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SUBJECT: Preliminary Report on 2% U^{235}-Enriched UF_4-$C_{25}H_{52}$ Critical Assemblies

TO: Distribution

FROM: J. T. Mihalczo, J. J. Lynn, Dunlap Scott, and W. C. Connolly

ABSTRACT

A series of critical experiments with blocks of 2% U^{235}-enriched UF_4-$C_{25}H_{52}$ has been initiated at the ORNL Critical Experiments Facility. Thus far assemblies with H:U^{235} atomic ratios of 195 and 294 have been built in parallelepipedal and simulated cylindrical geometries, both reflected and unreflected. From the results the minimum critical masses for reflected spheres have been determined to be 16.3 and 8.5 kg of U^{235} for fuel mixtures with H:U^{235} atomic ratios of 195 and 294, respectively. The minimum critical masses for unreflected spheres of these two fuel mixtures are 24.3 and 12.7 kg of U^{235}, respectively.

NOTICE

DISCLAIMER

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INTRODUCTION

A knowledge of the nuclear properties of homogeneous, hydrogen-moderated assemblies of slightly enriched uranium will allow the establishment of bases for nuclear safety specifications and will also provide information of general use in reactor analysis. This information is currently being obtained in a series of measurements at the ORNL Critical Experiments Facility with blocks of homogeneously mixed uranium tetrafluoride (UF_4) and paraffin ($C_{25}H_{52}$) in which the U^{235} isotopic content of the uranium is 2.00%. This memorandum is intended to present the information obtained thus far.

I. MATERIALS

Two fuel mixtures have been prepared, one containing 92.13 wt% UF_4 and the other containing 88.6 wt% UF_4, corresponding to $H:U^{235}$ atomic ratios of 195 and 294, respectively. The uranium densities in the two mixtures are 3.1 and 2.6 g/cc, respectively. The UF_4-paraffin mixture is in the form of blocks 1, 2, and 4 in. high with base dimensions that are 1, 2, or 4 in. square. The blocks are covered with 0.8-mil-thick aluminum foil to enable easier handling of the material. The variation in the weights of the fuel blocks is shown in Appendix A, along with the results of spectrochemical analyses of the fuel materials and a screen analysis of the UF_4 particle size. The composition of the fuel material is uniform and free from significant amounts of neutron poisons. The UF_4 particle size is less than 297 microns, the average particle size being about 150 microns.

The reflector materials used in the assemblies reported here are in most cases plexiglas (ρ = 1.2 g/cc) on the bottom and paraffin (ρ = 0.93 g/cc) on the sides and top. The results of an analysis for hydrogen in the paraffin and the results of a spectrographic analysis of the paraffin, both of which are shown in Appendix B, indicate that the hydrogen in the paraffin is uniformly distributed and that the paraffin is free from significant amounts of neutron poisons. The paraffin used in the reflector was the same as that used in the fuel mixtures. The reflector paraffin is covered with muslin or onion skin paper. The results of chemical analyses for neutron poisons in the muslin and the paper are also given in Appendix B.

II. DESCRIPTION OF ASSEMBLIES

The UF_4-paraffin blocks were stacked on an aluminum table which has a movable half and a fixed half, each consisting of a honeycomb of horizontal aluminum tubes into which the bottom reflector material was placed. Each cell of the honeycomb, made of 0.047-in.-thick 2S aluminum, is 3 by 3 in. square (outside dimensions) and 3 ft long. Plexiglas blocks were inserted into the top two layers of cells, resulting in a 6-in.-thick bottom reflector. The plexiglas volume fraction in the bottom reflector was 0.918, and the aluminum volume fraction was 0.062. Blocks of paraffin making up the side and top reflectors were stacked around the fuel blocks. A typical assembly is shown in Fig. 1.

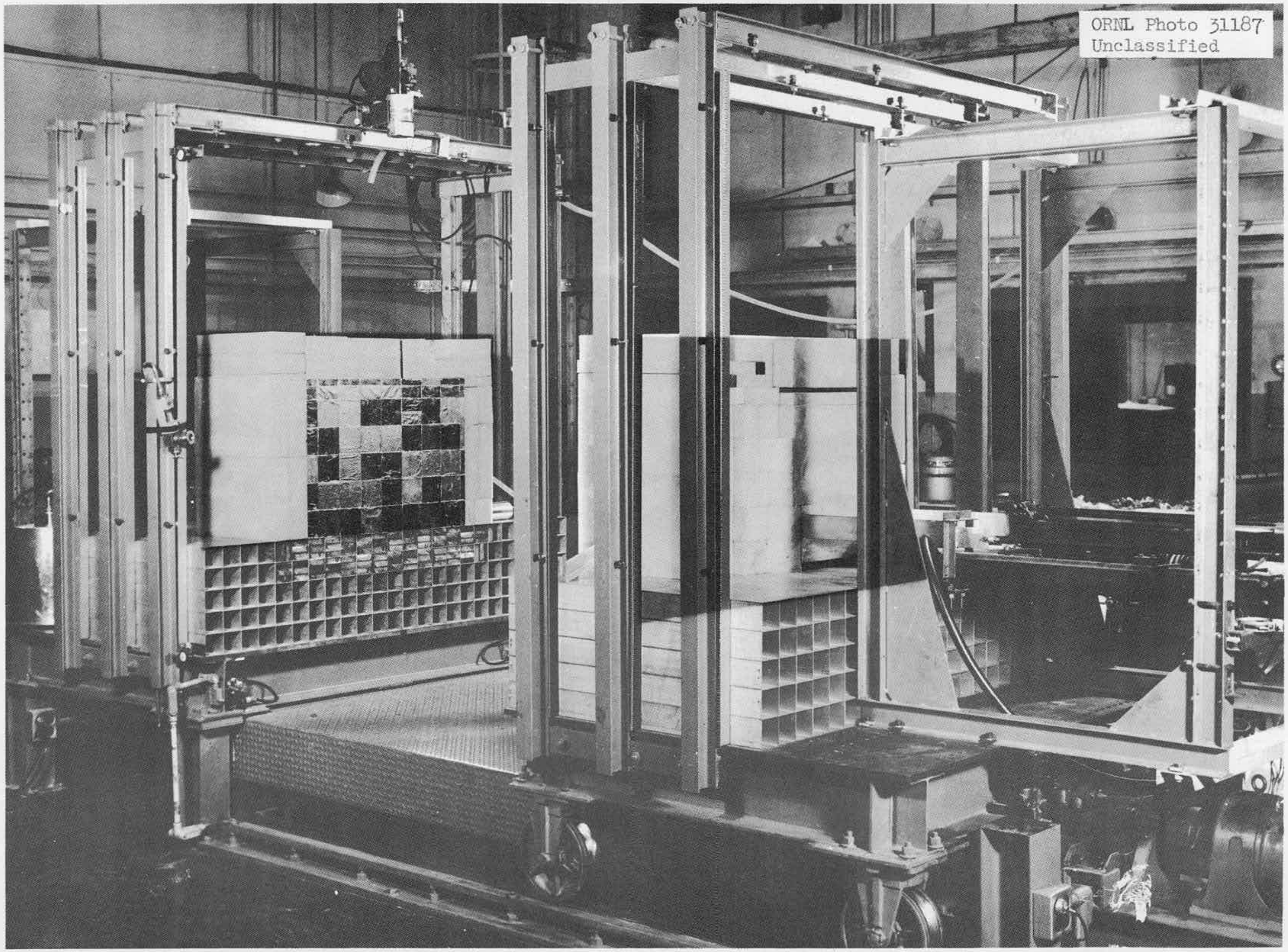

Fig. 1. View of a Reflected Assembly

Two horizontal aluminum-clad boron-filled safety blades and two similar horizontal control blades were used with each assembly. One safety and one control blade were located in each half of each assembly 15.5 in. apart and 4 in. above the table top. Special UF_4-paraffin blocks and reflector blocks were stacked around the control blade guide tubes. The guide tubes, which were aluminum, occupied between 60 and 100 cu in. of the core volume, depending upon the geometry.

Both parallelepipedal and cylindrical geometries were assembled, some of which were surrounded with an effectively infinite reflector of paraffin and plexiglas. The cross-sectional areas of the bases of the cylindrical assemblies, which were actually simulated cylinders, are shown in Figs. 2 and 3. The base of each parallelepiped was square.

Owing to the thickness of the aluminum foil covering the fuel, the variation in fuel block size, and small voids introduced in stacking the fuel blocks, the dimensions of the stacked assembly were slightly larger than the combined thicknesses of the individual fuel blocks. The dimensions given in the figures and tables are nominal; that is, they represent the combined thicknesses of the fuel blocks. Several measurements of the stacked assemblies were made to determine the increase in the nominal dimensions. Horizontal dimensions should be increased 0.61% to obtain actual dimensions of the core and vertical dimensions should be increased 0.45%.

III. EXPERIMENTAL RESULTS

The critical masses and critical heights of reflected assemblies of the blocks having an $H:U^{235}$ ratio of 195 are plotted as a function of the base dimensions in Figs. 4 and 5 and recorded in Table C-1 of Appendix C. The critical masses of both the reflected and the unreflected assemblies of blocks having an $H:U^{235}$ ratio of 294 are presented in Figs. 6 and 7 and Table C-2. The variation of the minimum critical mass with $H:U^{235}$ atomic ratio is shown in Fig. 8, and the variation of the minimum critical volume with the $H:U^{235}$ atomic ratio is plotted in Fig. 9. The method for determining the points for $H:U^{235}$ ratios of 245 and 400 is described on page 17. Several assemblies of the fuel blocks with an $H:U^{235}$ atomic ratio of 195 were built with reflector variations, the results of which are shown in Table 1.

Method of Extrapolating the Critical Height

Since the smallest fuel block dimension was 1 in., changes in the assembly heights of less than 1 in. could not be made directly. As a result, some of the experimental assemblies had top layers, either full or partial, that contained excess fuel which was compensated for by an inserted control rod. The worth of the inserted rod was evaluated for each such

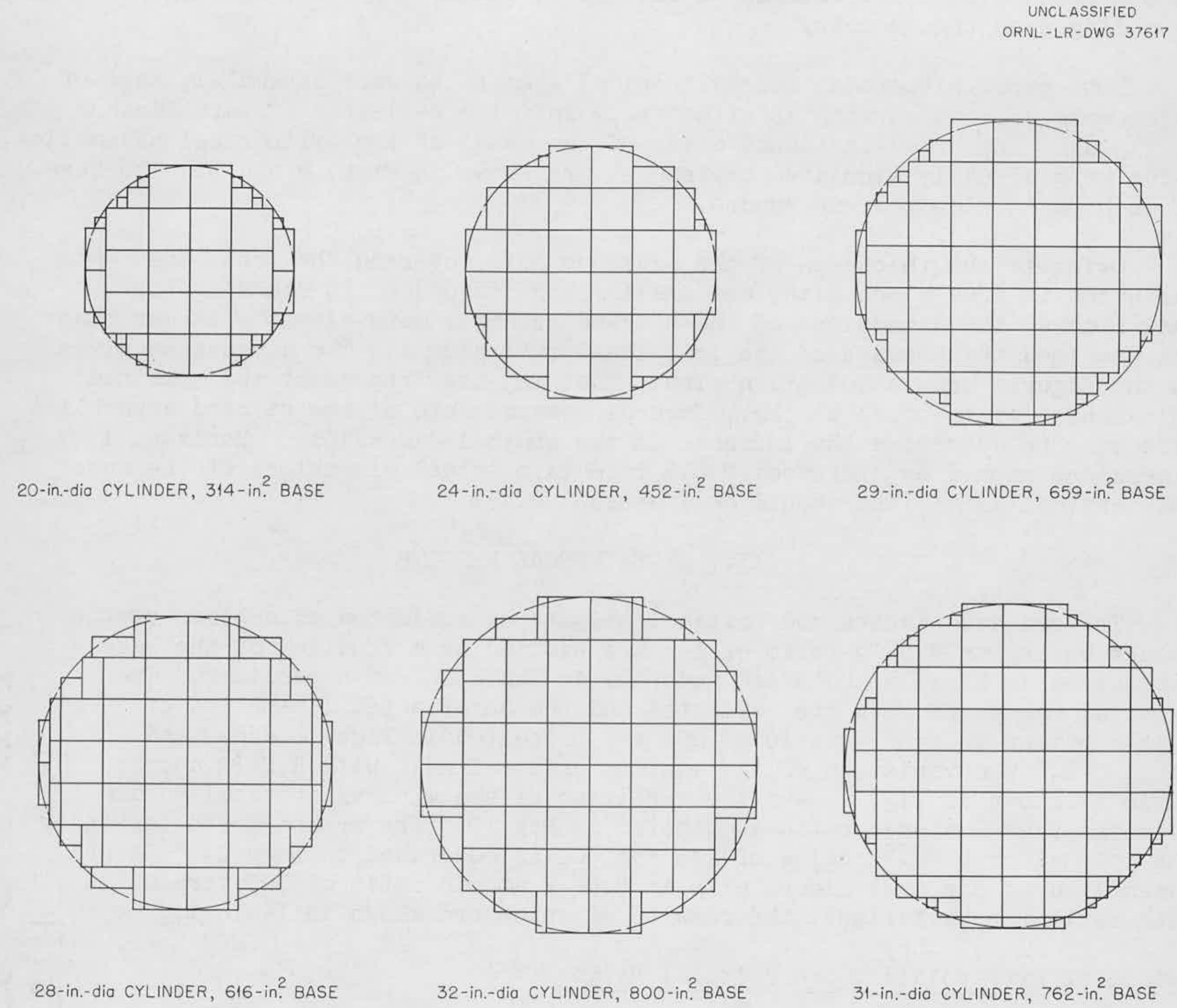

Fig. 2. Fuel Block Arrangement for Simulated 20-to 31-in.-dia Cylindrical Assemblies of 2% U^{235}-Enriched UF_4-$C_{25}H_{52}$

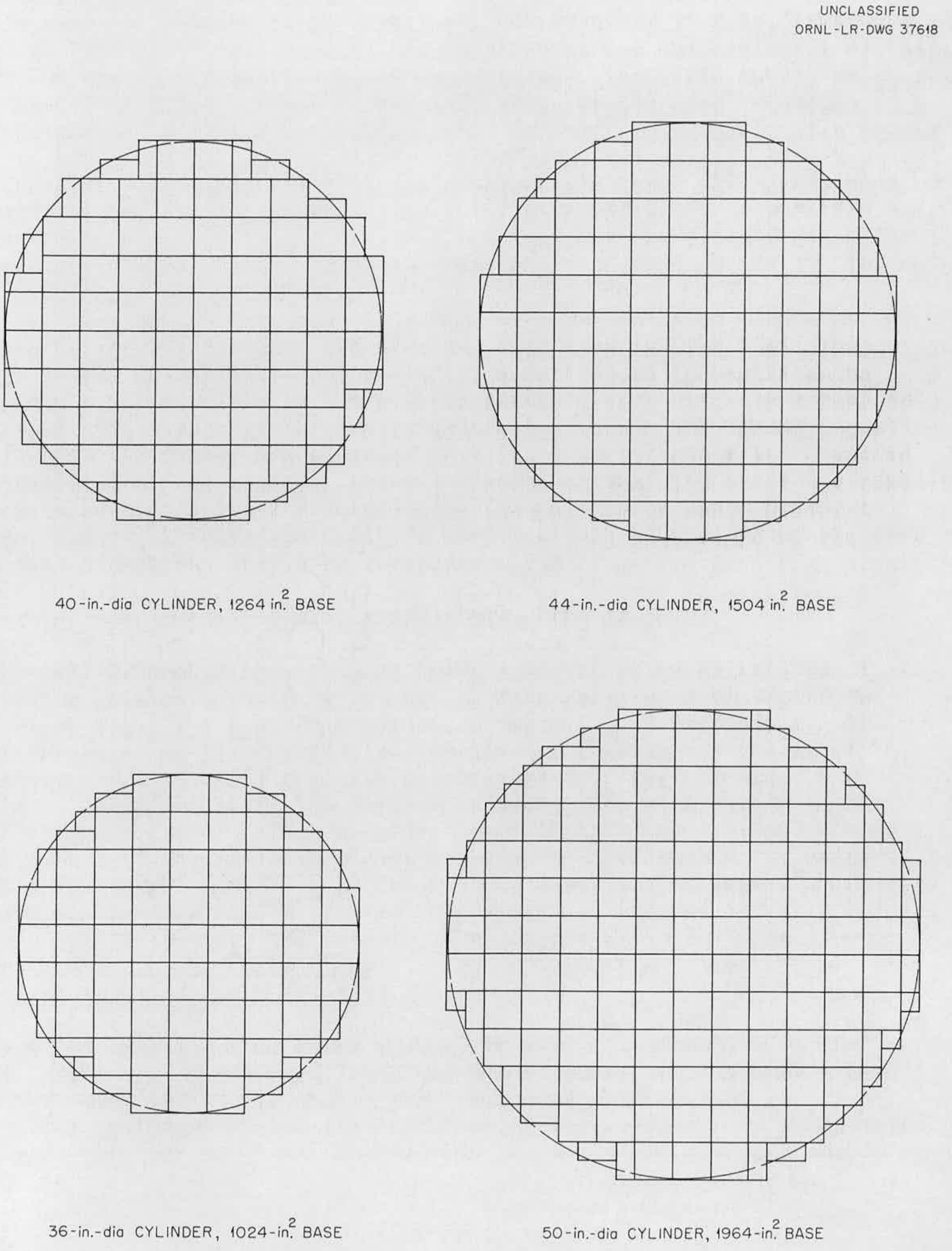

Fig. 3. Fuel Block Arrangement for Simulated 40- to 50-in.-dia Cylindrical Assemblies of 2% U^{235}-Enriched UF_4-$C_{25}H_{52}$

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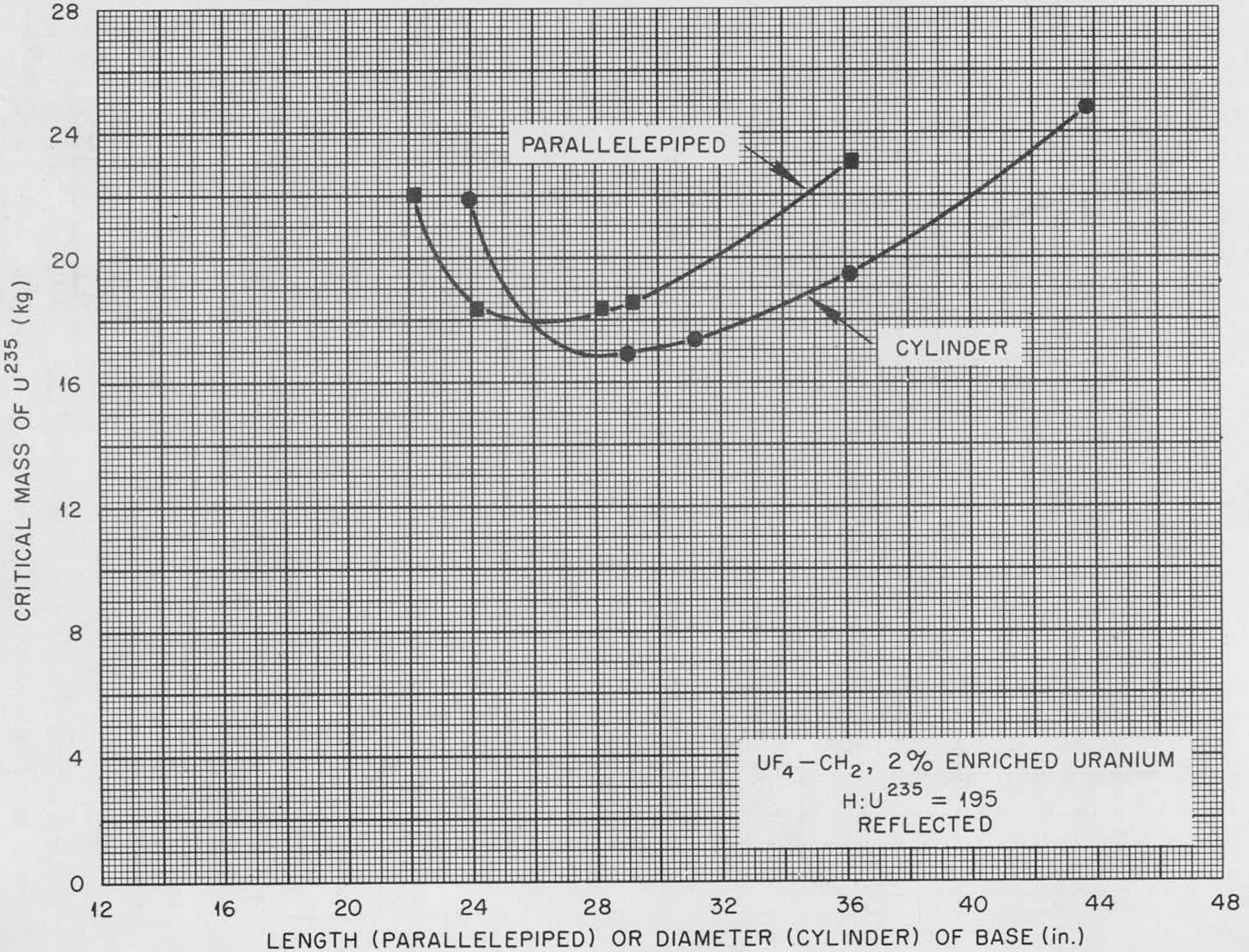

Fig. 4. Critical Masses as a Function of the Base Dimensions of Reflected Assemblies of a Fuel Mixture with an $H:U^{235}$ Atomic Ratio of 195

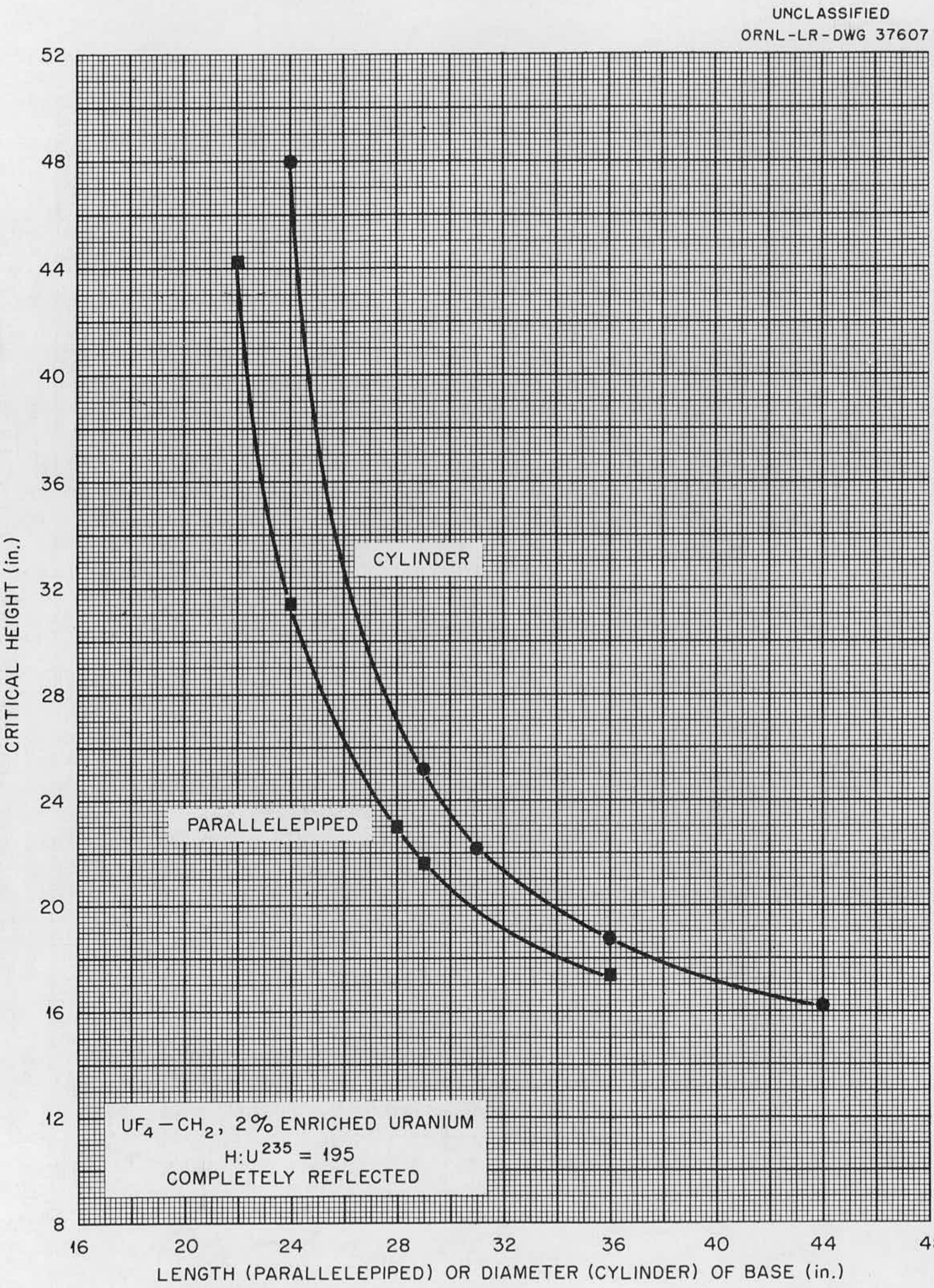

Fig. 5. Critical Heights as a Function of the Base Dimensions of Reflected Assemblies of a Fuel Mixture with an $H:U^{235}$ Atomic Ratio of 195

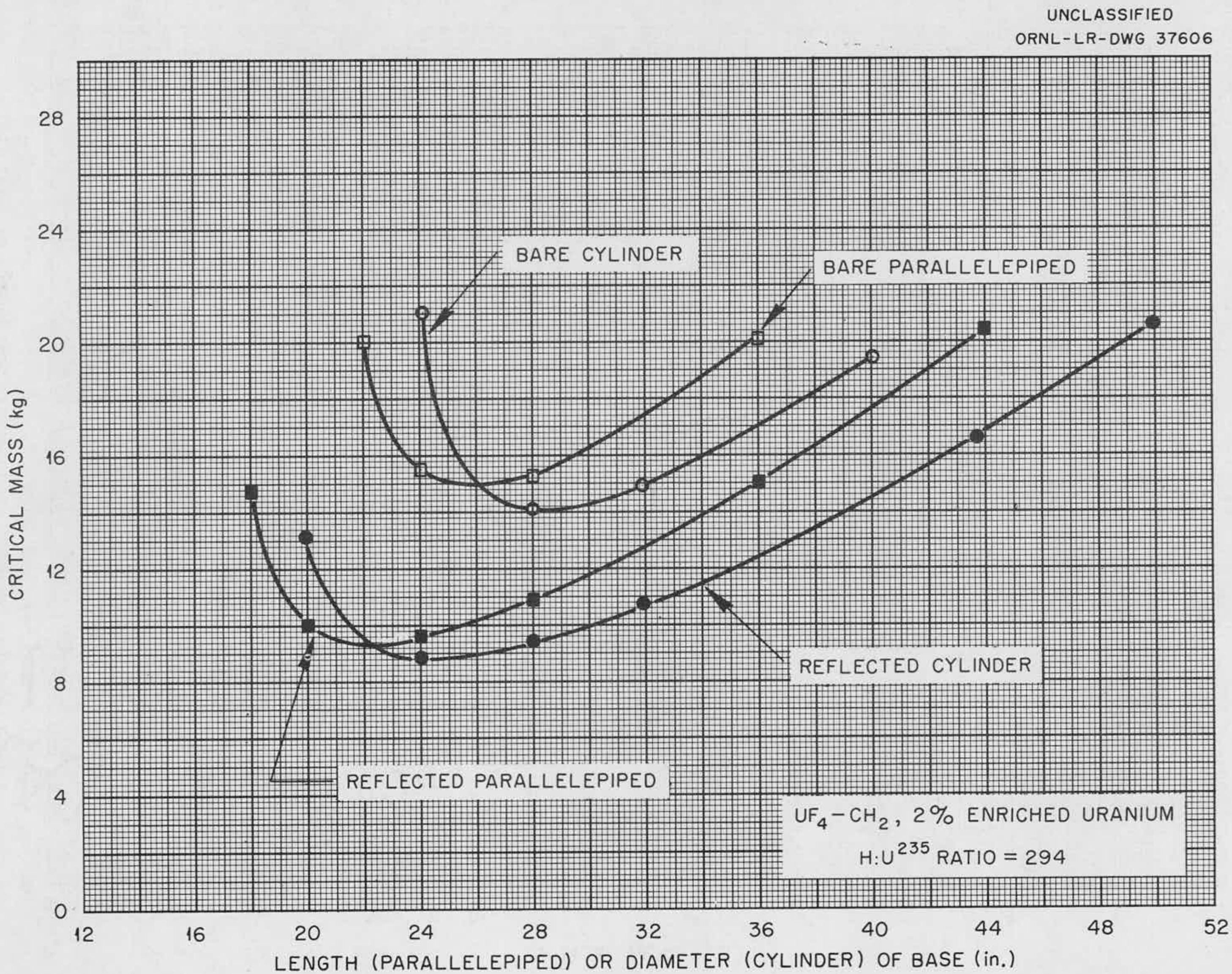

Fig. 6. Critical Masses as a Function of the Base Dimensions of Assemblies of a Fuel Mixture with an $H:U^{235}$ Atomic Ratio of 294

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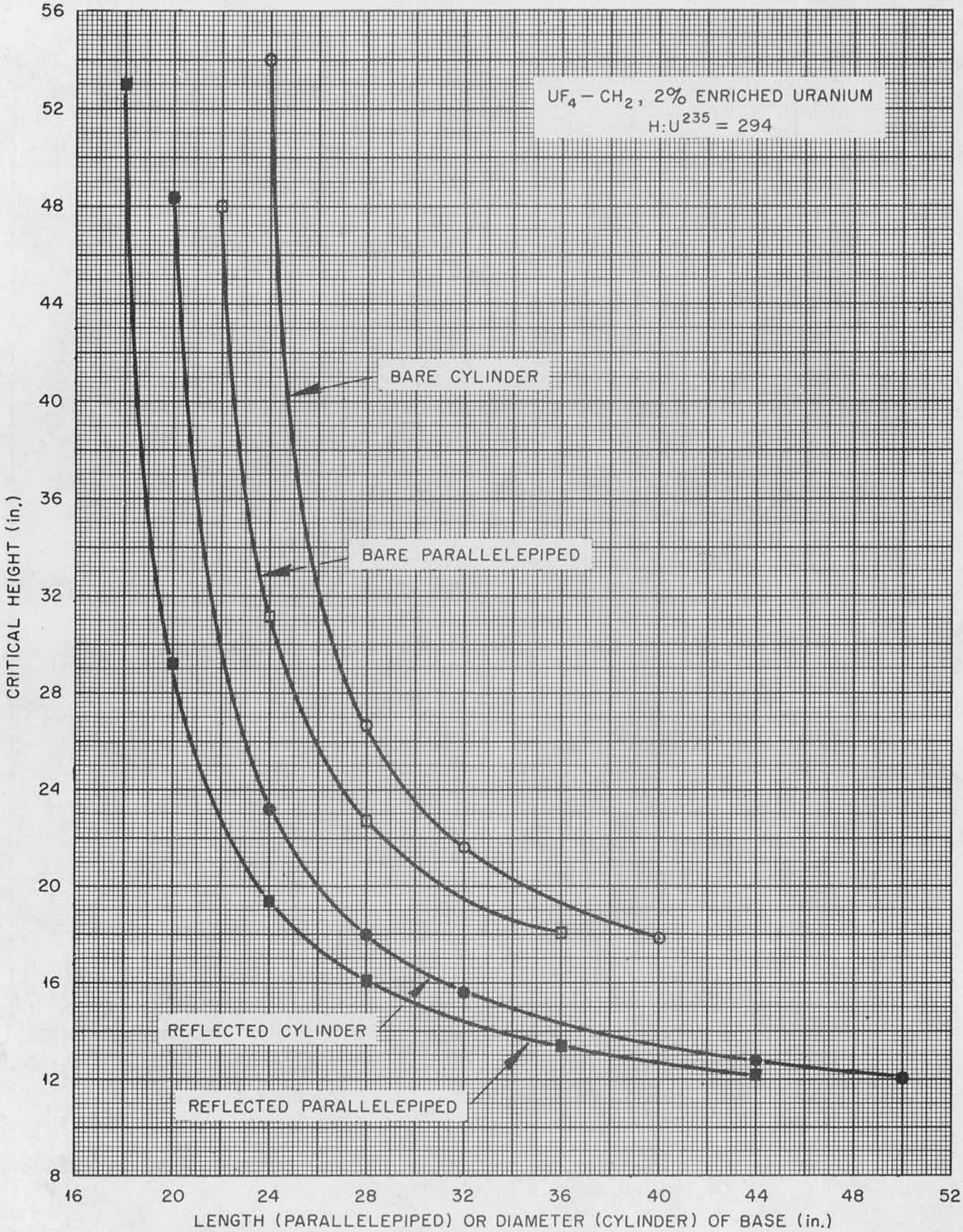

Fig. 7. Critical Heights as a Function of the Base Dimensions of Assemblies of a Fuel Mixture with an $H:U^{235}$ Atomic Ratio of 294

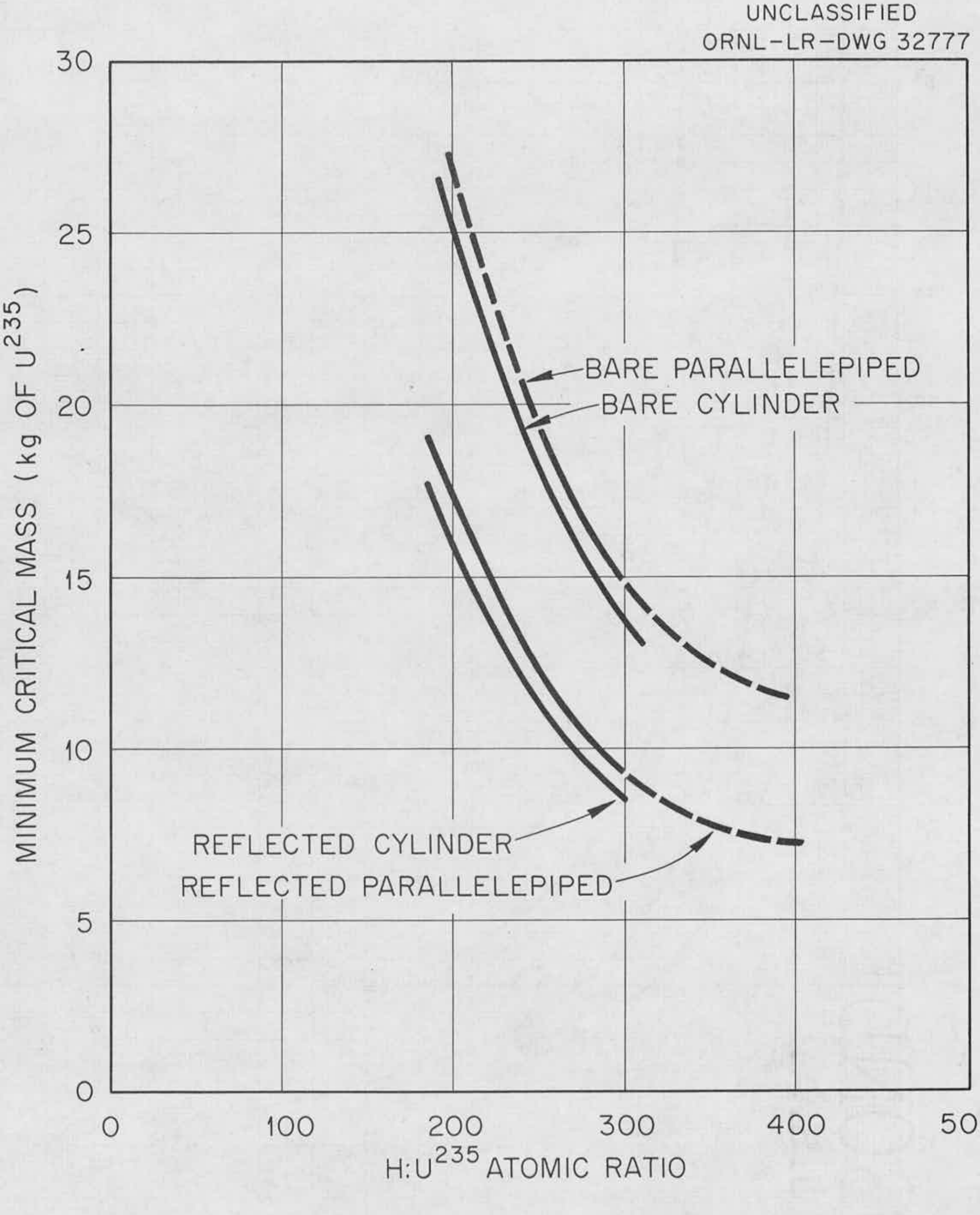

Fig. 8. Minimum Critical Masses of 2% U^{235}-Enriched UF_4-CH_2 Assemblies as a Function of the $H:U^{235}$ Atomic Ratio

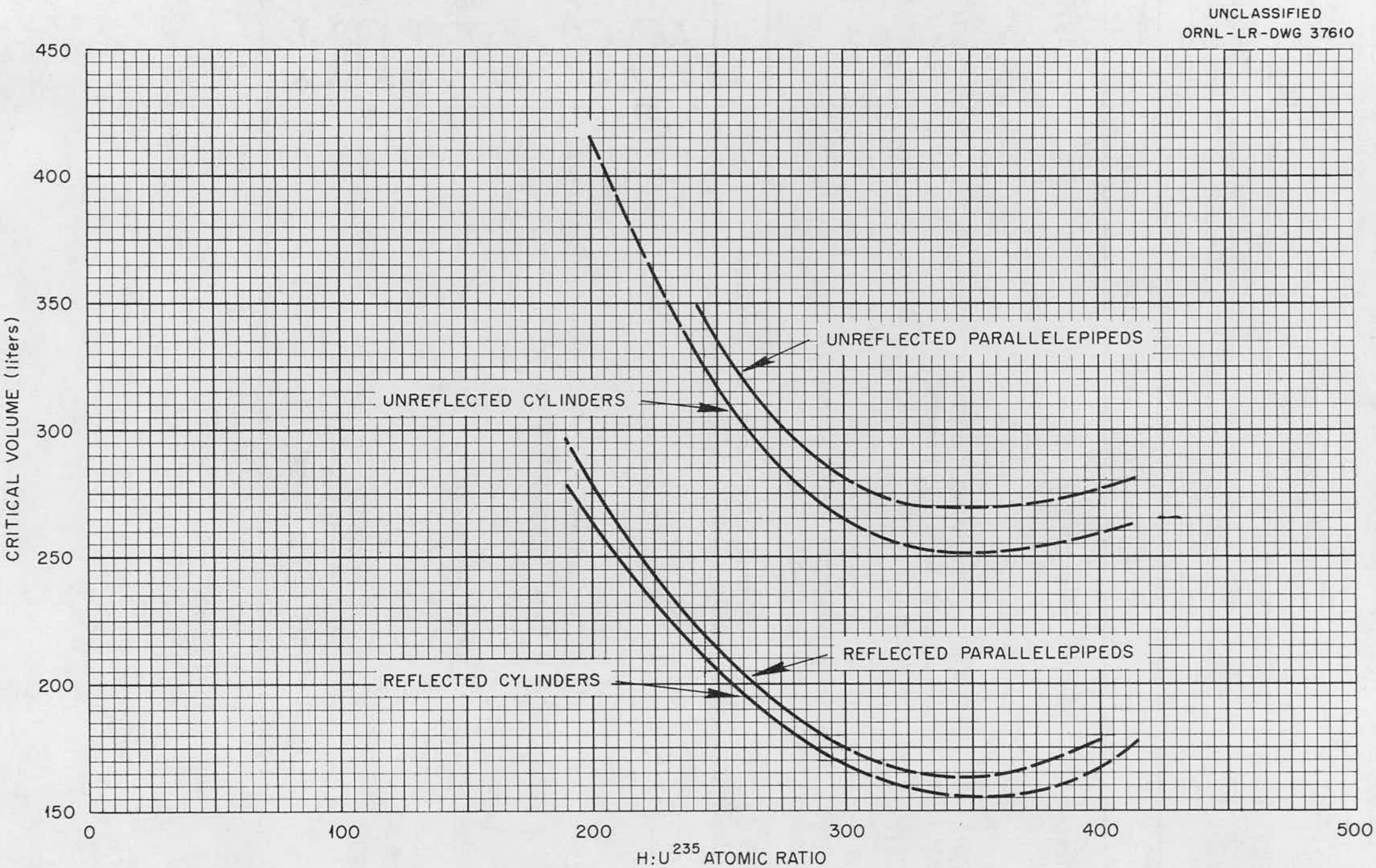

Fig. 9. Minimum Critical Volumes of 2% U^{235}-Enriched UF_4-CH_2 Assemblies as a Function of the H:U^{235} Atomic Ratio

Table 1. Critical Heights and Critical Masses of Assemblies with Various Reflectors

$H:U^{235}$ Atomic Ratio: 195

Length or Diameter of Core Base (in.)	Reflector	Critical Height (in.)	Critical Mass (kg of U^{235})
	Cylindrical Assemblies		
29	6 in. of paraffin on sides; top and bottom unreflected	29.5	19.9
31	6 in. of paraffin on sides; top and bottom unreflected	26.7	20.8
36	6 in. of paraffin on sides; top and bottom unreflected	23.2	24.3
	Parallelepipedal Assemblies		
28	6 in. of paraffin on two sides; two sides, top, and bottom unreflected	31.0	24.9
28	6 in. of paraffin on sides; top and bottom unreflected	27.1	21.7
29	6 in. of paraffin on sides; top and bottom unreflected	26	22.3
29	6 in. of paraffin on top; 6 in. of plexiglas on bottom; sides unreflected	29.0	24.9

assembly, and an extrapolation to the critical height of the assembly with a uniform top layer was made. For this extrapolation it was assumed that the reactivity of the assembly was proportional to the amount of excess fuel in the top layer. It was further assumed that the distribution of the fuel in the top layer had no effect on the critical system; that is, a 1-in.-thick layer of fuel covering one quadrant of the top of the assembly was equivalent to a 1/4-in.-thick layer covering the entire top of the assembly. The critical heights of both the reflected and the unreflected assemblies were determined in this manner.

In order to check the validity of this extrapolation, an experiment was performed in which various thicknesses of plexiglas were placed in different positions on the top of an assembly that was reflected on the sides. The reactivity effects of all the arrays are shown in Table C-3 of Appendix C, and the variation in the reactivity of the assembly with the thickness of the plexiglas on one quadrant of the top of the assembly is shown in Fig. 10. It was found that a 1/2-in. thickness of plexiglas on one quadrant of the top was approximately equivalent to a 1/8-in. thickness over the entire top. For the system studied, 1 in. of plexiglas was approximately equivalent to 1 in. of fuel.

The error in reported critical heights introduced by the irregular top fuel layer is, therefore, estimated to be less than ± 0.1 in. Fuel blocks with thicknesses of 1/4 and 1/2 in. are being prepared. The use of these fuel blocks will enable further verification of the above assumptions.

Effect of Aluminum Control Blade Guide Tubes

In order to determine the magnitude of the effect of the four control blade guide tubes present in all of the assemblies, an additional guide tube was placed in a completely reflected 24 by 24 by 20 in. assembly of the fuel mixture with an $H:U^{235}$ atomic ratio of 294, and its effect on the reactivity was determined. As explained previously, the four standard guide tubes were placed in pairs in each of the two halves of the assemblies 4 in. from the bottom of the core and 15.5 in. apart. In this assembly this resulted in the tubes each being positioned 4 in. from the side of the core; therefore, the additional guide tube was inserted in the upper portion of the movable half of the assembly 4 in. from one side and 4 in. from the top. It caused the reactivity of the system to be decreased by 6 cents.

The top fuel layer of this assembly was 1 in. thick, and the value of one quadrant of the top layer was determined to be worth 24 cents. Since the combined worth of the four standard guide tubes was also about 24 cents, the four tubes increased the critical height of the assembly by 1/4 in. or 1.25%. The data reported in the tables and figures of this memorandum are not corrected for the effect of the control blade guide tube.

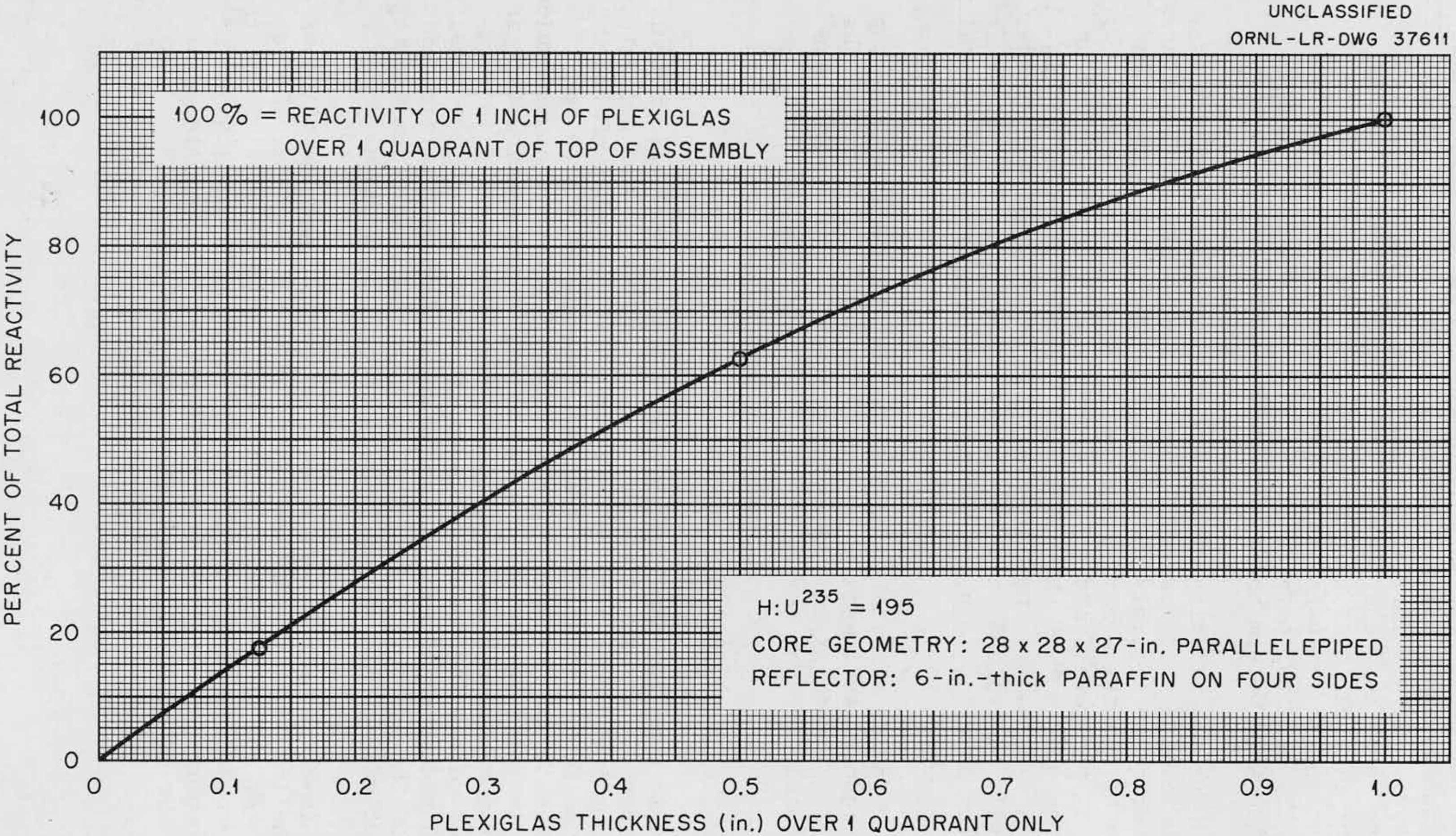

Fig. 10. Variation in Reactivity with the Thickness of a Reflector on One Quadrant of the Top of a 2% U^{235}-Enriched Assembly of UF_4-CH_2

Comparison of Paraffin and Plexiglas as Reflectors

As a structural convenience, the bottom reflector in the reflected assemblies was plexiglas while the side and top reflectors were paraffin. In order to determine the relative effectiveness of paraffin and plexiglas as reflector materials, various thicknesses of each were used as the top reflector of a parallelepipedal assembly of the fuel mixture with an $H:U^{235}$ atomic ratio of 195. This assembly, which had dimensions of 26 by 26 by 24 in., was completely reflected on all other sides. The dependence of the reactivity of the assembly upon the top reflector thickness for the two materials is shown in Fig. 11 and in Table C-4 of Appendix C. For thicknesses greater than about 2.4 in., plexiglas is a better reflector than paraffin because of its smaller absorption cross section. For thicknesses less than 2.4 in., paraffin is the better reflector because of its larger scattering cross section. The critical masses and critical heights given for reflected assemblies in Figs. 3 through 6 are for systems whose bottom reflectors consisted of 6 in. of plexiglas and top and side reflectors consisted of 6 in. of paraffin. Since the difference in reactivity between plexiglas and paraffin was about 1 cent for 18 percent of the top reflector, an assembly that was totally reflected with paraffin would have been about 5 cents less reactive than the assemblies studied. This is a small correction to the observed critical masses and critical heights which was not included in the data presented in this memorandum.

Assemblies with "Effective" $H:U^{235}$ Atomic Ratios

In order to investigate the variation of the critical mass and volume with the $H:U^{235}$ atomic ratio, several assemblies were constructed in which blocks of the fuel mixtures were latticed with plexiglas to increase the $H:U^{235}$ atomic ratio. By using plexiglas with blocks of the mixture having an $H:U^{235}$ atomic ratio of 294, for example, assemblies with "effective" $H:U^{235}$ atomic ratios of 385 and 402 were constructed. Similarly, by using plexiglas with blocks of the mixture having an $H:U^{235}$ atomic ratio of 195, assemblies with an effective ratio of 286 were constructed.

The validity of using this method to obtain the higher $H:U^{235}$ ratios was checked with an assembly in which blocks of the fuel having an $H:U^{235}$ atomic ratio of 195 were latticed with plexiglas to obtain an effective ratio of 295. The critical mass of the assembly was 9.87 kg of U^{235}. This is to be compared with a critical mass of 9.60 kg of U^{235} which was determined directly with the fuel blocks having a ratio of 294.

In four additional assemblies, blocks of the two available fuel mixtures were alternated to obtain an effective $H:U^{235}$ atomic ratio of 245. In another assembly enough blocks of the fuel mixture having an $H:U^{235}$ atomic ratio of 294 were distributed in an unreflected assembly of the fuel mixture having a ratio of 195 to make the assembly critical. (An unreflected system

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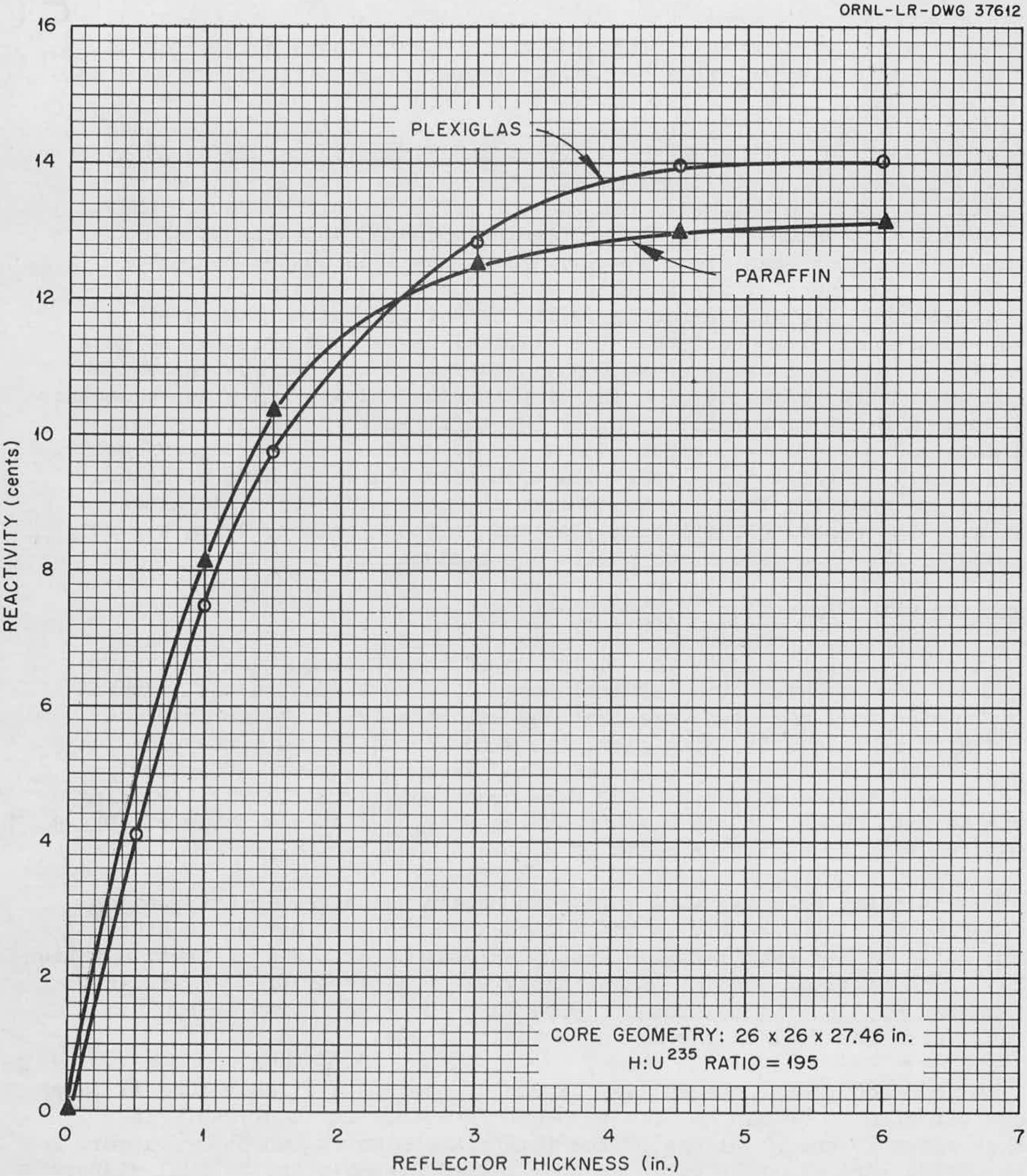

Fig. 11. Comparison of the Reactivity Effects of Paraffin and Plexiglas as a Function of the Thickness of the Material on Top of a 2% U^{235}-Enriched UF_4-CH_2 Assembly

with blocks having the ratio of 195 could not be made critical with the 25 kg of U^{235} available.) The final effective ratio of the critical assembly was 199.

The results of this series of experiments are presented in Tables 2 and 3 and serve as a basis for the extrapolations of the plots of minimum critical mass and minimum critical height versus the $H:U^{235}$ atomic ratio shown in Figs. 7 and 8. The error made in the extrapolations may be as large as 10%.

Table 2. Critical Heights and Critical Masses of Cylindrical Assemblies with Effective $H:U^{235}$ Atomic Ratios

Effective $H:U^{235}$ Atomic Ratio	Diameter of Core Base (in.)	Core Description	Critical Height (in.)	Critical Mass (kg of U^{235})
		Reflected* Assembly		
245	26	Alternate blocks of $H:U^{235}$ = 294 mixture and $H:U^{235}$ = 195 mixture	23.8	11.8
		Unreflected Assemblies		
245	30	Alternate blocks of $H:U^{235}$ = 294 mixture and $H:U^{235}$ = 195 mixture	28.4	18.9
199	33	Blocks of $H:U^{235}$ = 195 mixture with enough blocks of $H:U^{235}$ = 294 mixture to make system critical	30.0	25.8

*Reflected assembly had 6 in. of plexiglas on the bottom and 6 in. of paraffin on the top and sides.

Table 3. Critical Heights and Critical Masses of Parallelepipedal Assemblies with Effective $H:U^{235}$ Atomic Ratios

Effective $H:U^{235}$ Atomic Ratio	Base Dimensions (in.)	Core Description	Critical Height (in.)	Critical Mass (kg of U^{235})
		Reflected* Assemblies		
402	22 x 22	Blocks of $H:U^{235}$ = 294 mixture latticed with 1/2-in.-thick plexiglas in two dimensions	22.6	7.7
286	24 x 24	Blocks of $H:U^{235}$ = 195 mixture latticed with 1-in.-thick plexiglas in one dimension	24.6	12
286	24 x 24.5	Blocks of $H:U^{235}$ = 195 mixture latticed with 1/2-in.-thick plexiglas in one dimension	20.2	9.9
245	24 x 24	Alternate blocks of $H:U^{235}$ = 294 mixture and $H:U^{235}$ = 195 mixture	23.2	12.6
		Unreflected Assemblies		
385	26 x 26	Blocks of $H:U^{235}$ = 294 mixture latticed with 1/2-in.-thick plexiglas in two dimensions	24.6	11.8
245	28 x 28	Alternate blocks of $H:U^{235}$ = 294 mixture and $H:U^{235}$ = 195 mixture	27.0	19.9

*Reflected assemblies had 6 in. of plexiglas on the bottom and 6 in. of paraffin on the top and sides.

Determination of Fast Fission Factors

Fast fission factors were determined for two assemblies from measurements made with two miniature fission counters which were identical except that one chamber was lined with almost pure U^{238} (the U^{235} content was 7 ppm) and the other chamber was lined with uranium highly enriched in U^{235} (99.7% U^{235}). The counters were placed in flux-symmetric positions near the centers of the cores.

The ratio of the U^{238} fissions to the U^{235} fissions in the core of each assembly is given by

$$\delta = \frac{N_R^{28}}{N_R^{25}} \frac{\int_0^{28} \sigma_f^{28} \phi \, dE}{\int_0^{25} \sigma_f^{25} \phi \, dE} \tag{1}$$

where N_R^{28}/N_R^{25} is the $U^{238}:U^{235}$ atomic ratio in the core. The ratio of the response of the two counters in the core is given by

$$C = \frac{R_D}{R_E} = \frac{N_D^{28} \int_0 \sigma_f^{28} \phi \, dE + N_D^{25} \int_0 \sigma_f^{25} \phi \, dE}{N_E^{28} \int_0 \sigma_f^{28} \phi \, dE + N_E^{25} \int_0 \sigma_f^{25} \phi \, dE} \tag{2}$$

where the subscripts D and E refer to depleted (U^{238}) and enriched (U^{235}) chambers, respectively, and E is the fission fragment counting efficiency of the chamber.

By combining these two relations the ratio of U^{238} fissions to U^{235} fissions in the core can be written as

$$\delta = \frac{N_R^{28}}{N_R^{25}} \frac{N_E^{25}}{N_E^{28}} \frac{C(E_E/E_D) - N_D^{25}/N_E^{25}}{N_D^{28}/N_E^{28} - C(E_E/E_D)} \tag{3}$$

Since the response of the counting system was the same for the same current and the chambers were identical except for the uranium deposits, the ratio of the efficiency of the chambers was assumed to be equal.

The value for C obtained for a completely reflected 26 by 26 by 27 in. parallelepipedal assembly of the fuel mixture with an H:U^{235} ratio of 195 was 2.08×10^{-3}. The value for C obtained in the center of a reflected 28 by 28 by 23.4 in. parallelepipedal assembly of the same fuel mixture was 2.21×10^{-3}.

Using the relation

$$\epsilon - 1 = \frac{\nu^{28} - 1}{\nu^{25}} \delta$$

where $\nu^{28} = \nu^{25} = 2.5$, the fast fission factor ϵ was found to be 1.044 for the assembly with the 26-in.-square base and 1.047 for the 28-in.-square base.

The use of the two fission counters to determine the fast fission factor is based on the assumption that the neutron spectrum as seen by the counters is the same as that seen by the uranium in the fuel particles.

Foil Activation Measurements

Activation measurements were made with various foil detectors, both bare and cadmium-covered, in several fuel block assemblies, both cylindrical and parallelepipedal, having an H:U^{235} atomic ratio of 195. The foils were counted by scintillation counter techniques, and some of the resulting activities are shown in Figs. 12 through 15. The cadmium fractions for one reflected parallelepipedal assembly are given in Table 4, along with a description of the foils.

Extrapolation Distances; Reflector Savings; Bucklings

The flux distributions from the foil activation measurements reported in the preceding paragraph were used to obtain best fits to appropriate cosine or Bessel functions for assemblies with an H:U^{235} atomic ratio of 195. A least squares iteration technique was applied using the IBM-704 computer, and the data considered were confined to the asymptotic region to eliminate boundary effects. A three-parameter fit determined the buckling, the amplitude, and the best center of the distribution for each assembly. The buckling was then used with the actual dimensions of the assembly to obtain the extrapolation distance for that assembly. The extrapolation distance thus determined for a 26 by 26 by 27 in. parallelepipedal assembly with no top or bottom reflector was found to be about 2.9 cm at an unreflected boundary.

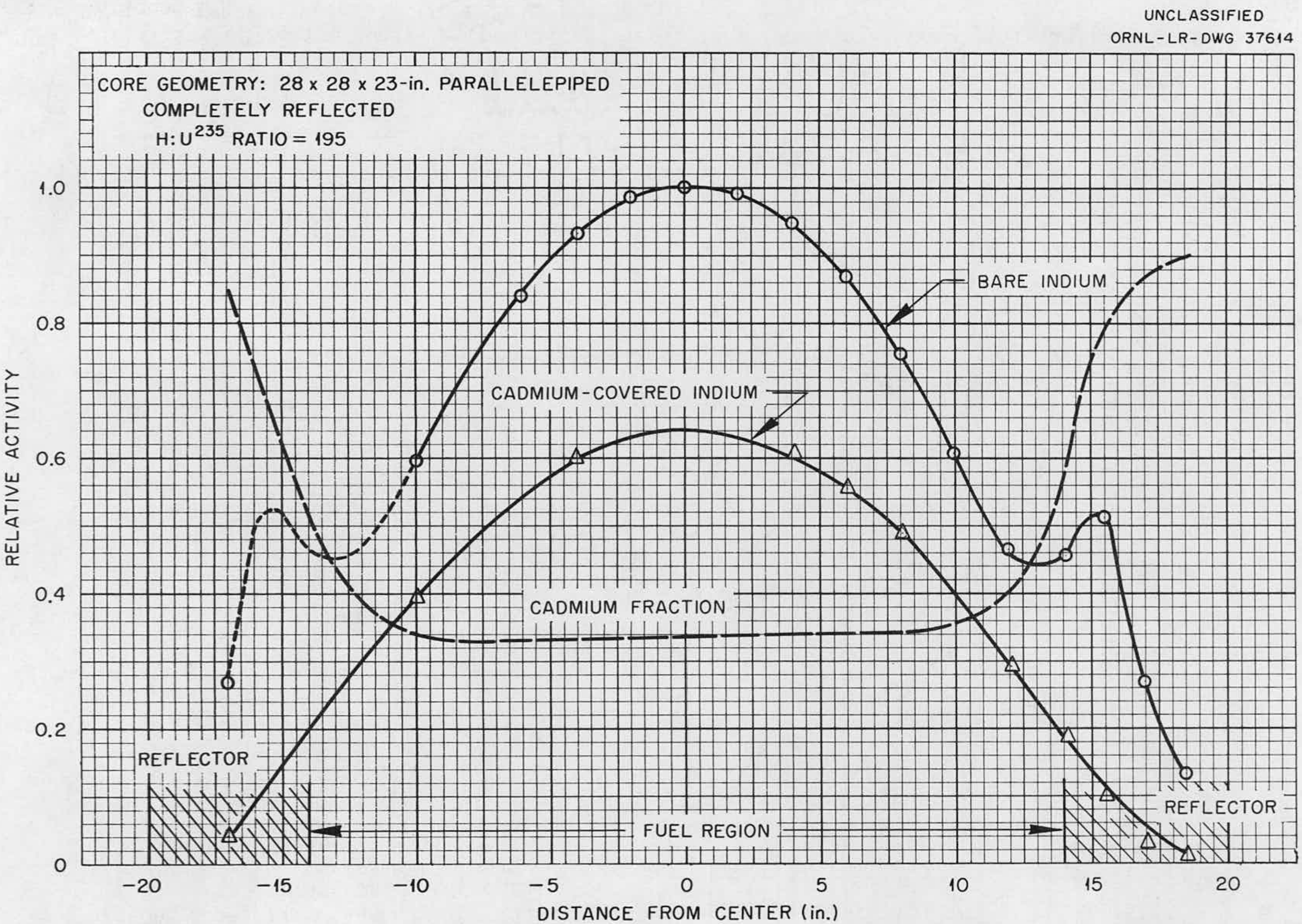

Fig. 12. Activities of Indium Foils Exposed Along a Horizontal Axis of a Completely Reflected 2% U^{235}-Enriched UF_4-CH_2 Assembly (Parallelepiped)

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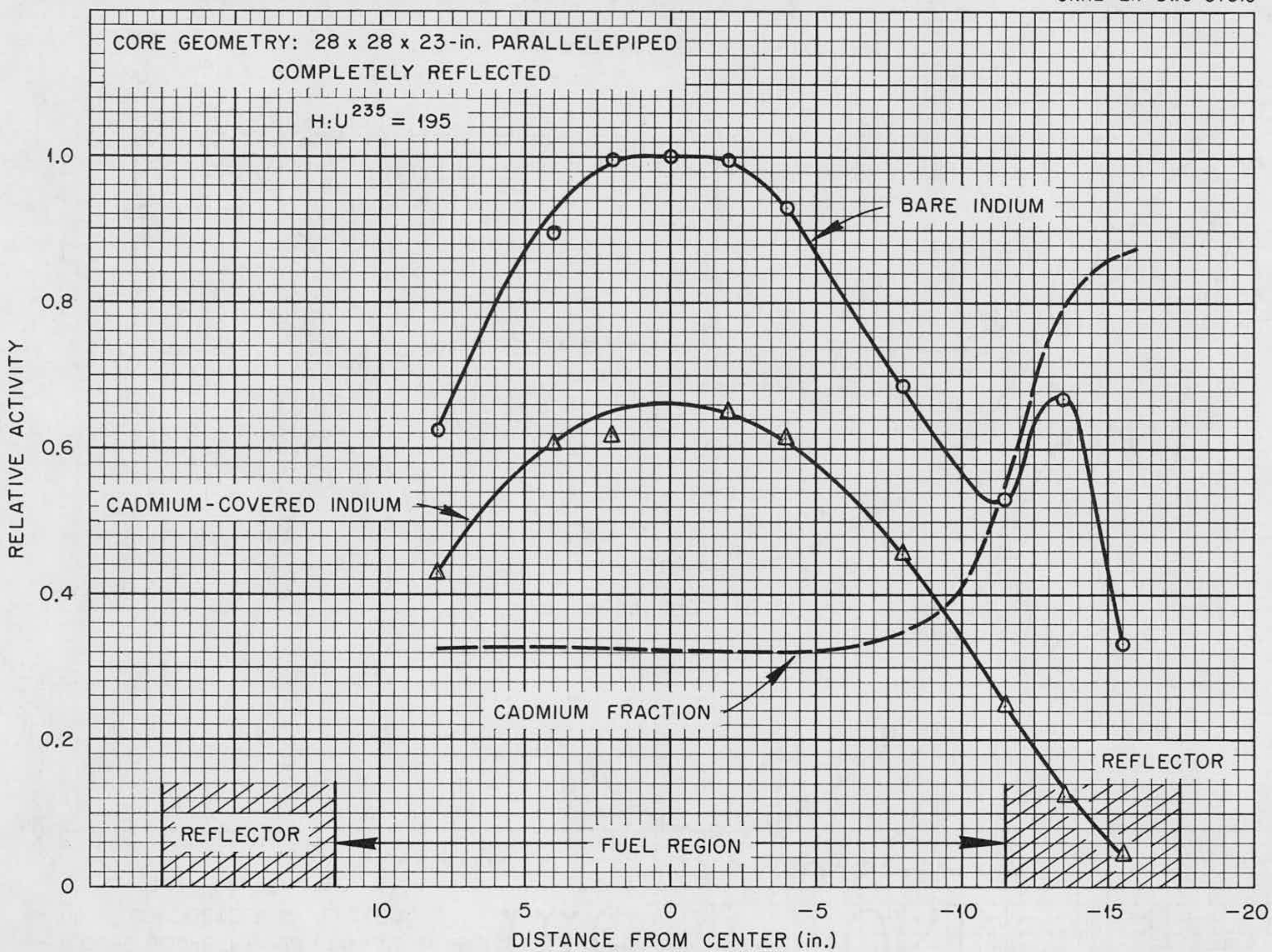

Fig. 13. Activities of Indium Foils Exposed Along the Vertical Axis of a Completely Reflected 2% U^{235}-Enriched UF_4-CH_2 Assembly (Parallelepiped)

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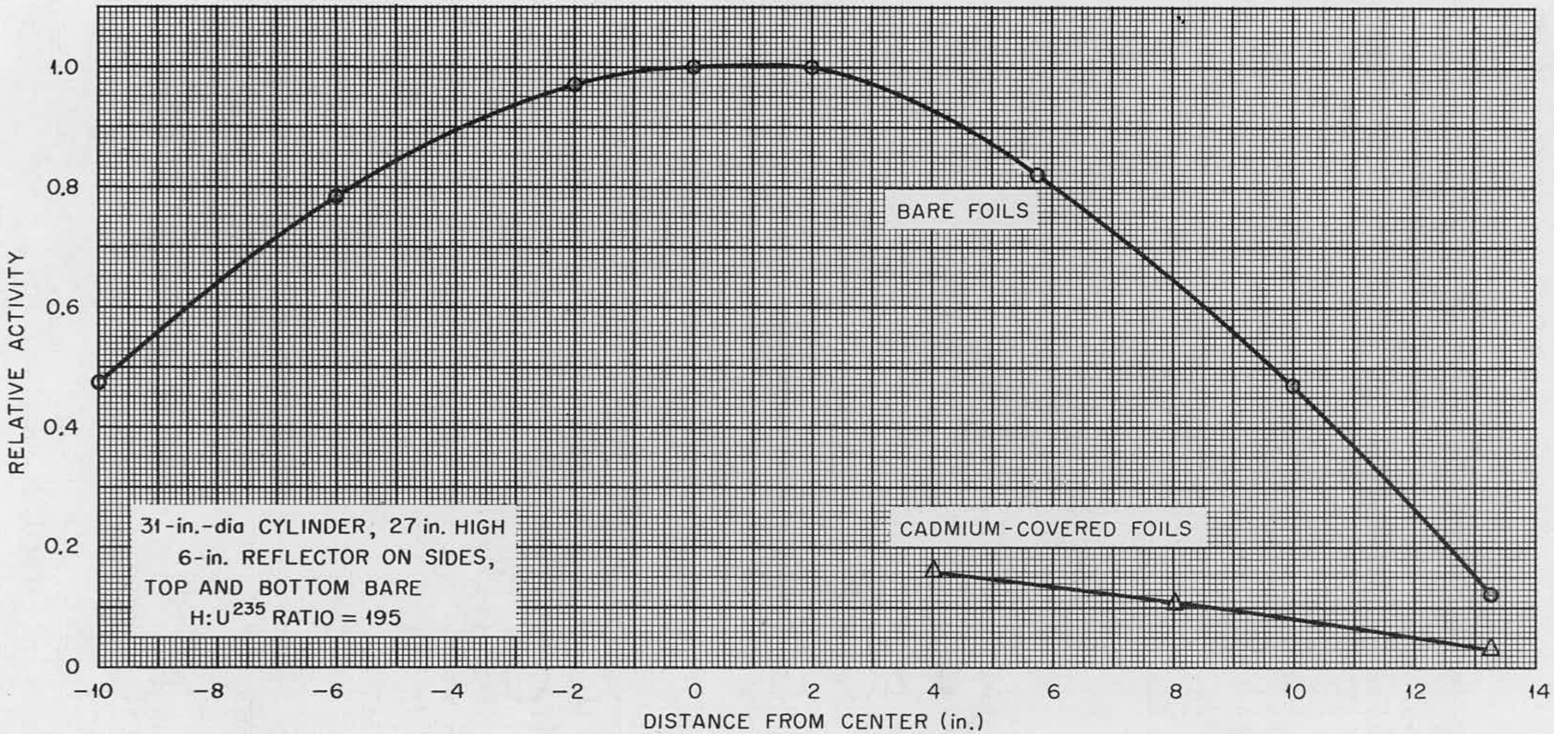

Fig. 14. Activities of UF_4 Foils Exposed Along the Axis of a Partially Reflected 2% U^{235}-Enriched UF_4-CH_2 Assembly (Cylinder)

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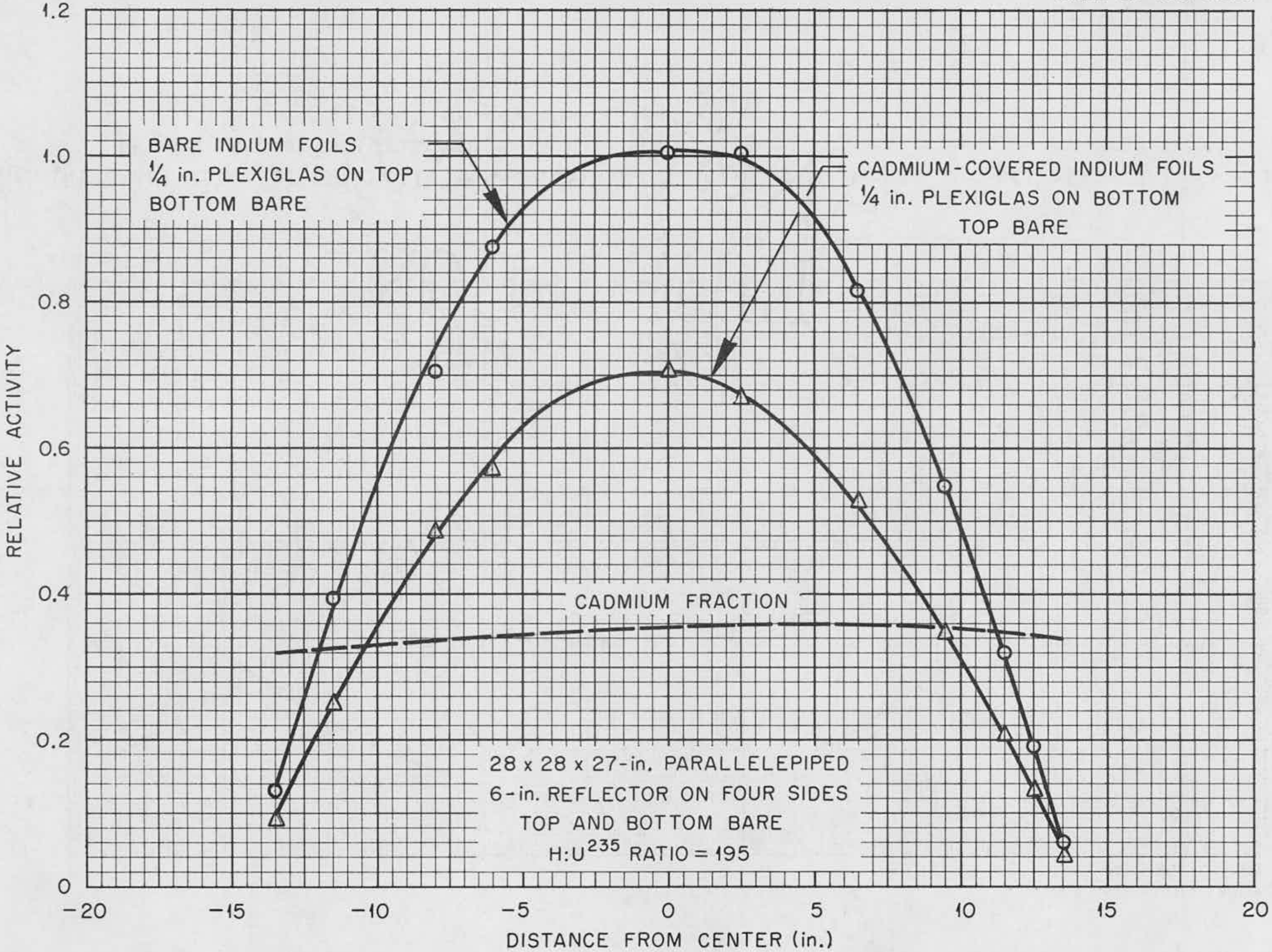

Fig. 15. Activities of UF_4 Foils Exposed Along the Vertical Axis of a Partially Reflected 2% U^{235}-Enriched UF_4-CH_2 Assembly (Parallelepiped)

Table 4. Cadmium Fractions in an Assembly with an $H:U^{235}$ Atomic Ratio of 195

Core Geometry: 26 by 26 by 27 in. parallelpiped
Reflector: Effectively infinite reflector on all sides

Detector				Cadmium Fraction**
Type		Thickness* (in.)	Diameter (in.)	
In	9.3 wt% In-Al alloy	0.010	5/16	0.34
Au	metal foil	0.002	5/16	0.48
UF_4	2% enriched, 98 wt% UF_4 + 2 wt% CH_2	0.020	1/2	0.80
U^{235}	93% enriched, 10 wt% U-Al alloy	0.005	5/16	0.88
U^{235}	93% enriched metal foil	0.002	5/16	0.87

*Cadmium cover thickness = 0.020 in.
**Cadmium fraction = (bare activity - cadmium-covered activity)/bare activity.

A comparison of the data of Tables 1 (on page 14) and Table C-1 (Appendix C) shows that the average reflector savings of an infinitely reflected parallelepipedal assembly having an $H:U^{235}$ atomic ratio of 195 is 5.6 cm.* By using this reflector savings and the extrapolation distance of 2.9 cm, the dimensions, and therefore the buckling, of the equivalent unreflected system for each reflected parallelepiped were obtained. The average buckling was found to be 4260×10^{-6} cm^{-2}, the maximum variation about this average being 20×10^{-6} cm^{-2}.

By interpolating the data of Table C-2 to a cubical geometry, an average reflector savings of 4.8 cm was obtained for an infinitely reflected assembly of the fuel mixture having an $H:U^{235}$ atomic ratio of 294. For this fuel mixture, the extrapolation distance is 2.5 cm; this value was obtained from the 2.9-cm extrapolation distance given for the $H:U^{235}$ = 195 assemblies

*The reflector savings as used here is the actual dimensional reduction of the fuel-bearing region and does not include the extrapolation distance.

and the ratio of the thermal transport cross sections for the two fuel mixtures. (The cross section used in these calculations were from Ref. 1.) Using this extrapolation distance and the data reported in Table C-2 for unreflected parallelepipeds gives an average buckling of 5868×10^{-6} cm^{-2} for the fuel mixture with an H:U^{235} atomic ratio of 294. The validity of the assumption that the flux extrapolates to zero at some fixed distance has not been investigated. The boundary condition of no return current may provide a different value for the buckling.

Minimum Critical Masses and Volumes for Spherical Assemblies of the Two Fuel Mixtures

By using the values of the buckling, the reflector savings, and the extrapolation distances for the two fuel mixtures, the minimum masses and volumes of reflected and unreflected spherical assemblies of each mixture could be determined. The results are presented in Table 5.

Table 5. Minimum Critical Masses and Volumes of Spherical Assemblies with H:U^{235} Atomic Ratios of 195 and 294

H:U^{235} Atomic Ratio	Reflector	Minimum Critical Mass (kg of U^{235})	Minimum Critical Volume (liters)
195	Infinite paraffin	16.3	259
195	Unreflected	24.3	386
294	Infinite paraffin	8.5	160
294	Unreflected	12.7	240

Effect of UF$_4$ Particle Size on Reactivity

In order to investigate the effect of the UF$_4$ particle size on the reactivity of an assembly, a special fuel block with UF$_4$ particles that were less than 44 microns was used in a completely reflected 26 by 26 by 27 in. parallelepipedal assembly with an H:U^{235} atomic ratio of 195. Substitution of this special fuel block for a standard one resulted in an increase in reactivity of less than 5×10^{-5} in $\Delta k/k$. The size of the block

1. C. B. Mills, Neutron Cross Sections for Fast and Intermediate Reactors, LA-2255 (Jan. 1959).

substituted was 4 by 4 by 4 in. This indicates that the effect of the UF_4 particle size on the reactivity is small. Additional experiments to investigate the effect of the particle size must be completed before a correction to a purely homogeneous system can be specified.

Appendix A

PROPERTIES OF FUEL BLOCKS

Table A-1. Compositions and Densities of Fuel Blocks

	$H:U^{235}$ Atomic Ratio = 195	$H:U^{235}$ Atomic Ratio = 294
UF_4 Content (wt%)	92.1	88.6
Paraffin ($C_{25}H_{52}$) Content (wt%)	7.9	11.4
Density of Mixture (g/cc)	3.93	4.5
Uranium Concentration (g/cc)	3.1	2.6

Table A-2. Dimensions and Weights of Fuel Blocks

Dimensions (in.)			$H:U^{235}$ Atomic Ratio = 195		$H:U^{235}$ Atomic Ratio = 294	
x	y	z	Average Mass (g)	Standard Deviation (g)	Average Mass (g)	Standard Deviation (g)
4	4	4	4715.9	6.09	4118.3	6.11
4	4	2	2356.7	1.65	2057	2.95
4	4	1	1178.4	1.88	1029.2	3.18
2	2	4	1176.0	2.81	1028.6	3.56
2	2	2	588	1.00	514.8	1.55
2	2	1	292.5	0.50	257.4	0.06
1	1	4	296	1.02	257.5	1.49
1	1	2	147	0.00	129.3	0.65
1	1	1	73.8	0.07	64.6	0.51
Special Blocks to Fit Around Control Guide Tubes			4253.8	2.15	3722.5	2.60

Table A-3. Homogeneity of Uranium Distribution in Typical Fuel Blocks

	g of Uranium per g of Mixture	
	$H:U^{235}$ = 195	$H:U^{235}$ = 294
Sample I	0.699	0.673
Sample II	0.697	0.673
Sample III	0.699	0.668
Sample IV	0.698	0.673
Sample V	0.700	
Sample VI	0.702	
Sample VII	0.698	
Sample VIII	0.601*	

* Only inhomogeneity visually observed in the surface of fuel blocks of this fuel mixture.

Table A-4. Impurities* in the Fuel Mixture with an $H:U^{235}$ Atomic Ratio of 195

Element	ppm	Element	ppm
Zn	< 0.3	K	< 50
Ni	< 25	Fe	25
Sn	< 10	Cu	< 2
Si	< 10	Cr	145
Pb	< 2	Ca	< 50
P	< 100	Ba	< 10
Na	< 10	B	< 1
Mo	< 200	Al	< 7
Mn	< 5	Ag	< 1
Mg	< 5		

* Determined by spectrographic analysis.

Table A-5. Impurities* in the Fuel Mixture with an $H:U^{235}$ Atomic Ratio of 294

Element	Sample I	Sample II	Sample III	Sample IV
Be	< 0.01	< 0.01	< 0.01	< 0.01
Ni	10	8	20	40
Si	8	8	6	8
Li	< 0.2	< 0.2	< 0.2	< 0.2
P	< 100	< 100	< 100	< 100
Na	< 1	< 1	< 1	< 1
Mn	5	5	5	8
Fe	40	100	30	50
Cu	40	100	20	50
Cr	30	30	30	60
Al	2	6	2	3
Cd	< 0.1	0.1	0.1	0.1
Co	< 1	< 1	1	< 1
V	1	< 1	1	2
Hg	< 2	< 2	< 2	< 2

* Determined by spectrographic analysis.

Table A-6. Screen Analysis of UF_4 Particle Size

Range of UF_4 Particle Size (microns)	Percent in Fuel
< 297	100
149 - 297	52.5
105 - 149	9.3
88 - 105	6.6
74 - 88	6.9
53 - 74	9.5
44 - 53	6.2
< 44	9.0

Table A-7. U^{235} Enrichment of Uranium

	Weight Precent
Sample I	1.99
Sample II	2.00
Sample III	1.99
Sample IV	1.99

Appendix B

ANALYSES OF PARAFFIN REFLECTOR BLOCKS AND COVERS

Table B-1. Hydrogen Content of Paraffin

Sample	Hydrogen Content (wt%) Run I	Run II	Run III	Run IV	Average	Standard Deviation (wt%)	Coefficient of Variation
1	14.49	14.62	14.32	14.45	14.47	0.12	0.86
2	14.54	14.49	14.41	14.49	14.48	0.054	0.37
3	14.53	14.73	14.50	14.59	14.59	0.051	0.35
4	14.52	14.69	14.58	14.76	14.64	0.11	0.74
5	14.57	14.63	14.62	14.67	14.62	0.041	0.28
6	14.67	14.47	14.53	14.67	14.57	0.10	0.70
			Combined Average:		14.56	0.11	0.7

Table B-2. Impurities in the Paraffin Used in the Fuel Mixtures and Reflector

Element	ppm	Element	ppm	Element	ppm
Be	< 0.01	B	< 0.1	Ho	< 0.1
Ni	< 1	Al	4	Lu	< 0.1
Si	20	Cd	0.7	Nd	< 0.6
Li	< 0.2	Co	< 0.1	Pr	< 0.1
Na	9	V	< 0.1	Sm	< 0.1
Mn	< 1	Ce	< 0.2	Tb	< 0.3
Mg	6	Dy	< 0.1	Tm	< 0.1
Cu	10	Er	< 0.1	Y	< 0.1
Cr	2	Eu	< 0.1	Yb	< 0.01
Ca	30	Gd	< 0.1		

Table B-3. Impurities* of the Muslin Covers

Element	%	Element	%
Al	0.3	Li	0.1
B	< 0.01	Mg	2
Ba	0.05	Mn	0.02
Ca	0.3	Na	2
Cd	< 0.05	Rb	0.3
Cu	0.1	Si	0.5
Fe	0.3	Sr	0.2
K	>> 5	Ti	< 0.02

*Approximate values, within factor of 2.

Table B-4. Impurities* of the Onion Skin Paper Covers

Element	%	Element	%
Al	> 5	Li	< 0.01
B	< 0.01	Mg	1.5
Ba	0.05	Mn	0.02
Ca	1.5	Na	1
Cd	< 0.05	Pb	0.15
Cu	0.2	Si	0.7
Fe	0.3	Ti	>> 5
K	0.1		

*Approximate values, within factor of 2.

Appendix C

TABLES OF EXPERIMENTAL DATA

Table C-1. Critical Masses and Critical Heights of Reflected* Assemblies with an H:U^{235} Atomic Ratio of 195

Length or Diameter of Core Base (in.)	Area of Base (in.^{2})	Critical Height (in.)	Critical Mass (kg of U^{235})
Right Cylindrical Assemblies			
24	452	47.7	21.9
29	659	25.1	16.9
31	762	22.2	17.3
36	1024	18.6	19.3
44	1504	16.2	24.8
Parallelepipedal Assemblies			
22		44.4	22.0
24		31.3	18.4
28		22.9	18.4
29		21.6	18.6
36		17.3	22.9

*Reflector: 6 in. of plexiglas on bottom and 6 in. of paraffin on tops and sides.

Table C-2. Critical Masses and Critical Heights of Assemblies with an H:U^{235} Atomic Ratio of 294

Length of Diameter of Core Base (in.^{2})	Area of Base (in.^{2})	Critical Height (in.)	Critical Mass (kg of U^{235})
Reflected* Right Cylindrical Assemblies			
20	314	48.4	13.1
24	452	23.1	8.9
28	616	17.9	9.5
32	800	15.7	10.7
44	1504	12.8	16.6
50	1964	12.1	20.6
Unreflected Right Cylindrical Assemblies			
24	452	54.0	21.0
28	616	26.7	14.1
32	800	21.7	14.9
40	1264	17.9	19.5
Reflected* Parallelepipedal Assemblies			
18		53.0	14.8
20		29.2	10.0
24		19.5	9.60
28		16.2	10.9
36		13.5	15.0
44		12.3	20.5
Unreflected Parallelepipedal Assemblies			
22		48.0	20.0
24		31.2	15.5
28		22.7	15.3
36		18.1	20.1

*Reflector: 6 in. of plexiglas on bottom and 6 in. of paraffin on top and sides.

Table C-3. Variation in the Reactivity of an Assembly with the Thickness and Distribution of the Top Reflector

$H:U^{235}$ atomic ratio: 195
Core geometry: 28 by 28 by 27 in. parallelepiped
Reflector: Effectively infinite paraffin reflector on four sides

Top Reflector	Reactivity* Worth of Top Reflector (¢)
Unreflected	0
1/8 in. of plexiglas on one quadrant	2.5
1/8 in. of plexiglas on entire top	10.1
1/2 in. of plexiglas on one quadrant	9.0
1 in. of plexiglas on one quadrant	14.4
1 in. of fuel on one quadrant	13.3

*G. R. Keepin *et al.*, *Phys. Rev.* 107, 1044 (1957).

Table C-4. Comparison of the Reactivity Effects of Paraffin and Plexiglas Reflectors on Top of an Assembly

$H:U^{235}$ Atomic Ratio: 195
Core Geometry: 26 by 26 by 24.4 in. parallelepiped
Reflector: Effectively infinite reflector on four sides and bottom

Thickness of Top Reflector (in.)	Reactivity Worth of Material (¢)	
	Paraffin	Plexiglas
0	0	0
0.5	-	4.1
1.0	8.2	7.5
1.5	10.3	9.8
3.0	12.5	12.9
4.5	13.0	14.0
6.0	13.2	14.1

Appendix D

LIST OF FIGURES

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