination of the worth of any one rod is impossible. At best, the effective worth of a given rod in a particular loading as influenced by the possible positions of the other rods is the most that can be achieved.

For the first time since the BSR has been in operation there was sufficient excess reactivity in the core to obtain complete calibrations of the regulating rod without changing the positions of some of the other rods. The regulating rod was calibrated with the auxiliary rods fully inserted (0 cm), half withdrawn (30 cm), and fully withdrawn (61 cm). The reactor was completely water-reflected in each case. The calibration curves are shown in Figs. A-2a and A-2b. It will be noted that, although the total worth of the rods does not vary drastically, the shapes of the curves are quite different.

The regular BSR safety rods were also calibrated with the auxiliaries at 0 and 30 cm in a completely water-reflected reactor. The results are shown in Figs. A-3a and A-3b. Other calibration

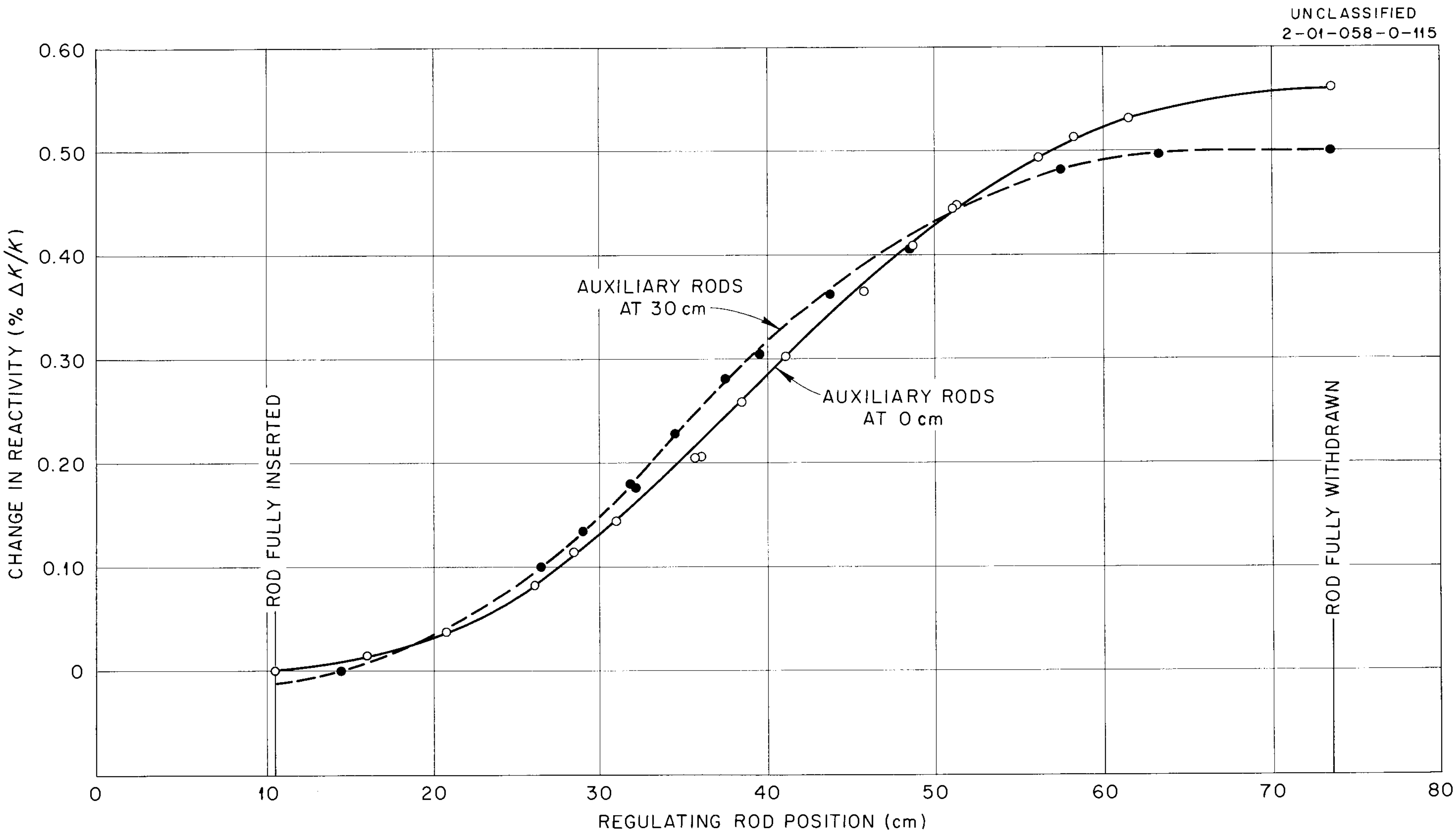

Fig. A-2a. Integral Curves for Stainless Steel Regulating Rod for Different Positions of the Auxiliary Rods in BSR Loading 41 (Completely Water-Reflected).

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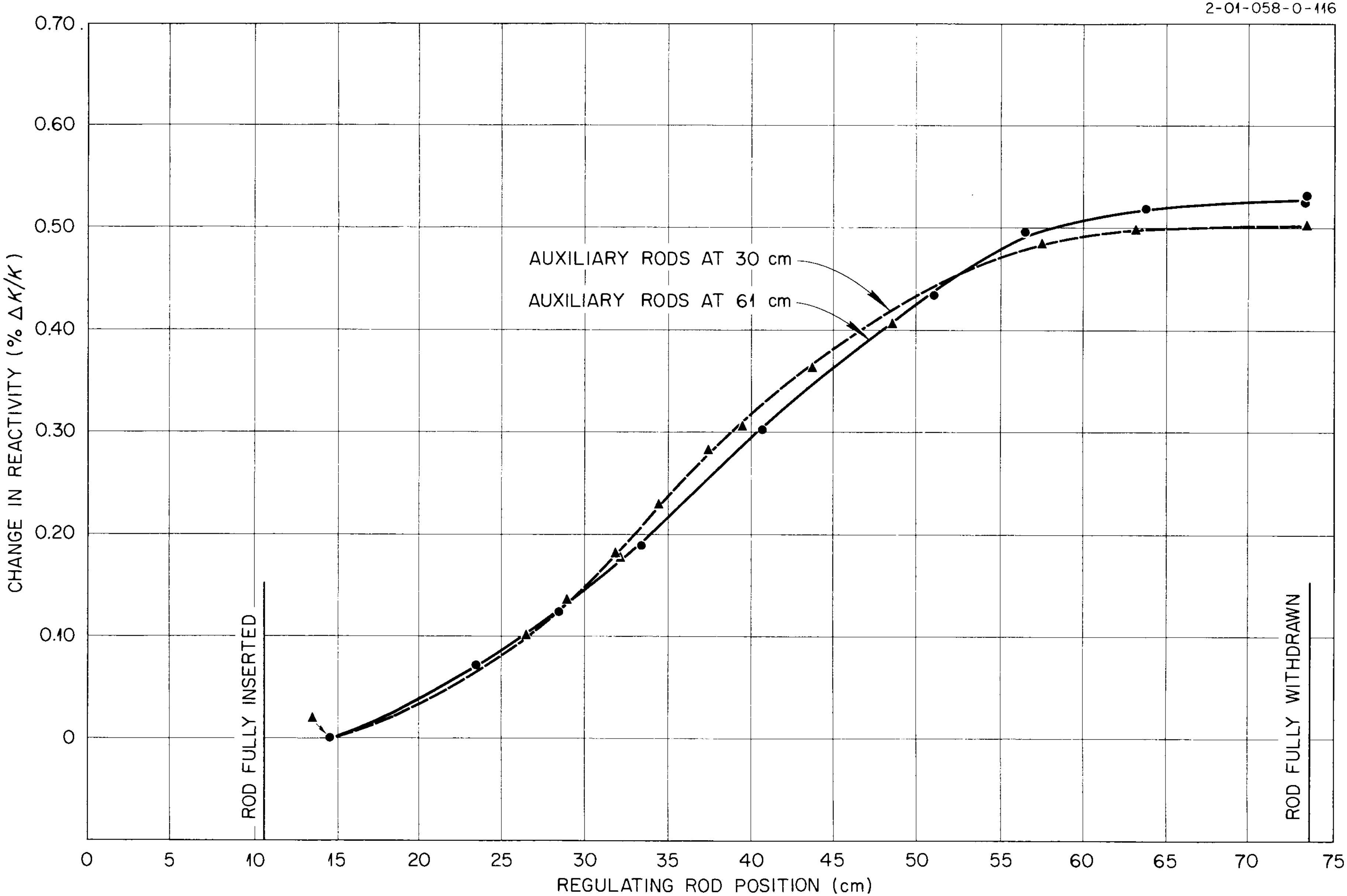

Fig. A-2b. Integral Curves for Stainless Steel Regulating Rod for Different Positions of the Auxiliary Rods in BSR Loading 41 (Completely Water-Reflected).

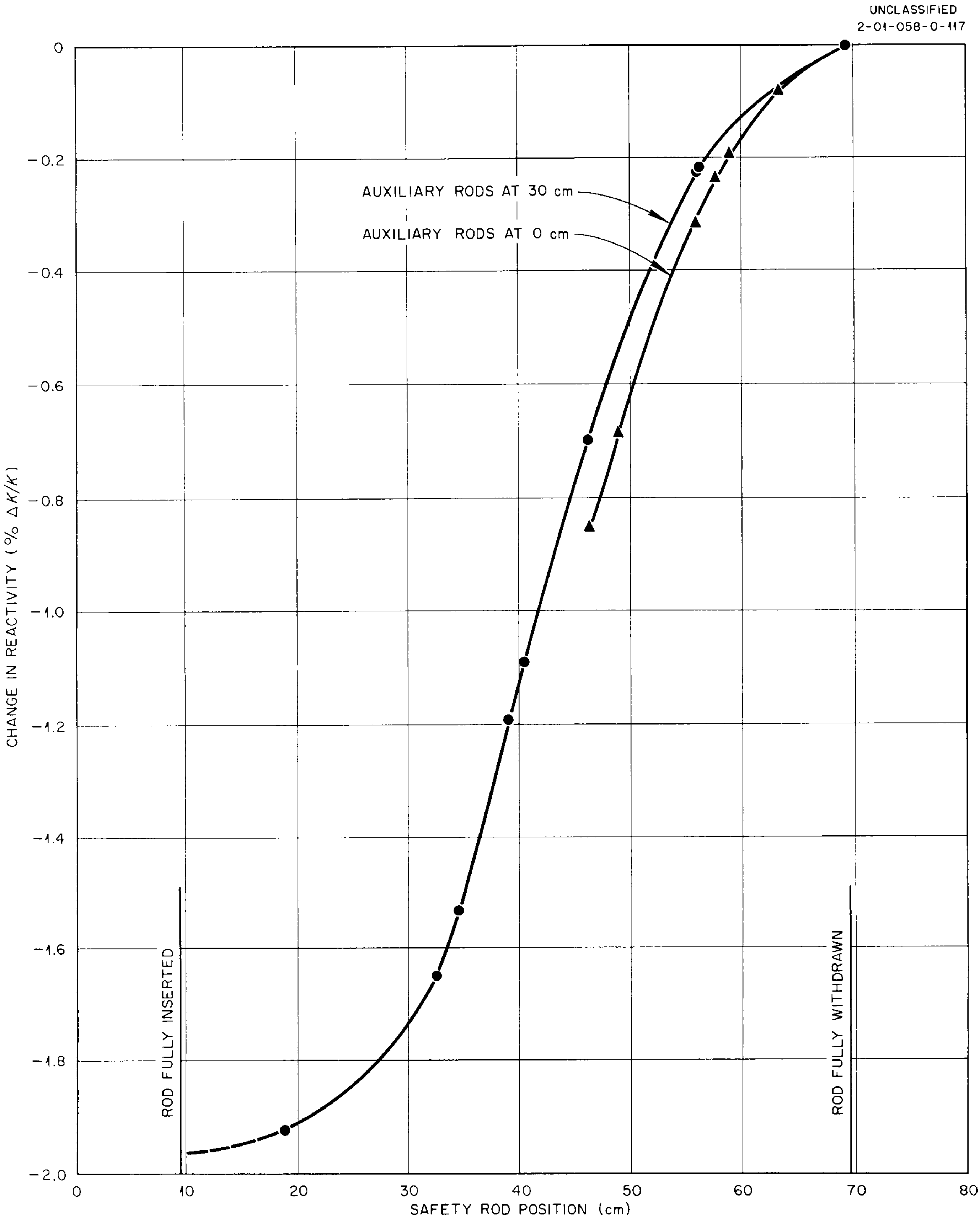

Fig. A−3a. Integral Curves for No. 1 Safety Rod in BSR Loading 41 (Completely Water-Reflected).

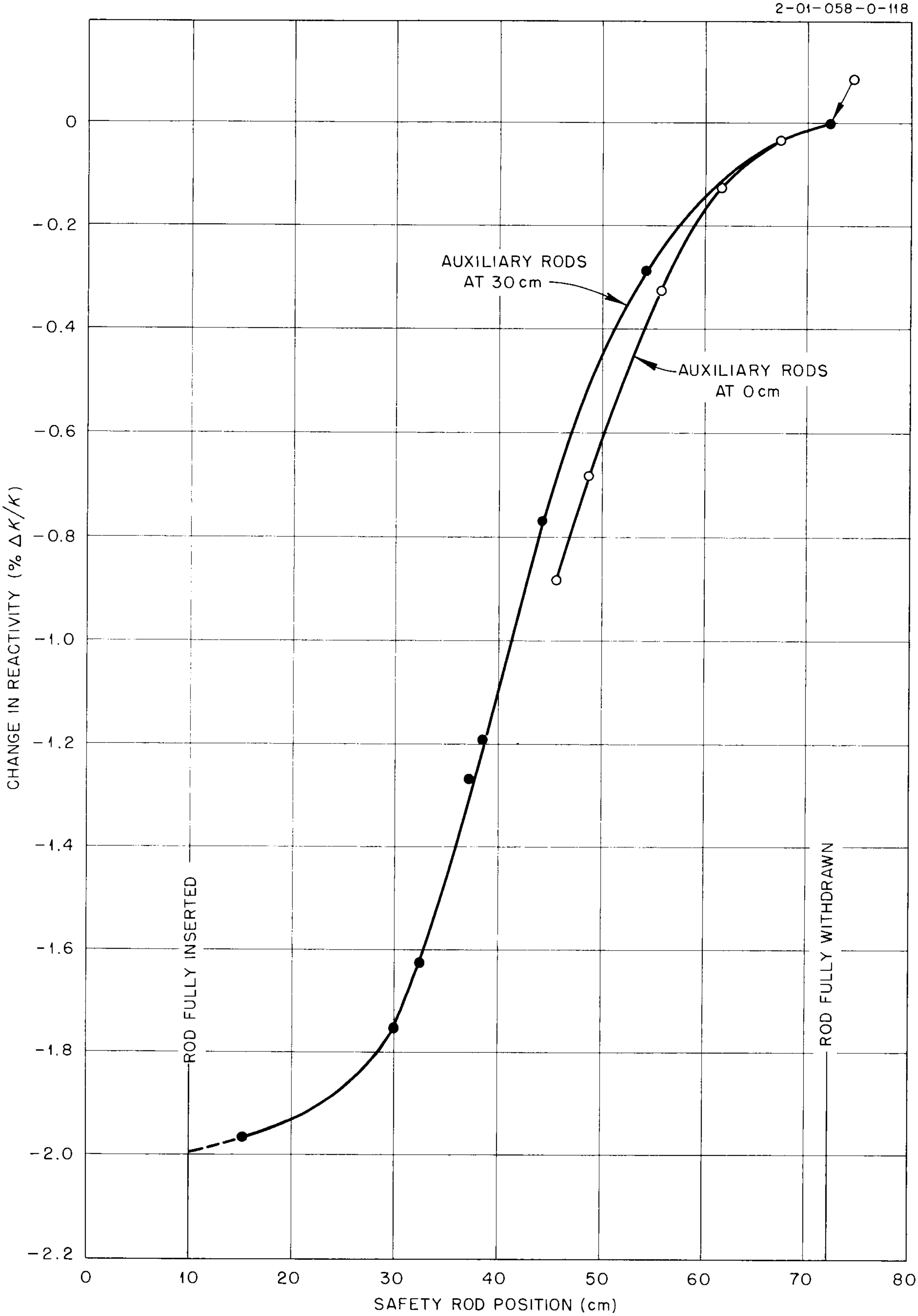

Fig. A-3b. Integral Curves for No. 2 Safety Rod in BSR Loading 41 (Completely Water-Reflected).

curves of the safety rods were obtained with the auxiliary rods at 61 cm (fully withdrawn) with the air-filled void in position and with each neutron-absorbing curtain between the void and the lattice. There was not sufficient excess reactivity to obtain the total worth of the safety rods under these conditions, but the calibration points which were obtained fall on the same curves (Fig. A-4.).

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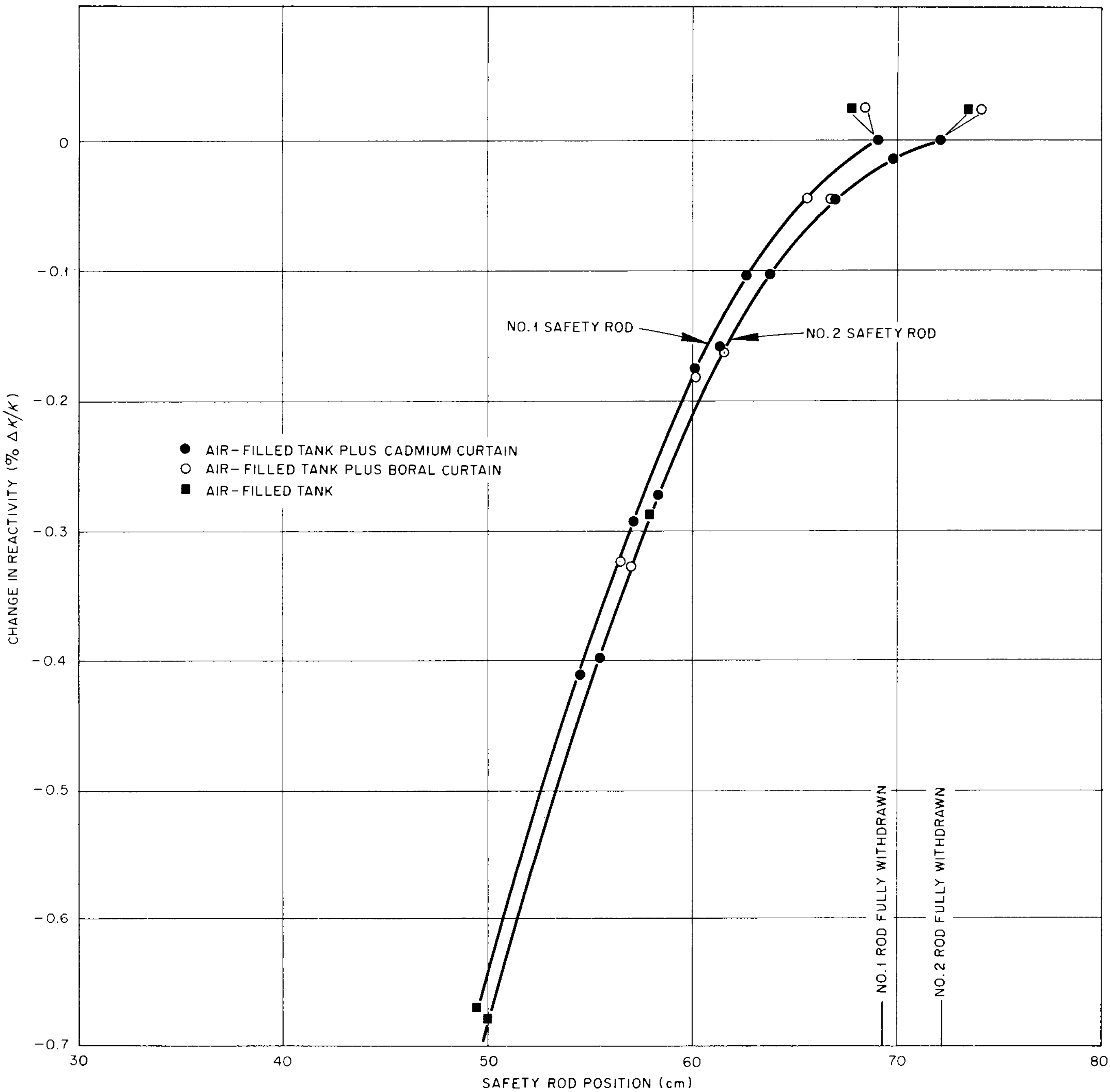

Fig. A-4. Integral Curves for Boron Corbide Safety Rods in BSR Loading 41 for Various Reflector Conditions, Auxiliary Rods Completely Withdrawn (61 cm).