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Critical Measurements on Near-Homogeneous BeO–Moderated, Enriched-Uranium Fueled Systems*

FRED A. KLOVERSTROM, RICHARD M. R. DECK, AND ARNOLD J. REYENGA

Lawrence Radiation Laboratory, University of California, Livermore, California

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A series of critical measurements on unreflected systems, fueled by thin enriched uranium (93.2%) foils, is described. Fuel density is varied by use of different foil thicknesses and spacings between foils. Five fuel densities have been used which correspond to atomic BeO/U^{235} ratios from 246 to 7660. For three of these ratios, the fuel foil thickness was varied to find effects of self-shielding and flux depression on the critical dimensions.

I. INTRODUCTION

The experiments herein described were undertaken in order to provide data for multigroup criticality calculations on homogeneous BeO-moderated, U^{235}-fueled systems. In order to satisfy this purpose, the experimental setup was designed to provide test systems as free as possible from extraneous structural materials and core nonuniformities such as control-rod voids. Effects of rod-guide voids were found to be the principal source of error in similar critical measurements on graphite-moderated systems (*1*). The BeO experiments were therefore designed so that no such voids were necessary.

II. EXPERIMENTAL METHOD

A. General

Test systems are parallelepipeds, built up of moderator blocks having nominal base dimensions of 6 × 6 in. Fuel is available in the form of thin foils, which are sandwiched in horizontal planes between the moderator blocks (Fig. 1). Variations in the overall average fuel density are achieved by varying either the moderator thickness (i.e., number of blocks) between the foils or the fuel foil thickness. If the vertical spacing between fuel foil layers is S, the bottom foil layer is at height $S/2$ (Fig. 1). The maximum fuel density obtainable in a system is limited by the number of foils that can be inserted without causing a gap between the moderator blocks. The minimum fuel density for which a critical measurement can be made is limited by the volume of moderator available.

B. Fuel Foils

Fuel is provided in the form of 5.25-in.^{2} foils having nominal thicknesses of 0.001 and 0.002 in. Foils of half- and quarter-area (triangular) were also used in cases where the spacing between foil planes became large. The foils were coated with Teflon to minimize oxidation and erosion. The average coating weight on coating on a square foil is 0.92 g.

C. BeO Parts

BeO blocks are 6 × 6 × 1 in. and 6 × 6 × 0.5 in., with a 0.015-in. deep, 5.375-in. wide groove on one face to accommodate the fuel foils (Fig. 1). The 1-in. thick parts that comprise the bulk of the test systems have an average weight of 1690 g. The BeO density in a test parallelepiped is 2.86 g/cm^3.

During inspection of the BeO parts it became apparent that iron was present in an amount exceeding the specification figure of 0.01%. Since neutron absorption is the primary effect of impurities insofar as analysis of the critical results is concerned, a pulsed neutron source experiment was conducted on the unfueled BeO, one of the results of which is measurement of the effective thermal-neutron absorption rate $\Sigma_a v$. It was found that $\Sigma_a v = 107 \pm 55$ sec^{-1} which leads to an effective thermal-neutron absorption cross section for BeO of 7 ± 4 mb. Since the currently accepted value is 10 mb, the excess absorption due to impurities is less than 1 mb per BeO molecule.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

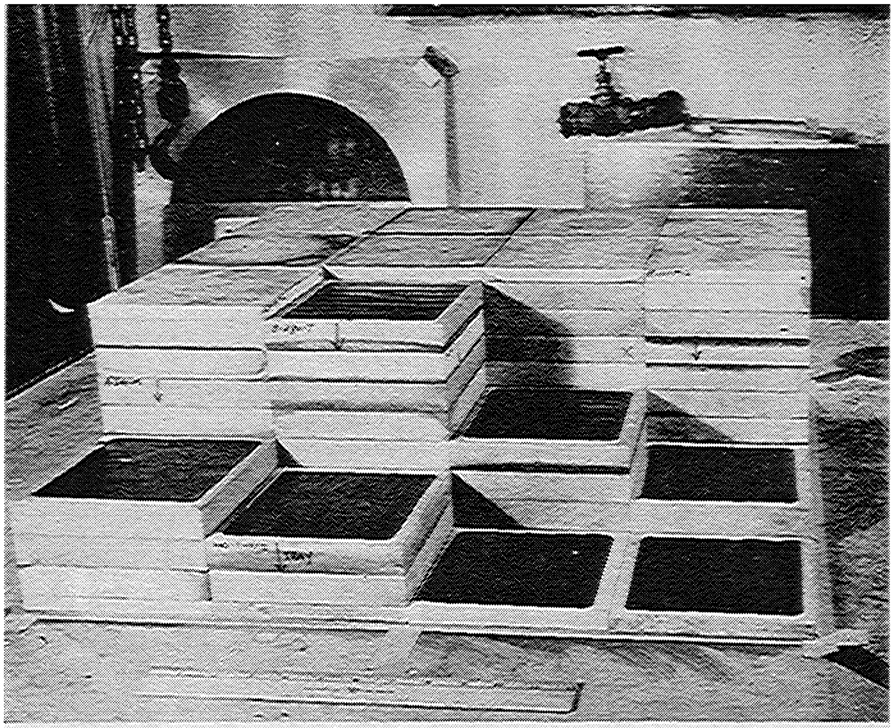

FIG. 1. Ram portion of BeO-moderated system during stacking (loading 3 of Table III).

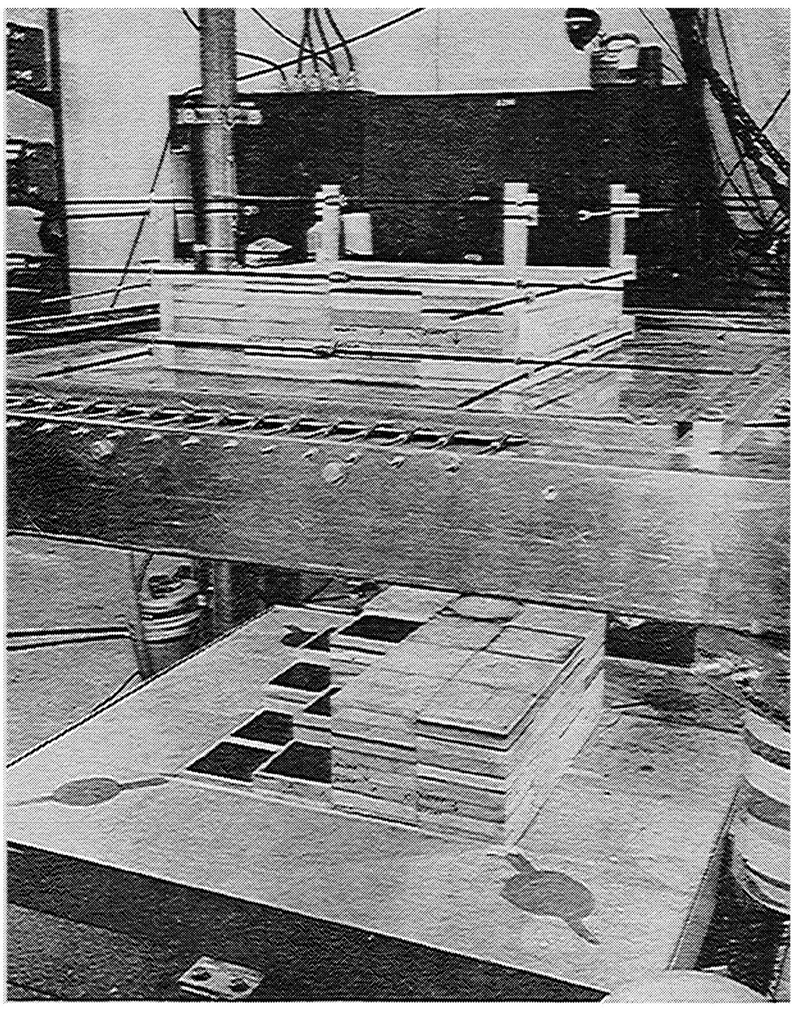

FIG. 2. Assembly machine.

D. Assembly Machine and Measurement Method

Figure 2 illustrates the assembly technique. The machine consists of a vertically moving hydraulic ram, upon which is fitted a 4-ft² platform. The ram platform is a 4-in. thick section of aluminum honeycomb slab, which has an over-all density of 0.37 g/cc, primarily due to aluminum. This type of fabrication was chosen in order to minimize neutron reflection by the platform. The top surface of the platform is covered by 0.020-in. thick Cd, to minimize effects of floor-reflected neutrons.

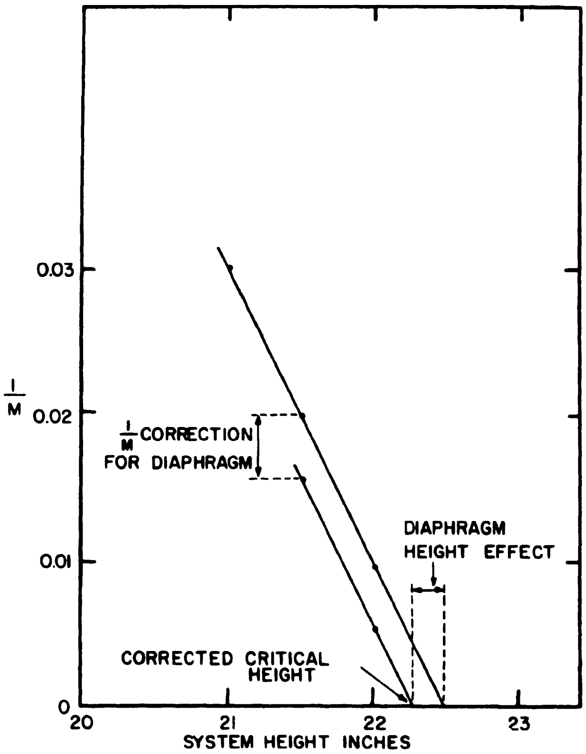

Fig. 3. Extrapolation to critical height and determination of diaphragm effect.

Suspended above the ram platform is a 0.019-in. thick stainless steel diaphragm (Fig. 2). In general, the larger part of a test assembly is stacked on the ram platform, the remainder on the diaphragm. The diaphragm portion is held together by a low-mass framing arrangement, which prevents lateral shifting of the moderator blocks due to diaphragm sag. The two parts are assembled remotely by raising the ram. A ½-in. diameter hole at the top center of the ram assembly (Fig. 1) contains a Po-Be neutron source which supplies neutrons for the multiplication measurements.

Four slow-neutron detectors are used to monitor neutron emission from the systems. Scram mechanisms, causing the ram to drop, are actuated if the count rate from any of the four detectors exceed a preset level.

The measurement technique is to leave the base dimensions of the test parallelepiped fixed, and to increase the height of the system toward critical. Critical height is established by extrapolation of inverse-multiplication ($1/M$) vs system-height curves, as shown in Fig. 3. Near critical, the system height is increased by ½-in. steps, as shown. A $1/M$ vs height curve was obtained for each of the four de-

TABLE I

Critical Dimensions of BeO-Moderated, Unreflected Systems ρ_{BeO} = 2.86 g/cm³

Foil thickness (in.)	Spacing between foil planes, (in.)	BeO/U^{235} atomic ratio	Average U^{235} density, (g/cm³)	System base, (in.)	Critical height, (in.)	$B^2 \times 10^{3}$ [a] (cm^{-2})
0.008	1	247	0.109	24 × 24	20.2	8.28 ± 0.04
0.004	1	493	0.0545	24 × 24	22.0	7.77 ± 0.04
0.008	2	493	0.0545	24 × 24	22.3	7.70 ± 0.04
0.002	1	986	0.0272	24 × 24	25.0	7.15 ± 0.05
0.004	2	986	0.0272	24 × 24	25.8	7.01 ± 0.05
0.006	3	986	0.0272	24 × 24	27.5	6.77 ± 0.05
0.001	1	1920	0.0140	30 × 30	21.1	6.30 ± 0.08
0.002	2	1920	0.0140	30 × 30	21.6	6.17 ± 0.08
0.002	2	1920	0.0140	30 × 24	26.0	6.13 ± 0.08
0.003	3	1920	0.0140	30 × 24	27.3	5.94 ± 0.08
0.001[b]	1	3830	0.00702	36 × 36	22.9	4.91 ± 0.10
0.002[b]	2	3830	0.00702	36 × 36	24.2	4.64 ± 0.10
0.001	2	3830	0.00702	36 × 36	22.7	4.95 ± 0.10
0.002	4	3830	0.00702	36 × 36	24.2	4.64 ± 0.10
0.001[c]	1	7660	0.00351	36 × 36	36.2	3.34 ± 0.12

[a] Computed using an extrapolation distance of 1.3 cm.
[b] Half-area fuel foils (triangular).
[c] Quarter-area fuel foils (triangular).

tectors; critical heights to be quoted are based on an average of the four results, which have been found to agree consistently on critical height within ±0.050 in.

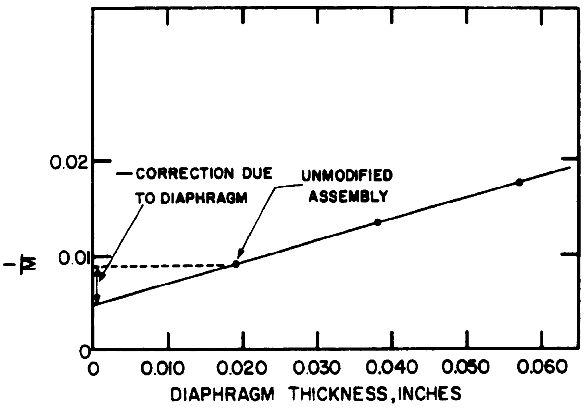

FIG. 4. Variation of $1/M$ with diaphragm thickness

III. RESULTS

Table I summarizes loading details and results of the critical-height measurements. The BeO/U^{235} ratios and U^{235} densities given are calculated on the basis of what might be called an "average fuel element." This consists of a fuel foil in the center of a BeO sandwich, the thickness of the BeO on each side of the foil being half the spacing between foil planes. In general the critical height will not fall exactly on a "fuel element" boundary; the exact amount of fuel in a critical assembly will therefore be a few percent different from that found by use of the density data of Table I. These discrepancies are believed to be unimportant, since deviations from the periodic nature occur only in relatively unimportant regions of the assemblies.

The following corrections have been made to the data of Table I.

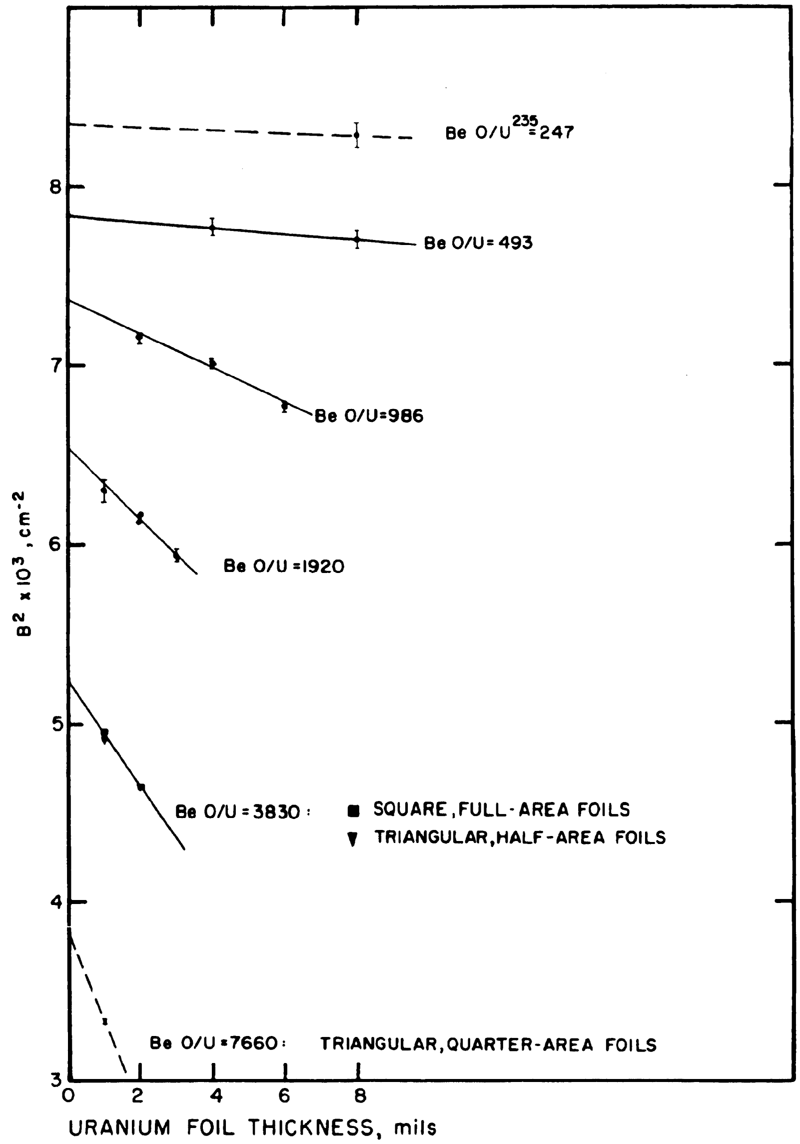

FIG. 5. Critical bucklings vs fuel-foil thickness.

TABLE II

ESTIMATES OF HOMOGENEOUS BeO-ENRICHED URANIUM CRITICAL BUCKLINGS

BeO/U atomic ratio	Critical $B^2 \times 10^5$ (cm^{-2})	
	Linear	Parabolic
247	8.35	—
493	7.85	—
986	7.30	7.21
1920	6.42	6.38
3830	5.18	5.04
7660	3.8	3.5

A. *Diaphragm Correction.*—The effect of the diaphragm on critical height was found by measurement of its effect on $1/M$ of the test system nearest critical. The procedure is illustrated in Fig. 4. Three diaphragm thicknesses were used, $1/M$ being measured for each. Extrapolation to zero diaphragm thickness then yields the $1/M$ that would be found if the diaphragm were absent. The $1/M$ correction is then used in the original $1/M$ vs height curve (Fig. 4) to find the critical height of the system without the diaphragm. Diaphragm corrections were ranged from 0.1 in. (BeO/U = 247) to 0.5 in. (BeO/U = 7660) in critical height.

B. *Effects of Incidental Neutron Reflection.*—Test systems are normally unshielded from room-reflected neutrons, which were found to affect previous measurements on unreflected graphite-U^{235} systems. No change in the measured critical height was found when the BeO/U = 491 system was surrounded with 0.020-in. thick cadmium, indicating that the thermal-neutron room effect is smaller than the systematic inaccuracies. No change was measurable when the ram half of this system was surrounded by a framing structure identical to that used on the diaphragm portion, indicating again a negligible effect.

C. *Foil Coating and Source Hole Effects.*—Corrections due to these perturbations have not been experimentally investigated; they are believed to be small and in opposite directions.

IV. CRITICAL-HEIGHT ACCURACIES

In order to establish limits of error in the measured critical heights unambiguously, each measurement should be repeated independently a large number of times, using different BeO blocks and enriched uranium (93.2%) foils when possible. This was done on a BeO/U = 247 system to a limited extent: four independent critical-height measurements agreed within ±0.1 in., which corresponds to about 5% in BeO/U. A pessimistic estimate of errors in B^2 for other BeO/U ratios can be obtained by assuming all of the ±0.1-in. spread to be due to variation in BeO and U weights, and none to the height-measurement method. The 5% uncertainty in BeO/U would then apply to all test system; the resulting errors in critical buckling are given in Table I.

V. ESTIMATES OF HOMOGENEOUS CRITICAL PARAMETERS

The results obtained for systems having equal BeO/U^{235} ratios but different foil thicknesses may be used to estimate the critical parameters of homogeneous systems. The bucklings of Table I were extrapolated to zero foil thickness as shown in Fig. 5. The shape of the extrapolation curves is purely empirical: the BeO/U 986 and 1920 data suggest a parabola although it is not obviously a better fit than a straight line. Results of both extrapolations are given in Table II.

REFERENCE

1. H. L. REYNOLDS, UCRL-5175 (March 31. 1958).