CRITICAL ASSEMBLIES OF GRAPHITE AND ENRICHED
URANIUM WITH BERYLLIUM REFLECTORS*

G. E. Hansen, J. C. Hoogterp,

J. D. Orndoff, H. C. Paxton

UNIVERSITY OF CALIFORNIA
LOS ALAMOS SCIENTIFIC LABORATORY
LOS ALAMOS, NEW MEXICO

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 - 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.

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

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, the Commission, nor any person acting on behalf of the Commission: A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report. As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Honeycomb Assembly Machine

The Honeycomb assembly machine (Fig. 1) consists of two stacks of aluminum tubes 3 in. square 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 (1100F) throughout core and reflector is 0.165 gm/cm³.

Assemblies to Establish Dependence upon C/Oy

Summarized in Table I 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 diagram, in Fig. 2):

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

2. and 3. Small carbon regions, designated (Δ FE) and (Δ FW), butted against the east and west cylindrical faces of (F) and having the same cross-sectional area as (F).

*Oralloy (symbol "Oy") designates uranium enriched in U²³⁵. Oy (93.2) indicates uranium that is 93.2 w/o U²³⁵.

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 $(F) + (T)$.

Typical cross-sectional stacking diagrams are shown in Fig. 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 of oralloy with an island radius of 25.3 cm.

Approximately 12% of the 0.002 in. foils in Assembly 7 were replaced with equal weight of 0.005 in. foils to establish the effect of foil self-shielding. A ΔK of -81.2 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 1/2 in. diameter) Oy foils distributed throughout the mockups. 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 Fig. 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

galloy, 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 II.

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

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 III.

Comparison of Experimental and Computed Data

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

1. For graphite, $\bar{P}_C = 1.336 \text{ gm/cm}^3$
2. For beryllium, $P_{Be} = 1.80 \text{ gm/cm}^3$
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 IV, together with corresponding S_4 computed values. These data are also compared in Fig. 9. The basic nuclear cross sections used in the S_4 calculations are given in Table V.

FIGURE CAPTIONS

- Fig. 1. Honeycomb assembly machine
- Fig. 2. Regions specifying assemblies.
- Fig. 3. Typical cross-sectional diagrams of assemblies.
- Fig. 4. Radial fission distributions at C/Oy 116, 371, and 952.
- Fig. 5. Axial oralloy fission traverses and cadmium ratios for Assembly 8.
- Fig. 6. Radial oralloy traverses and cadmium ratios for Assembly 8. Longitudinal position 8 inches from end of core.
- Fig. 7. Gold detector radial traverse in Assembly 8. Longitudinal position 8" from end of core.
- Fig. 8. Indium detector radial traverse in Assembly 8. Longitudinal position 8" from end of core.
- Fig. 9. Critical parameters of spherical oralloy-graphite cores with beryllium reflectors.

407
7

LOS ALAMOS
PHOTO LABORATORY

EG. 56781
NO.

PLEASE RE-ORDER
BY ABOVE NUMBER

- - CORE OF FUEL MATERIAL
- ⊗ - SAFETY AND/OR CONTROL ROD OF FUEL MATERIAL
- ▨ - BERYLLIUM

ASSEMBLY 1

ASSEMBLY 7

FIG. 3.

FIG. 4.
407 60

407

12

FIG. 6.

Fig. 7, Page 13

FIG. 9.

TABLE I.
CRITICAL CONDITIONS FOR VARIABLE C/OY SERIES²

Assem- bly No.	C/Oy	Fuel Region				Wall Reflector		East End Reflector		West End Reflector	
		Critical Mass, kg Oy	Effective Graphite Density, gm/cm ³	Radius, cm	Length, cm	Effective Beryl- lium Density, gm/cm ³	Thick- ness, cm	Graphite Thick- ness in AEP, cm	Beryl- lium Thick- ness, cm	Graphite Thick- ness in AEP, cm	Beryl- lium Thick- ness, cm
1	116	57.5	1.42 ₁	31.3 ₀	77.7	1.65 ₉	12.4	2.5 ₄	10.1	1.0 ₂	20.2
2	116	57.5	1.42 ₁	31.3 ₀	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 ₄	1.66 ₆	12.9 ₆	2.5 ₄	11.4 ₇	0	8.1 ₂
4	368	36.0	1.29 ₀	46.1 ₀	78.7 ₄	1.65 ₅	14.0	2.5 ₄	7.6 ₀	0	7.6 ₀
									+3.2 ₂ ^{**}		+3.2 ₂ ^{**}
5	371	40.4	1.29 ₈	48.8 ₃	78.7 ₄	1.66 ₁	12.8	2.5 ₄	8.5 ₃	0	8.5 ₃
6	952	17.4	1.47 ₇	48.8 ₃	76.2	1.66 ₄	12.0	2.5 ₄	9.7 ₆	2.5 ₄	23.0 ₃ ^{***}
7	952	17.4	1.47 ₇	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 gm/cm³.

*** Graphite at 1.47₇ gm/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.

407-16

II.
TABLE IV.

CRITICAL CONDITIONS FOR TWO-DIMENSIONAL CHECK SERIES

As- sem- bly No.	C/Oy	Critical Mass, kg Oy	Fuel Region			Wall Reflector		End Reflectors	
			$\bar{\rho}_C$, gm/cm ³	Radius, cm	Length, cm	$\bar{\rho}_{Be}$, gm/cm ³	Thick- ness, cm	East	West
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.

407 17

CRITICAL DATA FOR SMALL-CORE ASSEMBLIES

Assem- bly No.	Critical Mass, kg Oy	C/Oy	$\bar{\rho}_C$, gm/cm ³	$\bar{\rho}_{Be}$, gm/cm ³	Beryllium Island Radius, cm	Core Outside Radius, cm	Reflector thickness, cm		
							Wall	East End	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
Core Length: 76.2 cm									

*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.

407-18

IV.
TABLE ~~III~~

ADJUSTED EXPERIMENTAL AND COMPUTED CRITICAL MASSES

11 cm thick Be reflector,

$$\bar{\rho}_C = 1.34 \text{ gm/cm}^3, \bar{\rho}_{Be} = 1.80 \text{ gm/cm}^3$$

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

*The formulae 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 formulae should be compared with the corresponding values for Assemblies 8 and 9 to indicate calculational difficulties rather than a reactivity index of Assembly 10.

TABLE ~~III~~ ^V.
PARAMETERS FOR S_4 CALCULATIONS

Cross Sections Are 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

Notes: Values of average logarithmic energy decrement per collision are $\xi(\text{Be}) = 0.209$ and $\xi(\text{C}) = 0.158$ except for the 10th group, where $\xi(\text{Be}) = 0.146$ and $\xi(\text{C}) = 0.133$.

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

$$\sigma_{10 \rightarrow 9}(U^{235}) = 1.0, \sigma_{10 \rightarrow 8}(U^{235}) = 0.3, \sigma_{9 \rightarrow 8}(U^{235}) = 0.45,$$

$$\sigma_{10 \rightarrow 9}(U^{238}) = 1.5, \sigma_{10 \rightarrow 8}(U^{238}) = 0.4, \sigma_{9 \rightarrow 8}(U^{238}) = 0.6.$$

The $\text{Be}(n, 2n)$ cross section in the tenth group is 0.11 and the associated transfer cross section is

$$\sigma_{10 \rightarrow 8}(\text{Be}) = 0.22.$$

High with
- plug

TABLE V.
II. (continued)

$\sigma_c(U^{238})$	$\sigma_f(U^{238})$	$\sigma_{tr}(U^{238})$	$\sigma_c(Be)$	$\sigma_{es}(Be)$	$\sigma_{tr}(Be)$	$\sigma_c(C)$	$\sigma_{es}(C)$	$\sigma_{tr}(C)$
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