[redacted]

ORNL-3272
C-44c – Nuclear Technology–
Reactor Engineering and Technology
M-3679 (25th ed. Rev.)

AEC RESEARCH AND DEVELOPMENT REPORT

CRITICAL MASS STUDIES: PART XI. CRITICAL PARAMETERS OF URANIUM-ALUMINUM ALLOY SLUGS

J. K. Fox
L. W. Gilley

OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

[redacted]

[redacted]

ORNL-3272

Copy No. ____

Contract No. W-7405-eng-26

Neutron Physics Division

CRITICAL MASS STUDIES: Part XI.
Critical Parameters of Uranium-Aluminum Alloy Slugs

J. K. Fox and L. W. Gilley

Date Issued

MAY 14 1962

[redacted]

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

[redacted]

ABSTRACT

Critical and near-critical experiments have been performed with cylindrical pieces of two alloys of 93%-U^{235}-enriched uranium and aluminum to establish safe practices in fabrication and in other procedures. In one set of experiments the uranium content of the alloy was 5.4 wt% and the diameter of the pieces was 1.015 in. The minimum critical number of 12-in.-long slugs in a single water-reflected and -moderated tier was 134; the minimum number in a double tier was about 165. Experiments with 8-ft-long, optimumly spaced rods gave the diameter of an infinitely high, unreflected cylindrical array as between 15 and 17.5 in. and as approximately 12 in. for a totally water-reflected cylindrical array.

The second alloy, which was studied in detail earlier, contained 7.6 wt% uranium and was made into cylinders 1.35 in. in diameter. The minimum number of 8-in.-long slugs which could be made critical in a square lattice was 101, arranged in two tiers, and this agreed with the earlier results. The minimum critical number in a similar hexagonal lattice was 100. A double tier of 1000 closely packed 8-in.-long slugs was subcritical when submerged in water. The diameter of an infinitely long, unreflected critical cylindrical array of optimumly spaced rods was between 15 and 17.5 in.; the diameter of a water-reflected cylindrical array was about 12 in. It was shown that randomly spaced slugs produce less source neutron multiplication than do lattices of the same over-all density.

[redacted]

TABLE OF CONTENTS

[redacted]

INTRODUCTION

Critical parameters affecting the safe storage and handling of 93%-U^{235}-enriched uranium-aluminum alloy slugs were previously given by Callihan et al.[1] These data have been extended to cover additional geometries of the same material and also to include data obtained with a similar alloy of lower uranium content. The alloy used previously and also in some of the tests reported here contains 7.6 wt% uranium and is referred to as "J" alloy. The new alloy contains 5.4 wt% uranium and is designated as "SRO" alloy.

The usual quantity of interest in these studies is the minimum number of slugs or rods required for criticality in various lattices and arrays, usually when completely immersed in water. A number of special experiments have been performed, however, to provide answers to specific questions posed by project personnel. Generally the critical mass was actually assembled; in a few cases, where the number of slugs available was insufficient, only values of source neutron multiplication were obtainable. These experiments were performed during the period 1952-1954.

EXPERIMENTAL MATERIALS AND APPARATUS

The gross properties of the materials used in these experiments are given in Table 1, while the general experimental arrangement is shown in Fig. 1. The plastic used for the support table and the spacers was Plexiglas (methyl methacrylate). The apparatus pictured was used for most of the slug experiments, with the magnetically supported cadmium blade shown in the photograph as the primary safety device. No control rod was used, fine control of reactivity being obtained readily by monitoring the rate of addition of water used for moderator and reflector. The water contained $<$ 10 ppm of total impurities.

Experiments utilizing the 8-ft-long rods described in Table 1 employed tall cylinders as containers. Figure 2 shows a diagram of such an apparatus. Three cylinders, 15, 17.5, and 20 in. in diameter, were used. The 15- and 20-in.-dia cylinders were of stainless steel; the 17.5-in.-dia cylinder was of Type 1100 aluminum.

---

1. Dixon Callihan et al., Critical Mass Studies, Part VI, ORNL Y-801 (Aug. 8, 1951).

Table 1. Properties of Experimental Materials

	SRO Slugs	J Slugs*	J Rods
Material	U-Al Alloy	U-Al Alloy	U-Al Alloy
Average U^{235} Enrichment, wt%	93	93	93
U^{235} Concentration	5.0 ± 0.25 wt%	7.1 wt%	7.1 wt%
Type Aluminum	3003	3003	3003
Diameter (in.)	$1.015 \begin{smallmatrix} + 0.000 \\ - 0.003 \end{smallmatrix}$	1.35	1.37
Length (in.)	12.00 ± 0.1	8.00	96
Weight (g)	446.4 ± 2.1	542.7	6520
Density (g/cm^3)	$2.816 \begin{smallmatrix} + 0.0004 \\ - 0.0000 \end{smallmatrix}$	~ 2.89	~ 2.89
Uranium Content (g)	23.96 ± 0.59	41.49	~ 498
U^{235} Content (g)	22.37 ± 0.06	38.71	~ 465

*This material is the same as that called "P-10 Slugs" by Callihan _et al._, _Critical Mass Studies, Part IV_, ORNL Y-801 (Aug. 8, 1951).

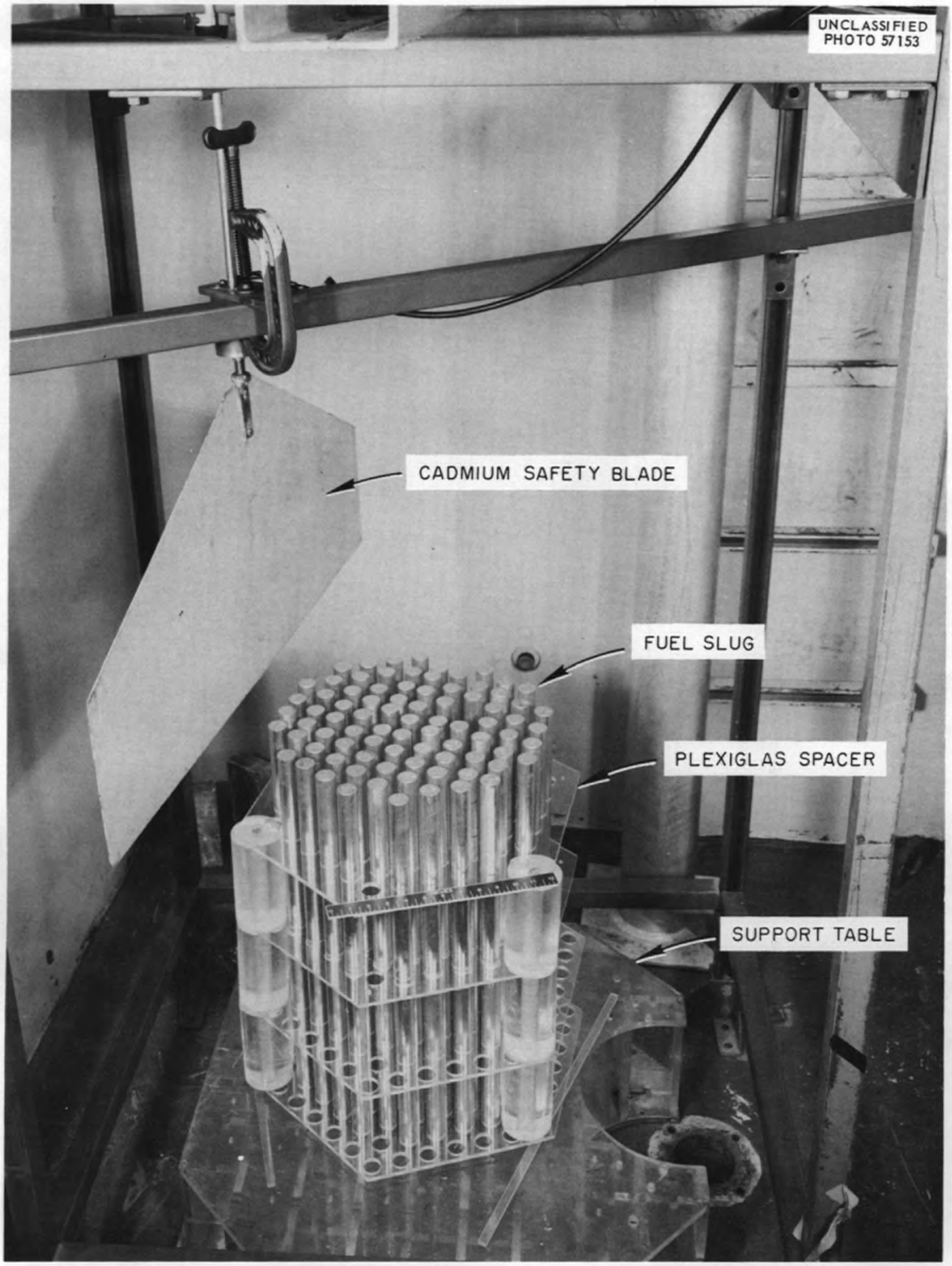

Fig. 1. Experimental Arrangement.

UNCLASSIFIED
ORNL-LR-DWG 39547

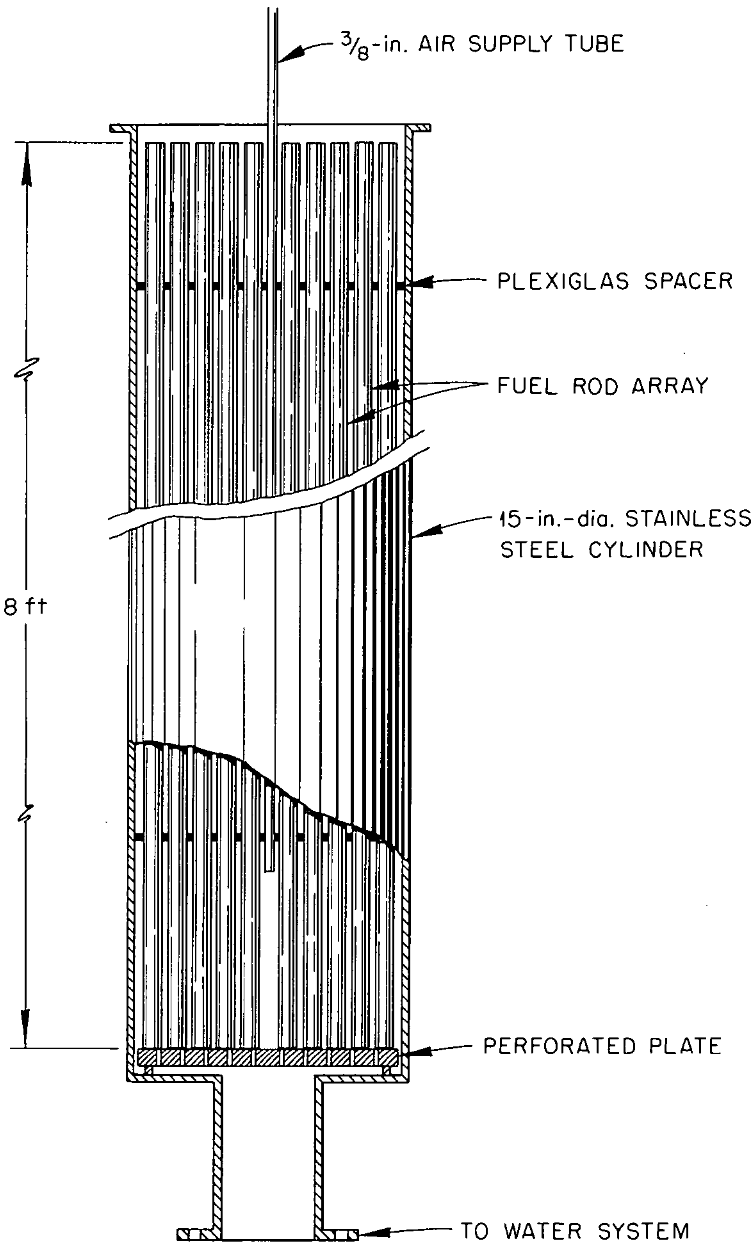

Fig. 2. Experimental Arrangement for SRO- and J-Rod Tests: Vertical Section Through 15-in.-dia Assembly.

Since use of an internally placed safety rod would have disturbed the symmetry of the fuel lattice, the primary safety device for the rod experiments was the displacement of water by air. A small tube, extending vertically into the center of the lattice to a point about 10 in. above the bottom of the cylinder, was connected to a source of compressed air through a valve operated by the scram system. Upon operation of the scram, water throughout the center of the array was displaced by air, thus quickly lowering the reactivity of the system. A 3-in. water dump valve, independently operated, served as a secondary safety mechanism.

A series of experimental arrays was studied to provide information for the design of a device, then under consideration, intended to evaluate the uniformity of mass-produced pieces of uranium-aluminum alloy. The device is called a Nuclear Test Gauge (NTG) and has been described by Parkinson et al.[2] It consists essentially of a latticed array of 24-in.-long, 1-in.-dia uranium-aluminum alloy rods with provision for insertion of standard and of test samples into the central region. The neutron multiplication observed is a comparative measure of the uranium content of the samples. The study reported here included determination of the most reactive lattice spacing and the corresponding critical number of pieces, a comparison of the reactivity value of central and peripheral units, and the reactivity of these central and peripheral units as a function of their displacement from the assembly in their axial direction. For these experiments the element of fuel consisted of two SRO slugs placed end-to-end in a type 3003 aluminum tube of 0.045 in. thickness. The general appearance of these arrays was similar to that of Fig. 1. An empty fuel tube, located in the second "ring" of elements from the center was intended to contain the source in the NTG.

All experiments utilized a neutron source attached to the end of an aluminum rod, which was inserted vertically between the elements of an array by a remotely operable drive mechanism.

In order to clarify the nomenclature used in describing the various experiments, Fig. 3 shows typical element arrangements. "Rounding" was

2. T. F. Parkinson et al., The Nuclear Test Gauge, DP-147 (June 1956) (Confidential).

UNCLASSIFIED
ORNL-LR-DWG 58124

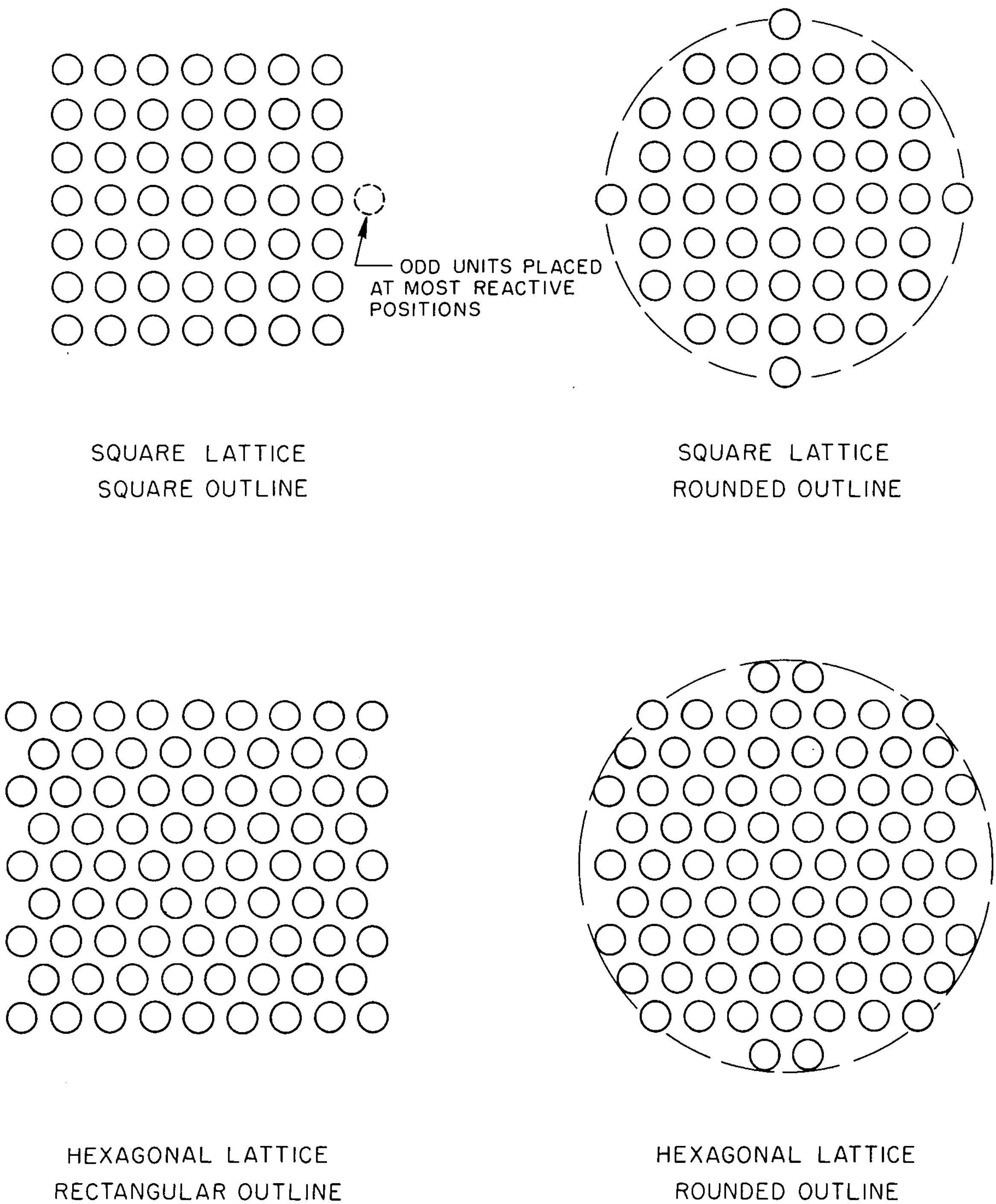

Fig. 3. Diagrams of Lattices and Outlines.

accomplished by moving corner elements to positions most nearly fitting a circular outline, without altering the chosen lattice spacing.

Instrumentation was conventional and included a period scram. A log-N amplifier was used for positive period measurements.

EXPERIMENTAL PROCEDURE

Fuel elements, whether rods or slugs, were assembled by hand in the absence of water. During this assembly instruments operated continuously to detect any neutron multiplication, although in no case was any appreciable multiplication observed. After the dry assembly of a specified array was completed, moderator and reflector water was added by remote control. Any modification desired in an assembly required the draining of the water before making changes.

EXPERIMENTAL RESULTS

Savannah River (SRO) Slugs

The first experiments with this material determined the effect of spacing, of lattice type, and of array outline upon the minimum number of slugs required for criticality. Slugs were arranged in both single and double tiers. The data appear in Fig. 4 and in Table 2. For uncanned slugs in square lattice and square outline, the minimum critical number was 142, with optimum center-to-center spacing of 1.45 in. Rounding the perimeter of this array reduced the minimum critical number to ~ 136 slugs. Data from hexagonal lattices gave a minimum critical number of 134 uncanned slugs, in a rounded array, with the center-to-center spacing optimized at 1.60 in. The effect of canning the slugs in aluminum, readily seen in Fig. 4, is to increase the minimum critical number to 152 in a hexagonal lattice with a rounded outline. The optimum center-to-center spacing was then ~ 1.63 in.

A part of the data of Table 2 has been replotted in Fig. 5, showing critical number of slugs as a function of the volume fraction of water in the assembly. It will be noted that the minima for square and hexagonal lattices both occur between 0.62 and 0.65 water volume fraction and that the critical number is relatively insensitive to the type of lattice.

UNCLASSIFIED
ORNL-LR-DWG 39548

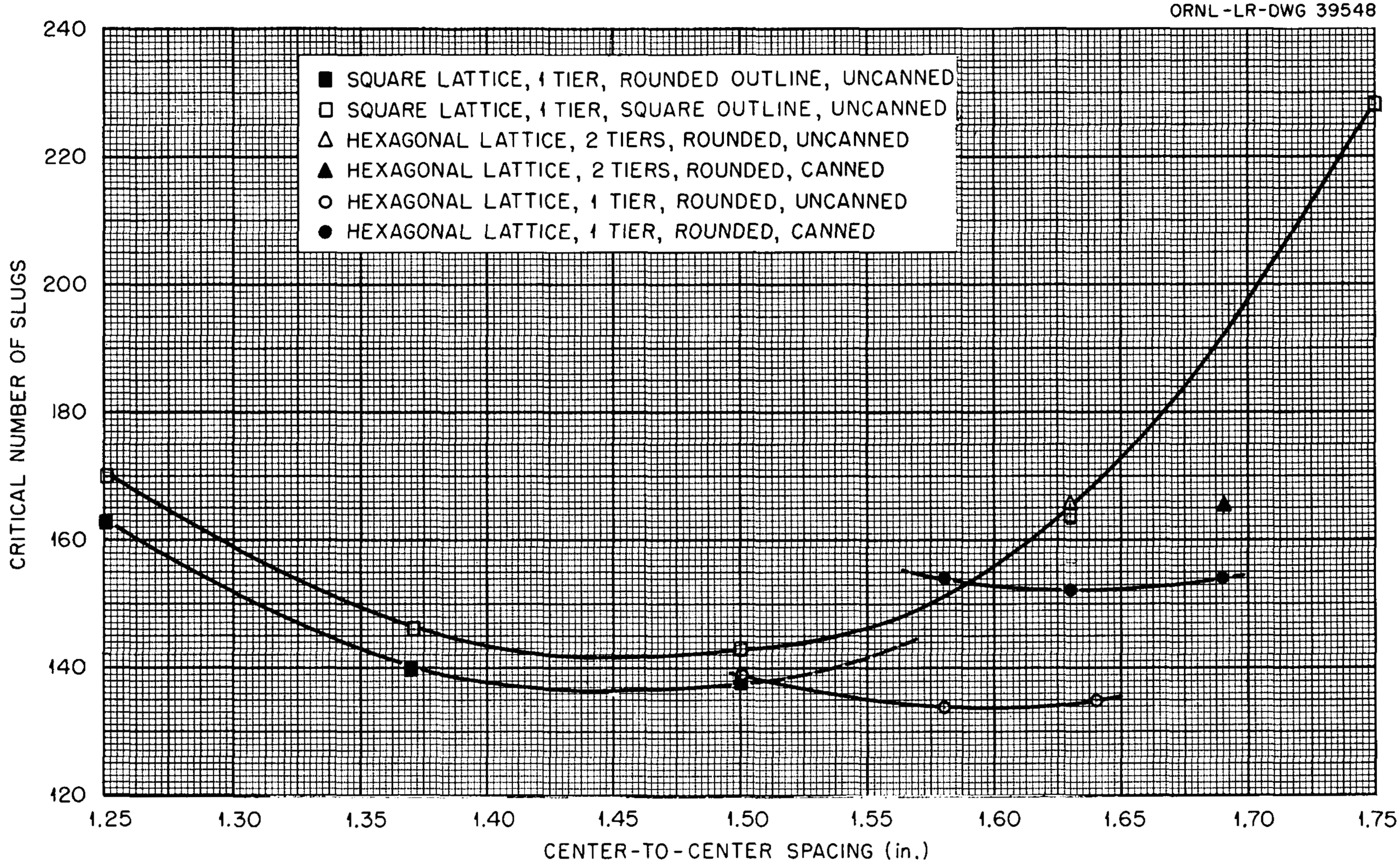

Fig. 4. Critical Number of SRO Slugs vs. Center-to-Center Spacing for Various Lattices.

Table 2. Critical Parameters of Water-Moderated and -Reflected SRO Slugs

Spacing, Center-to-Center (in.)	Water Volume Fraction	Array Outline[a]	Minimum Critical Number
Uncanned Slugs; Single-Tier Square Lattice			
1.25	0.500	Square	170
		Rounded	163
1.37	0.583	Square	146
		Rounded	140
1.50	0.652	Square	143
		Rounded	138
1.63	0.705	Square	164
1.75	0.745	Square	228
Uncanned Slugs; Single-Tier Hexagonal Lattice			
1.50	0.597	Rounded	139
1.58	0.638	Rounded	134
1.64	0.663	Rounded	135
Uncanned Slugs; Two-Tier Hexagonal Lattice			
1.63	0.656	Rounded	165
Canned Slugs; Single-Tier Hexagonal Lattice			
1.58		Rounded	154
1.63		Square	157
		Rounded	152
1.69		Rounded	154
Canned Slugs; Two-Tier Hexagonal Lattice			
1.69		Rounded	165

a. See Fig. 3

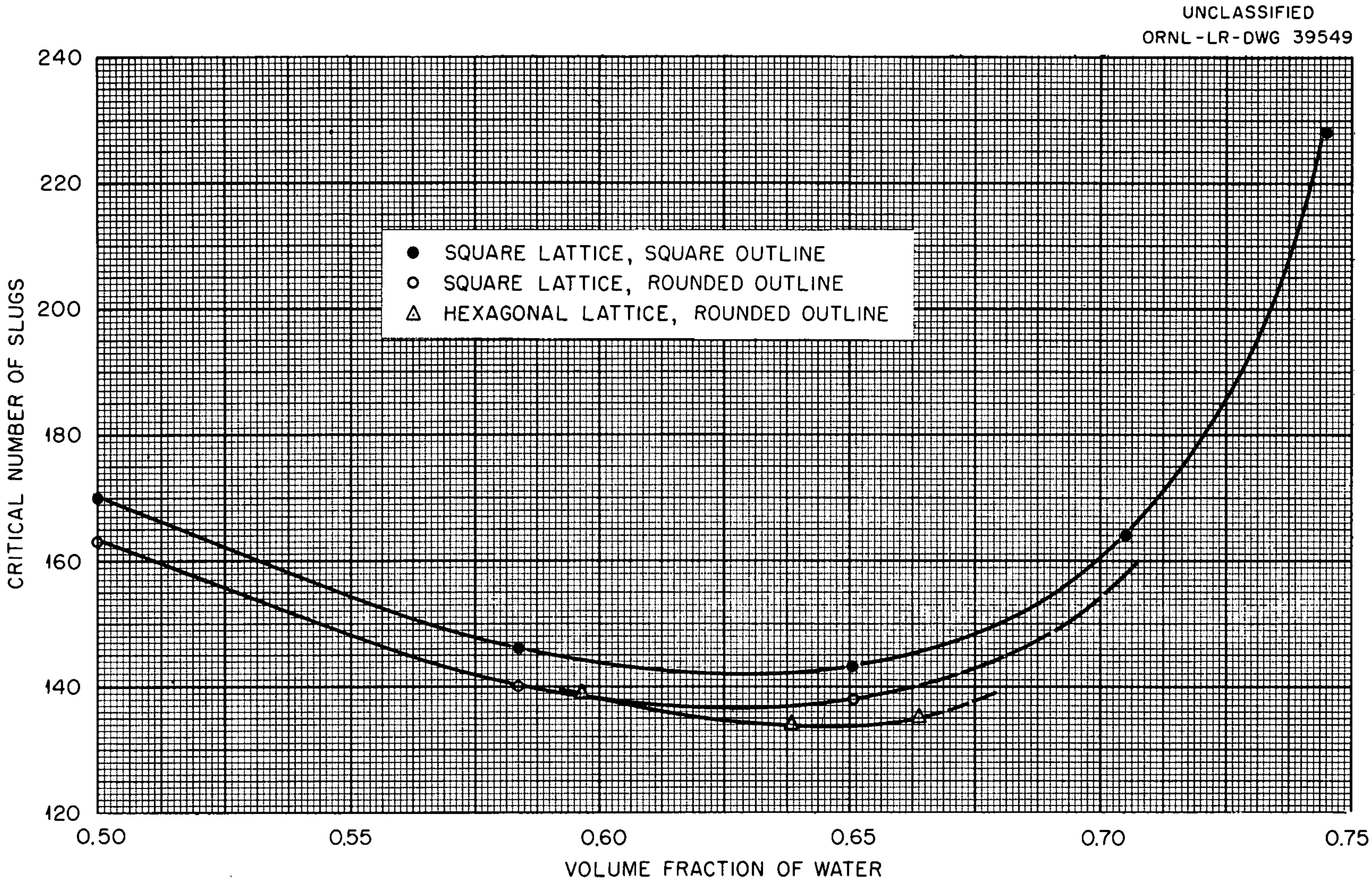

Fig. 5. Critical Number of Uncanned SRO Slugs in Single Tier vs. Volume Fraction of Water for Various Lattices.

Mockup of Savannah River Nuclear Test Gauge

Elements used for experimentally mocking up the Savannah River NTG were of two kinds. For the first experiments, canned elements were simulated by pushing two uncanned slugs into 0.045-in.-wall type 3003 aluminum tubing; later experiments used SRO slugs canned in 0.045-in.-thick type 3003 aluminum. From the data presented as Table 3 and Fig. 6, it is evident that results from similar experiments do not agree, the discrepancy amounting to about 14 slugs. This difference has not been satisfactorily explained. It is possible that the uncanned slugs and the canned SRO slugs did not have the same U^{235} content, but this was not determined by analyses. Repetition of the canned-slug experiments, using other slugs from the same lot, showed essential reproducibility. The difference in the aluminum cladding of the two types of elements is not believed to be significant.

The relative worth of center elements versus peripheral elements in the above array was evaluated in a series of experiments in which 1, 4, and 7 of the central elements were replaced by aluminum rods, with the elements optimumly spaced. The data (lines 5-7 of Table 3) show that the ratio of fuel removed from the center to fuel added on the perimeter decreases with each step. Removal of one two-slug element from the center required the addition of 5 slugs at the outside, while 7 elements (14 slugs) at the center were equivalent to 57 slugs on the perimeter.

The relative worth of center fuel versus peripheral fuel was independently evaluated in another series of experiments using the same lattice. In this series a fuel element, either central or peripheral, was vertically displaced in successive steps. At each displacement, the system was made critical by addition of elements and/or by a small adjustment in the thickness of the top reflector. The specific reactivity, in cents per inch, associated with these displacements of both central and peripheral elements was determined from the period resulting from the displacement. These data are presented as Table 4. Element worth as a function of position is plotted in Fig. 7 where the position for each data point is located at the center of travel of the element corresponding to a given period.

Table 3. Critical Parameters from Mockup of Savannah River Nuclear Test Gauge

Spacing, Center-to-Center (in.)	Configuration	Minimum Critical Number of Slugs[a]
2 SRO Slugs in 0.045-in.-wall Type 3003 Aluminum Tube		
1.50	Clean critical, 1 vacant tube in second ring from center.[b]	199
1.63		183
1.69		182
1.75		183
1.69	As above except center tube replaced by aluminum rod	187
1.69	As above except 4 center tubes replaced by aluminum rods	210
1.69	As above except 7 center tubes replaced by aluminum rods	239
1.69	Original configuration, with 90 1-in.-dia, 3-in.-long Plexiglas rods displacing water reflector on top of slugs	181
1.69	Original configuration, lattice distorted by increasing space between second and third rows either side of center to 1.84 in. center-to-center	183
2 SRO Slugs, Individually Canned in 0.045-in.-Thick Type 3003 Aluminum		
1.69	Clean critical, 1 lattice vacancy in second ring from center[b]	168
1.69	Same, using different slugs	167

a. The precision of these measurements is estimated at ±0.5 slug.
b. For source.

UNCLASSIFIED
ORNL-LR-DWG 39550

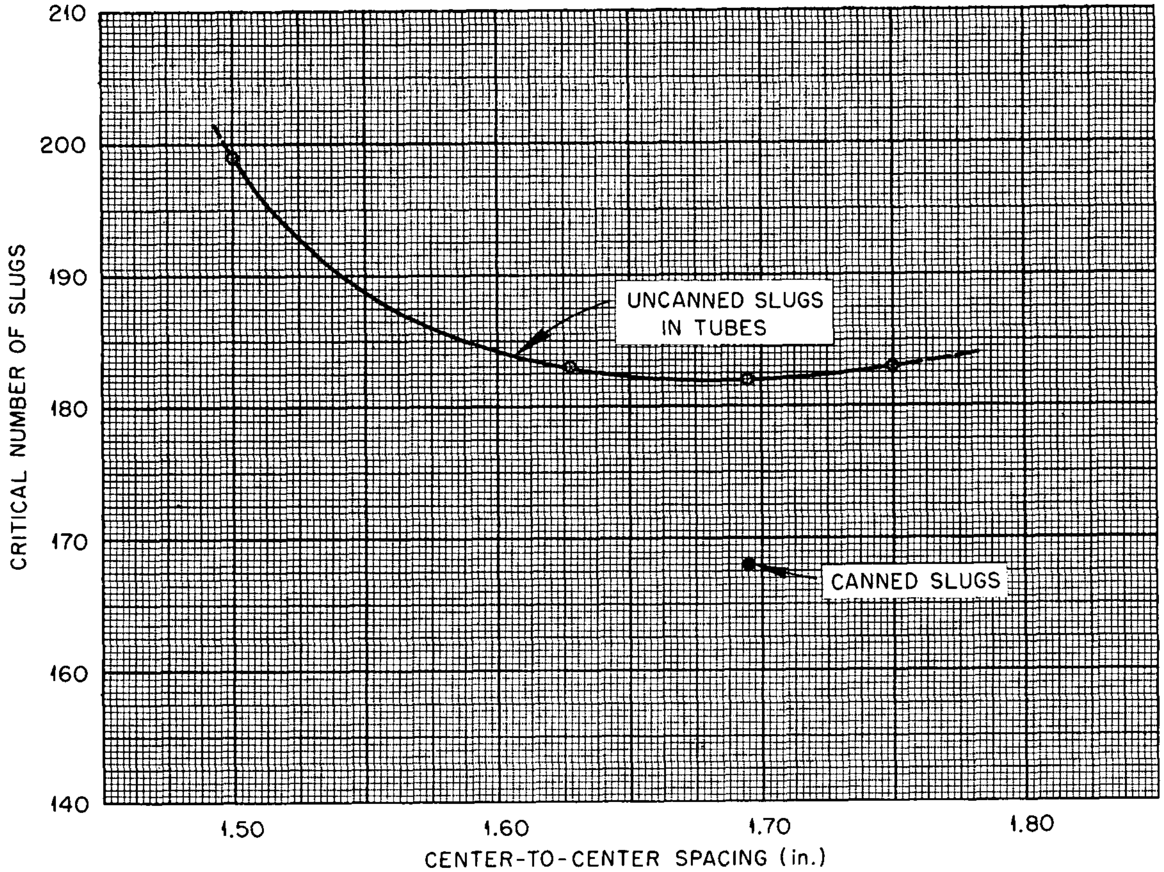

Fig. 6. Critical Number of Slugs in SRO Test Facility Mockup (Hexagonal Lattice) vs. Center-to-Center Spacing.

Table 4. Reactivity Measurements for Evaluation of Relative Value of Central Fuel Versus Peripheral Fuel

Moveable Fuel Element Position[a] At Critical (in.)	Moveable Fuel Element Position[a] For Positive Period (in.)	Stable Period (sec)	Number of Stationary Slugs in Array	Thickness of Top Water Reflector (in.)	Fuel Element Reactivity Worth (cents/in.)
Moveable Fuel Element in Center					
21.00	18.90	190	190	2.56	2.77
18.00	16.65	192	190	2.05	4.28
15.00	13.25	109	188	2.24	5.27
12.00	10.50	124	186	~ 2.4	5.52
9.00	7.00	105	186	1.81	4.77
6.00	3.50	138	184	2.01	3.05
Moveable Fuel Element on Periphery					
21.00	16.1	190	184	3.27	1.19
18.00	14.2	179	184	2.83	1.61
15.00	11.3	144	184	2.40	1.98
12.00	8.0	140	184	2.13	1.88
9.00	4.5	185	182	4.17	1.32
6.00	1.1	381	182	2.83	0.64

a. Distance above fully inserted position.

UNCLASSIFIED
ORNL-LR-DWG 39551

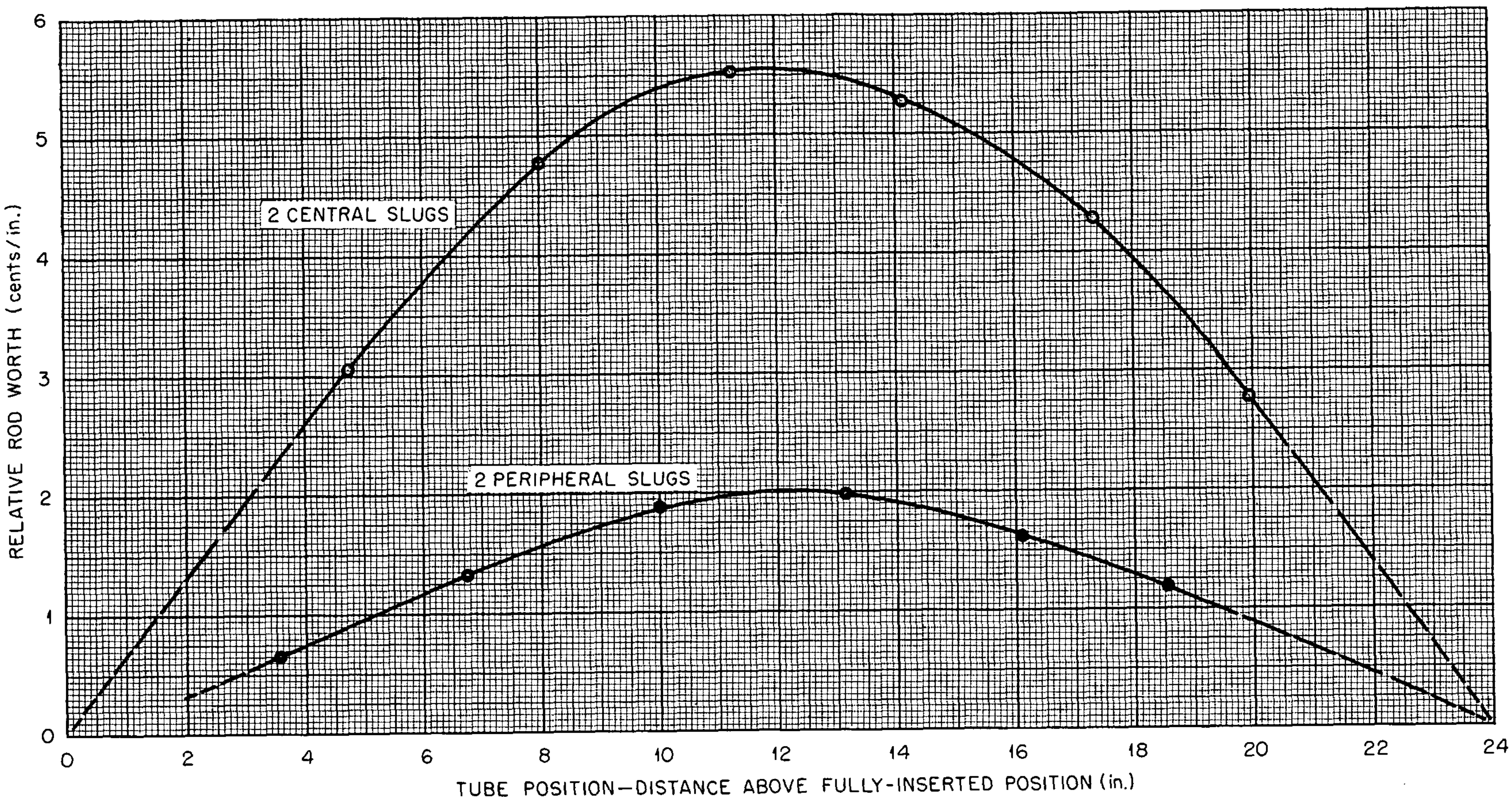

Fig. 7. Reactivity vs. Fuel Tube Position (Distance Above Fully Inserted Position) for SRO Slugs in Central or Peripheral Locations.

From the curves of Fig. 7, the ratio of fuel worth from center to perimeter is about 2.7 to 1. This agrees fairly well with the value obtained by the previously described method.

Returning to the data of Table 3, the results of two additional experiments are also shown. The first involved the replacement of a portion of the top reflector water by Plexiglas. In particular, when the fuel elements were topped by 1-in.-dia, 3-in.-long Plexiglas rods the number of slugs required for criticality was reduced by about one which may not be significant because of the precision of the measurements.

A second experiment measured the effect of increasing the space between the second and third rows of elements either side of center to about 1.84 in. center-to-center. Such a distortion might be desired to allow insertion of safety blades, and was found to require the addition of between one and two slugs to restore criticality.

SRO- and J-Alloy Rods

A series of experiments utilizing both the SRO- and the J-alloy, in 8-ft-long rods, was performed in configurations similar to that shown in Fig. 2. The data are given in Table 5. The rods were spaced in hexagonal lattices inside 15-, 17.5-, and 20-in.-dia cylinders that could be remotely filled with water. The cylinders were unreflected. Although none of the arrays of J-alloy rods within the 15-in.-dia cylinder were critical, the neutron multiplications indicate that the optimum spacing for such rods was 1.84 in., center-to-center. It will be noted that the arrays completely filled the containing cylinder in each experiment. When the J-alloy rods were assembled within a 20-in.-dia cylinder, criticality was achieved with 39 rods spaced 1.87 in. center-to-center, thus forming a 13-in.-dia array with an annular water reflector 3-1/2 in. thick.

The importance of reflection was again demonstrated in the experiments with the SRO rods. A total of 86 SRO rods, spaced 1.5 in. center-to-center and forming a 15-in.-dia array within a 15-in.-dia cylinder, was not critical. When the assembly was constructed within the 17.5-in.-dia cylinder, however, an array of 78 rods, spaced 1.5 in. center-to-

Table 5. Arrays of 8-ft-long J- or SRO-Alloy Rods as Hexagonal Lattices in Water-Filled Cylinders

Cylinder Diameter (in.)	Approximate Array Diameter (in.)	Center-to-Center Spacing (in.)	Number of Rods in Array	Maximum Neutron Multiplication	Water Reflector[a] Thickness (in.)
		Array of J-Alloy Rods			
15	15	1.37	96	1.3	0
15	15	1.77	55	2.3	0
15	15	1.84	55	3.6	0
15	15	1.97	43	3.0	0
20	13	1.87	39	Critical	~ 3.5
		Arrays of SRO-Alloy Rods			
15	15	1.5	86	6	0
17.5	~ 13.5	1.5	78	Critical	~ 2.0
20	~ 13	1.5	70	Critical	~ 3.5

a. No reflector external to the cylinders was used; the reflector thicknesses given are the thickness of water from edge of the array to the cylinder wall.

center was critical. The diameter of this array was approximately 13-1/2 in., thus resulting in a 2-in.-thick annular water reflector. The experiment was performed by filling the cylinder to capacity with rods (a total of 109), then removing rods uniformly from the periphery and noting the height of water needed for criticality. Successive data points are plotted in Fig. 8, showing water height at critical versus number of rods in array. The critical height was insensitive to the number of rods in arrays greater than about 15.5 in. in diameter (95 rods), showing that the exterior 1.0-in. of water alone, as reflector, was worth about as much in reactivity as the lattice of fuel and water previously filling that space. In the 20-in.-dia cylinder, it was found that an 13-in.-dia array of only 70 rods, having an annular reflector about 3-1/2 in. thick, was critical when completely flooded.

From the above data it may be concluded that, using optimum spacing, the diameter of a bare, infinite cylinder of either SRO- or J-alloy rods is between 15 and 17.5 in. If the infinite cylinder is water-reflected, its diameter is reduced to about 12 in.

Extension of J-Alloy Slug Data

Although the original work with J-alloy slugs was done with square lattices, most of the present experiments utilized hexagonal lattices to complement the previous data. As a check on the agreement of the two programs, one experiment was performed with a square, two-tier lattice and the optimum separation of 1.98 in., center-to-center. The results, 103 slugs for a critical square array and 101 slugs for a rounded critical array, agreed exactly with the data given by Callihan *et al.*[1]

Data from the J-alloy slug experiments are shown in Table 6 and a portion is plotted in Fig. 9 as critical number of slugs versus center-to-center spacing. The optimum spacing is apparently about 2.16 in., center-to-center, for a hexagonal, two-tier lattice. For the square lattice this value was 1.98 in., the difference being due largely to the lesser amount of water moderator present in the hexagonal lattice at a given spacing.

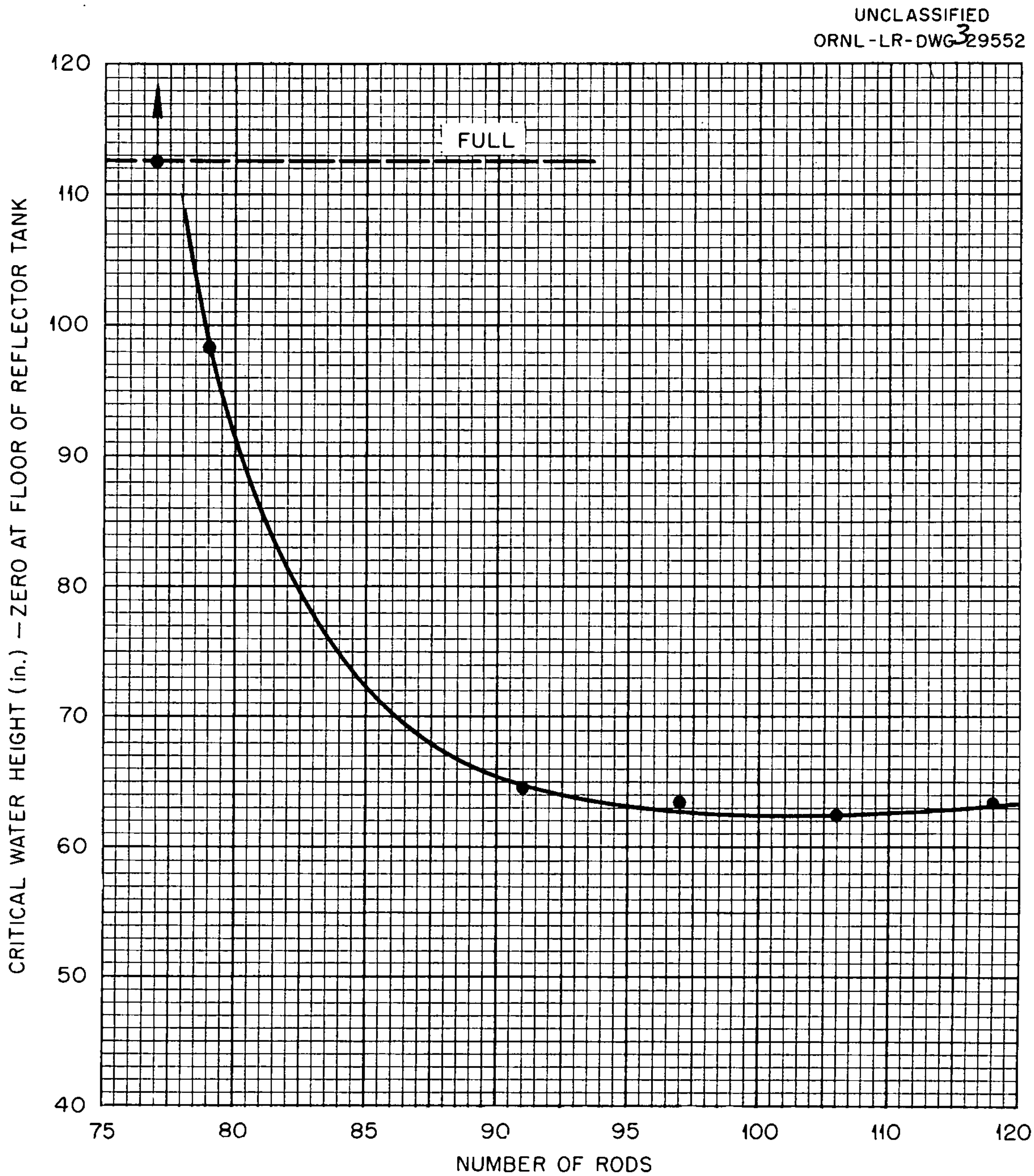

Fig. 8. Critical Water Height vs. Number of Rods in Lattice. SRO Rods in 17.5-in.-dia cylinder, hexagonal lattice, 1.5-in. center-to-center.

Table 6. Miscellaneous Experiments Using J-Alloy Slugs; Water-Moderated Arrays

Center-to-Center Spacing (in.)	Outline of Array	Minimum Critical Number of Slugs
Two-Tier Square Lattice, Reflected		
1.98	Square	103
	Rounded	101
2.10	Square	163[a]
One-Tier Hexagonal Lattice, Reflected		
1.35	Rounded	> 1000
Two-Tier Hexagonal Lattice, Reflected		
1.35	Rounded	> 1000
1.85	Rounded	122
1.95	Rounded	111
2.10	Rounded	100
2.22	Rounded	101
Random Array, Unreflected		
Random	15-in.-dia Cylinder Container	> 600[b]

a. Moderator was 53% wood.
b. 15-in.-dia tank filled to a height of 92 in. Maximum source neutron multiplication was 1.4.

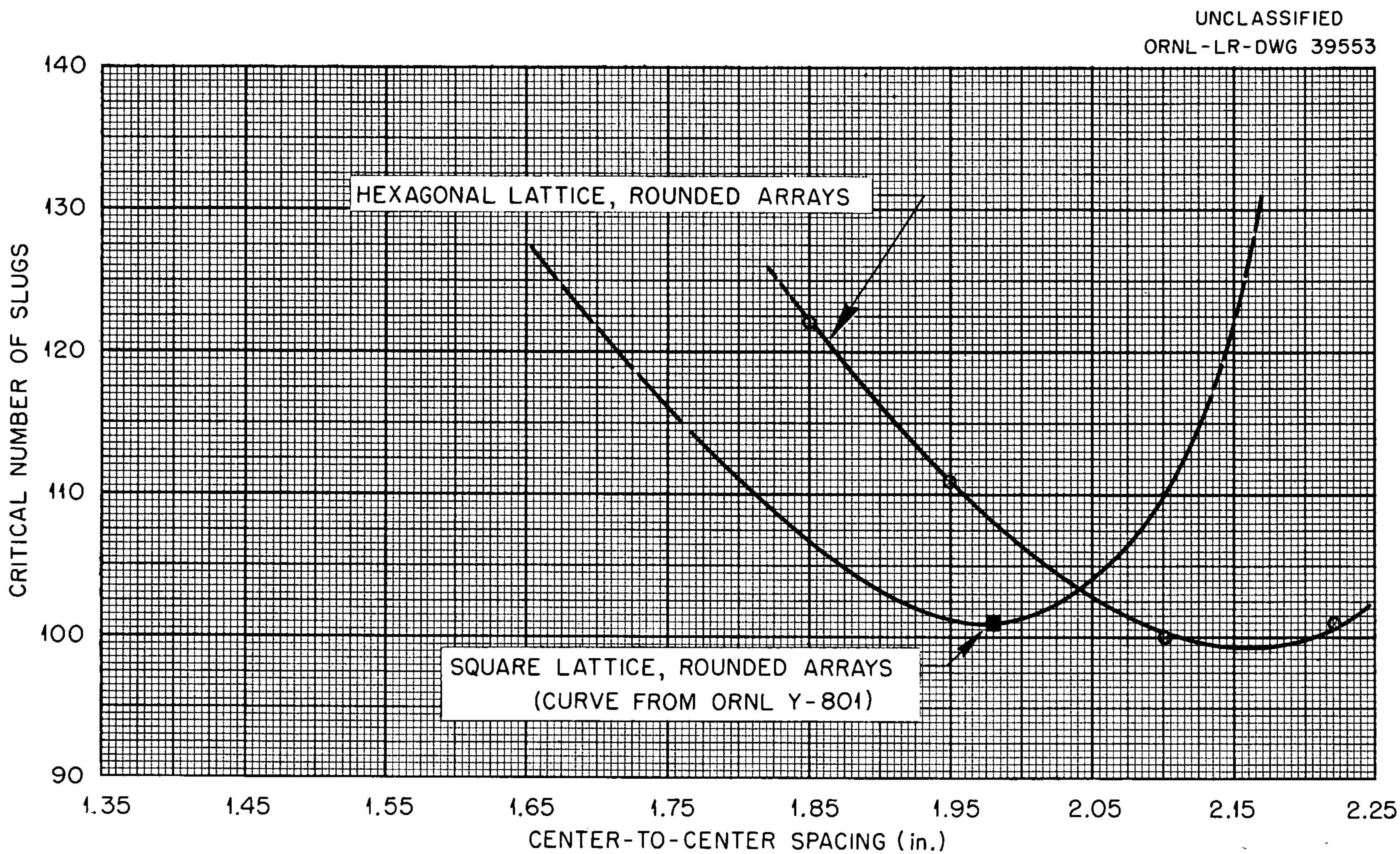

Fig. 9. Critical Number of J-Alloy Slugs vs. Lattice Spacing for 2-Tier Arrays.

A two-tier, hexagonal lattice of closely packed slugs containing 1000 units in a rounded array was subcritical when flooded with water. Extrapolation of the reciprocal multiplication curves for this array indicated a minimum critical number of more than 1200 slugs, but insufficient data are available to establish a firm conclusion.

An experiment was performed using a random array of slugs in a 15-in.-dia unreflected cylinder to compare its reactivity with that of uniformly spaced slugs at the same moderation. J-alloy slugs were tossed into the cylinder at random. A total of 600 slugs filled the cylinder to a height of 92 in. This number of slugs was then equivalent, in terms of slug volume fraction, to a uniform, hexagonally latticed array of J-alloy rods spaced 2.0 in. center-to-center, neglecting edge effects. The maximum multiplication by a uniform lattice of approximately this spacing was 3.0 (see Table 5), while the random array of slugs produced only a multiplication of 1.4, only slightly higher than the value, 1.3, observed with the tightly spaced, less moderated rods listed in Table 5. The uniformly spaced array is, therefore, apparently more reactive than a similar random array.

In conjunction with the two-tier, square lattice experiments, the effect of substituting wood (nominally about 49% carbon, 44% oxygen, 6% hydrogen, and 1% ash) for 53% of the water moderator was evaluated. The center-to-center slug spacing was 2.10 in. The number of slugs required for criticality was 163, whereas the value for 100% water moderation, from previous work, was 110.

Special Experiments with SRO Slugs

A number of experiments was done with SRO slugs in order to give answers to specific storage and handling problems. Data from these measurements are grouped for convenient reference in Table 7. The results of the experiments are as follows:

1. Two experiments were performed to investigate the effect of slots in arrays at optimum spacing. The 90-deg cross slots, one 1-3/4 and the other 1-3/8 in. wide through the center, almost doubled the number of slugs required for criticality.

Table 7. Miscellaneous Special Experiments with SRO Slugs

Configuration	Slug Spacing Center-to-Center (in.)	Minimum Critical Number
Experiments Using Canned Slugs		
One-tier, hexagonal lattice, 28-in.-wide by 38-in.-long rectangular array; 1-3/8 in. slot lengthwise through center of array	1.63	258 ± 1
One-tier, hexagonal lattice, square array with crossed slots through center; 1 slot 1-3/4 in. wide; other slot 1-3/8 in. wide	1.63	294 ± 2
One-tier, closely packed hexagonal lattice, rounded outline, 624 slugs, flooded	Contact	Not Critical[a]
76 slugs in one-tier hexagonal lattice plus 548 slugs in closely packed ring	1.63 / Contact	624 (total)
85 slugs in one-tier hexagonal lattice plus 258 slugs in closely packed ring	1.63 / Contact	343 (total)
Four Savannah River tote baskets, 120 slugs each, stacked in two tiers; small multiplication, flooded	b	Not Critical
Four Savannah River tote baskets, slugs optimumly spaced; total of 245 slugs stacked in two tiers	1.63	Not Critical
Experiments Using Uncanned Slugs		
One-tier, square lattice, rows of slugs in contact, rows 0.5 in. apart in a rectangular arrangement of 8 rows		338 ± 2

a. Low multiplication when flooded.
b. See text for description of stacking.

2. The closely packed array of the 624 slugs available gave only a small source neutron multiplication when flooded.

3. Two experiments using an optimumly spaced center region and a closely packed outer ring were performed in an effort to get a better idea of the effect of closely packed slugs on the reactivity. It will be noted that a change of 9 slugs in the central, spaced region was equivalent to a change of 290 in the number of closely packed slugs in the outer region.

4. The Savannah River tote baskets, proposed for routine shipment of slugs, which were used in two experiments, had inside dimensions of 9-1/2 by 12-1/2 in. and were 16 in. high. In one case the slugs were laid in horizontal rows with adjacent layers separated by 0.080-in.-thick plastic spacers. The basket capacity then was 120 slugs and represents the proposed normal loading. In the other experiment, the baskets were filled with slugs held in a hexagonal lattice at optimum spacing (1.6 in. center-to-center) by plastic plates. Neither of the basket experiments was critical.

5. In one experiment testing the effect of nonuniform spacing of slugs in an array, slugs were placed in contact in rows and the rows were separated 0.50 in.

[redacted]

ORNL-3272
C-44c — Nuclear Technology—Reactor Engineering and Technology

INTERNAL DISTRIBUTION

1. C. E. Larson
2. Biology Library
3-4. Central Research Library
5. Reactor Division Library
6. ORNL - Y-12 Technical Library, Document Reference Section
7-41. Laboratory Records Department
42. Laboratory Records, ORNL R.C.
43. A. M. Weinberg
44. J. A. Swartout
45. R. G. Jordan (Y-12)
46. J. P. Murray (K-25)
47. W. H. Jordan
48. E. P. Blizard
49. M. J. Skinner
50. J. E. Cunningham
51. C. D. Cagle
52. D. A. Gardiner
53. P. R. Kasten
54. A. M. Perry
55-57. A. D. Callihan
58. J. K. Fox
59. L. W. Gilley
60. L. B. Holland
61. W. E. Kinney
62. D. W. Magnuson
63. F. C. Maienschein
64. J. T. Mihalczo
65. F. J. Muckenthaler
66. J. T. Thomas
67. P. F. Gast (consultant)
68. R. A. Charpie (consultant)
69. Gale Young (consultant)
70. R. F. Taschek (consultant)
71. T. J. Thompson (consultant)

EXTERNAL DISTRIBUTION

72. H. K. Clark, duPont Company, Aiken
73. D. F. Cronin, National Lead Company of Ohio
74. A. J. Mallett, Union Carbide Nuclear Company (ORGDP)
75-76. W. B. Lewis and Don Reid, Phillips Petroleum Company
77. O. C. Kolar, University of California, Livermore
78. H. C. Paxton, Los Alamos Scientific Laboratory
79-281. Given distribution as shown in M-3679 (25th ed. Rev.) under Nuclear Technology - Reactor Engineering and Technology category

[redacted]