Critical Assemblies of Graphite and Enriched Uranium With Beryllium Reflectors*

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Abstract

Collected in this report are data on properties of three sets of cylindrical beryllium reflected, graphite moderated critical assemblies. The first set was primarily to establish characteristics as functions of C/Oy atomic ratio of core with nearly constant reflector thickness. Fission distributions were determined.

The second set consisted of three assemblies with fixed core to determine the effect of redistributing reflector from the ends to the cylindrical wall. This series was done to provide the Los Alamos Scientific Laboratory's Theoretical Division checks for a two-dimensional diffusion code. Flux distributions in the uniformly reflected assembly were mapped extensively with bare and cadmium shielded foils of oralloy, gold, and indium.

The third set was to establish the minimum volume core at C/Oy $\approx$350 that could be made critical with available beryllium.

Experimental critical data converted to equivalent spherical systems are compared with results of S_4 calculations.

HONEYCOMB ASSEMBLY MACHINE

The Honeycomb assembly machine (Figure 1) consists of two stacks of aluminum tubes 3 in.^{2} by 36 in. long with 0.047-in. wall. The two stacks are brought together by remote control to form a 6-ft cubic matrix of tubes. Critical assemblies are built up by slipping fuel and reflector material into the aluminum tubes. Fuel subassemblies consist of graphite plates 16 in. long by 2.9 in. wide with 0.002 or 0.005-in. thick foils of Oy (93.2)** interleaved to give the average desired C/Oy ratio. The average density of aluminum (1100 F) throughout core and reflector is 0.165 g/cm^3.

ASSEMBLIES TO ESTABLISH DEPENDENCE UPON C/Oy

Summarized in Table 1 are data on a set of cylindrical beryllium reflected, graphite moderated critical assemblies supported by the aluminum matrix of the Honeycomb machine. Radial dimensions are obtained by converting pseudocylinders to cylinders of equal cross-sectional area. Critical conditions are specified by the dimensions and component densities (region averages) of the following six regions characteristic of each assembly (see Figure 2):

1. The fuel region, designated F, which is always loaded uniformly with carbon and oralloy foils.

2. and 3. Small carbon regions, designated ΔFE and ΔFW, butted against the east and west cylindrical faces of F and having the same cross-sectional area as F.

4. The cylinder wall reflector region, designated T and always loaded with beryllium. The length of T is always $F + \Delta FE + \Delta FW$.

5. and 6. East and west cylinder face reflector regions, designated ET and WT and having cross-sectional areas equal to $F + T$.

*Work done under the auspices of the Atomic Energy Commission.

**Oralloy (symbol "Oy") designates uranium enriched in U^{235}. Oy (93.2) indicates uranium that is 93.2 wt % U^{235}.

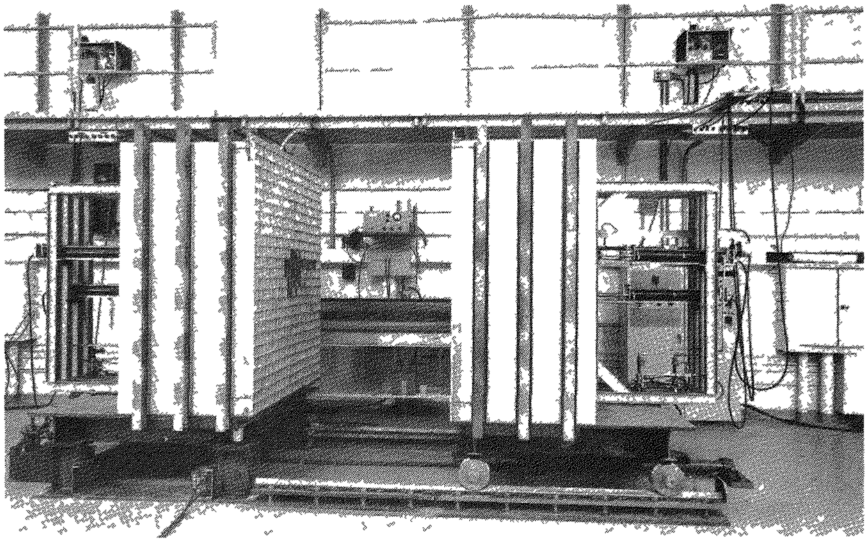

Figure 1 Honeycomb assembly machine

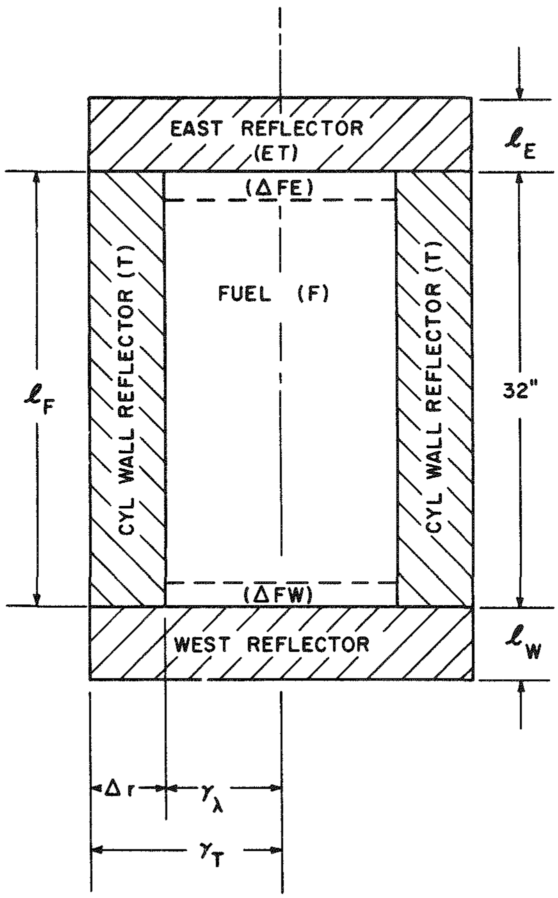

Figure 2 Regions specifying assemblies

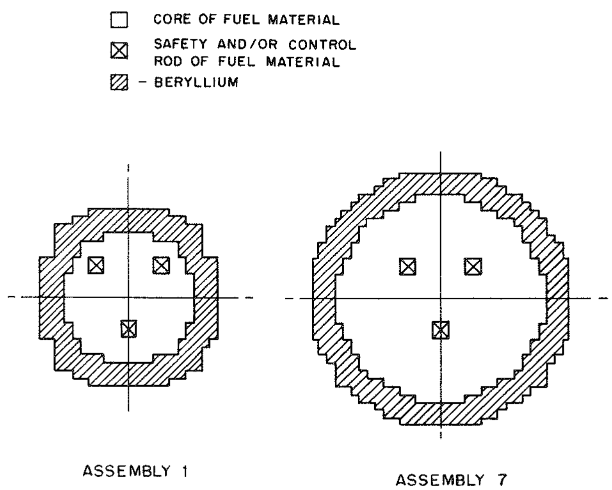

Figure 3 Typical cross-sectional diagrams of assemblies

Typical cross-sectional stacking diagrams are shown in Figure 3.

An axial beryllium island was stacked in assembly 3 by replacing central fuel until the assembly was just critical without changing reflector or fuel outside the island. The critical mass was reduced from 30.8 to 19 kg oralloy with an island radius of 25.3 cm.

Approximately 12% of the 0.002-in. foils in assembly 7 were replaced with equal

Table 1

Critical Conditions for Variable C/Oy Series[a]

			Fuel region			Wall reflector		East end reflector		West end reflector	
Assembly No.	C/Oy	Critical mass, kg Oy	Effective graphite density, g/cm³	Radius, cm	Length, cm	Effective Be density, g/cm³	Thickness, cm	Graphite thickness in ΔFE, cm	Be thickness, cm	Graphite thickness in ΔFW, cm	Be thickness, cm
1	116	57.5	1.42$_1$	31.3	77.7	1.65$_0$	12.4	2.5$_4$	10.1	1.0[illegible]	20.2
2	116	57.5	1.42$_1$	31.3	77.7	1.65$_9$	13.7	2.5$_4$	10.1	1.0$_2$	10.1
3	368	30.8	1.42$_1$	40.5$_6$	78.7$_1$	1.66$_0$	12.9$_0$	2.5$_4$	11.4[illegible]	0	8.1
4	368	36.0	1.29$_0$	46.1$_0$	78.7$_4$	1.65[illegible]	14.0	2.5$_4$	7.6	0	7.6$_0$
									+3.2[illegible]		+3.2[illegible]
5	371	40.4	1.29[illegible]	48.8$_1$	78.7$_1$	1.66$_1$	12.8	2.5$_4$	8.5$_3$	0	8.5$_3$
6	952	17.4	1.47[illegible]	48.8$_3$	76.2	1.66$_4$	12.0	2.5$_4$	9.7$_0$	2.5$_4$	23.0$_3$
7	952	17.4	1.47[illegible]	48.8$_3$	76.2	1.66$_4$	12.0	2.5$_4$	9.7$_6$	2.5$_4$	9.7$_6$

Unless otherwise specified, mean densities of graphite and beryllium in the east and west face reflectors are the same as listed in fuel and wall reflector regions.

Graphite at 1.42 g/cm³

Graphite at 1.47 g/cm³

Note Assemblies 6 and 7 contained 0.002-in. Oy foils only, others contained 17.5 kg Oy as 0.002-in. foils and the remainder as 0.005-in. foils

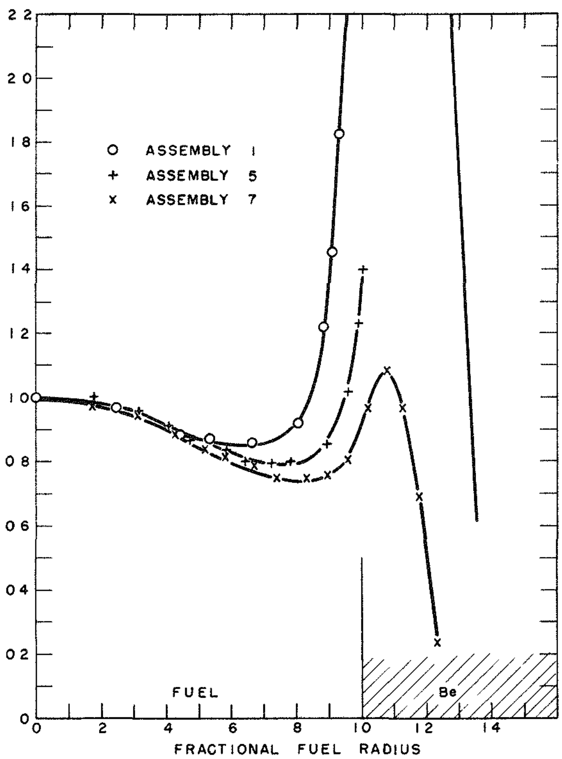

Figure 4. Radial fission distributions at C/Oy 116, 371, and 952

weight of 0.005-in. foils to establish the effect of foil self shielding. A ΔK of —$1.2 was estimated for 100% exchange of 0.002-in. foils with 0.005-in. foils.

Fission distributions are determined by counting the fission product gamma activity of small (0.005-in.-thick by ½-in.-diameter) Oy foils distributed throughout the mock-ups. The foils are activated by half-hour runs at delayed critical. Radial fission variation in assemblies at C/Oy of 116, 371, and 952 is shown in Figure 4.

ASSEMBLIES FOR CHECKS OF COMPUTATIONS

A refined beryllium reflected, graphite moderated critical assembly was made in Honeycomb to provide the Theoretical Division at the Los Alamos Scientific Laboratory with a check point for its two-dimensional diffusion code. The assembly was mapped with oralloy, gold, and indium detectors with and without cadmium. In a second experiment, end reflectors were removed from this core and peripheral reflector added to reach critical. This information is useful for conversion of cylindrical data to spherical data for one-dimensional calculations. Critical conditions are summarized in Table 2.

The results of axial and radial fission traverses with and without cadmium are plotted in Figures 5 and 6. Radial variation of gold and indium response and their cadmium ratios are shown in Figures 7 and 8.

Table 2

Critical Conditions for Two-Dimensional Check Series

Assembly No.	C/Oy	Critical mass, kg Oy	Fuel region: $\bar{\rho}_C$, g/cm^3	Fuel region: Radius, cm	Fuel region: Length, cm	Wall reflector: $\bar{\rho}_{Be}$, g/cm^3	Wall reflector: Thickness, cm	End reflectors East: Be thickness, cm	End reflectors West: Be thickness, cm
8	384	32.3	1.50	40.56	81.28	1.66	13.08	10.16	10.16
9	384	32.3	1.50	40.56	81.28	1.66	16.74	10.16	0
10	384	32.3	1.50	40.56	81.28	1.66	29.90*	0	0

*Extrapolated value. Actual critical configuration with 27.58 cm Be + 5.75 cm graphite ($\bar{\rho}$ = 1.56).
Note: All 0.005-in. foils.

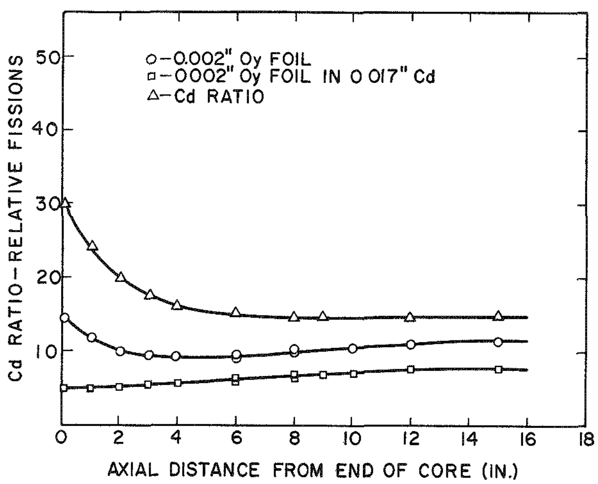

Figure 5. Axial oralloy fission traverses and cadmium ratios for assembly 8

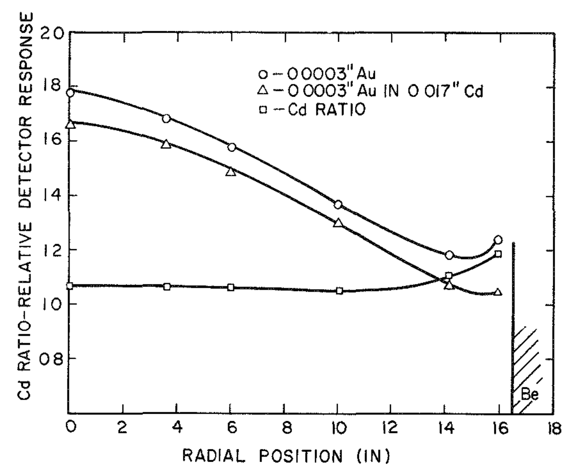

Figure 7. Gold detector radial traverse in assembly 8. Longitudinal position 8 in. from end of core

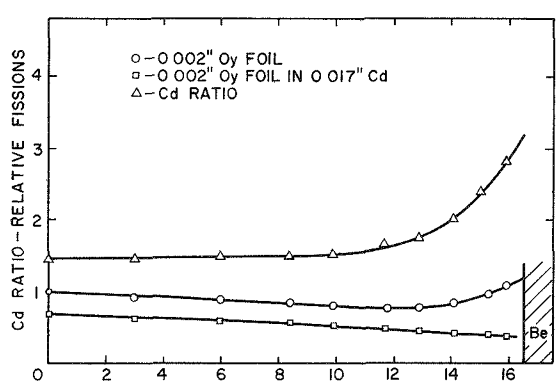

Figure 6. Radial oralloy traverses and cadmium ratios for assembly 8. Longitudinal position 8 in. from end of core

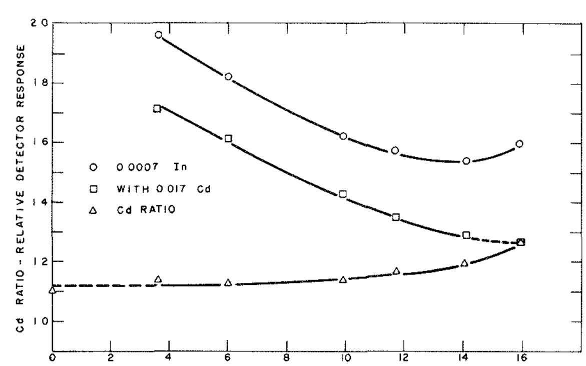

Figure 8. Indium detector radial traverse in assembly 8. Longitudinal position 8 in. from end of core

Table 3

Critical Data for Small-Core Assemblies (Core Length 76.2 cm)

Assembly No.	Critical mass, kg Oy	C/Oy	$\bar{\rho}_C$, g/cm^3	$\bar{\rho}_{Be}$, g/cm^3	Be island radius, cm	Core outside radius, cm	Reflector thickness, cm: Wall	Reflector thickness, cm: East end	Reflector thickness, cm: West end
11	12.81	354	1.42	1.66	—	25.25	24.71	2.54 C + 10.16 Be	2.54 C + 20.32 Be
12	16.69	351	1.41	1.66	—	28.83	23.65	2.54 C*	2.54 C + 20.32 Be
13	8.87**	356	1.38	1.66	19.38	28.83	19.99	2.54 C*	2.54 C + 20.32 Be

*Peripheral beryllium extends 4 in. beyond core.

**A safety rod fuel tube in east beryllium island was considered beryllium.

Note: These assemblies contained 0.002-in. oralloy foil only.

ASSEMBLIES WITH SMALL CORE VOLUMES

An experiment was performed to determine the minimum volume core that could be stacked with available beryllium in a limited C/Oy range. Data on the three configurations studied are summarized in Table 3.

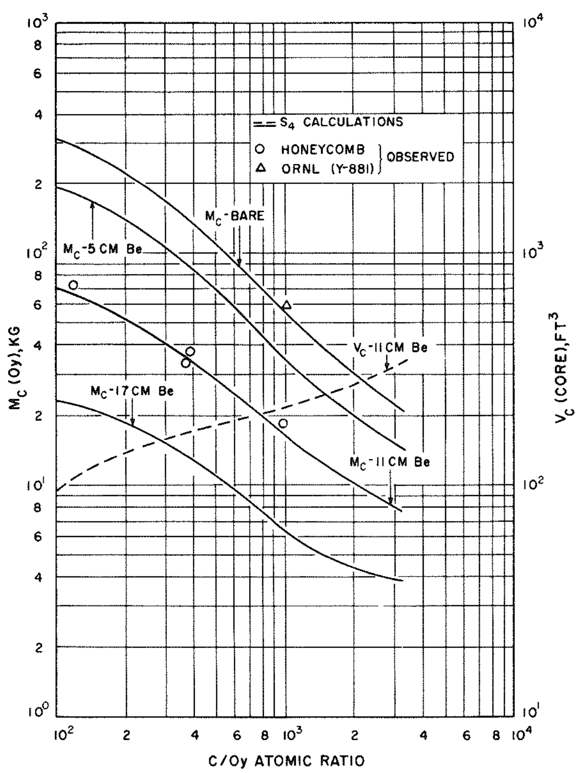

Figure 9. Critical parameters of spherical oralloy-graphite cores with beryllium reflectors

Table 4

Adjusted Experimental and Computed Critical Masses

(11-cm-thick Be reflector, $\bar{\rho}_C$ = 1.34 g/cm^3, $\bar{\rho}_{Be}$ = 1.80 g/cm^3)

Assembly No.	C/Oy	Sphere critical mass, kg Oy: Honeycomb converted	Sphere critical mass, kg Oy: S_4
1	116	74.2	66
2	116	72.0	66
3	368	34.1	35
4	368	34.6	35
5	371	33.2	35
6	952	18.4	17
7	952	18.5	17
8	384	39.2	34
9	384	35.8	34
10	384	30.5*	34

*The formulas used for the cylinder-to-sphere conversions should not be applicable to the asymmetrically reflected assembly 10. The value 30.5 kg obtained from these formulas should be compared with the corresponding values for assemblies 8 and 9 to indicate calculational difficulties rather than a reactivity index of assembly 10.

COMPARISON OF EXPERIMENTAL AND COMPUTED DATA

In order to compare directly with S_4 calculations, the experimental data of Table 1 were converted to spherical systems with a fixed beryllium reflector thickness. Conversion was made to the following standard values:

1) for graphite, $\bar{\rho}_C = 1.336$ g/cm^3,
2) for beryllium, $\bar{\rho}_{Be} = 1.80$ g/cm^3,
3) beryllium reflector thickness = 11.0 cm.

The conversion of the experimental systems to "standard spheres" did not vitally affect the precision of critical configuration specifications, and preserved the specific dependence on the C/Oy atomic ratio.

Cylindrical systems were converted to spheres by assuming constant buckling. A check on the validity of this assumption was made by S_4 calculations on infinite cylinders. Conversion of these results to spheres by the same procedure as that applied to experimental data resulted in critical radii exceeding by 1.5% the radii computed directly by the S_4 method.

A summary of the converted cylinder data is given in Table 4, together with corresponding S_4 computed values. These data are also compared in Figure 9. The basic nuclear cross sections used in the S_4 calculations are given in Table 5.

Table 5

Parameters for S_4 Calculations
(Cross sections in barns)

Group No.	Energy interval	Fission spectrum	Neutrons per fission	$\sigma_c^{U^{235}}$	$\sigma_f^{U^{235}}$	$\sigma_{tr}^{U^{235}}$
1	0.025 ev	0	2.45	95	513	620
2	0.21–3.1 ev	0	2.45	22	83	115
3	3.1–22.7 ev	0	2.45	17.5	46	74
4	22.7–168 ev	0	2.45	17.2	37	64.5
5	0.168–123 kev	0	2.45	6.4	13.6	33.2
6	1.23–9.1 kev	0	2.45	2.3	5.8	18.2
7	9.1–67 kev	0.008	2.45	0.7	3.0	13.8
8	67–500 kev	0.116	2.45	0.3	1.57	9.0
9	0.50–1.35 Mev	0.301	2.51	0.18	1.24	5.1
10	1.35–3.25 Mev	0.575	2.70	0.08	1.30	4.6

$\sigma_c^{U^{238}}$	$\sigma_f^{U^{238}}$	$\sigma_{tr}^{U^{238}}$	σ_c^{Be}	σ_{es}^{Be}	σ_{tr}^{Be}	σ_c^{C}	σ_{es}^{C}	σ_{tr}^{C}
3	0	10	0.010	—	5.65	0.005	—	4.5
2	0	10	0.002	5.9	5.5	0.001	4.7	4.5
102	0	110	0.001	5.9	5.5	0	4.7	4.5
43	0	50	0	5.9	5.5	0	4.7	4.5
2	0	11	0	5.9	5.5	0	4.7	4.5
1	0	11	0	5.9	5.5	0	4.7	4.5
0.4	0	11	0	5.6	5.2	0	4.6	4.4
0.2	0	8.7	0	4.3	4.0	0	3.9	3.7
0.11	0.02	4.9	0	2.7	2.5	0	2.4	2.2
0.03	0.53	4.4	0.11	1.8	1.5	0	1.8	1.5

Notes: Values of average logarithmic energy decrement per collision are $\xi_{Be} = 0.209$ and $\xi_C = 0.158$ except for the tenth group, where $\xi_{Be} = 0.146$ and $\xi_C = 0.133$.

Except for the following cases, inelastic scattering cross sections are zero:

$$\sigma_{10\to 9}^{U^{235}} = 1.0,\quad \sigma_{10\to 8}^{U^{235}} = 0.3,\quad \sigma_{9\to 8}^{U^{235}} = 0.45,$$

$$\sigma_{10\to 9}^{U^{238}} = 1.5,\quad \sigma_{10\to 8}^{U^{238}} = 0.4,\quad \sigma_{9\to 8}^{U^{238}} = 0.6.$$

The Be(n, 2n) cross section in the tenth group is 0.11 and the associated transfer cross section is $\sigma_{10\to 8}^{Be} = 0.22$.