REFERENCE 193

C. L. SCHUSKE, C. L. BELL, G. H. BIDINGER, AND D. F. SMITH, "INDUSTRIAL CRITICALITY MEASUREMENTS ON ENRICHED URANIUM AND PLUTONIUM. PART II," DOW CHEMICAL CO., ROCKY FLATS PLANT REPORT RFP-248 (JANUARY 1962).

RFP-248 RFP-248

AEC RESEARCH AND DEVELOPMENT REPORT

Industrial Criticality Measurements on Enriched Uranium and Plutonium
Part II

by

C. L. Schuske

C. L. Bell

G. H. Bidinger

D. F. Smith

THE DOW CHEMICAL COMPANY

ROCKY FLATS PLANT DENVER, COLORADO

U.S. ATOMIC ENERGY COMMISSION CONTRACT AT (29-1) -1106

LEGAL NOTICE

Printed in USA. Price 50 cents. Available from the Office of Technical Services, Department of Commerce, Washington 25, D. C.

RFP-248

UC-46 - CRITICALITY STUDIES
(TID-4500, 16th Edition)

THE DOW CHEMICAL COMPANY
ROCKY FLATS PLANT
DENVER, COLORADO

U. S. Atomic Energy Commission Contract AT(29-1)-1106

INDUSTRIAL CRITICALITY MEASUREMENTS

ON ENRICHED URANIUM AND PLUTONIUM

PART II

by

C. L. Schuske
C. L. Bell
G. H. Bidinger
D. F. Smith

L. A. Matheson - Technical Director

J. G. Epp - Assistant Technical Director

Date Distributed: January 10, 1962

ABSTRACT

This report contains a series of neutron multiplication measurements made on sub-critical systems containing enriched uranium and plutonium.

These measurements involve both aqueous and metal systems.

ACKNOWLEDGMENT

The authors express their thanks to Mr. I. B. Venable and Mr. L. L. Zodtner and staffs for their assistance in securing materials for these tests.

1. INTRODUCTION

This report contains a compilation of four experiments. Each experiment is discussed separately. The electronic equipment consists of General Electric B^{10}-lined counters coupled to decade scalers.

No additional neutron source other than that available from the spontaneous fissioning of Pu^{240} was used in the measurements involving plutonium. A source of $\sim 10^{6}$ neutrons per second was used in all enriched uranium measurements.

2. EXPERIMENT 1 - PLUTONIUM-SALT ASSEMBLIES

2.1 Discussion

These assemblies were constructed of alternate layers of salt moderator and plutonium metal discs (see section on materials and Figures 1 and 2). These measurements indicate that thin reflectors, <2.5 in., of KCl or CsCl are at least as effective as thin reflectors of graphite.(1) Table I and Figures 1 and 2 provide information on the experimental assemblies.

---

(1) A. Goodwin, Jr., C. L. Schuske, "Plutonium Graphite Assemblies", USAEC Report RFP-123, September 29, 1958.

TABLE I

Experimental Data

Core Composition	Experimental Core Height (in.)	Extrapolated Critical Height (in.)	End Reflector Thickness (in.)
1-plutonium disc per 1-KCl disc	8.00	∞	None
2-plutonium disc per 1-KCl disc	6.84	Probably ∞ (See Fig. 1)	None
Solid plutonium slab	0.81	~1.36	KCl ~2.81
Solid plutonium slab	0.75	~1.36	KCl 1.75 CsCl 0.75 Total 2.5

2.2 Materials

Fuel

Plutonium density $\cong$15.8 g/cm^3

Dimensions of discs diameter ~13.5 in.

thickness ~0.578 in.

Mass/disc ~2141 g.

Moderator and Reflector

KCl - Density $\cong$1.722 g/cm^3 (2)

Disc diameter = 12.5 in.

Average thickness = 0.553 in.

CsCl - Density $\cong$3.124 g/cm^3

Disc diameter = 12.5 in.

Average thickness = 0.75 in.

3. EXPERIMENT 2 - THREE DIMENSIONAL AND PLANE ARRAYS OF PLUTONIUM BUTTONS

3.1 Discussion

Neutron multiplication measurements were made on four arrays of buttons. Figures 3 and 4 give plots of the reciprocal multiplication as a function of the amount of metal in the array.

---

(2) Theoretical densities of KCl and CsCl are 1.984 g/cm^3 and 3.970 g/cm^3.

The array densities were calculated in the following manner:

Plane array - Average density (3.38 g/cm^3) was calculated as the average mass per unit hexagonal cylinder around each can. (Hexagonal cylinder - 2.309 in. edge by 2.69 in. high.)

Three dimensional array - Average density was calculated as the average mass per unit square cylinder around each can. (Square cylinder - 4.0 in. edge by 2.69 in. high ≅2.88.)

Figure 5 was drawn from the extrapolated results of Figures 3 and 4. The two asymptotes of Figure 5 were determined by assuming that the plane array and the 3 x 3 array both extrapolate to critical at infinity (this is perhaps conservative). With these asymptotes and the two points obtained from the critical extrapolations of the 4 x 4 and 5 x 5 arrays, the hyperbola in Figure 5 was drawn.

From Figure 5 the array minimum critical mass was determined by plotting the critical mass as a function of H/D ratios of each array. (See Figure 6.) This analysis revealed that eighty-seven cans containing a total of 177 kg of plutonium at an array density of 2.88 g/cm^3 could be made critical. The approximate array dimensions in terms of cans is a 4.4 x 4.4 x 4.5 array. Using this minimum critical mass, and M_o = 15 kg (equivalent to a partially tamped single plutonium mass), the density ratio exponent can be determined.

$$177 \text{ kg} = 15 \text{ kg} \left(\frac{15.8}{2.88}\right)^x$$

$$x = 1.45$$

Plutonium metal storage array calculation may now be made using this exponent. For any metal storage system tamped on one surface in which the array density is 2.88 g/cm^3 or less, a conservative estimate of the critical number of units in the array may be calculated. See the sample calculation for an illustration of the method for calculating the critical number of units in an array. Note that these data approximate critical arrays and the calculated masses would need to be reduced for an actual storage array.

3.2 Sample Calculation

Calculate the number of units that would be required to form a critical array given the following:

Two kilograms of plutonium at a density of 15.8 g/cm^3

equivalent mass per unit

Five-inch cubical lattice

1. Array density $= \frac{2000}{5 \times 5 \times 5 \times 16.387} = 0.976$ g/cm^3

2. Critical mass $\cong 15 \left(\frac{15.8}{0.976}\right)^{1.45} = 15 \times 56.67$

3. Number of units critical $= \frac{850}{2} = 425$ units.

3.3 Materials

Fuel

Plutonium density ~15.8 g/cm^3

Average button weights for planar array	2065 g
for three-dimensional array	2030 g

Button dimensions - truncated cone

base diameter 2.75 in.

top diameter 2.375 in.

height 1.25 in.

Container

Thin walled steel can 4 in. in diameter and 2.69 in. in height

Reflector

All arrays were bottom reflected by effectively ∞ concrete.

4. EXPERIMENT 3 - ENRICHED URANIUM SLAB GRAPHITE REFLECTED

4.1 Discussion

A slab assembly of enriched uranium was constructed out of pieces, the dimensions of which are given in the section on materials. The reciprocal multiplication as a function of the number of kilograms of metal in the assembly is given in Figure 7. An extrapolation of the data to the critical state gives 76 kg as the critical mass of this slab.

4.2 Materials

Fuel

Enriched uranium ~90% U^{235}

Density ~18.7 g/cm^3

Dimension of slab assembly 1-9/16 in. x 9-7/16 in. x L

Weight of experimental pieces - 9719, 4022, 3999, 5216, 5373, 2856, 2830, 2830, 2850, 2863, and 2885 g

Reflector

Graphite (National carbon grade Cs-312)

Density - 1.76 g/cm^3

Dimensions of cylindrical reflector - 11 in. diameter x 12 in. length

Dimension of slab shaped cavity - 1-5/8 in. x 9-5/8 in. x 12 in.

5. EXPERIMENT 4 - SYSTEMS CONTAINING METAL SLABS IMMERSED IN AQUEOUS SOLUTIONS OF $UO_2(NO_3)_2$ OR WATER

5.1 Discussion

Neutron multiplication measurements were made on enriched uranium plates moderated and reflected by water or various concentrations of aqueous $UO_2(NO_3)_2$ solutions. See Figure 8 for the experimental equipment. The experimental data are presented in Table II and Figure 9. The edge to edge separation of the metal plates in Figure 9 is zero inches.

It was found that the 8-in. diameter container 12 in. long could not be made critical for a plate separation of 1/4 in. or greater even when the metal plate assemblies were reflected and moderated with the 294 g U/l solution.

TABLE II

Moderator and Reflector Solutions	Plate Separation (in.)	Number of Plates in Experiment	Critical Number of Plates	H:U Atomic Ratio of Core	Thickness of End Reflector (in.)	Thickness of Lateral Reflector (in.)
H_2O	0.008	24	32	0.1	3.5	0.36
H_2O	0.222	24	-	3.0	2.0	0.36
H_2O	0.456	17	∞	6.3	0.75	0.36
H_2O	0.962	8	∞	13.3	0.75	0.36
$UO_2(NO_3)_2$ 195 g U/l	0.008	21	26	0.1	3.5	0.36
$UO_2(NO_3)_2$ 294 g U/l	0.008	20	25	0.1	3.5	0.36
294 g U/l	0.232	24	-	2.6	1.0	0.36
294 g U/l	0.470	16	∞	5.2	0	0.36

5.2 Materials

Fuel (Metal)

Enriched uranium ~90% U^{235}

Density ~18.7 g/cm^3

Weight of plate - 1246 g

Thickness of plate 0.102 in.

Dimension of plate - Octagon (3.5 in. inside circle radius) 0.875 in. hole in center

Moderator and Reflector

Water, 195 g U/l $UO_2(NO_3)_2$ excess HNO_3 ~0.75 N

294 g U/l $UO_2(NO_3)_2$ excess HNO_3 ~0.75 N

Experimental Equipment

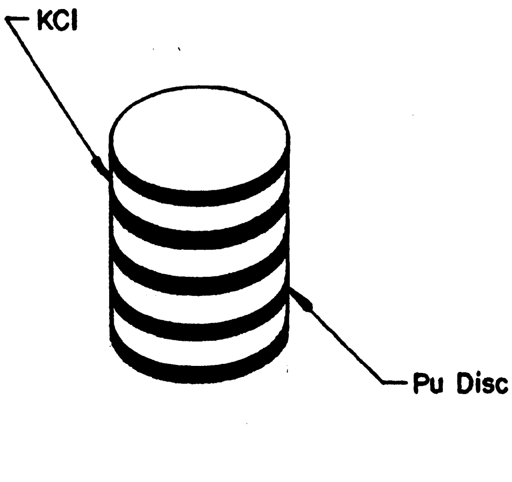
Stainless steel vessel 1/8 in. wall thickness and diameter 8 in., height 12 in.

Central spacer rod ~0.75 in. diameter

Stainless spacers ~0.75 in. ID by 1.0 in. OD.

FIGURE I

PLUTONIUM MODERATED BY SALT



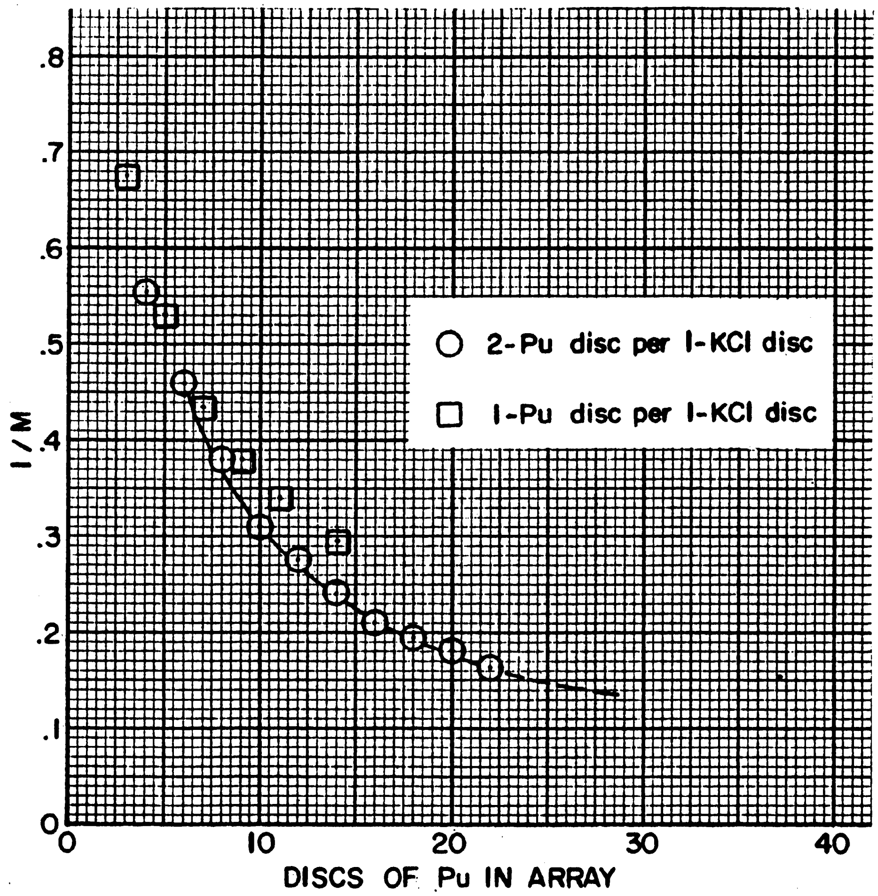
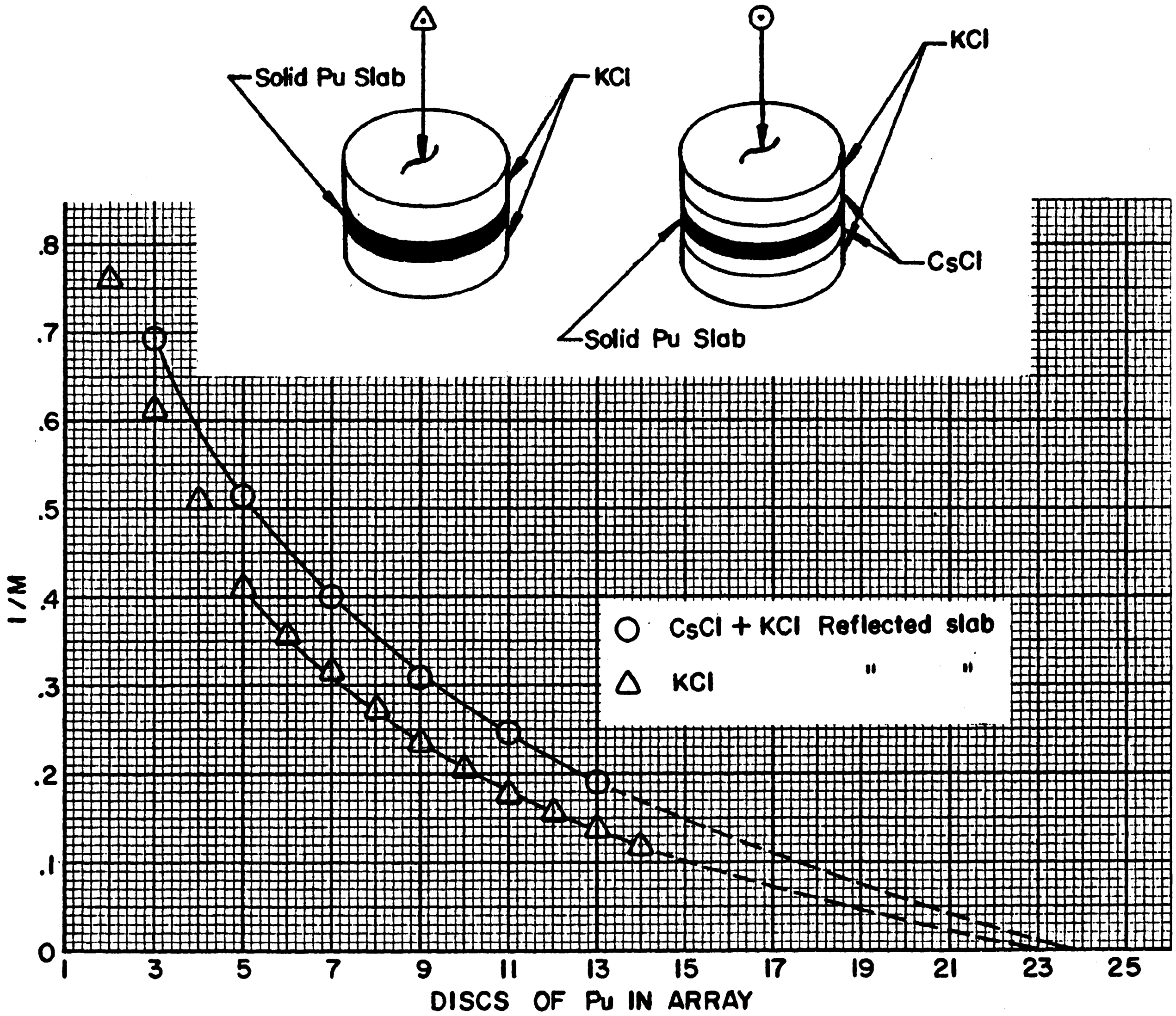


FIGURE 2

PLUTONIUM METAL SLAB SALT REFLECTED



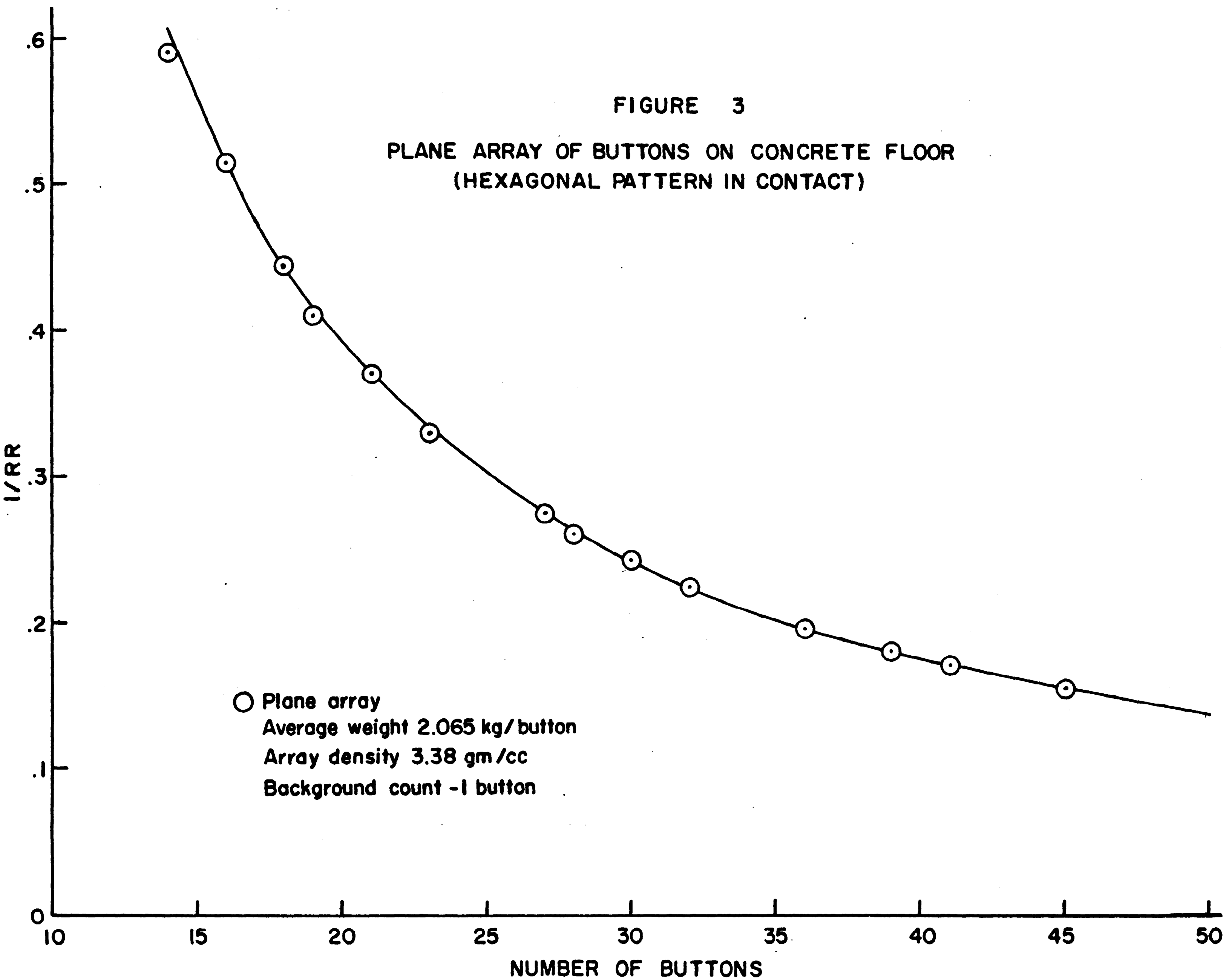


FIGURE 3

PLANE ARRAY OF BUTTONS ON CONCRETE FLOOR
(HEXAGONAL PATTERN IN CONTACT)

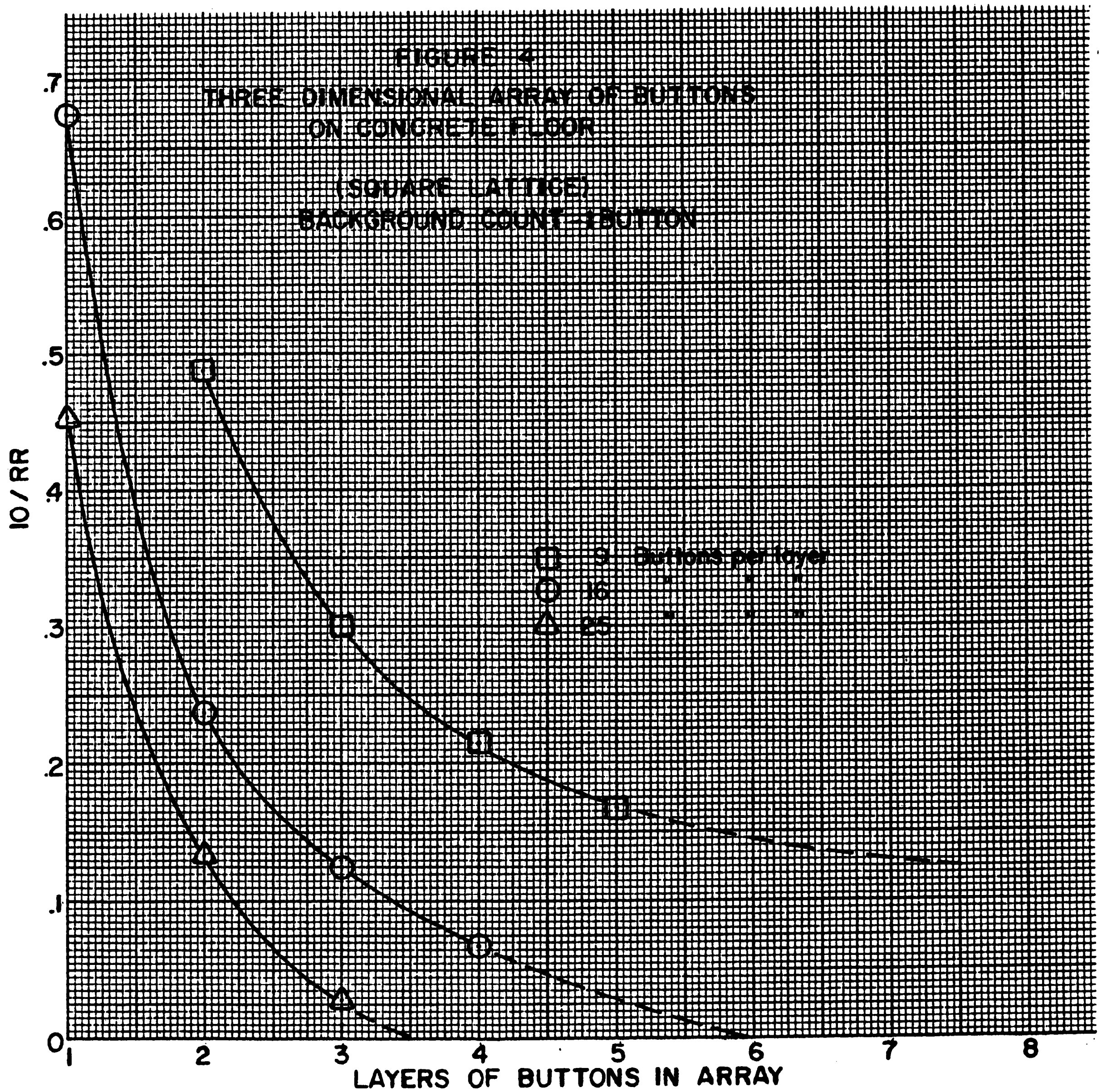


FIGURE 4
THREE DIMENSIONAL ARRAY OF BUTTONS
ON CONCRETE FLOOR
(SQUARE LATTICE)
BACKGROUND COUNT - 1 BUTTON
9 Buttons per layer
16 " " "
25 " " "
10 / RR
.7
.6
.5
.4
.3
.2
.1
0
1
2
3
4
5
6
7
8
LAYERS OF BUTTONS IN ARRAY

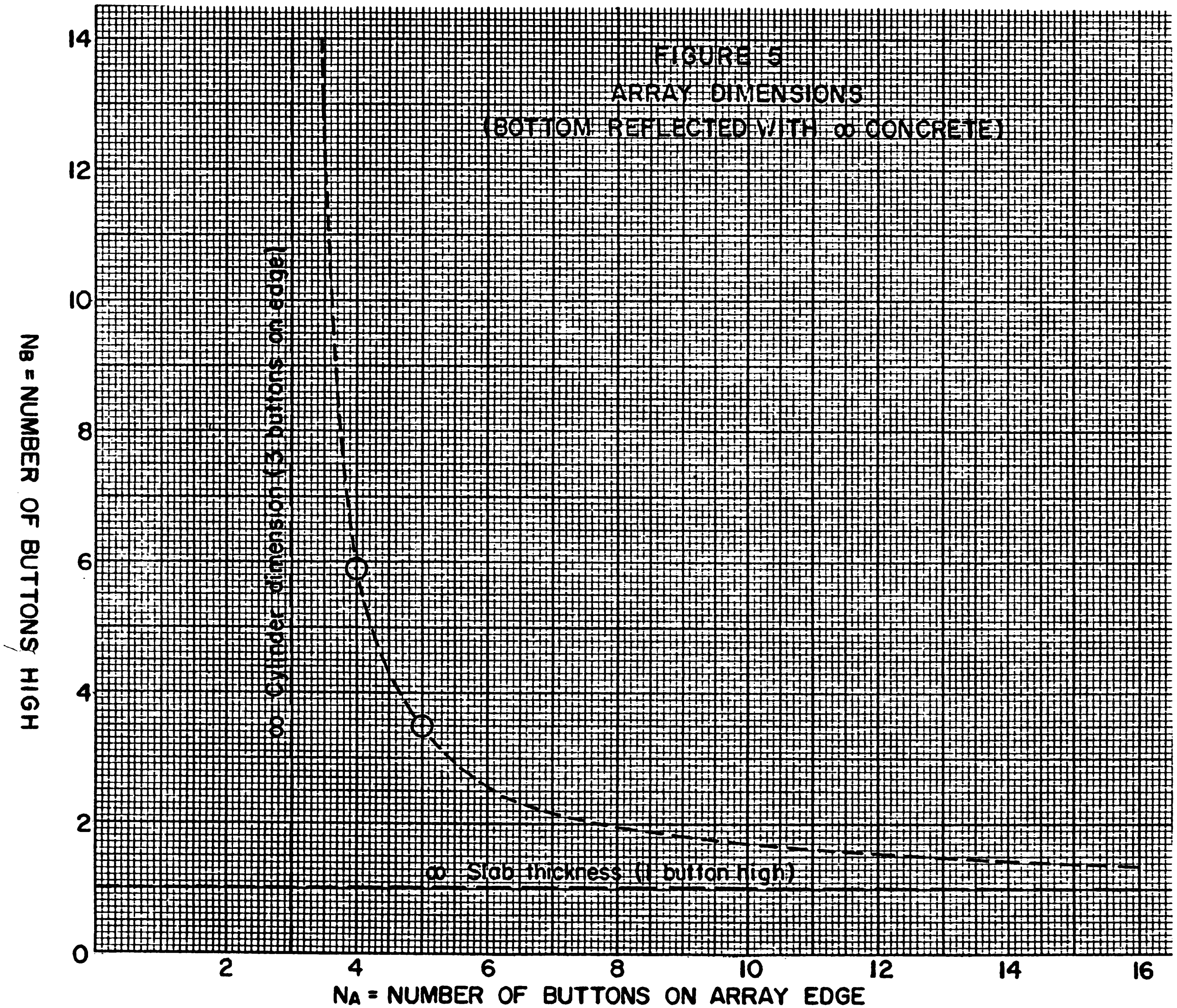
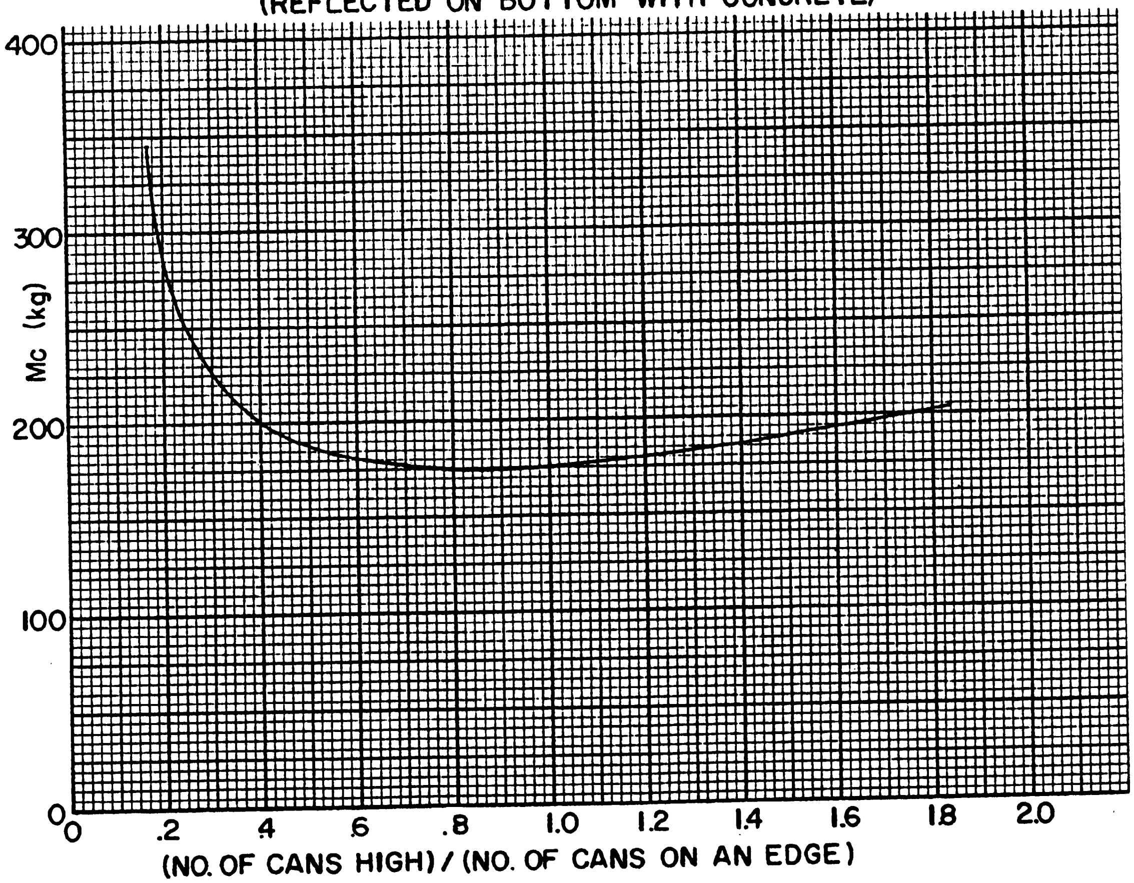


FIGURE 5
ARRAY DIMENSIONS
(BOTTOM REFLECTED WITH ∞ CONCRETE)
∞ Cylinder dimension (3 buttons on edge)
∞ Slab thickness (1 button high)
N_B = NUMBER OF BUTTONS HIGH
N_A = NUMBER OF BUTTONS ON ARRAY EDGE
0
2
4
6
8
10
12
14
16

FIGURE 6

CRITICAL MASS AS A FUNCTION OF ARRAY SIZE
(REFLECTED ON BOTTOM WITH CONCRETE)



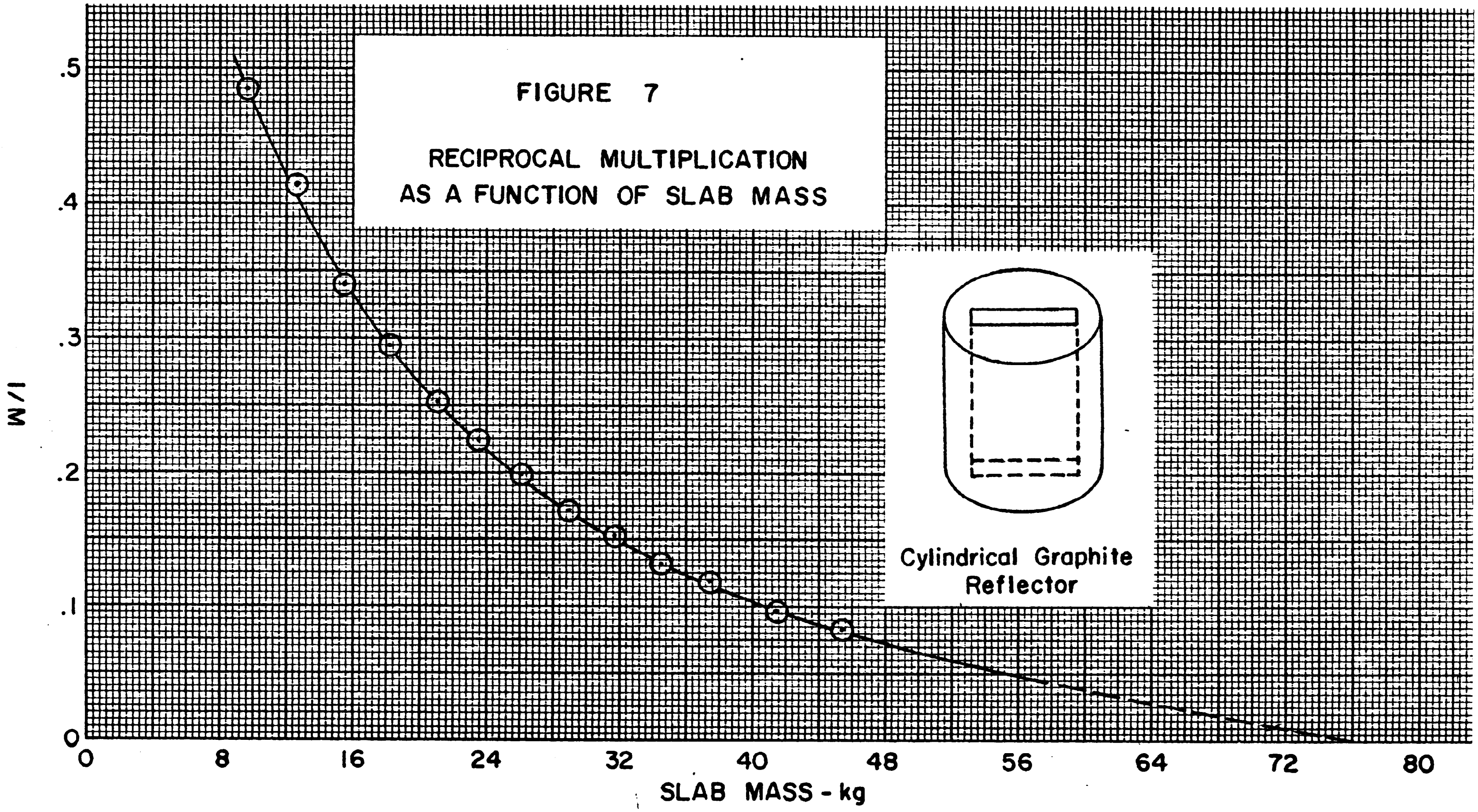
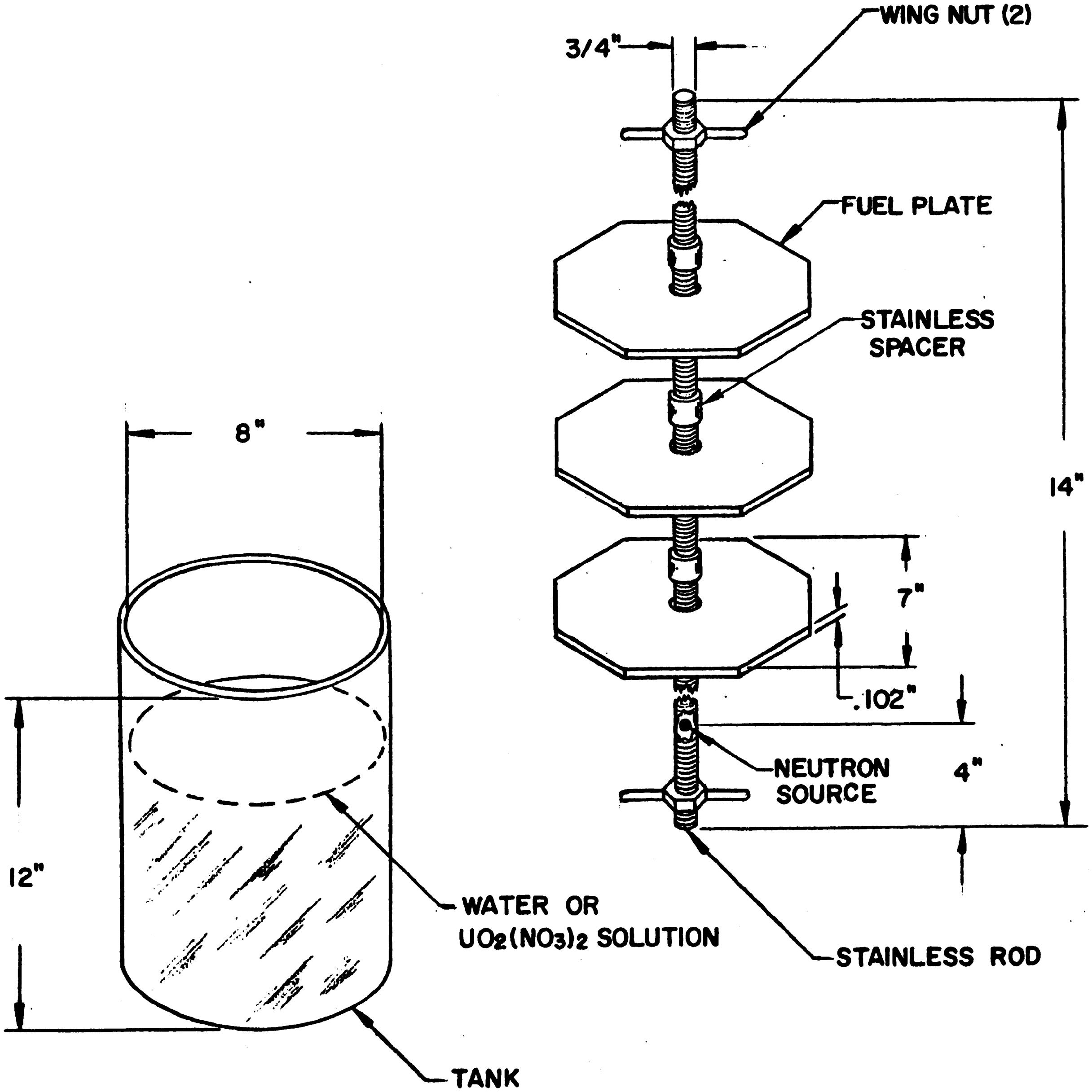


FIGURE 7

RECIPROCAL MULTIPLICATION AS A FUNCTION OF SLAB MASS

FIGURE 8
METAL SOLUTION COMBINATIONS



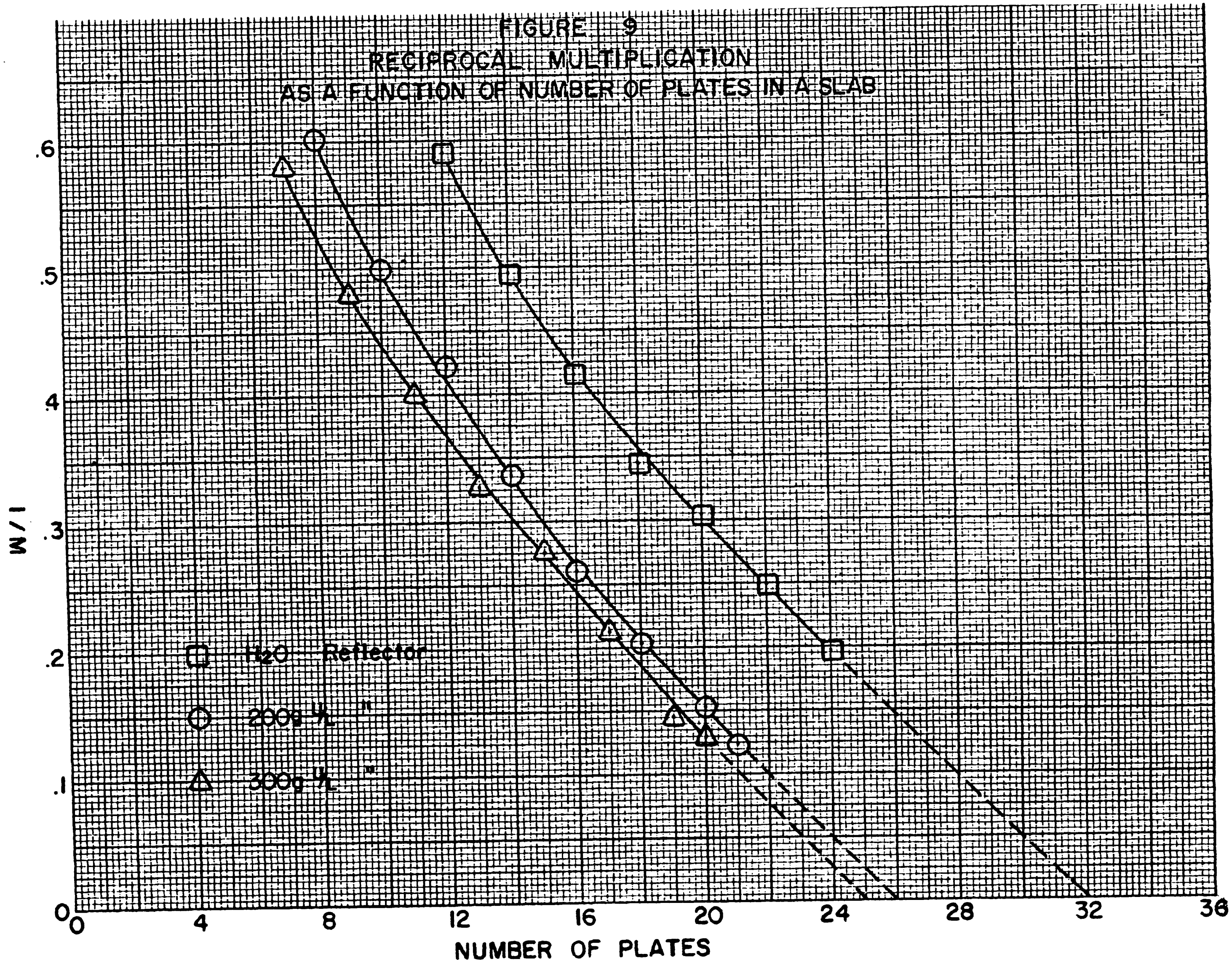


FIGURE 9
RECIPROCAL MULTIPLICATION
AS A FUNCTION OF NUMBER OF PLATES IN A SLAB