UNCLASSIFIED

CENTRAL RESEARCH LIBRARY
DOCUMENT COLLECTION

ORNL-1871
Physics 4

MARTIN MARIETTA ENERGY SYSTEMS LIBRARIES
3 4456 0349843 6

REACTIVITY MEASUREMENTS WITH THE BULK SHIELDING REACTOR: CONTROL ROD CALIBRATIONS; BEAM HOLE COEFFICIENTS; PARTIAL REFLECTOR ~~GEO~~FFICIENTS
COE

E. B. Johnson
F. C. Maienschein
K. M. Henry
R. G. Cochran
J. D. Flynn

CENTRAL RESEARCH LIBRARY
DOCUMENT COLLECTION
LIBRARY LOAN COPY
DO NOT TRANSFER TO ANOTHER PERSON
If you wish someone else to see this document, send in name with document and the library will arrange a loan.

OAK RIDGE NATIONAL LABORATORY
OPERATED BY
UNION CARBIDE NUCLEAR COMPANY
A Division of Union Carbide and Carbon Corporation
UCC
POST OFFICE BOX P · OAK RIDGE, TENNESSEE

UNCLASSIFIED

UNCLASSIFIED

ORNL-1871

Copy No. 4

Contract No. W-7405-eng-26

Applied Nuclear Physics Division

REACTIVITY MEASUREMENTS WITH THE BULK SHIELDING REACTOR: CONTROL ROD CALIBRATIONS; BEAM HOLE COEFFICIENTS; PARTIAL REFLECTOR COEFFICIENTS

E. B. Johnson
F. C. Maienschein
K. M. Henry
R. G. Cochran
J. D. Flynn

Date Issued

SEP 6 1955

OAK RIDGE NATIONAL LABORATORY
Operated by
UNION CARBIDE NUCLEAR COMPANY
A Division of Union Carbide and Carbon Corporation
Post Office Box P
Oak Ridge, Tennessee

MARTIN MARIETTA ENERGY SYSTEMS LIBRARIES

3 4456 0349843 6

INTERNAL DISTRIBUTION

1. C. E. Center
2. Biology Library
3. Health Physics Library
4-5. Central Research Library
6. Reactor Experimental Engineering Library
7-11. Laboratory Records Department
12. Laboratory Records, ORNL R.C.
13. C. E. Larson
14. L. B. Emlet (K-25)
15. J. P. Murray (Y-12)
16. A. M. Weinberg
17. E. H. Taylor
18. E. D. Shipley
19. A. H. Snell
20. F. C. VonderLage
21. W. H. Jordan
22. S. J. Cromer
23. G. E. Boyd
24. R. A. Charpie
25. J. A. Swartout
26. S. C. Lind
27. F. L. Culler
28. A. Hollaender
29. J. H. Frye, Jr.
30. W. M. Good
31. M. T. Kelley
32. G. H. Clewett
33. R. S. Livingston
34. K. Z. Morgan
35. T. A. Lincoln
36. A. S. Householder
37. C. P. Keim
38. C. S. Harrill
39. C. E. Winters
40. D. S. Billington
41. D. W. Cardwell
42. E. M. King
43. E. O. Wollan
44. A. J. Miller
45. J. A. Lane
46. R. B. Briggs
47. L. D. Roberts
48. R. N. Lyon
49. W. C. Koehler
50. E. P. Blizard
51. M. E. Rose
52. D. D. Cowen
53. W. M. Breazeale (consultant)
54. M. J. Skinner
55. J. E. Sherwood
56. R. B. Murray
57. E. D. Klema
58. C. E. Clifford
59. E. P. Epler
60. T. E. Cole
61. A. D. Callihan
62. J. A. Cox
63. M. L. Nelson
64. A. Simon
65. E. B. Johnson
66. K. M. Henry
67. J. D. Flynn
68-117. F. C. Maienschein
118. L. B. Holland
119. ORNL Document Reference Library, Y-12 Branch

EXTERNAL DISTRIBUTION

120. R. F. Bacher, California Institute of Technology
121. W. K. H. Panofsky, Stanford University
122. J. R. Bohannon, Wright Air Development Center
123. H. Pearlman, North American Aviation, Inc.
124. Division of Research and Medicine, AEC, ORO
125. R. G. Cochran, Pennsylvania State University
126-434. Given distribution as shown in TID-4500 under Physics category

DISTRIBUTION PAGE TO BE REMOVED IF REPORT IS GIVEN PUBLIC DISTRIBUTION

TABLE OF CONTENTS

ABSTRACT..... vii

INTRODUCTION..... 1

I. REACTOR LOADINGS..... 2

Loading 22A..... 2

Loading 32..... 2

Loading 33..... 5

Loading 38..... 8

II. CONTROL ROD CALIBRATIONS.....10

Distributed Poison Method for Loading 32.....10

Inhour Method for Loadings 22A, 33, and 38.....14

Results of Calibrations.....20

III. THE EFFECT OF BEAM HOLES ON REACTIVITY.....22

IV. THE EFFECT OF PARTIAL REFLECTORS ON REACTIVITY.....27

ABSTRACT

A series of experiments designed to yield information on reactivity changes due to the presence of beam holes and partial reflectors adjacent to a swimming pool type research reactor were performed at the Bulk Shielding Facility. The beam holes consisted of 4-1/4 to 17-3/4-in.-dia cylindrical ducts that varied in length from 12 to 47-3/4 in.; the ducts were filled with either air or borated water. Reactivity changes caused by placing the ducts against the fuel of the Bulk Shielding Reactor (water-reflected Loading 22A) or against a beryllium oxide reflector of the BSR (Loading 32) were determined. Similar determinations were made for three partial reflectors: a 1/4-in.-thick boral sheet against the reflector of Loading 32; a 1-ft-thick graphite slab against the reflector of Loading 32; and a 1-7/8-in.-thick lead slab against the fuel of Loading 22A. Since the most practical method available for measuring the change in reactivity of a reactor is by means of calibrated control rods, safety and regulating rod calibrations were made for the pertinent reactor loadings. Further studies were made of the effectiveness of these same rods in other reactor loadings.

INTRODUCTION

Specific information on the change in reactivity due to the presence of beam holes and partial reflectors adjacent to the reactor is needed for the design of swimming pool type reactors. A series of experiments designed to measure this change in reactivity was performed with the Bulk Shielding Reactor.[1]

The BSR is an assembly of MTR-type[2] fuel elements that can be arranged in many critical configurations. The fuel is enriched uranium contained in aluminum-clad fuel plates. Several of these plates are supported in a rigid assembly, or fuel element, in such an arrangement that water can flow freely between the individual plates. A full fuel element contains a total of about 140 g of U^{235}.

The reactor is controlled by means of two safety rods and one regulating rod. The elements through which the control rods move contain only half the normal number of fuel plates, and, therefore, only half the normal amount of fuel. The reactor is cooled, moderated, shielded, and at least partially reflected by water. A beryllium oxide reflector may be used on any or all of the four vertical sides. The reflector elements are hot-pressed beryllium oxide blocks encased in water-tight aluminum cans of the same outside dimensions as the fuel elements.

---

1. W. M. Breazeale, "The New Bulk Shielding Facility at Oak Ridge National Laboratory," ORNL-991 (May 8, 1951). A later and more complete description of this reactor was contained in the pool-type reactor section of the Geneva Conference Report.

2. C. D. Smith, F. W. Droston, F. Kerze, Jr., "Production of Fuel Assemblies for the Materials Testing Reactor Mock-up Critical Experiments," ORNL-951 (April 9, 1951).

I. REACTOR LOADINGS

Several different reactor configurations were used for the series of experiments reported here. Loadings 22A and 32 were used for the beam hole and partial reflector experiments. The control rods were calibrated in Loadings 22A, 32, 33, and 38. Each of these lattice configurations is described below.

Loading 22A

Loading 22A consisted of 30 fuel elements in a 5 by 6 array which was completely reflected by water (Fig. 1). This loading was composed of the original or "old" BSR fuel elements which had been fabricated before it was realized that the brazing process then in use left an appreciable residue of lithium from the brazing flux, thus poisoning the elements. The control rods consisted of two cadmium-lead safety rods and a cadmium-lead regulating rod. This lattice configuration and the calibration of the rods in this critical assembly have been discussed in detail in an earlier report.[3]

Loading 32

Loading 32 was an arrangement of 20 fuel elements reflected on the four vertical sides by 3 in. of beryllium oxide (Fig. 2). The fuel elements used in this lattice configuration were the "new" BSR elements, which were fabricated by a modified process that minimizes

---

3. R. G. Cochran, J. L. Meem, T. E. Cole, and E. B. Johnson, "Reactivity Measurements with the Bulk Shielding Reactor," ORNL-1682 (Nov. 9, 1954).

UNCLASSIFIED
ORNL-LR-DWG 5892

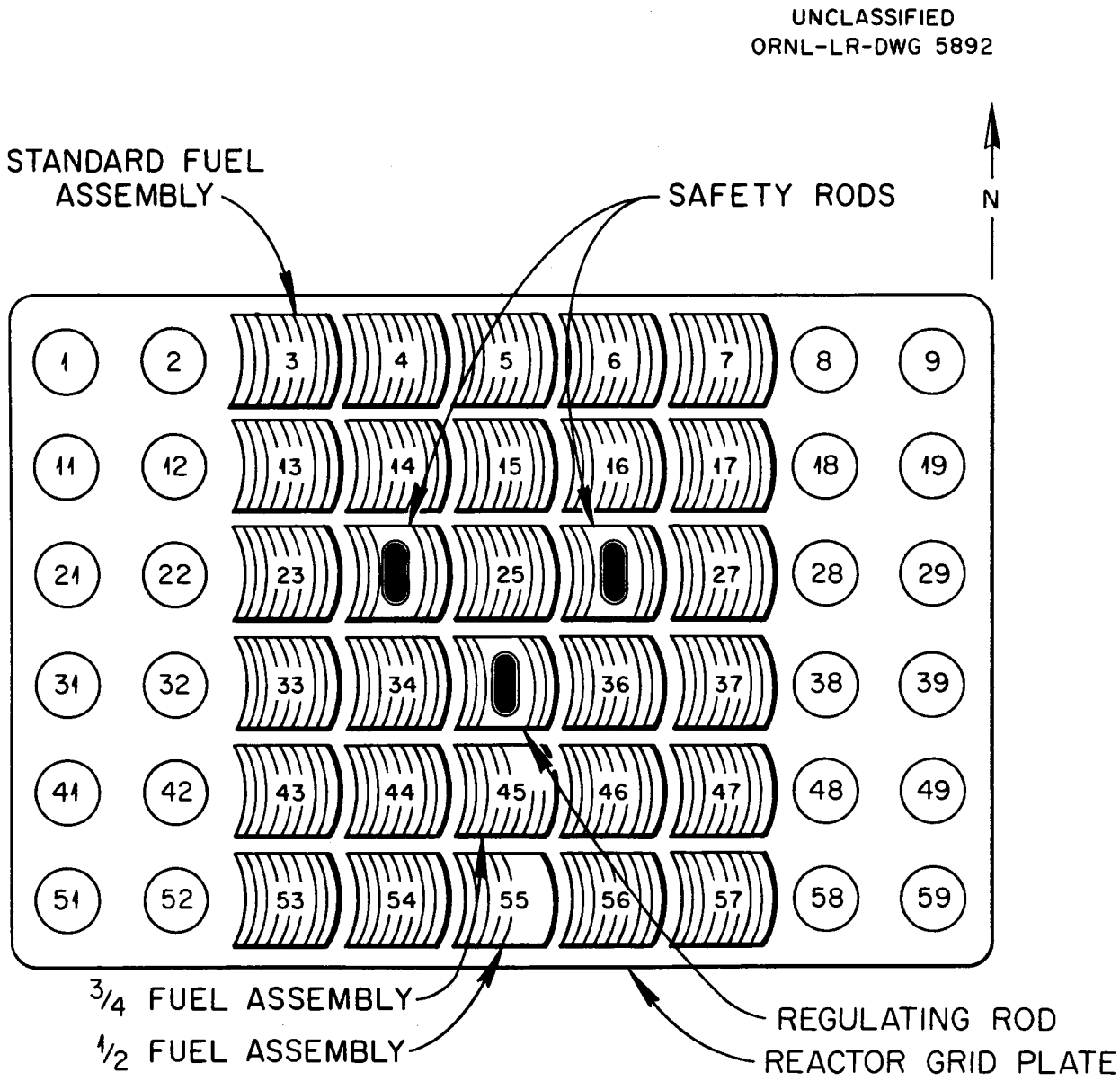

Fig. 1. Bulk Shielding Reactor Loading 22A.

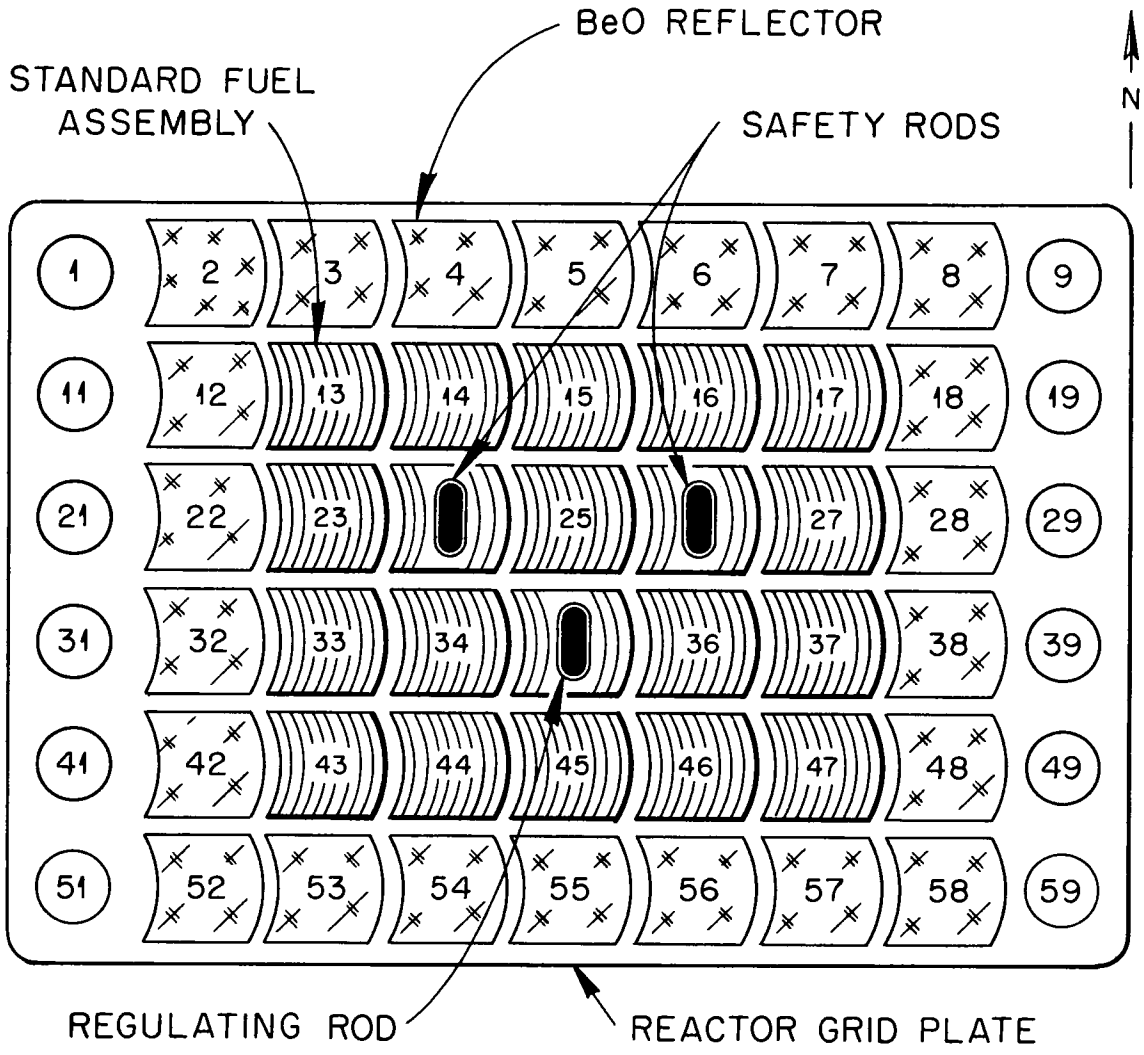

Fig.2.Bulk Shielding Reactor Loading 32.

the residual lithium from the brazing flux. It should be pointed out that it appears that the full effect of the beryllium oxide reflector was not realized in this loading, which was quite similiar to another loading (Loading 1, Fig. 3) composed of the original lithium-poisoned fuel elements. A comparison of Figs. 2 and 3 shows that Loading 32 contains one more fuel element than Loading 1, although Loading 1 had been assembled with "poisoned" fuel elements. (Each loading contained about the same amount of excess reactivity.) At the time the critical experiment for Loading 32 was performed, at least two of the reflector elements were leaking gas. The precise effect on reactivity due to the gas and possible water in these elements is difficult to evaluate but it is felt that, had the reflector been optimum, Loading 32 would have contained two or three fewer fuel elements.

The control rods used for Loading 32 consisted of two safety rods containing boron carbide powder as the neutron absorbing material and a water-filled hollow type 347 stainless steel regulating rod with an 87-mil-thick wall.

Loading 33

Loading 33 (Fig. 4) was essentially a 5 by 6 completely water-reflected fuel arrangement with two elements missing at the corners of the back (south) face. The new BSR fuel elements were used to assemble this loading. The two boron carbide safety rods and the stainless steel regulating rod were used in this configuration.

UNCLASSIFIED
ORNL-LR-DWG 5891

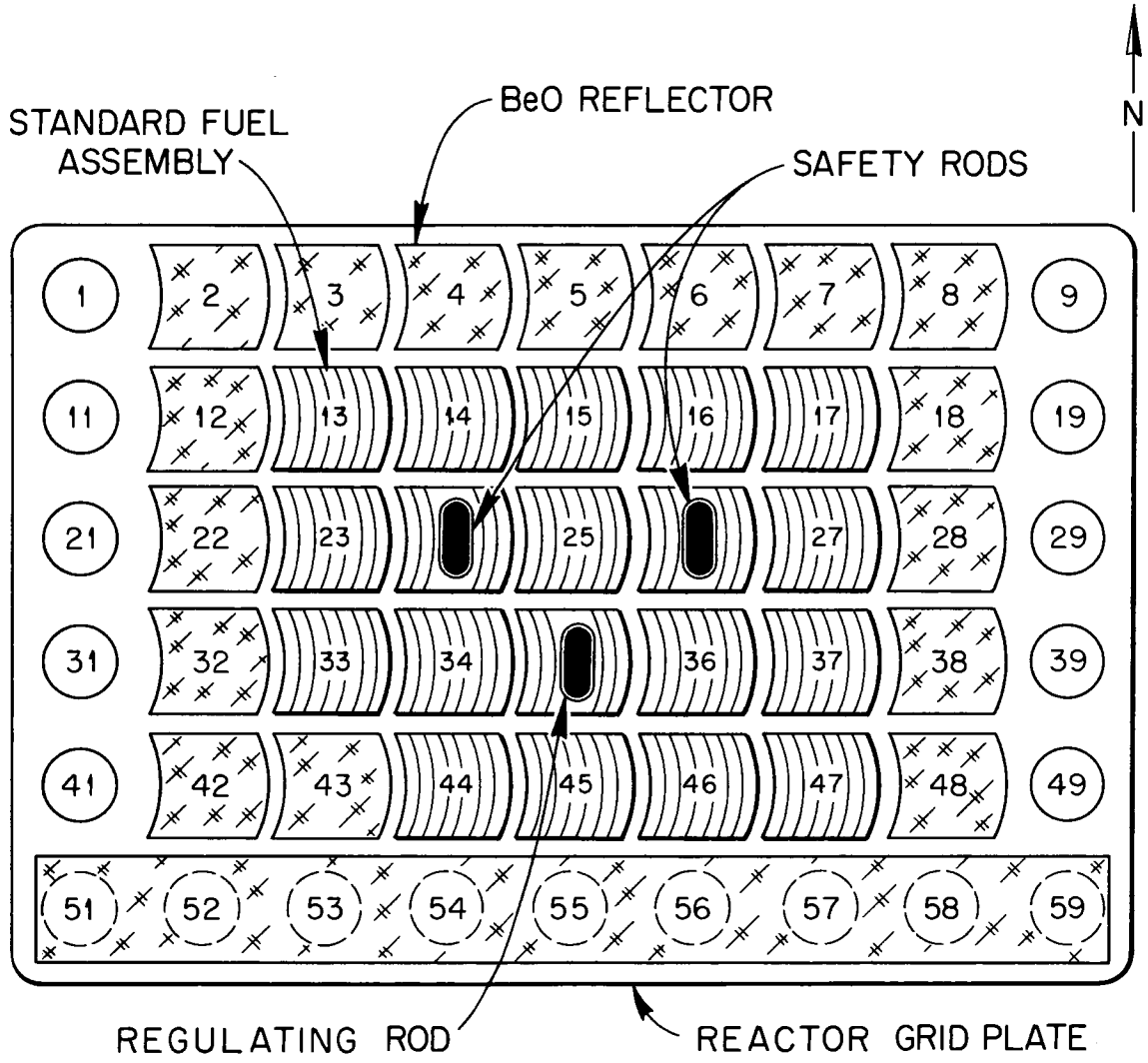

Fig.3. Bulk Shielding Reactor Loading 1.

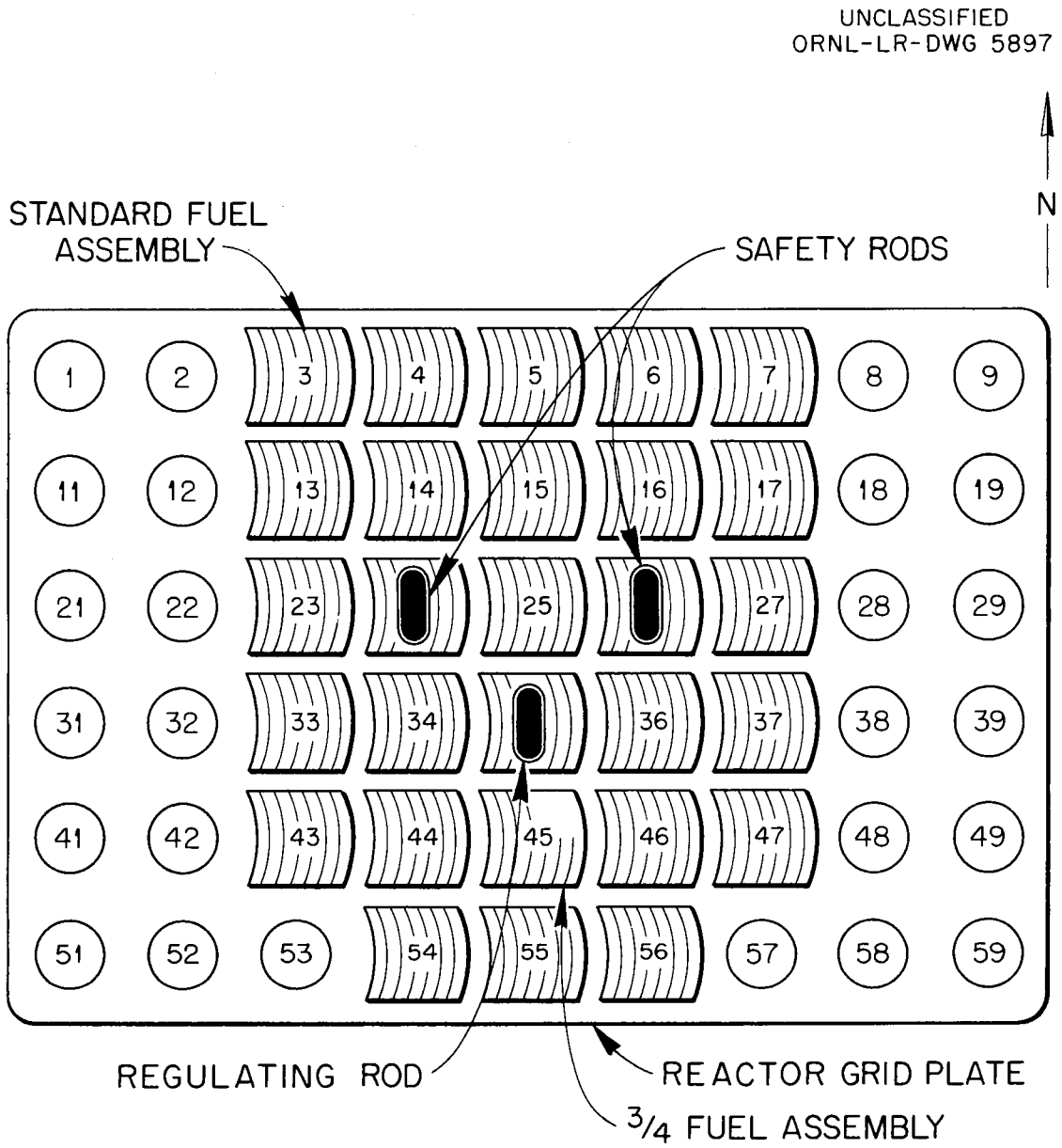

Fig. 4. Bulk Shielding Reactor Loading 33.

Loading 38

Loading 38 (Fig. 5) was reflected along the north face by 3 in. of beryllium oxide and was water reflected on the other five sides. This loading was also composed primarily of new fuel elements. The stainless steel regulating rod and boron carbide safety rods were used in this configuration; however, only the regulating rod was calibrated.

UNCLASSIFIED
ORNL-LR-DWG 5898

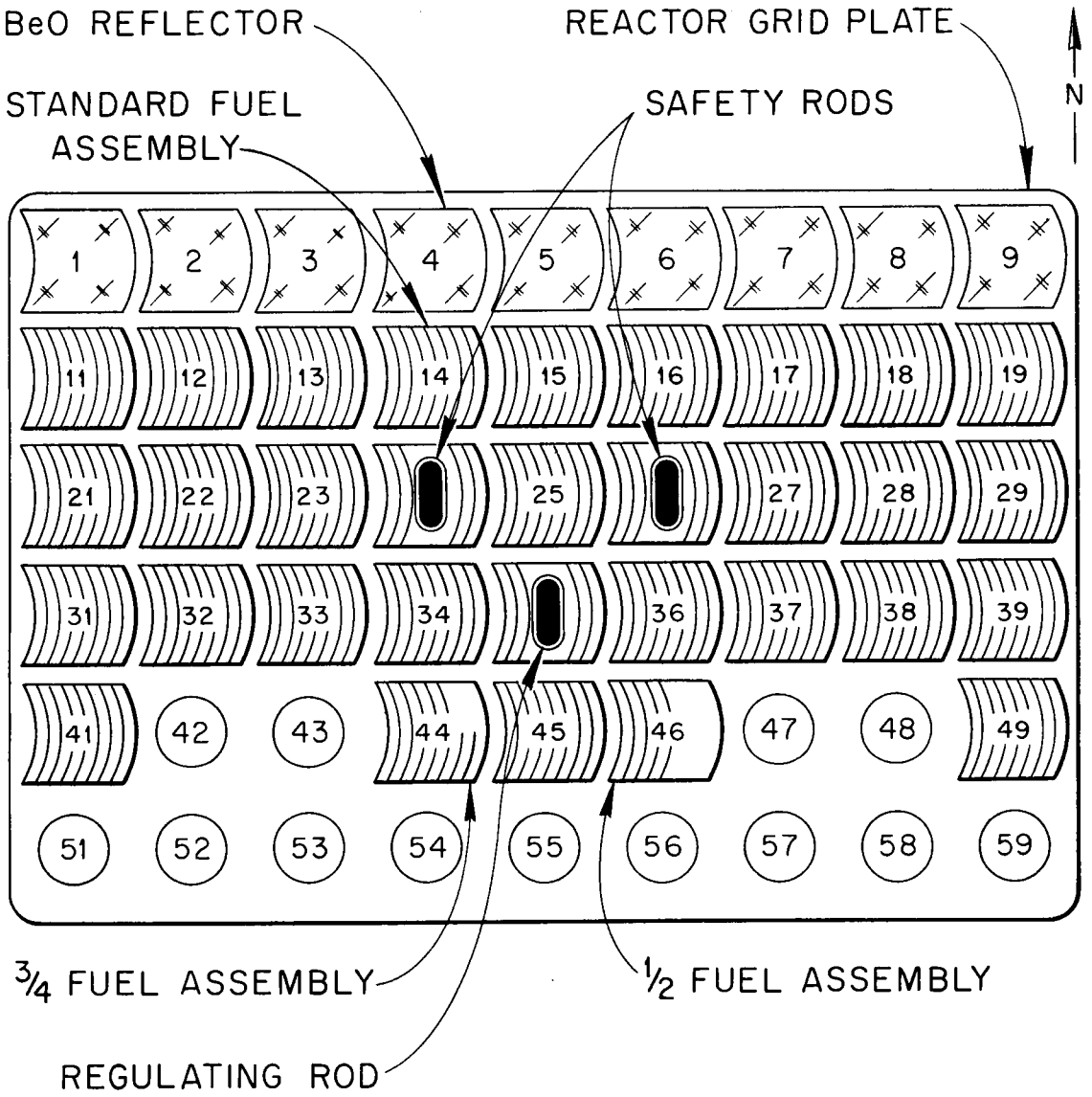

Fig. 5. Bulk Shielding Reactor Loading 38.

II. CONTROL ROD CALIBRATIONS

The most convenient method of rod calibration in a water-reflected loading is by means of the inhour equation, which relates the stable reactor period to the change in reactivity. However, the effect of photoneutrons from beryllium on the reactor period makes rod calibrations by this method questionable for a lattice containing beryllium in any form. Therefore a method was employed for the beryllium oxide--reflected loading which involved uniformly poisoning the reactor with gold and relating the resulting change in thermal utilization to the change in reactivity. The application of each of the two methods to the calibration of the control rods in the loadings used in these experiments is discussed below.

Distributed Poison Method for Loading 32

Since Loading 32 (Fig. 2) was reflected on the four vertical sides by beryllium oxide, it was impractical to attempt the calibration of the regulating rod by the inhour method. It was further necessary to keep the fuel elements cold* until other experiments involving these elements had been completed. Rod calibration by the distributed poison method can be accomplished at any convenient power level, while the inhour method requires operation over a power level range of at least 100.

The distributed poison calibration method for Loading 32 involved attaching gold foils to lucite strips, which were then inserted in the fuel elements of the reactor lattice in such a pattern that the poisoning

---

* Cold fuel elements have not been previously operated at power levels greater than 1 watt.

was approximately uniform. The reactor was brought to a low, stable power level, and the position of the stainless steel regulating rod was measured both with and without the poison, the safety rod positions remaining unchanged. Six different amounts of poison were used, all with the safety rods at the same positions. The position of the regulating rod with no gold or lucite in the lattice corresponding to these safety rod settings was 18.5 cm. Finally, all the gold was removed from the lucite strips and they were inserted in the same positions which they had occupied when loaded with gold. With the safety rods at the same positions as previously, the regulating rod was inserted only 1.5 cm farther because of the presence of the lucite instead of water. A selsyn is used with each control rod to indicate on a dial the position of that rod relative to its fully inserted position for reactor control purposes. However, for a more accurate method of determining rod positions, pointers were installed on the tops of the rods of the lift magnets and the rod positions were measured directly. By this method, the safety rods could be restored to a previous position with an uncertainty of ± 0.05 cm. Uncertainties in the regulating rod positions were ± 0.5 cm.

The reactor cross section was computed as 5900 cm^2 by considering only the active portion of the lattice. Using a thermal-neutron absorption cross section for gold of 98 barns,[4] the change in reactivity

---

4. J. A. Harvey and D. J. Hughes, "Effect of Recent Cross Section Measurements on Pile Constants," BNL-221 (Jan. 26, 1953).

($\Delta k/k$) resulting from the insertion of a known amount of gold could be calculated from $\Delta\tau/\tau$. Since the presence of the gold should cause no appreciable change in the Fermi age, $\Delta\tau/\tau$ should be the same as $\Delta k/k$. The calibration curve for the regulating rod was then plotted as an integral curve showing the change in reactivity from the initial rod position of 17 cm (Fig. 6). It was necessary to extrapolate the upper portion of the curve above the measured points by assuming symmetry around the point at which the rod is half withdrawn from the lattice. This procedure indicated a total worth of approximately 1.2% $\Delta k/k$ for the regulating rod, which was much higher than had been expected.

Each of the boron carbide safety rods in Loading 32 was calibrated against the regulating rod. The reactor was brought to a stable power level of something less than 1 watt, was put on servo control, and the positions of all three rods were noted. Then the position of one of the safety rods was changed a known amount, the other safety rod remaining fixed, and the new position of the regulating rod necessary to maintain constant power was noted. This procedure was repeated until the entire available length of each rod had been covered. Since there was insufficient excess reactivity in the loading to permit the reactor to remain critical with only one safety rod and the regulating rod fully withdrawn, the calibration curves for both safety rods were extrapolated from about the 37-cm position to fully inserted by assuming symmetry around the midpoint of the rod. The calibration curves for these rods were

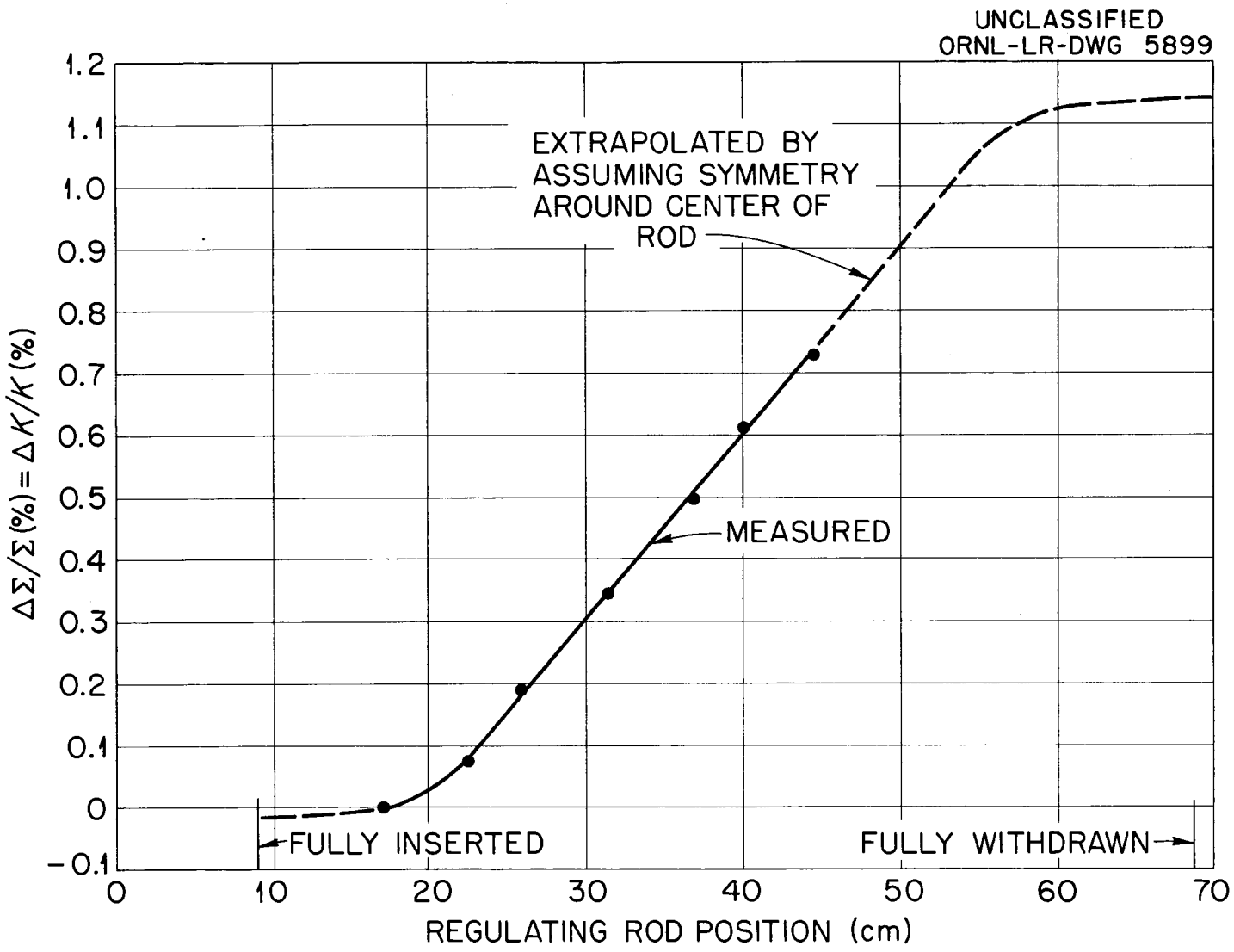

Fig. 6. Integral Curve for Stainless Steel Regulating Rod in BSR Loading 32 (Beryllium Oxide–Reflected)–Distributed Poison Calibration Method.

also plotted as integral curves to show the effect of insertion of the rod from the fully withdrawn position. Extrapolation of the curves to the fully inserted position indicated a total worth of about 3.8% $\Delta k/k$ for each safety rod in this loading (Fig. 7).

Inhour Method for Loadings 22A, 33, and 38

The usual inhour method was used to calibrate the cadmium-lead regulating rod in the water-reflected Loading 22A. The two cadmium-lead safety rods used in this loading were then calibrated in terms of the regulating rod. Each safety rod was worth $\sim$1.3% $\Delta k/k$ and the regulating rod was worth $\sim$0.6% $\Delta k/k$ over the last 12 in. of travel. The calibration of these rods was discussed in detail in an earlier report.[5]

Because the stainless steel regulating rod had shown an unexpectedly large effectiveness when calibrated by the distributed poison method in the beryllium oxide--reflected Loading 32, it was decided to calibrate this rod again using the inhour method in a water-reflected loading comparable to Loading 22A, which was a 5 by 6 array. The new loading (Loading 33, Fig. 4) was essentially a 5 by 6 array, but with two elements missing at the corners of the back (south) face. This difference in the number of elements required by Loadings 22A and 33 was necessitated by the use in Loading 33 of the new fuel elements which contained a minimum of residual lithium from the brazing flux.

The reactor was brought critical at a power level of about 10 w, was

---

5. R. G. Cochran et al., ORNL-1682, op. cit.

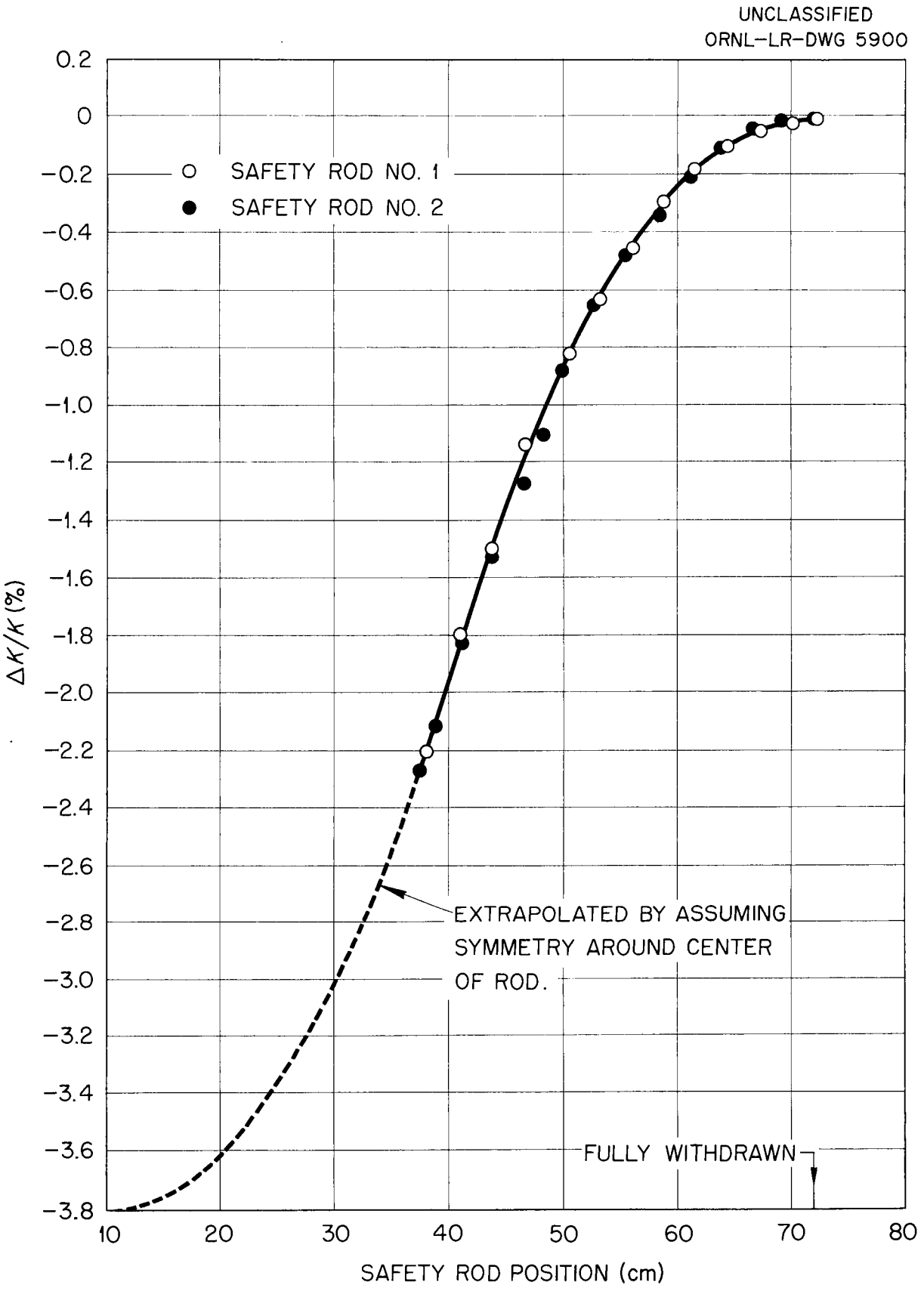

Fig. 7. Integral Curves for Boron Carbide Safety Rods in Loading 32 (Beryllium Oxide-Reflected).

allowed to stablize for at least 5 min, and the positions of all rods were noted. The regulating rod was then quickly withdrawn to a predetermined position (the safety rods were not moved), and the rate of increase of the flux level (the reactor period) between power levels of 100 w and 1 kw was determined. It was assumed that the effect of the transient terms on the reactor period would damp out between 10 and 100 w and that there would be no temperature effect at 1 kw. The period is related to the change in reactivity ($\Delta k/k$) by the inhour equation. The data is plotted in Fig. 8 as an integral curve. For this loading the stainless steel regulating rod had a worth of about 0.73% $\Delta k/k$, as compared with 1.2% in Loading 32.

The boron carbide safety rods of Loading 33 were calibrated by comparison with the regulating rod as described for Loading 32. Each one had an effectiveness of about 2.5% $\Delta k/k$ as compared with 3.8% in Loading 32. This data is shown in Fig. 9.

An inhour calibration of this same stainless steel regulating rod was carried out in a configuration partially reflected by beryllium oxide (Loading 38, Fig. 5). The same form of the inhour equation as for the bare thermal reactor was used; however, the validity of such a procedure is questionable. The results of this calibration are shown in Fig. 10. In this loading the regulating rod had an apparent effectiveness of about 0.5% $\Delta k/k$.

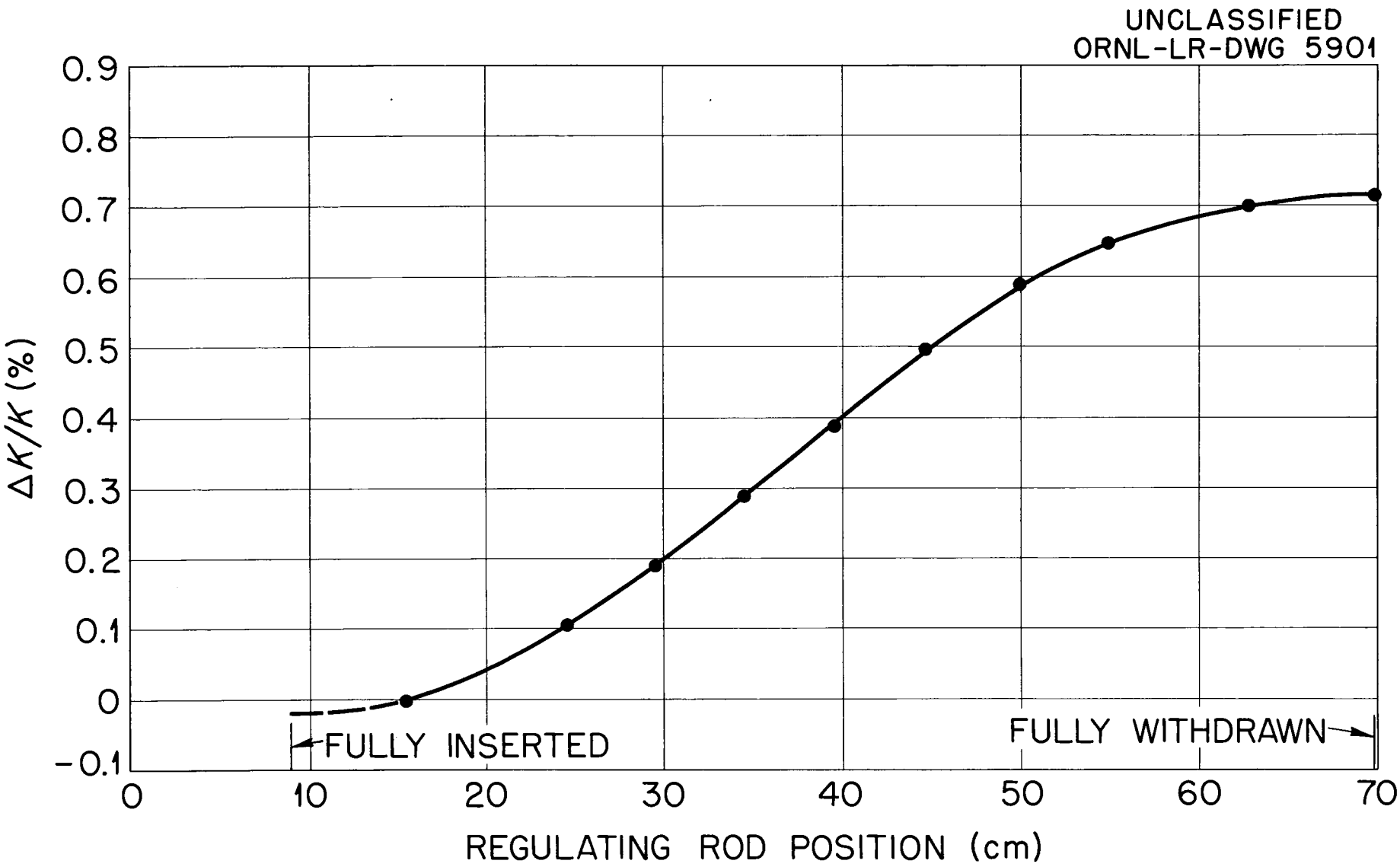

Fig. 8. Integral Curve for Stainless Steel Regulating Rod in BSR Loading 33 (Water Reflected) — Inhour Calibration Method.

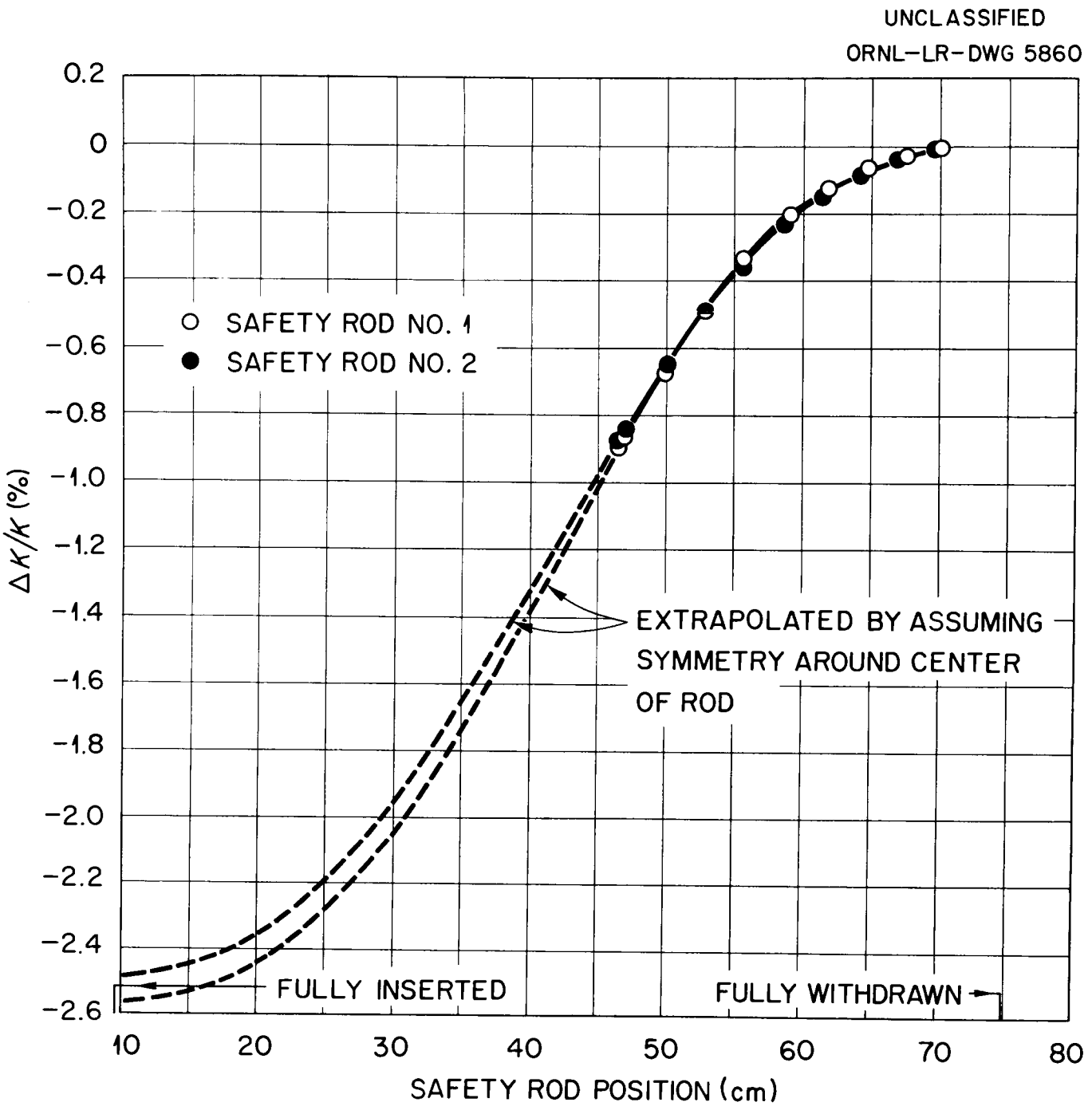

Fig. 9. Integral Curves for Boron Carbide Safety Rods in BSR Loading 33 (Water-Reflected)

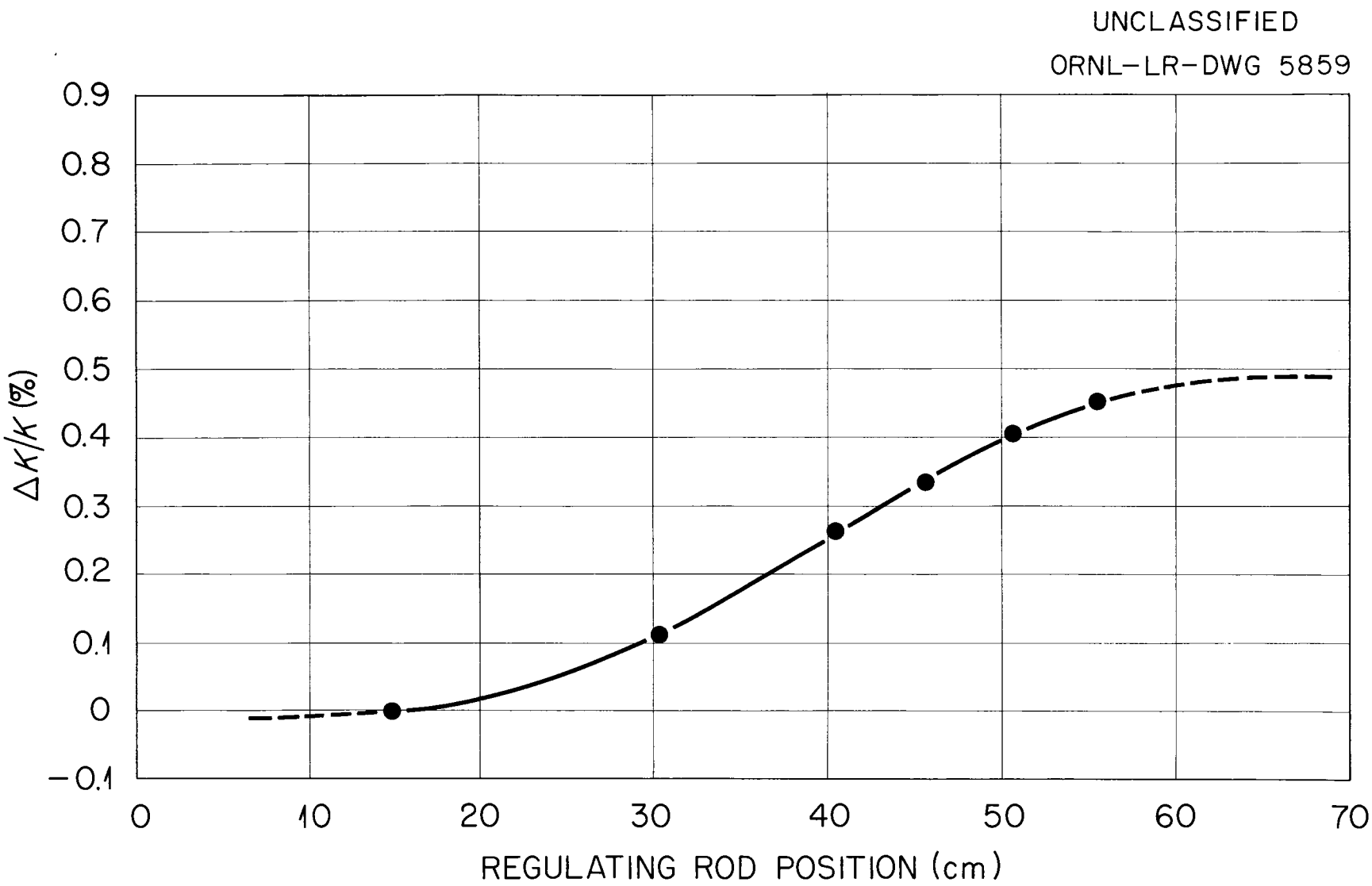

Fig. 10. Integral Curve for Stainless Steel Regulating Rod in BSR Loading 38 (Partially Beryllium Oxide-Reflected) Inhour Calibration Method.

Results of Calibrations

These results present some indication of the variation in effectiveness of a given rod, which is of course dependent upon the particular critical assembly in which it is used. A summary of the results obtained is given in Table 1.

Table 1

Effectiveness of Control Rods for Different Reactor Loadings

Rod	Reactivity Change (% $\Delta k/k$)			
	Loading 22A, H_2O-Reflected	Loading 32, BeO-Reflected	Loading 33, H_2O-Reflected	Loading 38, Partially BeO-Reflected
Cd-Pb Regulating Rod[a]	0.6[a]			
Cd-Pb Safety Rod[b]	1.3			
Stainless Steel Regulating Rod[c]		1.2	0.73	(0.5)
B_4C Safety Rod[d]		3.8	2.5	

a. An aluminum shell filled with a molten mixture containing 7 1/2 g of cadmium and the remainder lead. The effectiveness was measured over the last 12 in. of travel.

b. An aluminum shell filled with a molten mixture containing 17 1/2% cadmium.

c. An appropriately shaped cylinder of type 347 stainless steel with an 87-mil-thick wall.

d. An aluminum shell packed with boron carbide powder.

III. THE EFFECT OF BEAM HOLES ON REACTIVITY

Since air voids or ducts which are employed next to a reactor to create beam holes change the reactivity of the reactor, several tests have been performed at the BSF to determine the effect of specific ducts. The ducts used in these tests consisted of cylinders of various sizes. Each cylinder was either sealed after being filled with air or saturated boric acid solution or it was equipped with an air line so that pressure could be kept on it during the test. The ducts were positioned against the fuel of BSR Loading 22A (water-reflected loading) or against the beryllium oxide reflector of Loading 32.

Since the BSR is located in a pool of water with the top of the lattice approximately 17 ft below the surface, it was necessary to devise a method of remotely positioning each duct against the reactor so that it would be held rigidly and would be reasonably unlikely to escape while the test was being run. For this purpose, the pit in the large pool was filled with concrete blocks and ropes were run through the rings in the blocks to each side of the pool so that at least four ropes could be secured around the duct. With one exception, each duct was positioned against the reactor north face so that the axis of the duct coincided with the reactor centerline (Fig. 11). The reactor was then rolled away from the duct and brought to a low power level. The positions of all three rods were noted by actual measurement with a meter stick. The position of the regulating rod was initially (with reactor and duct separated) such that the power level could be

UNCLASSIFIED
ORNL-LR-DWG 5902

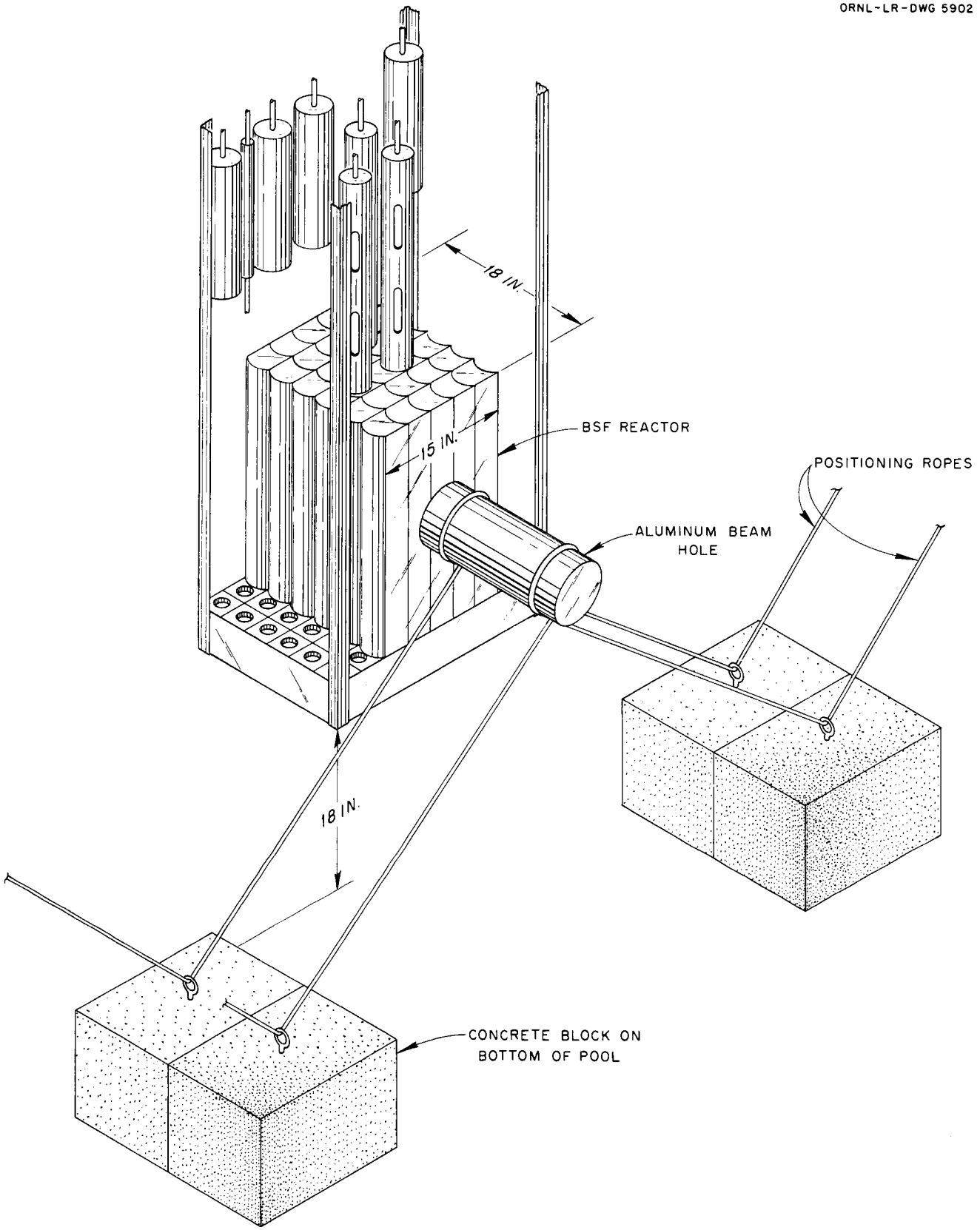

Fig. 11. Experimental Arrangement for Tests on the Effects of Beam Holes and Partial Reflectors Adjacent to the BSR.

maintained without moving the safety rods when the reactor and duct were brought together. The reactor was then cautiously rolled against the stationary duct, allowing the servo to maintain power level. The new position of the regulating rod was noted and the reactor was shut down. This procedure was repeated with each of the ducts. The data is recorded in Table 2 for both the water-reflected and the beryllium oxide-reflected loadings.

The change in reactivity due to the ducts was greater for the beryllium oxide--reflected loading than had been expected. The explanation may lie in an apparent inefficiency of the beryllium oxide reflector (see Section I, p 5). In any event, the major uncertainty in the experiment would appear to be in the condition of the beryllium oxide reflector elements. These are being recanned, but a simple rod calibration by the distributed poison method is no longer practical because of the large activity of the fuel elements.

The reactivity effect of the ducts may be related to their cross sectional area by the expression

$$\Delta k/k = CD^2$$

where D is the diameter of the duct in inches and C is a constant for a particular loading. Values of C for each duct are shown in Table 2. The results for the 6- and 8-in.-dia ducts are quite consistent, yielding an average value of C of 0.009 for a water-reflected reactor and 0.007 for a beryllium oxide--reflected reactor. The value of the

constants for the 17-1/2-in.-dia duct was low because this duct was larger than the reactor.

Table 2

BSR Reactivity Changes Caused by the Presence of Beam Holes

Description of Duct*		Reactivity Change (% Δk/k)		$C = \frac{\% \Delta k/k}{D^2}$	
O.D. (in.)	Length (in.)	Loading 22A, Water-Reflected	Loading 32, BeO-Reflected	Loading 22A, Water-Reflected	Loading 32, BeO-Reflected
17-3/4	36-3/4	-1.4[a]	-1.12[a]	0.004[b]	0.0035[b]
8-1/8	47-3/4	-0.55	-0.47	0.009	0.007
6	47-3/4	-0.36[c]	-0.25[c]	0.010	0.007
			-0.245[c,d]		
			-0.01[e]		
6	12		-0.26		0.007
			-0.10[f]		
4-1/4	44	-0.14[g]		0.007	

* All ducts were filled with air unless otherwise noted.

a. The cross-sectional area of this duct was larger than the active portion of the reactor lattice.

b. This low value was not unexpected because of the large size of the duct.

c. A weld on the end of this duct held it approximately 1/8 in. away from the reactor face.

d. Duct filled with borated water.

e. In this case the 1/4-in.-thick boral partial reflector described in Section IV was placed between the beryllium oxide reflector and the end of the duct. The reactivity change reported here is that obtained from the difference in the regulating rod position with only the boral sheet against the reflector and its position when the duct was placed against the boral.

f. The end of this duct was against the reflector elements in lattice positions 2 and 3.

g. This duct had a 1/8-in.-thick wall and a 1/2-in.-thick end, while the other beam holes had 1/16-in.-thick walls and ends.

IV. THE EFFECT OF PARTIAL REFLECTORS ON REACTIVITY

The change in the reactivity of the BSR caused by the presence of several partial reflectors was determined at the BSF. The reflectors consisted of a lead slab adjacent to the fuel of the water-reflected Loading 22A and of boral and graphite slabs adjacent to the beryllium oxide reflector of Loading 32. The graphite and lead slabs were mounted on concrete blocks in the bottom of the pool and the reactor was rolled cautiously against them for the necessary measurements. The boral sheet was hung from above, but the measurements were made in essentially the same way as in the case of the other reflectors. The experimental arrangement is shown in Fig. 11 and the results are given in Table 3.

Table 3

BSR Reactivity Changes Caused by the Presence of Partial Reflectors

Description of Partial Reflector[a]	Reactivity Change (% $\Delta k/k$	
	Loading 22A	Loading 32
1-7/8-in.-thick Lead Slab	+0.38	
1/4-in.-thick Boral Slab		-1.36[b]
1-ft-thick Graphite Slab		+0.68

a. All the reflectors extended well beyond the reactor face.

b. The boral sheet was held away from the bottom of the reactor face by the structure supporting the reactor itself.