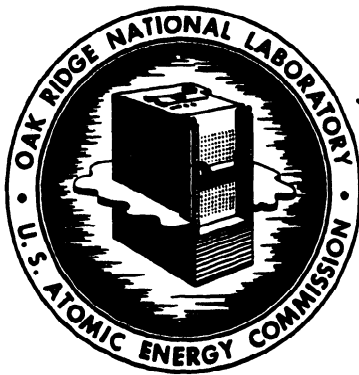**J. K. FOX AND L. W. GILLEY, "CRITICAL EXPERIMENTS WITH ARRAYS OF ORR AND BSR FUEL ELEMENTS," IN NEUTRON PHYSICS DIVISION ANNUAL PROGRESS REPORT FOR PERIOD ENDING SEPTEMBER 1, 1958," OAK RIDGE NATIONAL LABORATORY REPORT ORNL-2609 (OCTOBER 1958), PP. 34-36.**

NEUTRON PHYSICS DIVISION

ANNUAL PROGRESS REPORT

FOR PERIOD ENDING SEPTEMBER 1, 1958

OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
for the
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NEUTRON PHYSICS DIVISION ANNUAL PROGRESS REPORT

for Period Ending September 1, 1958

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3.4. CRITICAL EXPERIMENTS WITH ARRAYS OF ORR AND BSR FUEL ELEMENTS

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The increasing number of pool-type reactors being constructed throughout this and other countries has emphasized the need for defining the nuclear parameters which will assure the safe handling and storage of the fuel elements for these reactors. The important parameter to establish is the maximum number of fuel elements which will remain subcritical when arranged in patterns appropriate to the specific requirements. Although some data on square arrays are available from experiments performed with the Bulk Shielding Reactor, they are too limited in scope for general application. A number of experiments were therefore performed at the Critical Experiments Facility to determine critical lattices of this type of element.

Elements were available for these experiments from the inventories of the Oak Ridge Research Reactor and the Bulk Shielding Reactor. They contained uranium enriched to 93.2% in U^{235} and varied in total U^{235} content as follows:

1. 24 ORR elements, each containing 200 g of U^{235} (18 of these elements were received near the end of the experiments),

2. 28 ORR elements, each containing 168 g of U^{235},

3. 28 ORR elements, each containing 140 g of U^{235},

4. 70 BSF elements, each containing 135–140 g of U^{235},

5. 8 BSF elements, each containing 31–109 g of U^{235}.

The heavier loaded elements are always of the most interest for experiments of this type, but unfortunately only a few 200-g elements were available at the beginning of this series. As a result, the experiments largely consisted of various arrangements of 168-g elements. They were first arranged vertically in approximately square arrays, one element high, in water, and the spacing between elements was varied. The results are shown in Table 3.4.1 and Fig. 3.4.1 in terms of the critical number of fuel elements as a function of the distance between locating bosses. (The locating bosses are mounted on the end boxes of the elements and extend laterally on all four sides.) These distances can be converted to fuel-to-fuel

spacings by adding 0.44 in. to the distances between bosses parallel to the fuel plates and 0.164 in. to the distances between bosses perpendicular to the plates.

Because of the limited inventory of 168-g elements it became necessary to combine them with elements having other loadings for the larger spacings between elements. For the 1-in. spacing, for example, three 140-g elements were added on the edge of an array of twenty-eight 168-g elements. For the $1\frac{1}{4}$-in. spacing, twenty-eight 168-g elements were placed in a ring around six 200-g
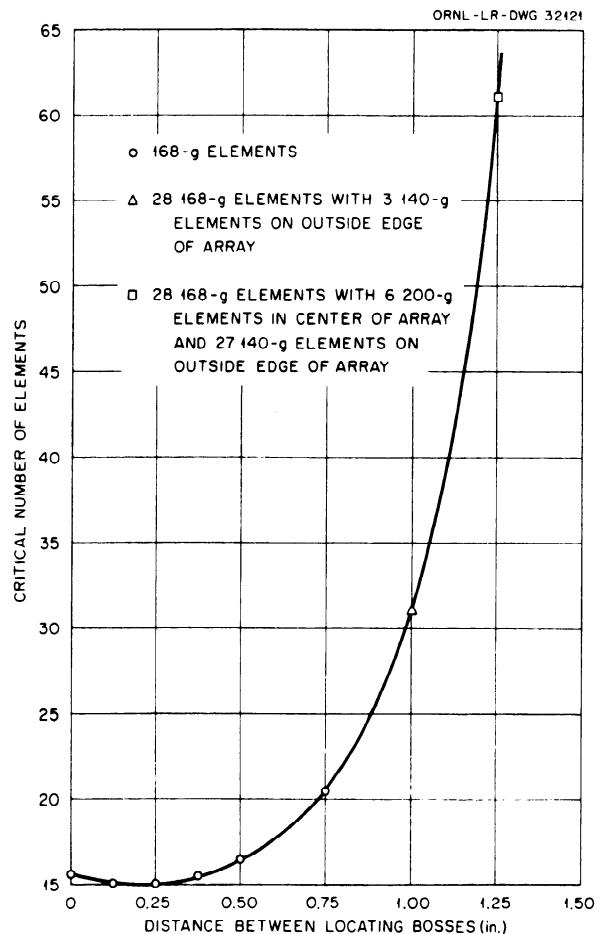

Fig. 3.4.1. Critical Number of ORR Fuel Elements in Approximately Square Arrays in Water as a Function of the Distance Between Locating Bosses.

center elements, and twenty-seven 140-g elements were positioned in an outer ring. Placing the heavier loaded elements in the center gave the maximum reactivity for the elements available at the time. This assumption can be substantiated by comparing the difference in the critical masses of two arrays shown in Table 3.4.1 which used approximately the same number of 168-g elements

in combination with 140-g elements. The reactivity was lower in the array in which the 140-g elements were grouped in the center of the array rather than being dispersed throughout the array.

The curve in Fig. 3.4.1 is quite flat for spacings less than $\frac{3}{8}$ in., but it increases rapidly for greater distances. The optimum spacing is about 0.2 in. This corresponds to a 0.364-in. fuel-to-fuel spacing

Table 3.4.1. Critical Number of ORR Fuel Elements in Approximately Square Arrays in Water

Distance Between Locating Bosses (in.)		Approximate Critical Array	Approximate Critical Mass (g of U^{235})
Bosses Parallel to Fuel Plates	Bosses Perpendicular to Fuel Plates		
0	0	15$\frac{1}{2}$ 168-g elements	2575
$\frac{1}{8}$	$\frac{1}{8}$	15 168-g elements	2510
$\frac{1}{4}$	$\frac{1}{4}$	15 168-g elements	2515
$\frac{3}{8}$	$\frac{3}{8}$	15$\frac{1}{2}$ 168-g elements	2575
$\frac{1}{2}$	$\frac{1}{2}$	16$\frac{1}{2}$ 168-g elements	2775
$\frac{3}{4}$	$\frac{3}{4}$	20$\frac{1}{2}$ 168-g elements	3450
1	1	28 168-g elements 3 140-g elements[a]	5200
1$\frac{1}{4}$	1$\frac{1}{4}$	28 168-g elements 6 200-g elements[b] 27 140-g elements[a]	9575
$\frac{1}{8}$	$\frac{3}{16}$	15 168-g elements	2510
0	$\frac{1}{8}$	15 168-g elements	2510
0	$\frac{1}{4}$	15 168-g elements	2505
0	$\frac{3}{8}$	15 168-g elements	2520
0	$\frac{1}{2}$	15$\frac{1}{4}$ 168-g elements	2550
$\frac{1}{8}$	0	15$\frac{1}{4}$ 168-g elements	2540
$\frac{1}{4}$	0	15$\frac{1}{4}$ 168-g elements	2545
0	0	12 168-g elements 4 140-g elements[c]	2575
0	0	13 168-g elements 3 140-g elements[b]	2622
0	0	18$\frac{3}{4}$ 140-g elements	2615
0	0	13 200-g elements	2620

[a]On outside edge of array.
[b]In center of array.
[c]Dispersed throughout array.

along a perpendicular to the fuel plates and a 0.64-in. spacing along a parallel to the fuel plates. This agrees fairly well with data on the spacing of U^{235}-enriched uranium-aluminum slugs[1] for which the optimum spacing was found to be about 0.5 in.

The increase in the number of ORR elements required for criticality at spacings greater than 1 in. indicates that an infinite array one element high would probably be subcritical with a $1\frac{1}{2}$-in. spacing between the elements. Since the increase in the number of elements required for criticality at larger spacings in water is due to the absorption of neutrons that would otherwise interact between elements, it would appear that the separations required for the isolation of individual elements would not vary much with the element loading. However, no attempt was made to show this experimentally.

The experiments with approximately square arrays also included arrays of elements in contact. For uniform arrays, that is, arrays of elements having the same U^{235} loading, variations in the fuel loading per element between 140 and 200 g affected the critical mass very little, although the number of elements required for criticality differed. This can be shown by comparing the critical masses reported in Table 3.4.1 for arrays with no spacings between locating bosses. This insensitivity of the critical mass to a variation in the fuel element loading is not surprising since the $H:U^{235}$ atomic ratio for 168-g elements in contact in water is about 370, which is near the optimum moderation for minimum mass. Hence small changes in the U^{235} loading within the elements would have little effect on the critical mass. As mentioned above, small changes in the spacing, that is, less than $\frac{3}{8}$ in., between elements would also have little effect on the critical mass.

In addition to the experiments reported in Table 3.4.1 and Fig. 3.4.1, a number of individual ex-

periments were performed to explore other parameters. In one of these the effect of placing 20-mil-thick cadmium sheets between rows of closely packed elements in water was determined. The elements, which had an average loading of 160 g per element, were stacked in an 11 by 12 array, with the heavier elements in the center to obtain maximum reactivity. The cadmium sheets between the rows were parallel to each other and perpendicular to the fuel plates within the elements. No appreciable multiplication of source neutrons was noted, nor was there any appreciable multiplication observed when both the cadmium sheets and water moderator and reflector were removed and the array was surrounded with a 12-in.-thick paraffin reflector.[2]

A study of slab-shaped arrays was also made with elements moderated and reflected by water at the optimum spacing of 0.2 in. between bosses. Step additions of elements were made to a two-row array which remained subcritical for all additions. The final two-row slab had twenty-four 200-g elements in the center and fourteen 168-g elements on each end. Increases in the source neutron multiplication were observed for all additions up to 17 elements per row; however, further additions to this 34-element array had no appreciable effect. The addition of three elements in a third row opposite the center of the 34-element array was sufficient to make the system critical. From these results it appears that two infinitely long rows of 168-g elements would be subcritical. There were insufficient data to determine the reactivity of two rows of 200-g elements.

This paper has been issued as a separate report.[3]

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[1] D. Callihan *et al.*, Y-801 (1951)

[2] The experiment in which no water was used was performed by D. Scott and J. J. Lynn.

[3] J. K. Fox and L. W. Gilley, *Critical Experiments with Arrays of ORR and BSF Fuel Elements*, ORNL CF-58-9-40.