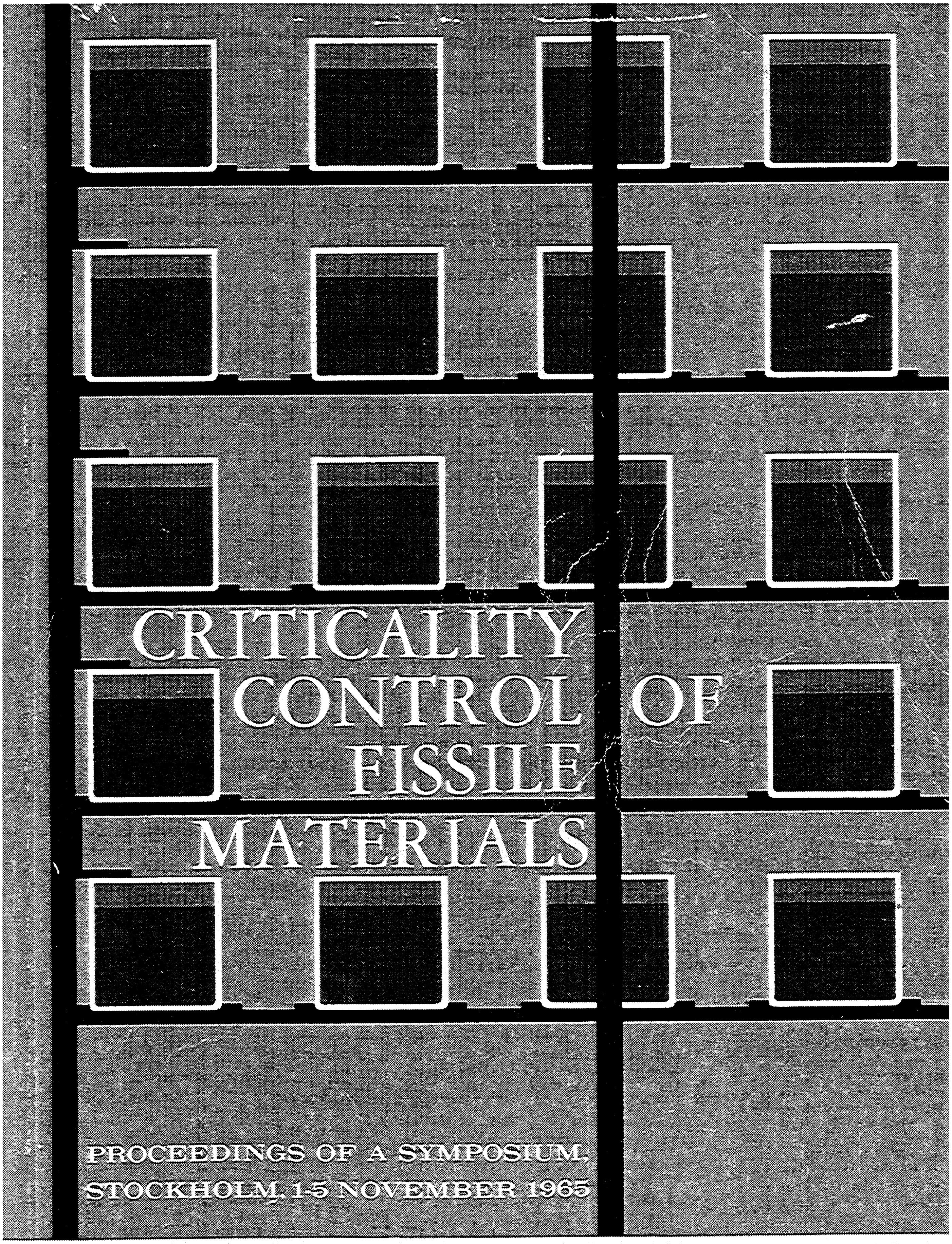
REFERENCE 43

R. C. LANE, "MEASUREMENTS OF THE CRITICAL PARAMETERS OF UNDER-MODERATED URANIUM-HYDROGEN MIXTURES AT INTERMEDIATE ENRICHMENT," IN PROCEEDINGS OF THE SYMPOSIUM CRITICALITY CONTROL OF FISSILE MATERIALS, STOCKHOLM, 1-5 NOVEMBER 1965 (INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1966), PP. 177-191.



INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1966

PROCEEDINGS SERIES

CRITICALITY CONTROL
OF FISSILE MATERIALS

PROCEEDINGS OF THE SYMPOSIUM ON
CRITICALITY CONTROL OF FISSILE MATERIALS
HELD BY THE INTERNATIONAL ATOMIC ENERGY AGENCY
AT STOCKHOLM, 1 - 5 NOVEMBER 1965

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 1966

MEASUREMENTS OF THE CRITICAL PARAMETERS OF UNDER-MODERATED URANIUM-HYDROGEN MIXTURES AT INTERMEDIATE ENRICHMENTS

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Abstract

MEASUREMENTS OF THE CRITICAL PARAMETERS OF UNDER-MODERATED URANIUM-HYDROGEN MIXTURES AT INTERMEDIATE ENRICHMENTS. The critical size of intimate mixtures of 30% enriched uranium oxide and wax with $H/^{235}U$ in the range 8 to 80 and of $37\frac{1}{2}$% enriched uranium metal, as used in Zebra, were estimated by extrapolation from high multiplication assemblies. The cores were constructed in rectangular geometry from small blocks to facilitate stacking changes. Reflectors included polyethylene, Perspex, concrete and wood. The effect of other reflectors was estimated by replacement of one face of an otherwise polyethylene-reflected near cube by the material of interest. Evidence is given that critical masses derived by this method are correct to within 5%, even when the spectrum of neutrons returned to the core from the replacement face is markedly different from that returned from the remainder of the reflector. Density exponents were estimated from measurements with low density blocks, and one carbon dilution exponent is reported. The critical size of half-reflected cores is of interest to the criticality assessor. The parameters obtained from a near cube and a long pipe suggest that their dimensions are the arithmetic mean of those of bare and completely reflected cores of the same shape. The neutron interaction between partially reflected cores can be greater than that for the uniformly reflected case. To check the magnitude of this effect, two identical cores were reflected on all but the adjoining faces by polyethylene, and their critical separation determined. The measurement was then repeated with the cores fully reflected, or with the polyethylene filling only the space between the reflector, leaving free space between the cores. Cadmium sheet in conjunction with a moderator is commonly used as a means of absorbing neutrons in transport and storage applications. Selected assemblies were rebuilt with a layer of cadmium sheet between core and reflector to estimate its effect on critical size.

1. INTRODUCTION

Measurements of the critical parameters of uranium at intermediate enrichments have been made by a number of workers [1, 2] using heterogeneous assemblies of UCF_6 and plastics [2, 3], metals [4, 5] and solutions [6, 7]. The present study was undertaken to provide more data on under-moderated mixtures of uranium and hydrogen. The cores were constructed from homogeneous mixtures to avoid the difficulty of interpreting the results from heterogeneous cores [2] and the use of structural materials was minimized. The experimental programme also included some studies of particular geometrical arrangements which are of interest in criticality assessment work.

2. MATERIALS

The uranium-hydrogen mixtures were studied using cores constructed from small blocks, mostly 2.54 cm cubes, manufactured from U(30.14)[1]

[1] Uranium enriched to 30.14 wt.% in the ^{235}U isotope.

TABLE I

DETAILS OF CORE MATERIAL

	Metal cores	Cores using UO_2/wax mixtures: (batch reference number) 8[a]	16[a]	40	80[a]	80C	Standard deviation
^{235}U density (g/cm^3)	6.71	1.569	1.126	0.608	0.331	0.243	± 0.5%
$H/^{235}U$	<0.03	8.2	16.3	39.5	81.6	82.0	± 0.5-1.0%
Composition by nuclei (10^{22} nuclei/cm^3)							
H	<0.03	3.29	4.72	6.14	6.92	5.10	± 1%
C	<0.02	1.63	2.34	3.05	3.43	5.30	± 1%
O	<0.02	2.72	1.96	1.05	0.574	0.422	± 1%
Al	0.05	0	0	0	0	0	
^{234}U	0.032	0.005	0.004	0.002	0.001	0.0008	
^{235}U	1.72	0.402	0.289	0.155	0.0848	0.0622	± 0.5%
^{236}U	0.008	0.001	0.0007	0.0004	0.0002	0.0001	
^{238}U	2.79	0.914	0.656	0.355	0.1928	0.1415	± 0.3%

[a] Batches 8L, 16L and 80L have densities 0.754, 0.748 and 0.746 (± 0.003) of batches 8, 16 and 80, respectively.

oxide and wax [8, 9]. The proportions of oxide and wax were changed at intervals during the experiment to provide a range of $H/^{235}U$ atomic ratios from 8 to 80. The work was extended to metal cores using U(37.67) plates, each 5.096 cm square and 0.318 cm thick.

Details of the core material are given in Table I. The batch numbers of the UO_2/wax refer to the approximate $H/^{235}U$ atomic ratio. Three other batches used were labelled 8L, 16L and 80L. These were identical with batches 8, 16 and 80, but the density of each block was reduced by incorporating seven cylindrical holes to reduce the average density to about 75% of the latter. Batch 80C contained pile quality graphite at an effective density of 2.10 g/cm^3.

The reflectors, normally 20 cm thick, included polyethylene $(CH_2)_n$ at a density of g/cm^3, and "Perspex" (methylmethacrylate, $C_5H_8O_2$) at 1.193 g/cm^3 which were chosen for their similarity to water as a reflector and for the ease with which the stacking could be changed. In the water-reflected experiment, the water was contained in an aluminium tank, 0.32 cm thick. Paraffin wax $(CH_{2.04})_n$ at 0.86 g/cm^3 was also used as a reflector. Reflectors of beech wood, "Jabroc" (a material manufactured from wood

TABLE II

COMPOSITION OF WOOD AND CONCRETE REFLECTORS[a]

Composition	Beech A	Beech B	Jabroc	Concrete A	Concrete B
H	2.65	3.00	4.9	1.23	1.36
C	1.60	1.77	3.23	0.034	0.030
N	0.0022	0.0021	0.0049	-	-
O	1.23	1.35	2.12	4.65	4.75
Si	-	-	-	1.650	1.743
K	0.0013	0.0020	0.139	0.004	0.008
Ca	0.0008	0.0009	0.0019	0.423	0.291
Fe	-	-	-	0.018	0.045
Density (g/cm^3)	0.69	0.68	1.30	2.37	2.37

[a] Units are 10^{22} nuclei/cm^3

and epoxy resin) and concrete, were used because of their value as shielding materials in storage and transport applications. Their compositions are given in Table II.

3. EXPERIMENTAL METHOD

The vertical assembly machine (Atlas) used for this work [10], has the load divided between an upper stationary platform and a lower platform mounted on a hydraulic ram. Fine control of the platform separation is achieved by allowing the ram to drive against three nuts whose position is determined by three screwed rods, and the separation is measured by the rotation of these rods. In most of the experiments, the core and all but one face of the reflector were mounted on the lower platform, but in cases where the reactivity worth of at least one face of the reflector was small, and for all the interaction measurements, part of the core was supported on the upper platform by a metal plate. The effect of this on the critical size was corrected by extrapolation from measurements with additional material.

The two platforms were driven together, and the neutron count rates of fully assembled stacks were measured. The counters were $^{10}BF_3$ proportional counters. For reflected systems, these were placed in the lower reflector and for bare systems, in blocks of moderator placed well away from the stack. The critical size was determined by extrapolating to zero a plot of the reciprocal count rate for a number of stacks having the same cross-section but different height or length. In some cases, the extrapolated

TABLE III

CRITICAL PARAMETERS OF UNIFORMLY REFLECTED ASSEMBLIES

Reflector (20 cm thick)	Core	Core dimensions (cm)
None	UO_2/wax batch 16	30.48 × 30.48 × 28.60 ± 0.05
	40	27.94 × 27.94 × 23.88 ± 0.1
	80	25.40 × 25.40 × 23.82 ± 0.1
Perspex	UO_2/wax batch 8	22.86 × 22.86 × 26.59 ± 0.1
	8	25.40 × 25.40 × 21.92 ± 0.1
	8L	30.48 × 30.48 × 30.05 ± 0.05
	8L	35.56 × 35.56 × 23.10 ± 0.02
	16	20.32 × 20.32 × 22.78 ± 0.08
	16L	27.94 × 27.94 × 24.94 ± 0.05
	40	20.32 × 20.32 × 16.36 ± 0.05
	80	17.78 × 17.78 × 18.47 ± 0.05
Polyethylene	Metal	20.41 × 20.41 × 15.11 ± 0.02
		15.31 × 15.31 × 29.15 ± 0.09
		30.61 × 30.61 × 9.14 ± 0.02
	UO_2/wax batch 8L	30.48 × 30.48 × 35.36 ± 0.1
	8L	33.02 × 33.02 × 29.87 ± 0.05
	16	22.86 × 22.86 × 19.68 ± 0.05
	16L	27.94 × 27.94 × 28.60 ± 0.05
	40	15.24 × 15.24 × 40.66 ± 0.1
	40	20.32 × 20.32 × 17.58 ± 0.05
	40	27.94 × 27.94 × 11.52 ± 0.02
	80	15.24 × 15.24 × 31.60 ± 0.05
	80	17.78 × 17.78 × 20.07 ± 0.05
	80	20.32 × 20.32 × 15.52 ± 0.05
	80	25.40 × 25.40 × 11.61 ± 0.02
	80L	22.86 × 22.86 × 26.31 ± 0.05
	80C	17.78 × 17.78 × 41.10 ± 0.1
	80C	22.86 × 22.86 × 20.33 ± 0.02
	80C	27.94 × 27.94 × 15.00 ± 0.05
Beech A	Metal	20.41 × 20.41 × 19.63 ± 0.02
	UO_2/wax batch 80	20.32 × 20.32 × 19.00 ± 0.05
Beech A with cadmium sheet surrounding core	Metal	20.41 × 20.41 × 29.85 ± 0.05
	UO_2/wax batch 80	20.32 × 20.32 × 30.73 ± 0.05
Concrete A	UO_2/wax batch 80	20.32 × 20.32 × 16.89 ± 0.05
Concrete A with cadmium sheet surrounding core	UO_2/wax batch 80	20.32 × 20.32 × 22.86 ± 0.05

(negative) count rate was plotted for a stack which would have been supercritical if fully assembled.

To provide an adequate neutron background for safety and to reduce the time taken in counting, a Po(α, n) source with simulated fission spectrum was placed within 1 cm of the core surface.

4. CRITICAL PARAMETERS OF BARE AND REFLECTED CORES

The extrapolated critical sizes are quoted in Table III.

Since the assemblies were constructed in rectangular geometry, the results were converted to the cube, rather than to the more usual sphere, geometry. This has been done using the one-group diffusion theory equation

$$B^2 = \frac{2}{[h + 2(\lambda + r)]^2} + \frac{2}{[b + 2(\lambda + r)]^2} = \frac{3^2}{[S + 2(\lambda + r)]^2} \quad (1)$$

where S is the side of the critical cube, and h and b the height and base length, respectively, of the critical prism of square cross-section; B^2, the buckling, and λ, the extrapolation length, are assumed independent of reflector type or core shape, and r, the reflector saving, is assumed independent of shape.

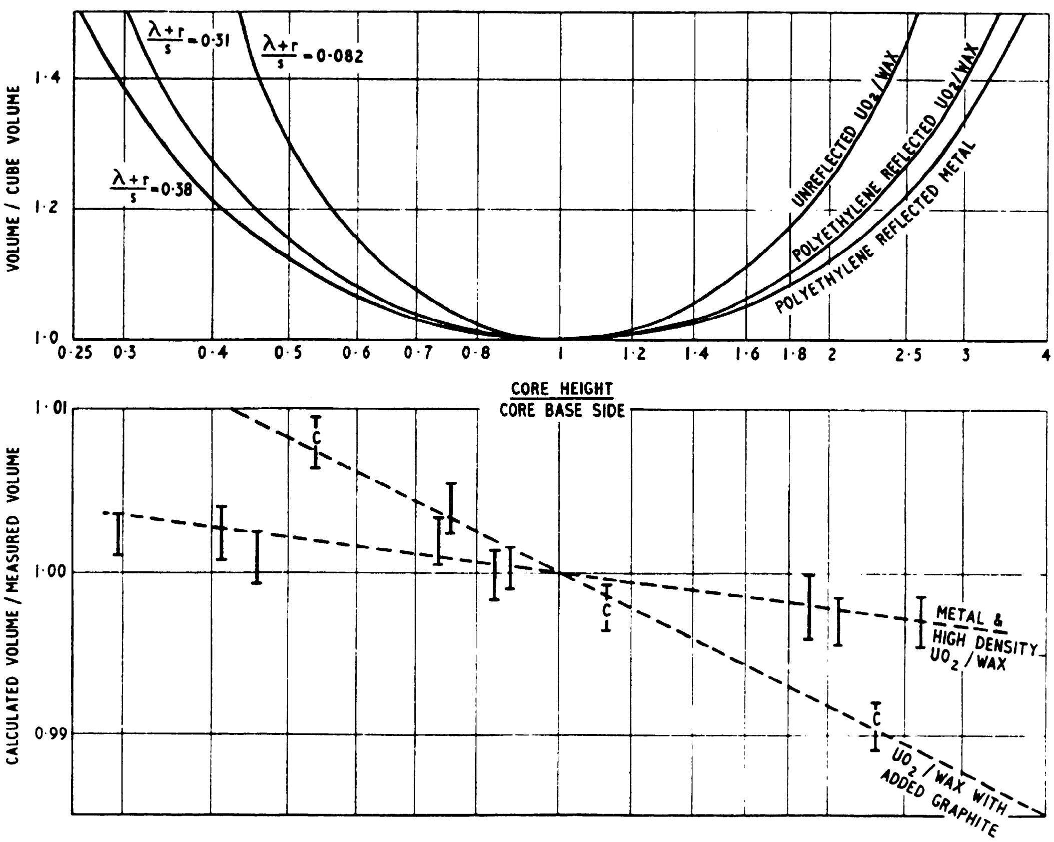

FIG. 1. Change of critical volume with shape according to 1-group diffusion theory, and errors introduced by its use.

TABLE IV

CRITICAL PARAMETERS OF POLYETHYLENE REFLECTED CORES

Core		Side of critical cube (cm)	$\frac{\lambda + r}{S}$	Cube critical volume (litres)	$\frac{V}{V_c}$
Metal		18.35 ± 0.02	0.38(4)	6.17	-
UO_2/wax batch	16	21.71 ± 0.02	-	10.23	1.005
	40	19.33 ± 0.01	0.31(0)	7.22	-
	80	18.47 ± 0.01	0.31(0)	6.30(5)	-
	8L	31.94 ± 0.03	-	32.6	1.002
	16L	28.16 ± 0.01	-	22.33	1.000
	80L	23.92 ± 0.02	-	13.68	1.005
	80C	21.96 ± 0.02	0.31(5)	10.59	-

On this basis, the ratio of the critical volume, V, of a prism of height h and base length b to the critical cube volume, V_c, is determined by the ratios h/b and $(\lambda + r)/S$. The dependence of V/V_c on these ratios is illustrated in Fig. 1. For those polyethylene reflected cores where the critical size was determined for a number of different shapes, the values of $(\lambda + r)/S$ were obtained by applying Eq. (1) to each shape to obtain a best fit. These values are listed in Table IV. The volume correction for the remaining cores is less than 0.5%, the exact values being quoted in Table IV.

Perspex was also available in a range of sizes, and near cubes were constructed with this reflector. The beech A and concrete A reflectors were only available in a form suitable for reflecting cores of 20.4 cm square cross-section and the correction to cube geometry was performed using values of $(\lambda + r)$ derived by replacing the side of a polyethylene reflected core by the material of interest and measuring the difference in the critical height. Then

$$(\lambda + r)_{\text{reflector}} = (\lambda + r)_{\text{polyethylene}} - \Delta H \qquad (2)$$

where ΔH is the increase in stack height due to the replacement.

The remaining reflectors were available as single slabs, each 76 cm square. For these, the side of the critical cube (S) was determined from replacement measurements by using the relation

$$S_{\text{reflector}} = S_{\text{polyethylene}} + 2\Delta H \qquad (3)$$

The error introduced by using the replacement technique may be estimated by comparing the critical cube side obtained by this method using

TABLE V

SIDE OF CRITICAL CUBE[a]

Reflector	UO_2/wax core (batch No.)				
	8	8L	16L	80L	80C
Perspex	24.07 ± 0.03	30.33 ± 0.01	26.87 ± 0.02	23.03 ± 0.04	21.29 ± 0.04
Water				23.38 ± 0.06	22.20 ± 0.06

Reflector	Metal core	UO_2/wax core (batch No.)		
		16	40	80
None	25.9 ± 0.2	29.83 ± 0.02	26.42 ± 0.04	24.90 ± 0.06
Perspex		21.10 ± 0.01	18.83 ± 0.02	17.93 ± 0.02
Water	18.98 ± 0.06	22.05 ± 0.06	19.61 ± 0.06	18.81 ± 0.06
Wax			19.81 ± 0.05	18.62 ± 0.05
Beech A	20.14 ± 0.02			19.87 ± 0.03
Beech B			21.17 ± 0.05	20.07 ± 0.05
Jabroc			18.77 ± 0.05	17.80 ± 0.05
Concrete A	18.52 ± 0.05			19.06 ± 0.03
Concrete B			20.47 ± 0.05	19.24 ± 0.05
Wax + Cd			24.3 ± 0.1	22.51 ± 0.1
Beech A + Cd	22.76 ± 0.03			22.75 ± 0.05
Beech B + Cd			24.0 ± 0.1	22.8 ± 0.1
Concrete A + Cd	20.3 ± 0.1			21.10 ± 0.03
Concrete B + Cd			22.65 ± 0.1	21.2 ± 0.1
Polyethylene + Cd	22.79 ± 0.1		24.25 ± 0.1	22.4 ± 0.1

[a] Dimensions in centimetres.

[b] + Cd signifies 0.040 cm of cadmium metal between core and reflector.

Eq.(3) with that obtained by cores which were fully reflected by the material of interest, the replacement measurements being using merely to provide values of $(\lambda + r)/S$ to aid the conversion to cube geometry using Eq.(2). This error is plotted in Fig. 2 against the difference in reflector saving between the material and polyethylene. The error is roughly proportional to this reflector saving difference, as shown by a line drawn in Fig. 2 to represent its most probable value.

The values of the side of the critical cube obtained by these methods are quoted in Table V. Those values derived solely by the replacement technique have been adjusted using corrections obtained from the line drawn in Fig. 2.

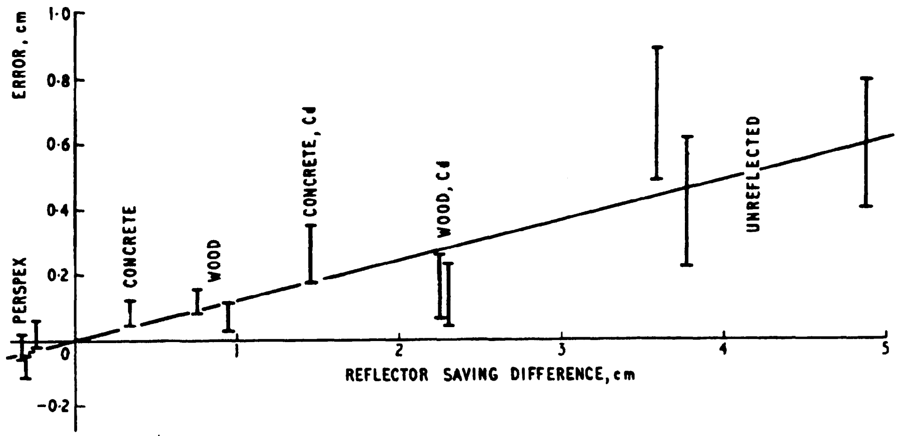

FIG. 2. Error introduced in the critical cube side by using the replacement technique with polyethylene reflected core.

It is of interest to compare the experimental values of the critical volume with the values derived by this method, as this indicates the extent of the error introduced by the use of the equal buckling relation. The lower graph in Fig. 1 shows that this is less than 1% in volume over the range of shapes studied.

5. COMPARATIVE REFLECTOR EFFICIENCIES AND THE EFFECT OF A CADMIUM REFLECTOR

One measure of the efficiency of a reflector (R) in reducing the critical parameter is the ratio of the reflected to the bare critical cube side, i.e. $R = 1 - (2r/S)$. Apart from a small effect due to the change of r with shape, the parameter R should be identical in cube, or sphere geometry, provided the cube side is replaced as appropriate by thickness or diameter.

For water, the values of R derived from Table V are as follows:

Metal	$UO_2/16$	$UO_2/40$	$UO_2/80$
0.73 ± 0.1	0.739 ± 0.002	0.742 ± 0.003	0.755 ± 0.003

For the moderated cores, these values agree within 1% with those derived from critical sphere diameters calculated by Mills [11] for 30 wt.% $^{235}U/H_2O$ cores, if the density differences are taken into account.

Of the hydrogenous reflectors, Perspex is the most efficient. Richey [12] found Lucite, a similar material to Perspex, to be slightly more efficient than water for a plutonium/plastic compact at H/Pu = 15. Richey points out that, although the hydrogen density of this material is less than that of water, the combined density of carbon and oxygen is much higher, and these nuclei will tend to reduce leakage at higher energies.

Wax is very similar to water as a reflector, and polyethylene is slightly more efficient. This agrees closely with measurements on such widely different cores as U(1.42) at $H/^{235}U = 420$ and 570 [13] and U(93)-metal slabs [14].

A sheet of cadmium 0.04 cm thick is frequently used as a means of reducing the effectiveness of a reflector, especially in storage or transport applications. To compare the effect of a cadmium sheet with different cores or reflectors, a figure of merit,

$$C = \frac{r_{no\text{-}Cd} - r_{Cd}}{r_{no\text{-}Cd}}$$

was derived, the terms r_{Cd} and $r_{no\text{-}Cd}$ being the reflector savings of the cadmium covered and non-cadmium-covered cores. Values of C are quoted in Table VI.

TABLE VI

COMPARISON OF THE EFFICIENCY OF A CADMIUM LINER

Reflector	$C = \frac{r_{no\text{-}Cd} - r_{Cd}}{r_{no\text{-}Cd}}$		
	Metal core	UO_2/wax core Batch No. 40	UO_2/wax core Batch No. 80
Polyethylene	0.41	0.69	0.61
Wax	-	0.68	0.62
Beech A	0.45	-	0.57
Beech B	-	0.54	0.57
Concrete A	0.24	-	0.35
Concrete B	-	0.37	0.35

6. VARIATION OF REFLECTOR THICKNESS

The way in which the efficiency of a reflector varies with thickness is of value in criticality assessment work [15]. For this reason, the effect of changing the thickness of a hydrogenous (polyethylene) reflector was estimated by the replacement technique as described in section 4, using the metal core and batches No. 40 and 80 of the UO_2/wax cores. The data given in Fig. 2 shows that the results of these measurements, which are quoted in Table VII, will be in error by a roughly constant factor.

TABLE VII

UNCORRECTED REFLECTOR SAVINGS FOR POLYETHYLENE MEASURED BY THE REPLACEMENT TECHNIQUE

Reflector thickness (cm)	Metal core	Reflector savings (cm)	
		UO_2/wax core	
		Batch No. 40	Batch No. 80
2.54	1.96	2.08	1.93
5.1	3.16	3.02	2.82
10.2	3.85	3.65	3.35
15.2	3.96	3.72	3.45
20	4.05	3.78	3.53

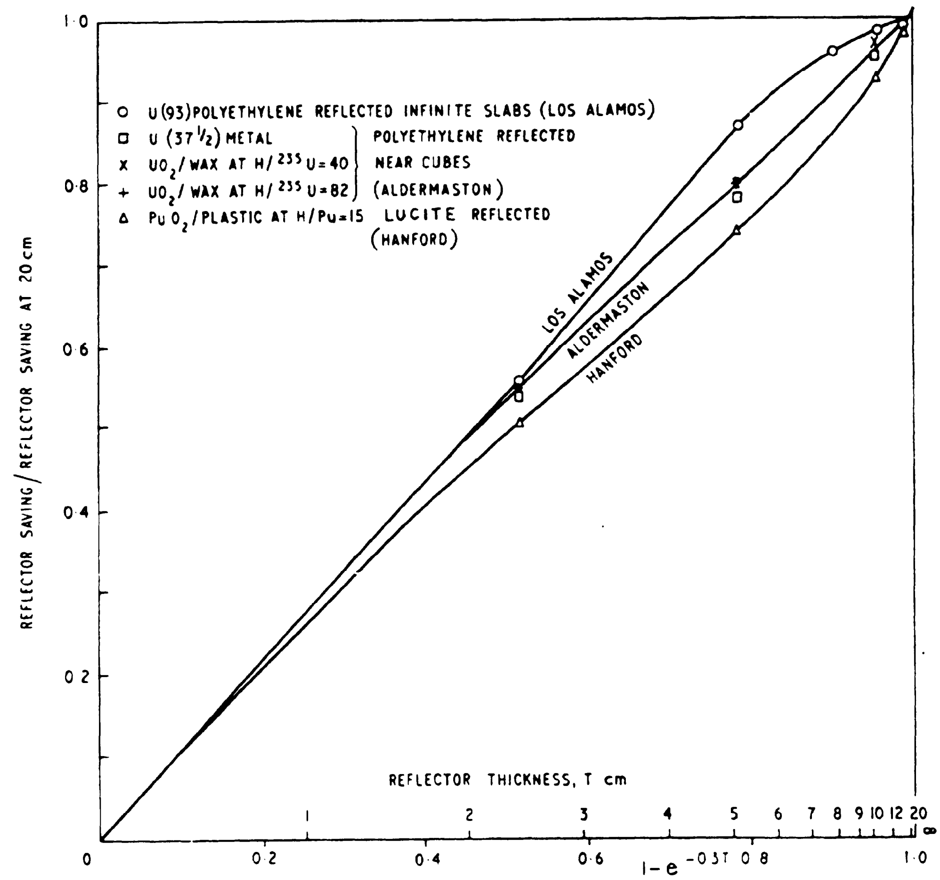

FIG. 3. Variation of reflector saving with thickness.

Other similar experiments have been performed by Hansen [14] with polyethylene reflected U(93)-metal slabs, and by Richey [12] with Lucite reflected Pu/H compacts. The results of this and the present work are plotted in Fig. 3 as r_t/r_{20}, where r_t is the reflector saving for a reflector t cm thick, thus minimizing the effect of the errors due to the use of the replacement technique. To simplify extrapolation to the infinite reflector, the reflector saving ratio is plotted against the function $(1 - e^{-0.3t})$, the factor 0.3 being arbitrarily chosen to give a nearly straight line. This plot confirms that 20 cm thick polyethylene is effectively infinite, having a reflector saving $\simeq$ 99.5% of that of the infinitely thick reflector. Lucite is seen to require a greater thickness than polyethylene to reach the same relative saving, a not unexpected result as seen from its greater proportion of C and O nuclei.

7. ESTIMATION OF DENSITY AND DILUTION EXPONENTS

The effect of density changes in the core may be defined in terms of the core mass density exponent, γ, defined by the relation

$$\frac{m_1}{m_2} = \left(\frac{\rho_1}{\rho_2}\right)^{-\gamma} \tag{4}$$

where m_1 and m_2 are the critical masses of two cores of identical composition, having densities ρ_1 and ρ_2. The exponent $\gamma = 2$ for unreflected cores, or for uniform density changes throughout the whole assembly.

TABLE VIII

MASS DENSITY AND GRAPHITE DILUTION EXPONENTS

Batches	$H/^{235}U$	Diluent	Reflector	Mass density or dilution exponent
8 and 8L	8.2	Air	Perspex	1.46 ± 0.04
16 and 16L	16.3	Air	Perspex	1.50 ± 0.04
			Polyethylene	1.69 ± 0.04
80 and 80L	81.6	Air	Perspex	1.56 ± 0.05
			Polyethylene	1.67 ± 0.04
			Water	1.65 ± 0.06
80 and 80C	82	Graphite at 2.10 g/cm^3	Polyethylene	0.70 ± 0.05
			Perspex	0.67 ± 0.06
			Water	0.61 ± 0.1

The concept of the density exponent is valuable in the criticality assessment of materials having densities other than that of a mixture of the metal with water [15] and in the conversion of experimental data to a standard form [16].

The mass density exponents were obtained by comparison of measurements with low density and standard density cores of the UO_2/wax. The low density blocks were constructed with seven cylindrical holes each 0.55 cm in diameter. By packing these blocks in one assembly with the holes aligned, in another otherwise identical assembly with the holes misaligned to minimize streaming, and in a third assembly packed in a random way, it was shown that the effect of streaming on the critical size was negligibly small. The effect of additional graphite on critical parameters may most simply be expressed as a dilution exponent, defined in a similar manner to the density exponent, the relevant density ratio in this case being that of the original core materials (UO_2 and wax), i.e. 0.734 ± 0.007. The density and dilution exponents are tabulated in Table VIII.

8. THE EFFECTS OF PARTIAL REFLECTION AND INTERACTION

Criticality assessment of nominally unreflected vessels frequently require the assumption of full reflection by thick water to cover the possibility of flooding, and other possible accidents [15]. A watertight hollow shield over a significant fraction of the surface of a plant item would reduce the reflection in such conditions, giving a worthwhile increase in size, while still allowing access for manipulation of controls. The simplest analysis, assuming that the inverse of the surface multiplication is linear with dimension, and that the fraction of neutrons leaving a fissile assembly and which are returned to it by the reflector is proportional to the fraction p of surface reflected, gives the dimension d as

$$d = (1 - p)d_B + pd_R \tag{5}$$

where d_B and d_R are corresponding dimensions of an unreflected and a fully-reflected core having the same shape.

The critical sizes of two batch No. 80 UO_2/wax cores partially reflected by 20 cm thick polyethylene were measured. One assembly was a near cube and the other a long prism. Both cores were as near half-reflected as practical, but the reflected part of the core was, in the case of the long prism, bare at the ends (Fig. 4).

For the near cube, for which $p = 0.488$, the measured size was 22.86 cm $\times$ 22.86 cm $\times$ 19.78 cm, and the size of the same shaped prism as calculated from the bare and reflected critical size using Eq. 5, 22.73 cm $\times$ 22.73 cm $\times$ 19.69 cm. Apart from the ends, the long prism was half-reflected. The measured size was 17.78 cm $\times$ 17.78 cm $\times$ 45.85 cm. That calculated from the bare and reflected critical sizes, allowing for the absence of end reflector, was 17.88 cm $\times$ 17.88 cm $\times$ 46.10 cm.

Thus for $p \simeq \frac{1}{2}$, the simple rule gives very good results and encourages the belief that it should be adequate for cores of other composition and shape.

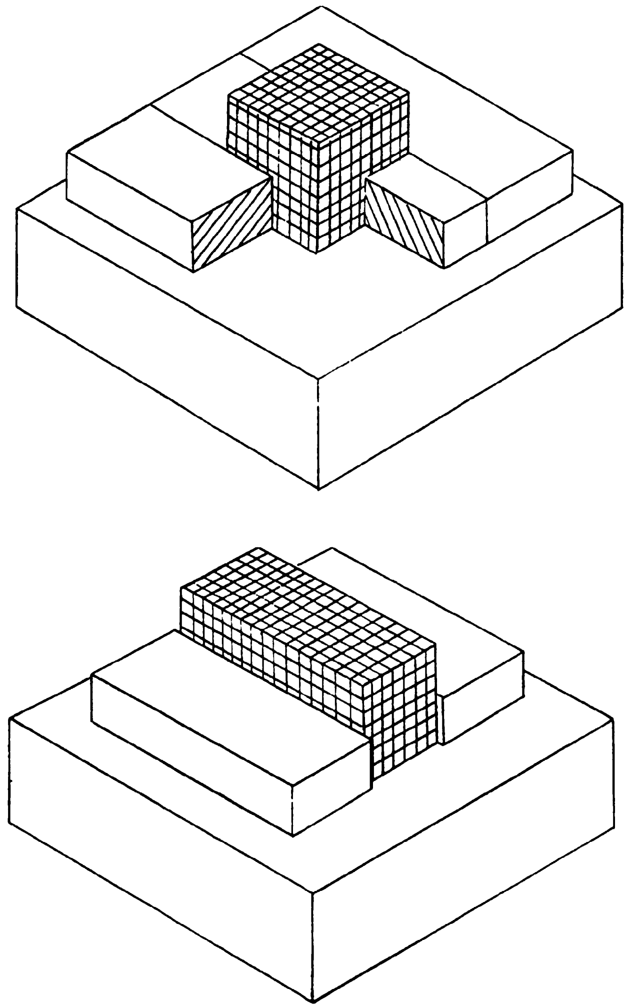

FIG. 4. Arrangement of core and reflector for experiments on partial reflection.

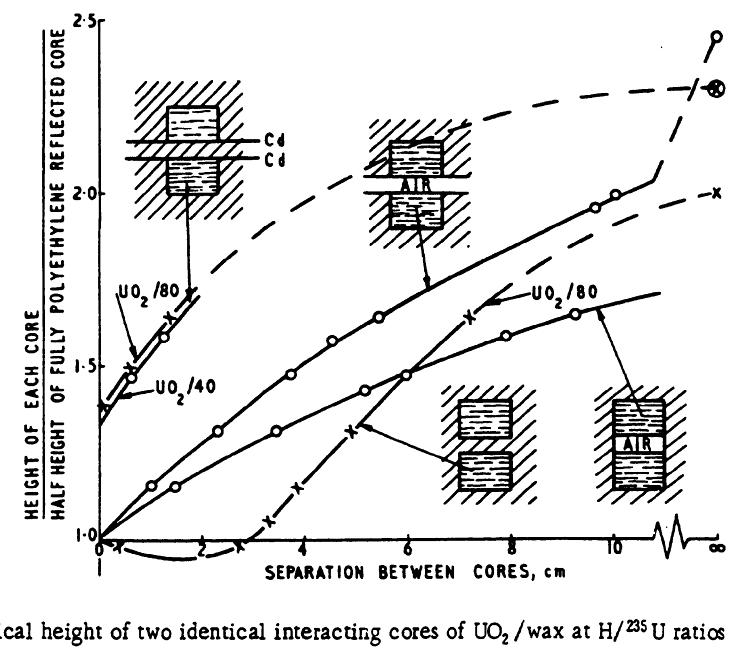

FIG. 5. Critical height of two identical interacting cores of UO_2/wax at $H/^{235}U$ ratios of about 40 and 80.

A related problem in criticality safety assessment is the enhancement of interaction effects that may be caused by partial reflection. A two-body interaction assembly of UO_2/wax was set up to study these effects. The experiment was performed with material from batches No. 40 and 80.

Two identical cores were constructed on a 20.3 cm square base and were reflected on all but the adjoining faces by 20 cm thick polyethylene. One assembly was supported on a 0.016-cm-thick, stressed steel plate fixed to the upper platform. The other assembly was supported on the lower platform and the required separating material was placed on top of it. The separating material was air, polyethylene, or polyethylene and cadmium as shown in Fig. 5.

The critical separation was determined by extrapolation from inverse count rates obtained at larger (or in one case, smaller) thicknesses of separating material.

For small separations, the polyethylene reflected core had the smallest critical size (Fig. 5). Beyond 6 cm, the "tunnel" geometry is the most reactive, but at very large separations, where the interaction effect is negligible, the reflection of the fully polyethylene-separated core would be the dominant factor.

The effect of cadmium, even at very small separations, was large (Fig. 5), and shows this material to be very suitable for shielding in applications where space is at a premium [15].

ACKNOWLEDGEMENTS

Parts of the work described in this paper were planned and supervised by J.R. Dominey and A.F. Thomas. Experimental assistance was provided throughout by O.J.E. Perkins. Acknowledgement is also due to the Chemical Technology Division at Aldermaston for the manufacture of the oxide/wax blocks and to the Zebra reactor team at Winfrith for the loan of the 37% enriched uranium metal.

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DISCUSSION

E.D. CLAYTON: With regard to comparative reflector efficiencies and the effect of a cadmium liner, I might say that we have performed experiments in the Hanford Plutonium Critical Mass Laboratory on a spherical vessel of plutonium solution covered with 0.03 in. of cadmium sheeting, reflected with water in some cases and with concrete in others. Our results showed that with a concrete reflector the cadmium was only about half as effective in reducing the reflector saving as with a water reflector*.

* LLOYD, R.C., et al., Critical studies with plutonium solutions, BNWL-SA-232, (Oct. 1965).