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A SMALL BERYLLIUM-REFLECTED UO_2 ASSEMBLY

J. T. Mihalczo

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ABSTRACT

An unmoderated, beryllium-reflected, critical assembly of UO_2 enriched to 93.2 wt% in U^{235} is described. The UO_2 pellets, density 9.71 g/cm^3, were contained in 253 1.27-cm-dia stainless steel tubes which, in turn, were packed with a center-to-center spacing of 1.506 cm in an aluminum container 25.96 cm in diameter. The beryllium reflector required to make the assembly critical was 11.37 cm thick on the side of the core, 7.62 cm thick on the bottom and 6.98 cm thick on top. The ratio of the peak to minimum fission-rate distribution along the axis of the assembly was 1.8; the ratio along a radius at the midplane of the core was 3.7. Reactivity coefficients of CH_2, C, W, Type 347 Stainless Steel, Nb, B_4C, Cd and K were measured. The reactivity resulting from filling the void between the fuel tubes with 3.4 kg of potassium was + 18.6 cents.

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A SMALL BERYLLIUM REFLECTED UO_2 CRITICAL ASSEMBLY

INTRODUCTION

A small, compact, unmoderated critical assembly of U^{235} enriched UO_2 reflected by beryllium, constructed in the ORNL Critical Experiments Facility, has provided data in support of reactor calculations. The critical configuration with each of two fuel tube arrangements, the U^{235} fission-rate distribution, cadmium ratios and the reactivity effects of a variety of materials were measured. The results of the experiments are reported in this memo.

MATERIAL AND EQUIPMENT

The core of the assembly, nominally 25.96 cm in diameter and 30.48 cm high, was an array of 253 type 347 stainless steel tubes containing UO_2 pellets having a density of 9.71 g/cc. The U^{235} content of the uranium was 93.2 wt%. The tubes were packed in a type 1100 aluminum can, the center-to-center triangular lattice spacing of the tubes being fixed at 1.506 cm by grid plates at the top and bottom. The grid plates were spaced by four type 347 stainless steel tubes which surrounded four equally spaced peripheral fuel tubes. The thickness of the beryllium reflector on the top and side was the variable that was adjusted in steps to make the assembly critical. The fuel tubes are described in Table I and one is shown together with the UO_2 pellets* in Fig. 1. The properties of the assembled core and of the reflector are given in Tables II and III, respectively. The parts of the assembly are shown in Fig. 2. The top and side reflector, resting on a 0.635 cm thick aluminum plate, are shown in Fig. 3. The assembly was built on a vertical assembly machine so that the movable part was the core and bottom reflector and the fixed part was the top and side reflector as shown in Figs. 2 and 3. Figure 4 is a sketch showing the dimensions of the assembly.

EXPERIMENTAL RESULTS

To check the reproducibility of assembling the core, the core tank was loaded twice with fuel tubes and assembled with the reflector as shown in Figs. 2, 3, and 4. No attempt was made to replace tubes in the former location. The reactivity of these assemblies differed by 1.2 cents and had an average value of + 11.8 cents.

Fission Distributions and Cadmium Ratios. Fission distributions were measured in the core and in the top reflector by irradiation of 0.75-cm-dia by 0.010-cm-thick U(93.2) metal foils and determining their relative gamma activity by two NaI scintillation counters. All foils placed in

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* The edges of the pellets were chipped during their removal from the tube preparatory to this photograph.

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Table I. Properties of a Typical Fuel Tube

Stainless Steel Tube

Type	347
Length (cm)	30.48
Outside Diameter (cm)	1.27
Wall Thickness (cm)	0.051
Weight with End Caps (g)	45.37
Weight of One End Cap (g)	0.64

Uranium Oxide

Number of UO_2 pellets per fuel tube	26
UO_2 Density (g/cc)	9.71
Mass of UO_2 per tube (g)	295.8
Diameter of pellets (cm)	1.141
Length of one pellet (cm)	1.145
Length of 26 pellets (cm)	29.88

Analyses of Uranium Oxide

Spectrochemical (ppm)		Isotopic (wt%)	
Ag	<40	U^{234}	1.01
Be	<0.3	U^{235}	93.15
Cr	6 to 40	U^{236}	0.47
Li	<1.5	U^{238}	5.37
Ni	<25		
Sn	5 to 25		
Al	3 to 30		
Ca	50		
Cu	3 to 35		
Mg	<12		
P	<100		
B	<1		
Fe	10 to 250		
Mn	<8		
Ba	<10		
K	<50		
Na	<10		
Si	10 to 50		

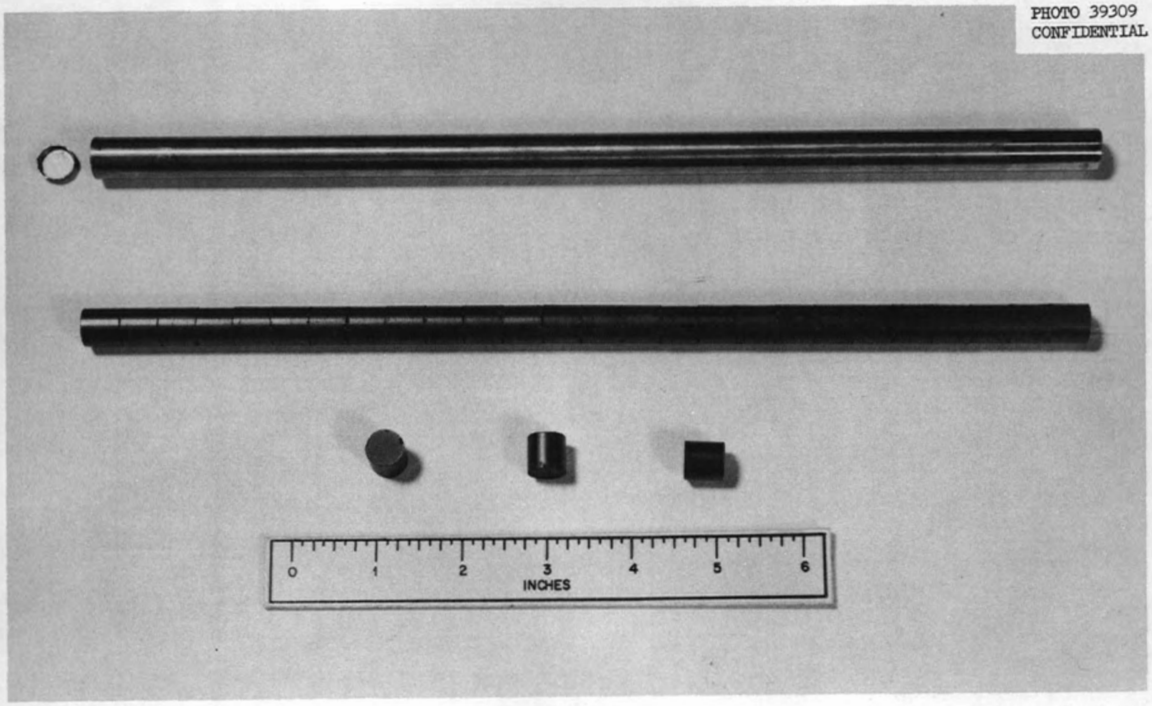

Fig. 1. Fuel Tube and UO_2 Pellets.

Table II. Core Properties

Core	
Mass of U^{235} (kg)	61.15
Mass of UO_2 (kg)	74.54
Mass of Stainless Steel Tubes, Type 347 (kg)	11.43
Core Tank (open top)	
Material	Type 1100 Aluminum
Side Wall Thickness (cm)	0.254
Bottom Thickness (cm)	0.33
Outside Diameter (cm)	25.96
Outside Length (cm)	31.04
Mass (kg)	2.125
Grid Plates (2)	
Material	Type 1100 Aluminum
Thickness (cm)	0.317
Mass (g)	139 (each)
Grid Plate Spacer Tubes (4)	
Material	Type 347 Stainless Steel
Outside Diameter (cm)	1.37
Wall Thickness (cm)	0.076
Length (cm)	27.94
Weight (g)	37.5 (each)
Fuel Tube Clips[a] (10)	
Material	Type 1100 Aluminum
Mass (g)	2.3 (each)

a. These clips were at the core midplane to hold pairs of outer fuel elements in position.

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Table III. Reflector Properties

Side Reflector - Beryllium[a]	
Height (cm)	30.63
Thickness (cm)	11.37
Inside Diameter (cm)	26.16
Mass (kg)	75.7
Top-Reflector[b] - Beryllium	
Thickness (cm)	6.985
Nominal Diameter (cm)	41.2
Mass (kg)	17.13
Top Reflector Tank[c] - Aluminum (Type 1100)	
Side Wall Thickness (cm)	0.635
Height (cm)	12.95
Bottom Thickness (cm)	0.22
Mass (kg)	4.38
Bottom Reflector[b] - Beryllium	
Thickness (cm)	7.62
Nominal Diameter (cm)	41.2
Mass (kg)	18.7
Bottom Reflector Tank[c] - Aluminum (Type 1100)	
Side Wall Thickness (cm)	0.635
Height (cm)	8.51
Bottom Thickness (cm)	0.89
Mass (kg)	5.75
Additional Reflector	
Radial - Beryllium Support Plate - Aluminum (Type 1100)	
Dimension (cm)	75 x 75 with 27.9 cm O.D. Hole
Thickness (cm)	0.635
Mass (kg)	8.7
Bottom Reflector - Stainless Steel (Type 304)	
Thickness (cm)	2.38
Diameter (cm)	45.72
Mass (kg)	31.2

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Table III - Continued

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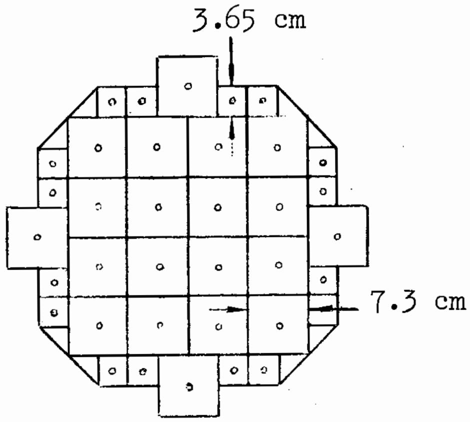
a. Built out of annular rings of beryllium.
b. Built out of blocks of beryllium 7.3 or 3.65 cm square and 2.54 or 0.635 cm thick and some triangular shaped pieces.



There is a 0.476-cm-dia hole through each block of square cross section perpendicular to the square face.

c. The purpose of the top and bottom reflector tanks is to support the beryllium blocks (See Figs. 2 and 4).

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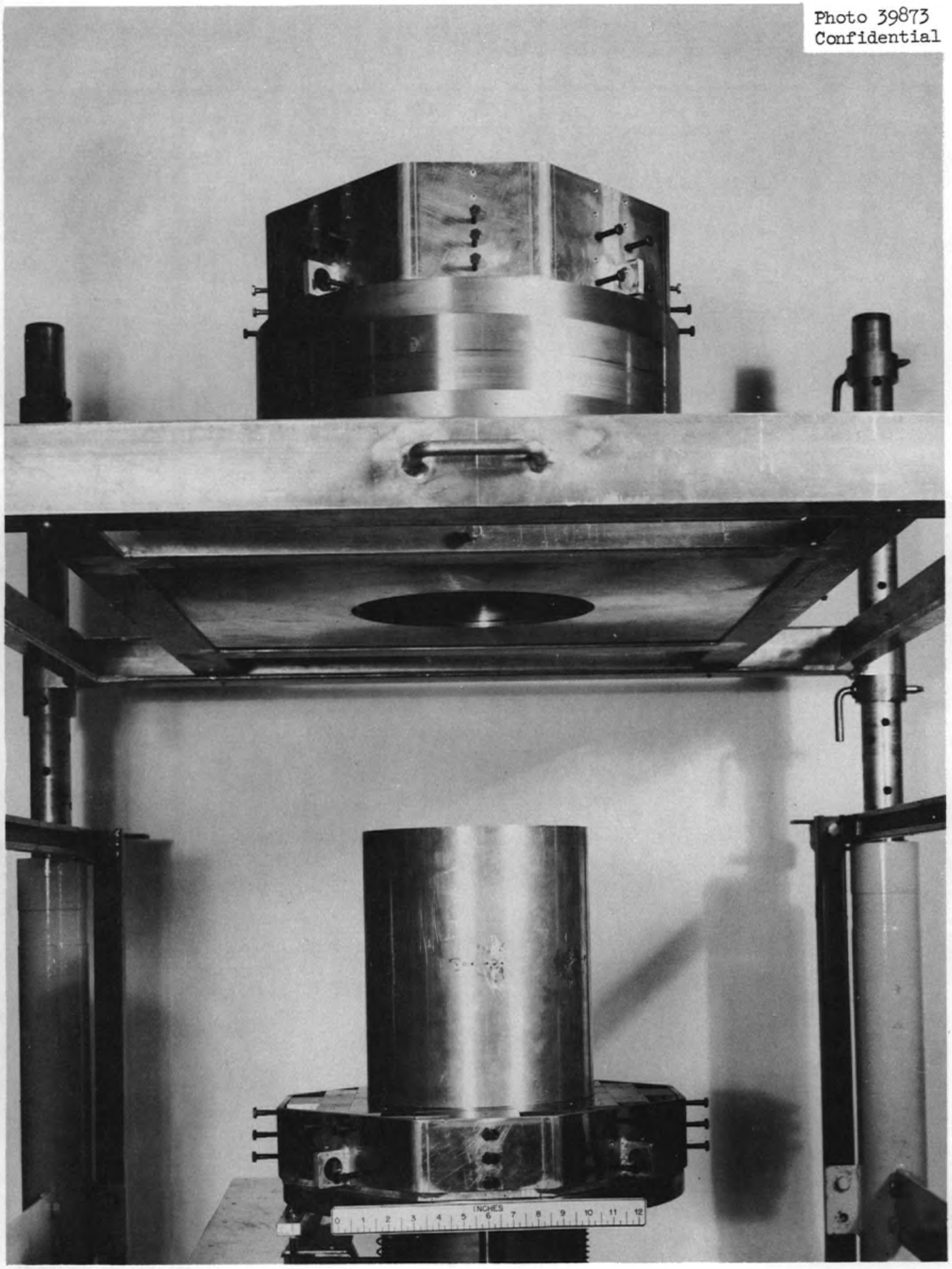

Fig. 2. Assembly Showing Movable Core and Bottom Reflector with Fixed Top and Side Reflector.

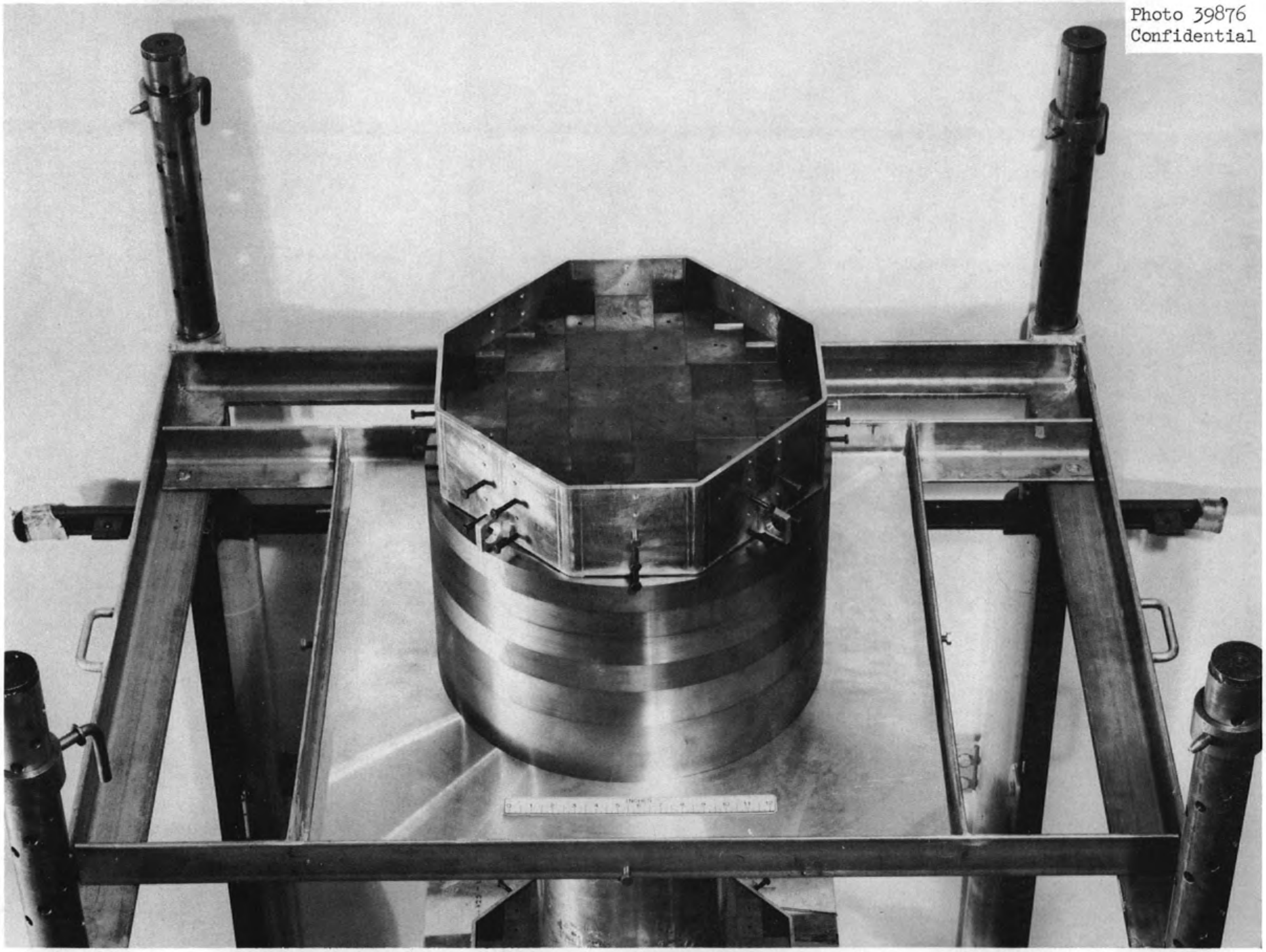

Fig. 3. Top and Side Reflector.

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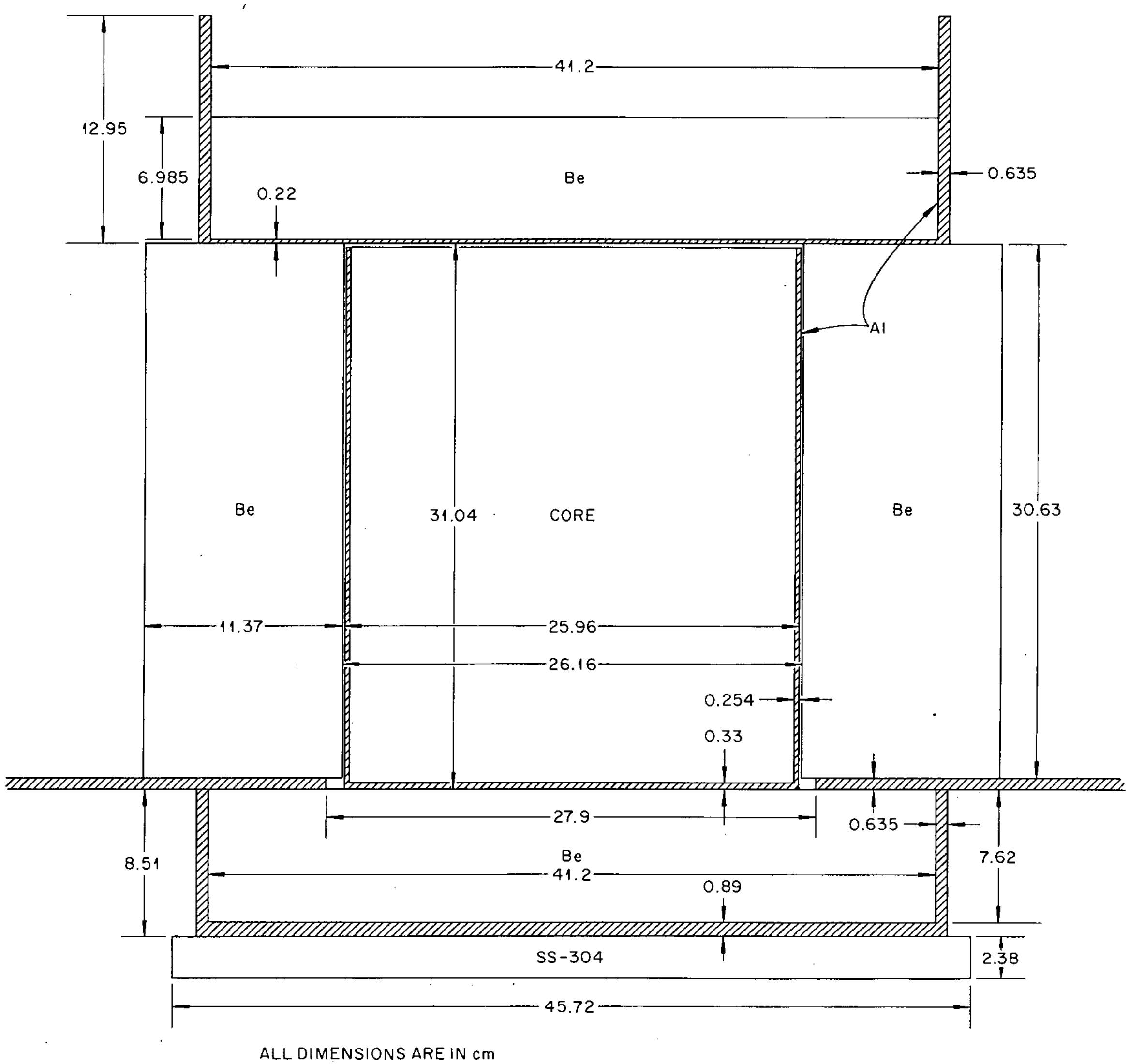

Fig. 4. Reflector-Core Assembly.

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the core were taped tangent to the fuel tubes. The flux distribution in the top reflector was measured by placing the foils between beryllium blocks. U^{235} fission cadmium ratios were measured in the top reflector and at one location in the core. The axial and radial fission distributions and cadmium ratios are shown in Figs. 5 and 6 and are listed in Tables IV and V. The location of the foils used for the radial distribution in the core are shown in Fig. 7. The radial fission rate distribution at the core midplane is flat to within 2.54 cm of the side reflector, where it increases to a maximum, at the core boundary, about 3.7 greater than at the center.

Reactivity Effects

Fuel Effects. The reactivity worth of the center fuel tube was measured by observing the change in the stable reactor period when the fuel tube was removed. The reactivity of other fuel tubes relative to the center fuel tube was also measured. From these two measurements the reactivity worth of a fuel tube as a function of radial position is obtained and given in Fig. 8 and Table VI.

The reactivity to be expected from displacement of the outer fuel tubes toward the reflector, a condition which might accidentally arise, can be estimated from the results of an experiment with 20 peripheral tubes. Displacement of these 20 tubes from their normal position in the lattice to one as close to the core-tank wall as possible, in the manner shown in Fig. 7, decreased the reactivity 8.2 cents.

The core was also assembled with the fuel tubes arranged in clusters of seven by grid plates illustrated in Fig. 9. The reactivity of this assembly was 10.5 cents higher than that of the assembly with uniform spacing of the fuel tubes on 1.506 cm centers. Although the overall effect of clustering the fuel is small, it may be made up of two large components. These are the negative effect of the increased streaming out of the core and the positive effect caused by peaking of the fast neutron flux within the fuel cluster.

Neutron Moderation and Absorption Effects. Reactivity coefficients of various neutron absorbing and moderating materials in the assembly were measured and the results given in Table VII. The location of some of the samples is given in Fig. 10. Increasing the thickness of the top beryllium reflector from 7.0 to 7.6 cm increased the reactivity of the assembly 40 cents.

Potassium Reactivity Coefficient. The effect on reactivity of surrounding the fuel tubes with potassium was investigated using the calandria type vessel, fabricated of type 304 and 347 stainless steel, see Fig. 11. The fuel tubes, loaded in the calandria, were in the same pattern as when loaded in the aluminum core tank. Substitution of the stainless steel vessel (13372 g of stainless steel) for the aluminum increased the reactivity 28 cents which was compensated by reducing the thickness of the top beryllium reflector to 6.35 cm. The reactivity of

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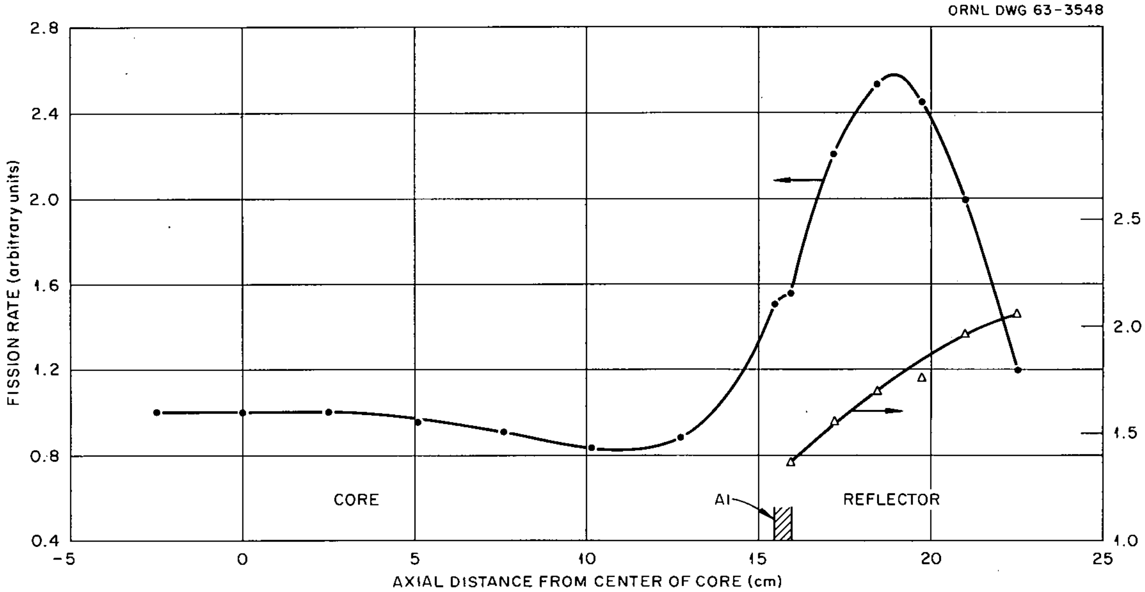

Fig. 5. Axial Fission Rate Distribution

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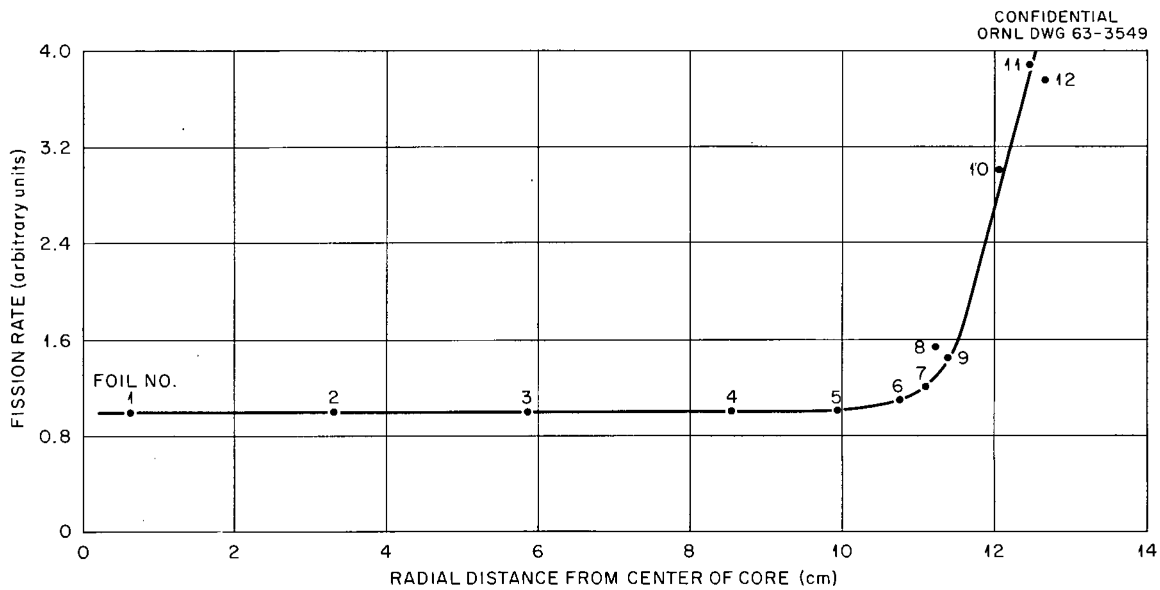

Fig. 6. Radial Fission Rate Distribution at Core Midplane.

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Table IV. Axial Fission Rate and Cadmium Ratio Distribution

Distance from Center of Fuel Tube (cm)	Relative Fission Rate (Arbitrary Units)	Cadmium Ratio[a]
- 2.54	1.02	
0	1.00	
2.54	1.00	
5.08	0.95	
7.62	0.91	
10.16	0.83	
12.7	0.88	
15.44	1.51	
15.91	1.56	1.37
17.18	2.21	1.56
18.45	2.53	1.70
19.72	2.45	1.76
20.99	2.00	1.97
22.26	1.20	2.06

a. The detectors were 0.010-cm-thick by 0.75-cm-dia U(93.2) metal foils; the cadmium covers were 0.051 cm thick. No correction has been made for self shielding in the foils.

[redacted]

Table V. Radial Fission Rate and Cadmium Ratio Distribution

Location[a]	Distance from Core Center (cm)	Relative Fission Rate	Cadmium Ratio[b]
Distribution at Core Midplane			
1	0.635	1.0	
2	3.25	0.98	
3	5.87	0.99	
4	8.53	1.04	
5	9.93	1.06	
6	10.74	1.12	
7	11.12	1.21	
8	11.2	1.55	
9	11.35	1.45	1.24
10	12.06	3.04	
11	12.47	3.68	
12	12.62	3.56	
Distribution at 15.44 cm Above Core Midplane			
13[c]	0	1.51	
14[c]	3.02	1.63	1.39
15[c]	12.06	2.50	1.87

a. Foil locations are shown in Fig. 7.
b. The detectors were 0.010-cm-thick by 0.75-cm-dia U(93.2) metal foils; the cadmium covers 0.051 cm thick. No correction has been made for self shielding in the foils.
c. Foils laid on top of fuel tubes.

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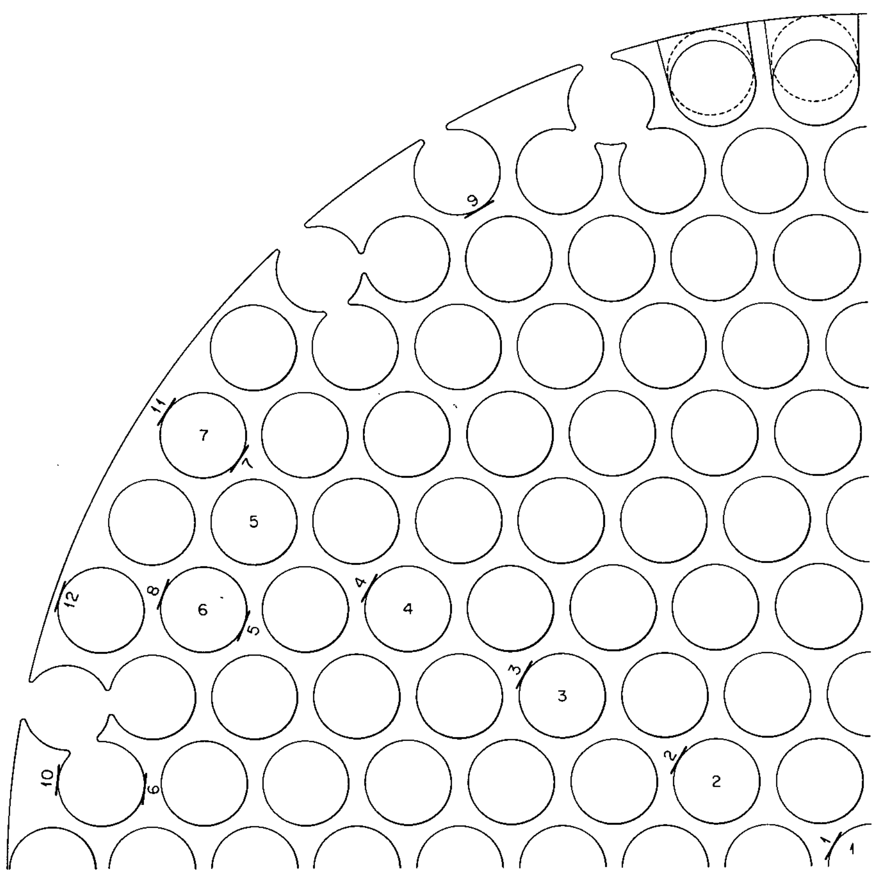

Fig. 7. Foil Locations for Radial Fission Rate Distribution and Fuel Tube Locations for Fuel Reactivity Measurements.

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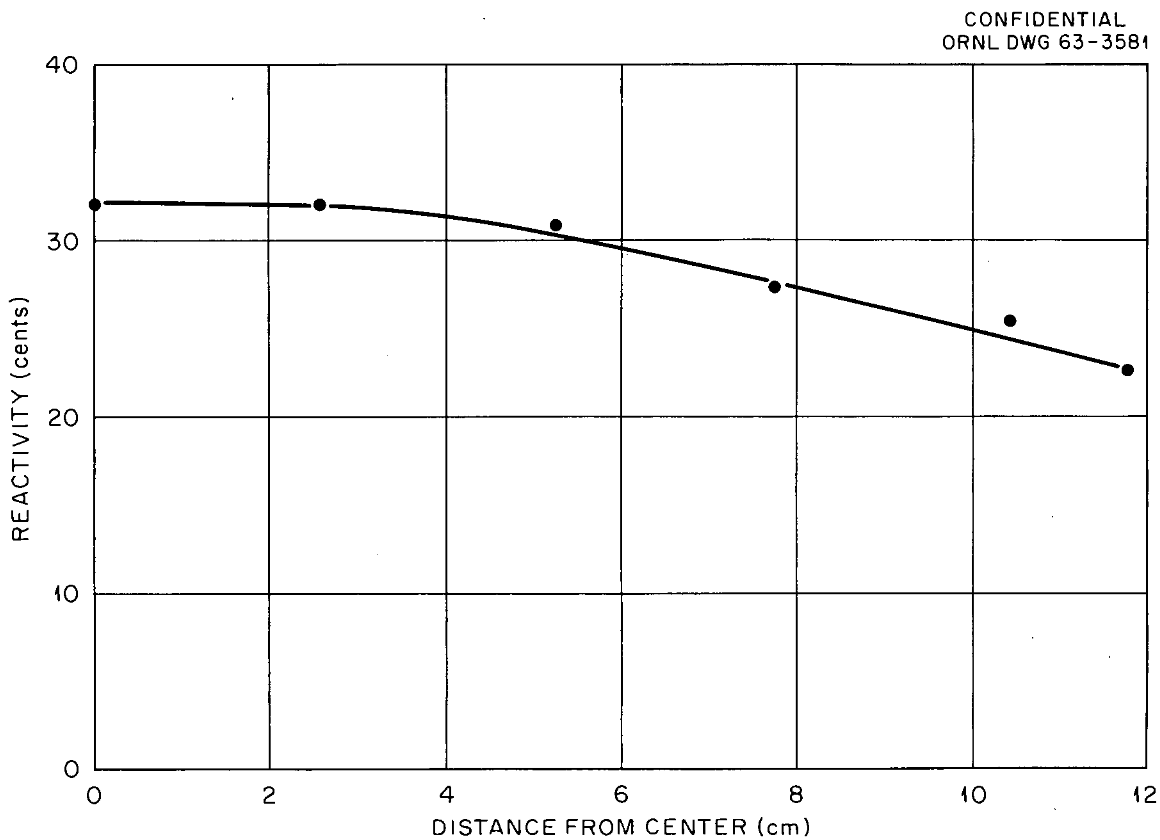

Fig. 8. Reactivity Worth of Fuel Tube vs Radius.

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Table VI. Fuel Tube Reactivity Worth at Various Radial Positions

Fuel Tube Position[a]	Distance From Core Center (cm)	Reactivity (cents)
1	0	32.0
2	2.59	32.0
3	5.23	30.8
4	7.75	27.2
5	10.48	25.5
6	10.56	25.6
7	11.78	22.6

a. Position given on Fig. 7.

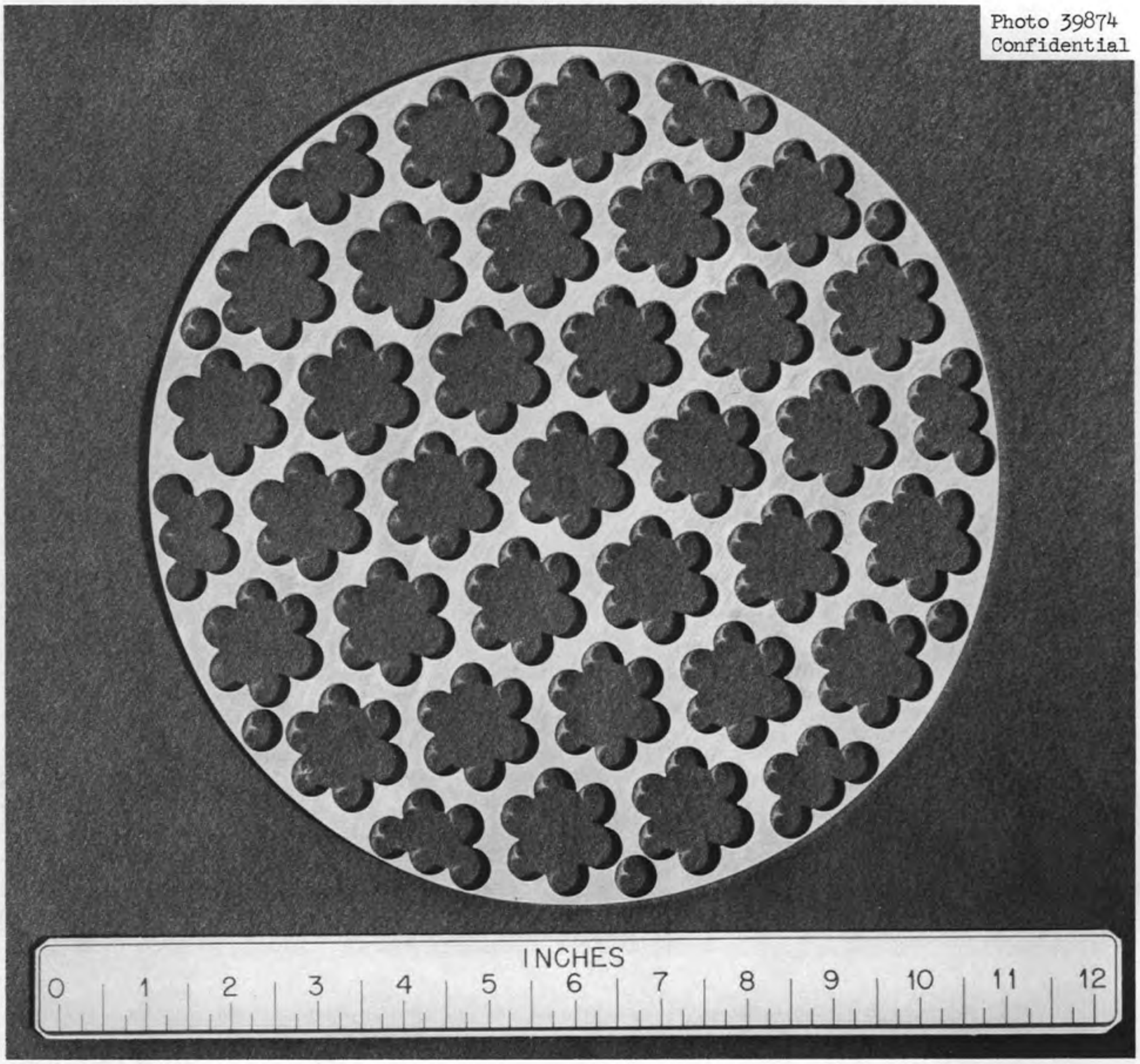

Fig. 9. Grid Plate for the 7-Tube Cluster Assembly.

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Table VII. Reactivity Effects in Core[a]

Material	Form	Number	Location	Total Weight (g)	Reactivity Coefficient (cents/kg)
Type 347 Stainless Steel	0.317 cm dia rods 30.5 cm. long	90	All positions filled	1704	+ 8.7
	0.317 cm dia rods 30.5 cm long	46	Every other position	871	+ 9.1
W	0.317 cm dia rods 30.5 cm long	46	Every other position	2110	- 2.0
Cb	0.317 cm dia rods 30.5 cm long	46	Every other position	1050	+ 4.7
CH_2	0.317 cm dia rods 30.5 cm long	8	Odd numbered holes between 43-57	18.4	+ 1320
C	0.305 cm dia rods 30.5 cm long	23	Every 4th position	82	+ 91
B_4C	Filled with B_4C	1	Center fuel tube position	30.5	- 220
Stainless Steel	Disc 0.317 cm thick for top of core tank	1	Top of core	1290	+ 18
Al	Lid for top of core tank, 0.317 cm thick	1	Top of core	464	36
Al	Lid for top of core tank 0.159 cm thick	1	Top of core	226	35
Cd	Lid for top of core, 0.066 cm thick	1	Top of core	287	160

a. See Fig. 10 for location of sample rods.

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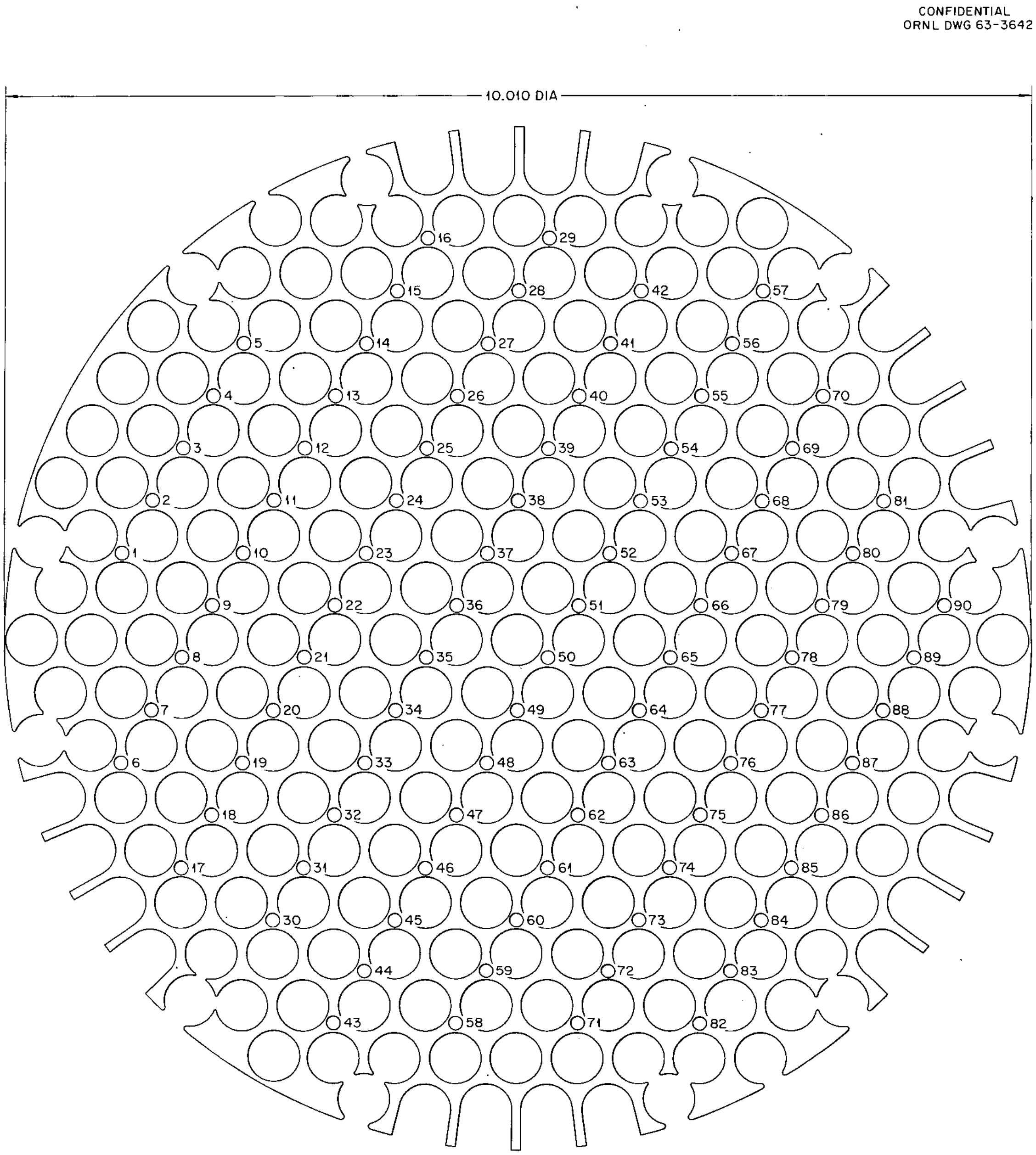

Fig. 10. Location of Samples in Reactivity Coefficient Measurements.

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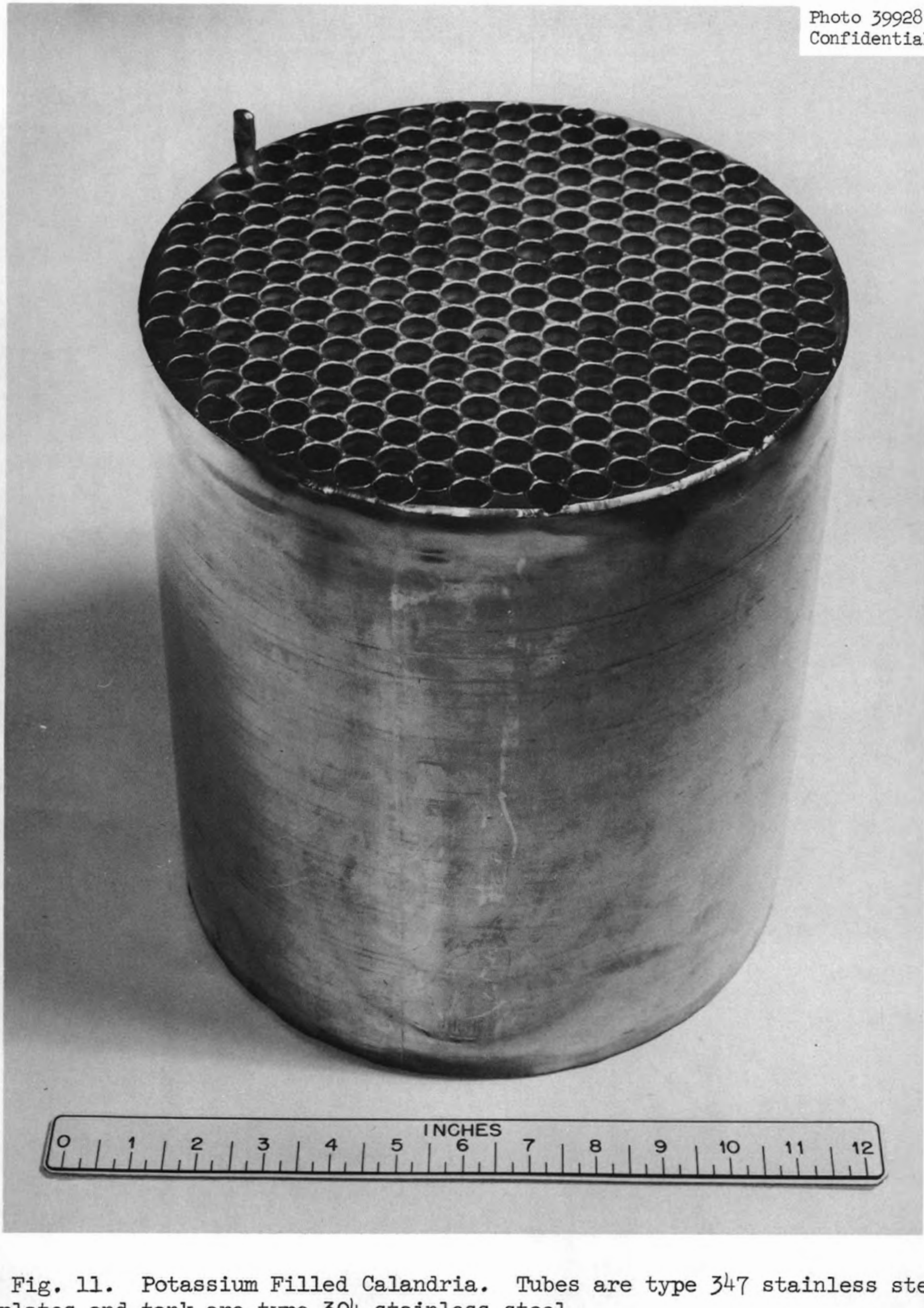

Fig. 11. Potassium Filled Calandria. Tubes are type 347 stainless steel; end plates and tank are type 304 stainless steel.

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the assembly with no potassium in the calandria was then +13.4 cents. Adding 3403 g of potassium resulted in a reactivity of +32 cents, corresponding to a potassium reactivity coefficient of +5.4 cents/kg.