REFERENCE 126

C. L. SCHUSKE AND G. H. BIDINGER, "NUCLEAR SAFETY MEASUREMENTS ON SYSTEMS CONTAINING BORON AND ENRICHED URANIUM," DOW CHEMICAL CO., ROCKY FLATS PLANT REPORT RFP-246 (OCTOBER 1961).

RFP-246 RFP-246

AEC RESEARCH AND DEVELOPMENT REPORT

Nuclear Safety Measurements on Systems Containing Boron and Enriched Uranium

by
C. L. Schuske
G. H. Bidinger

THE DOW CHEMICAL COMPANY

ROCKY FLATS PLANT DENVER, COLORADO

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

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor 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 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.

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

RFP-246

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

NUCLEAR SAFETY MEASUREMENTS
ON SYSTEMS CONTAINING BORON AND ENRICHED URANIUM

by

C. L. Schuske

G. H. Bidinger

L. A. Matheson - Technical Director

J. G. Epp - Assistant Technical Director

Date Distributed: October 24, 1961

ABSTRACT

Neutron multiplication measurements were made on two types of enriched uranium systems containing boron as a nuclear poison. They are:

(1) A 36-in. diameter partially tamped tank containing spaced vertical boron-stainless steel plates.

(2) Tamped and untamped assemblies of $UO_2(NO_3)_2$ salts at low hydrogen moderation containing Pyrex Raschig rings.

Attempts were made to calculate sphere masses and infinite cylinder and slab shapes from the experimental data. This work represents an extension of work reported in RFP-201.(1)

ACKNOWLEDGMENTS

The Phillips Petroleum Company initiated the boron-stainless plate experiment and supplied the boron-stainless steel plates and experimental vessel. Mr. Marx Weech of Phillips provided liaison between Phillips and Rocky Flats.

The authors wish to thank Mr. L. L. Zodtner and his staff for their cooperation and assistance during the measurements. We wish also to thank Dr. A. Goodwin, Jr., for his help and suggestions made during the evaluation of the experimental data.

---

(1) G. H. Bidinger, C. L. Schuske, D. F. Smith, "Nuclear Safety Experiments on Plutonium and Enriched Uranium Hydrogen Moderated Assemblies Containing Boron", USAEC Report RFP-201, July 7, 1960.

1. INTRODUCTION

Neutron multiplication measurements were made on partially reflected 36-in. diameter cylinders containing vertically spaced boron-steel plates. Several plate spacings and solution concentrations were examined.

In addition, work reported in RFP-201 on Pyrex Raschig rings as a nuclear poison was extended in this compilation to systems of low $H:U^{235}$ atomic ratios. Parallelepiped assemblies bare and reflected with 8 in. of concrete were examined. The $H:U^{235}$ ratios ranged from approximately 8 to 14.

2. EXPERIMENTAL MATERIALS

The measuring equipment used in these experiments included scalers, Atomic Model 1050-A, coupled to G.E. B^{10}-lined counters and LiI(Eu) scintillators.

2.1 Materials (for vertical boron-steel plate experiment)

2.1.1 Vessel

Stainless steel tank having 3/16-in. wall thickness and ID of 35-5/8 in.

2.1.2 Plates

Stainless steel - thickness 0.138 in. Boron content 1.02 $^{w}/o$* (Rocky Flats value).

---

*Plates and tank supplied by Phillips Petroleum Company, Idaho Falls, Idaho. Phillips' boron analysis was 1.196 $^{w}/o$ boron.

2.1.3 Fuel

Aqueous solutions of $UO_2(NO_3)_2$ enrichment ~90%

Uranium in Solution (g/1)	Excess HNO_3 Normality	Boron Impurity (ppm)	Cadmium Impurity (ppm)
106	0.25	~6	~100
237	0.31	~6	~100
322	0.21	~6	~100

2.2 Materials

2.2.1 Fuel

Aqueous solutions of $UO_2(NO_3)_2$ enriched to ~90%

Approximate formula $UO_2(NO_3)_2 \cdot 4H_2O$

Salt density 2.998 g/cm^3

Uranium concentration 0.52 g per gram of salt

Excess HNO_3 <0.1 normal

2.2.2 Raschig Rings

1.5 in. OD x 1.18 in. ID x 1.75 in. long

Glass density ~2.29 g/cm^3

Boron content ~19 $^w/o$ B_2O_3 in the glass

2.2.3 Aluminum Mold

11.25 x 11.25 x 1.875 in. inside dimensions

Aluminum density ~2.7 g/cm^3

Aluminum thickness ~0.0598 in.

2.2.4 Moderator

Plexiglas - $C_5H_8O_2$

Density ~1.2 g/cm^3

2.2.5 Reflector

Concrete block density 2.2 g/cm^3

3. RESULTS

Figure 1 is a schematic of the boron-stainless steel plate experiment. Figure 2 illustrates the parallelepiped arrays. A typical salt block of the array is also shown.

The H:U ratios of the latter were calculated on the basis that the Plexiglas and fuel blocks are homogeneously mixed.

The constant buckling equation $B^2 = \frac{J_o^{\,2}}{(R + \delta)^2} + \frac{\pi^2}{(H + 2\delta)^2}$ was used to convert the experimental dimensions of the bare assemblies to those of spheres, infinite cylinders, and infinite slabs. The extrapolation length δ used was 2.75 cm.

The constant buckling equation was also used to convert the tamped parallelepiped assemblies to spheres. The extrapolation length used was 6.0 cm. The spheres in turn were converted to infinite cylinders and infinite slabs by the method given in LA-399.(2)

Since error can be introduced by these techniques, the sphere, cylinder, and slab values should be used conservatively.

Tables I through VI contain the experimental data and shape conversions derived from the experimental geometric parameters.

---

(2) E. Greuling, et. al., "Theory of Water Tamped Water Boiler", USAEC Report LA-399, September 27, 1945.

Figures 3 through 8 are examples of the 1/M extrapolations of the boron-stainless steel plate experiment. Similar curves could be presented for the block assemblies.

In Figure 9, an attempt was made to evaluate the effectiveness of the Pyrex Raschig rings as a function of the H:U atomic ratio. In the method used, the following ratios were plotted as functions of the H:U atomic ratio.

$$\frac{\dfrac{M_e - M}{M} \times 100}{\%\ \text{Glass Volume}}$$

Where:

M_e = The bare or reflected experimental critical mass of a salt assembly containing the Raschig rings (normalized to spherical shapes).

M = The bare or reflected spherical critical mass for enriched uranium in water.(3)

The method thus described in evaluating the boron effectiveness should, in principle, be conservative for the following reason. M is arrived at, in Figure 9, by normalizing the U-H_2O sphere masses to the lower densities of the experimental core by the correction $(\rho_1/\rho_2)^2$. This is shown by Curve A in Figure 9. In Curve B, the uranium density has not been normalized to the experimental densities.

It can be seen that this method for arriving at M does not take into account the scattering cross sections of the

---

(3) H. C. Paxton, "Correlations of Experimental and Theoretical Critical Data", USAEC Report LAMS-2537, May 15, 1961.

glass, aluminum, and the salt molecule, which fill the void spaces in the experimental assemblies. Even though these materials are poor moderators, they will reduce the values of M and consequently increase the effectiveness ratio. Several 16-group diffusion calculations have been made on the experimental assembly materials minus the boron to arrive at values of M. The end result is that the effectiveness ratios were almost twice as large as those given in Figure 9.

Two obvious observations can be made from the data compilation. The first is that the effectiveness of the Pyrex Raschig rings greatly increases with the H:U atomic ratio. The second is that the effectiveness of the boron is strongly influenced by the cell size.

The information given in this compilation should be used conservatively when applied to plant operations.

The authors estimate the experimental error at ±10%. No estimate is given for the error expected in uranium-water curves given in LAMS-2537, from which the values of M were derived.

Figures 10, 11, and 12 are bare infinite cylinder slab and sphere dimensions as functions of the H:U atomic ratios.

These parameters were arrived at in the following manner: The values taken from Table IV were reduced directly by the ratios $D_o(\frac{\rho_o}{\rho})$ and $T_o(\frac{\rho_o}{\rho})$. This correction assumed that air and aluminum in the arrays were void volume. The salt density used in these calculations was determined by experiment to be 2.998 g salt/cc.

TABLE I

Vertical Boron-Stainless Steel Plates

Experiment Number	Uranium Density in Core (g/cm^3)	Experimental Mass (kg)	Critical Mass (kg)	Plate Separation (in.)	Unpoisoned Slab Bottom Thickness (in.)	Unpoisoned Annulus (in.)
1	0.287	69.5	82.2	1.0	0.875	1.0
2	0.211	106.2	∞	1.0	0.875	1.0
3	0.211	108.1	∞	1.0	1.875	1.0
4	0.219	32.2	40.1	1.5	0.875	1.19
5	0.098	31.4	∞	1.5	0.875	1.19
6	0.100	17.7	20.6	2.125	0.875	1.0

TABLE II

Vertical Boron-Stainless Steel Plates

Experiment Number	Sphere Mass (kg)	Sphere Radius (cm)	Cylinder Radius (cm)	Slab Thickness (cm)	$\frac{[(M_e-M_o)/M_o] \times 100^*}{\% \text{ Steel Vol}}$	$\frac{[(M_e-M_1)/M_1] \times 100^*}{\% \text{ Steel Vol}}$
1	56.9	36.2	27.1	33.6	92.0	119.1
2	~196	~60.5	~45.7	~58	~402.8	~508.8
4	22.0	28.9	21.5	26.4	61.5	72.2
5	~91	~60.5	~45.7	~58	~545.4	~633.7
6	5.3	23.3	17.2	20.8	27.8	32.6

* M_e = Mass in experiment.

M_o = Mass in UO_2F_2 (LAMS-2537) with density correction to experimental densities.

M_1 = Mass in UO_2F_2 (LAMS-2537) without density correction to experimental densities.

$\frac{[(M_e-M_o)/M_o] \times 100}{\% \text{ Steel Vol}}$ = Percentage mass increase per percentage steel volume.

TABLE III

Unreflected Parallelepipeds Containing Pyrex Raschig Rings

Experiment Number	Uranium Density in Core (g/cm^3)	H:U Atomic Ratio	Mass in Experiment (kg)	Critical Mass (kg)	Glass Volume Fraction	Critical Dimensions of Array (in.)
1	1.044	8.01	46.1	∞	0.188	11.33 x 11.33 x ∞
2	1.032	8.01	328.7	402	0.188	34 x 34 x 20.58
3	1.030	8.01	291.4	565	0.188	22.67 x 22.67 x 65.1
4	0.893	11.37	246.5	324	0.163	34 x 34 x 19.42
5	0.885	11.58	214.5	250	0.161	22.67 x 22.67 x 33.53
6	0.801	14.55	149.2	162	0.143	22.67 x 22.67 x 21.16
7*	0.296	~67.7	167.4	∞	0.178	42 (diameter) x ∞

*Reported in RFP-201.

TABLE IV

Unreflected Assemblies

Experiment Number	Sphere Mass (kg)	Sphere Radius (cm)	Cylinder Radius (cm)	Slab Thickness (cm)	$\frac{[(M_e-M_o)/M_o] \times 100*}{\% \text{ Glass Vol}}$	$\frac{[(M_e-M_1)/M_1] \times 100*}{\% \text{ Glass Vol}}$
2	285.2	40.4	30.3	37.7	1.76	31.7
3	284.6	40.4	30.3	37.7	1.72	31.5
4	219.4	38.9	29.1	36.1	4.97	37.8
5	191.7	37.3	27.9	34.5	3.97	33.6
6	135.2	34.3	25.6	31.5	5.03	33.2
7	422.5	69.8	53.3	67.5	403.6	521.8

* M_e = Uranium mass in experiments.

M_o = Uranium mass in $U\text{-}H_2O$ mixture corrected to experimental densities. (LAMS-2537)

M_1 = Uranium mass in $U\text{-}H_2O$ mixture. (LAMS-2537)

$\frac{[(M_e-M_o)/M_o] \times 100}{\% \text{ Glass Vol}}$ = Percentage mass increase per percentage glass volume.

TABLE V

Concrete Reflected Parallelepipeds Containing Pyrex Raschig Rings

Experiment Number	Uranium Density in Core (g/cm^3)	H:U Atomic Ratio	Mass in Experiment (kg)	Critical Mass (kg)	Glass Volume Fraction	Critical Core Dimensions (in.)
8	1.058	8.01	138.5	157.3	0.188	22.67 x 22.67 x 17.67
9	1.056	8.01	108.3	∞	0.188	11.33 x 11.33 x ∞
10	1.045	8.01	194.4	∞	0.188	11.33 x 22.67 x ∞
11	1.043	8.01	184.5	232.5	0.188	34 x 34 x 11.76
12	0.934	11.14	95.0	123.5	0.164	22.67 x 22.67 x 15.71
13	0.910	11.49	117.0	133.5	0.161	11.33 x 22.67 x 34.77

TABLE VI

Concrete Reflected Assemblies

Experiment Number	Sphere Mass (kg)	Sphere Radius (cm)	Cylinder Radius (cm)	Slab Thickness (cm)	$\frac{[(M_e-M_o)/M_o] \times 100*}{\%\ \text{Glass Vol}}$	$\frac{[(M_e-M_1)/M_1] \times 100*}{\%\ \text{Glass Vol}}$
8	134.5	31.19	20.1	20.9	13.7	45.6
11	116.4	29.87	19.4	20.0	10.9	38.3
12	102.7	29.72	19.3	19.8	19.0	50.9
13	76.7	27.20	17.7	18.0	13.6	38.9

* M_e = Mass in experiment.

M_o = Mass in UO_2F_2 (LAMS-2537) with density correction to experimental densities.

M_1 = Mass in UO_2F_2 (LAMS-2537) without density correction to experimental densities.

$\frac{[(M_e-M_o)/M_o] \times 100}{\%\ \text{Glass Vol}}$ = Percentage mass increase per percentage glass volume.

FIGURE 1

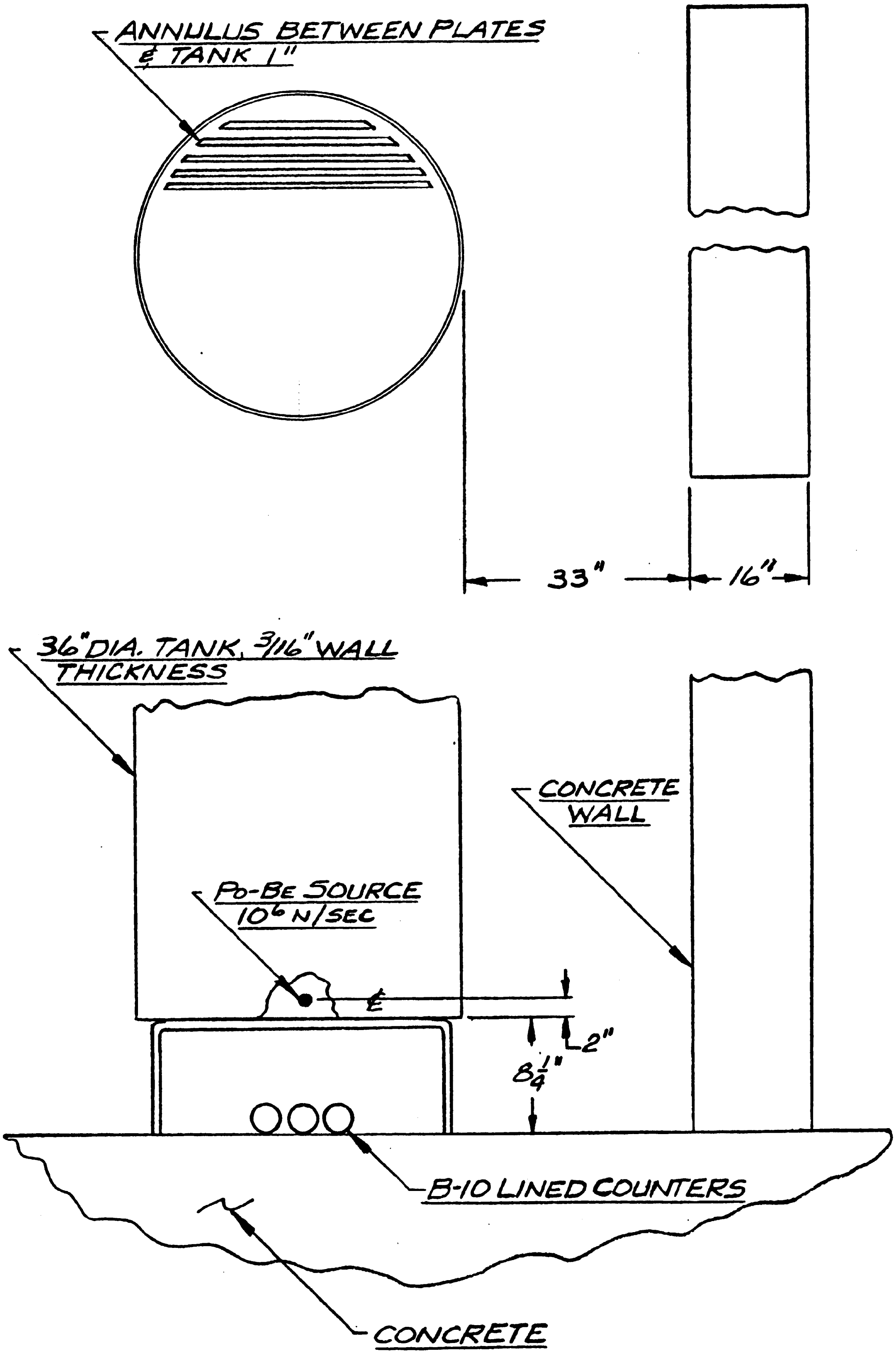
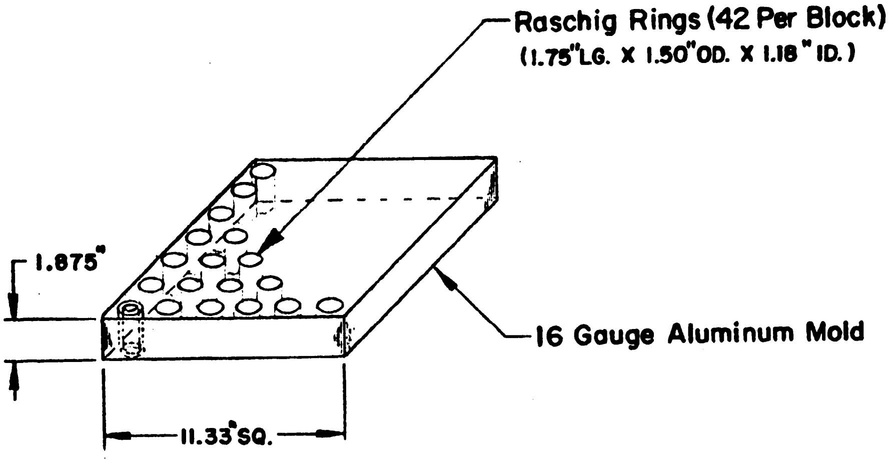
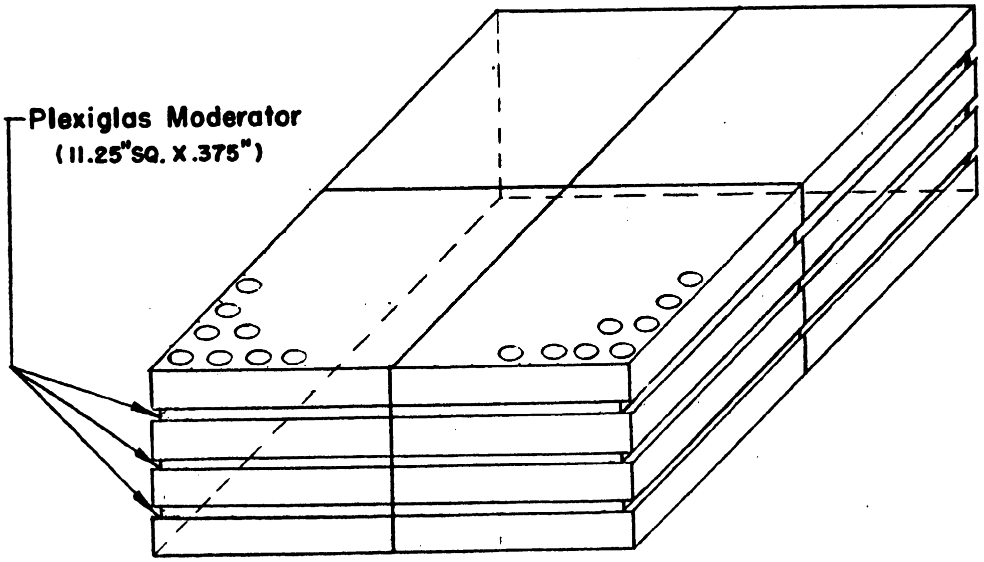

ANNULUS BETWEEN PLATES
& TANK 1"
33"
16"
36" DIA. TANK, 3/16" WALL
THICKNESS
CONCRETE
WALL
Po-Be SOURCE
10^6 N/SEC
℄
2"
$8\frac{1}{4}$"
B-10 LINED COUNTERS
CONCRETE

FIGURE 2

SCHEMATIC OF EXPERIMENTAL BLOCK ASSEMBLY



TYPICAL BLOCK



BLOCK ASSEMBLY

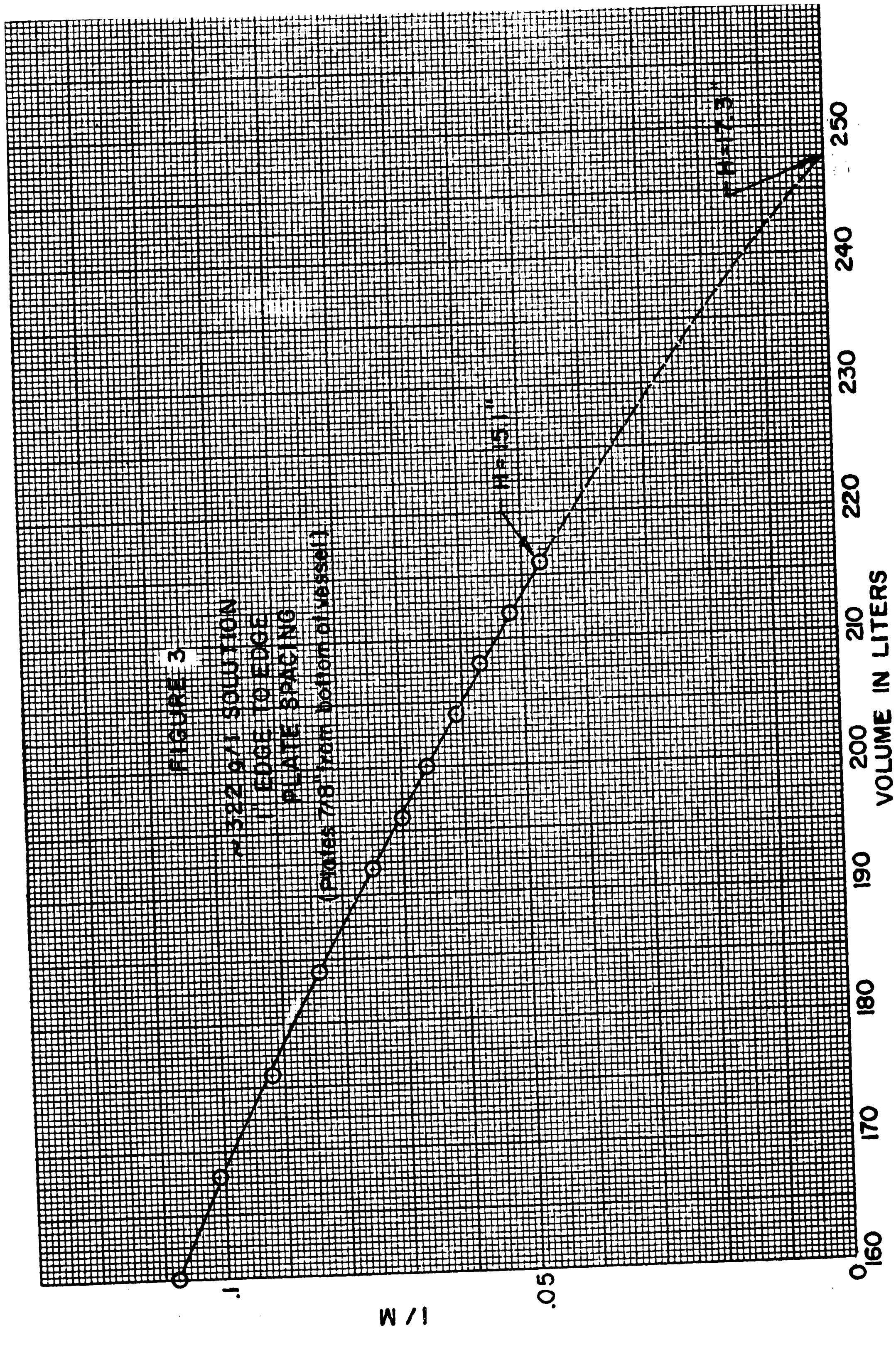


FIGURE 3
~322 g/l SOLUTION
1" EDGE TO EDGE
PLATE SPACING
(Plates 7/8" from bottom of vessel)
H=15.1"
H=17.3"
VOLUME IN LITERS
160
170
180
190
200
210
220
230
240
250
1/M
.1
.05
0

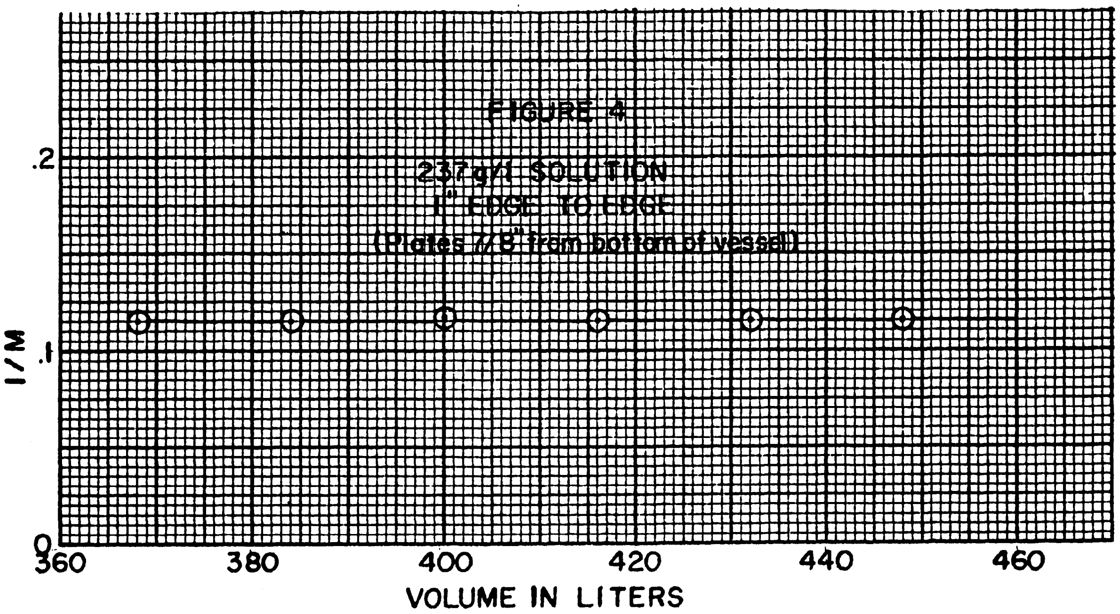


FIGURE 4

237g/l SOLUTION
1" EDGE TO EDGE
(Plates 7/8" from bottom of vessel)

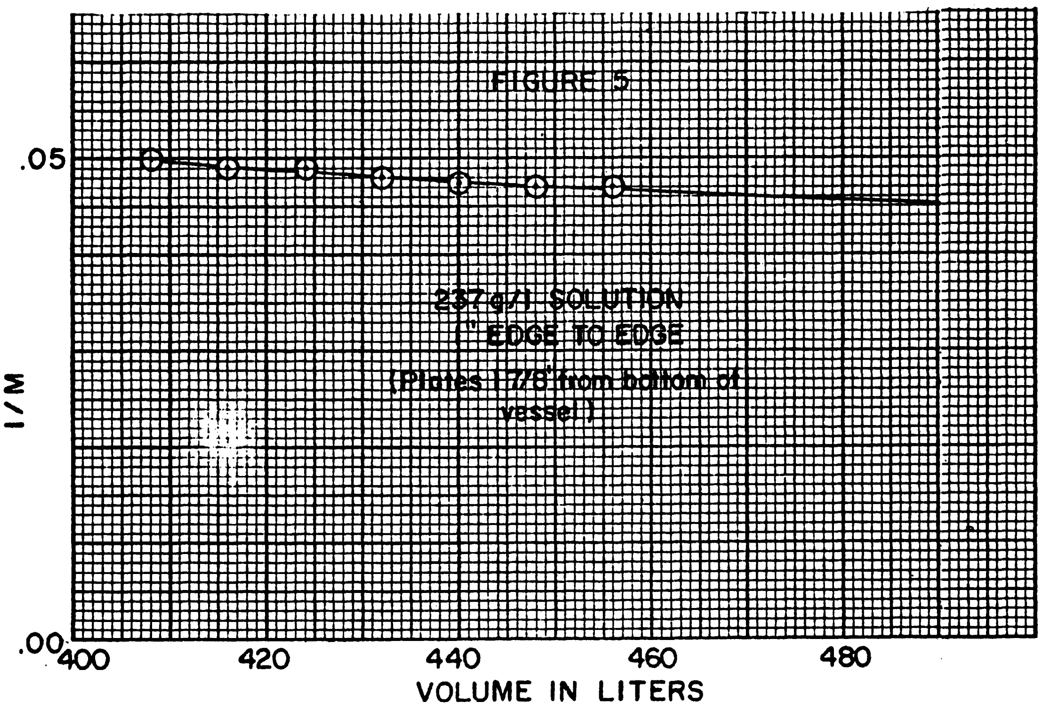


FIGURE 5

237g/l SOLUTION
1" EDGE TO EDGE
(Plates 17/8" from bottom of vessel)

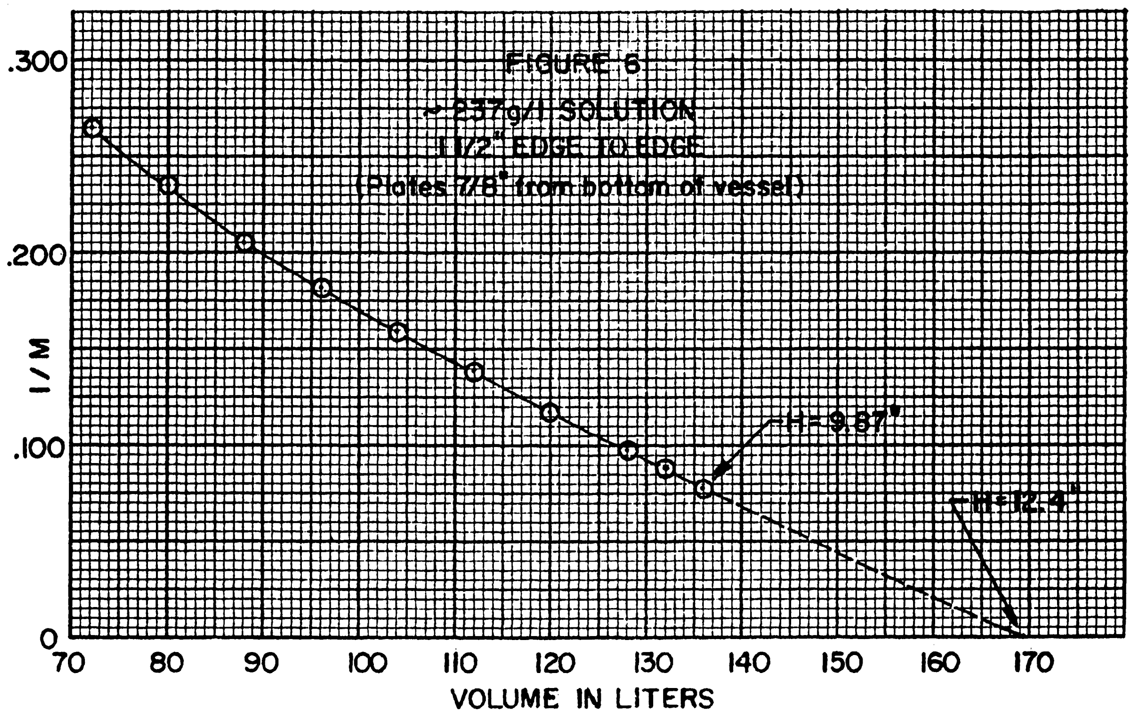


FIGURE 6

~ 237g/l SOLUTION

1 1/2" EDGE TO EDGE

(Plates 7/8" from bottom of vessel)

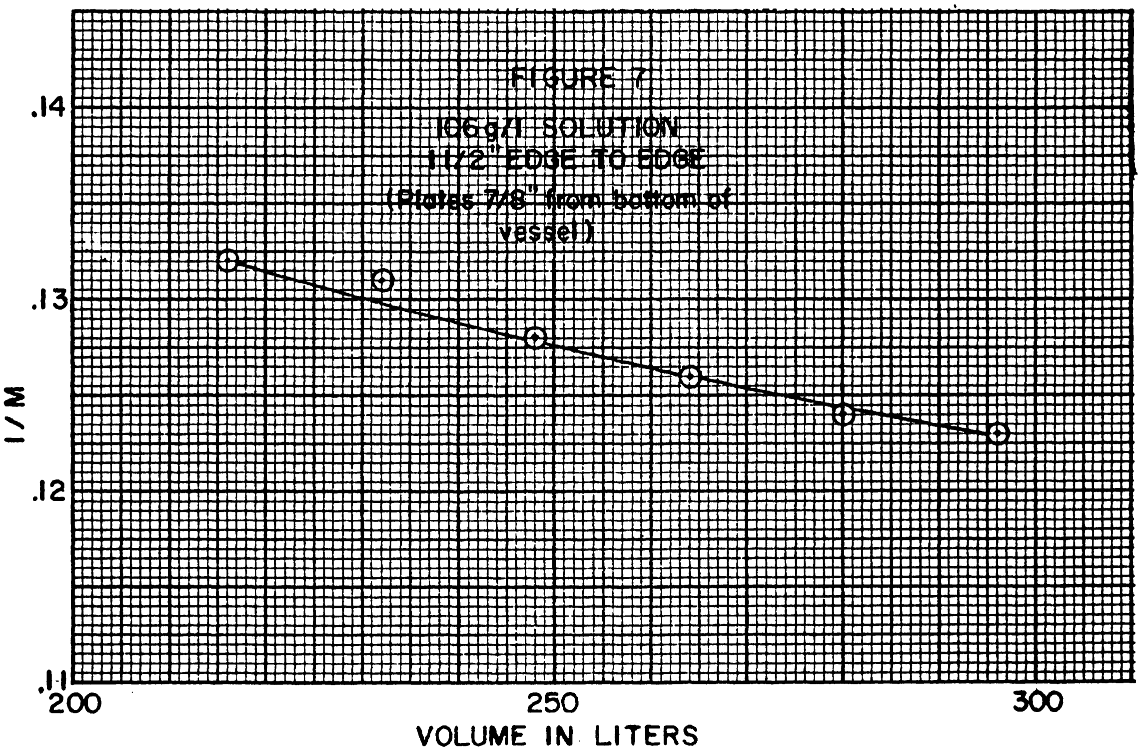


FIGURE 7

106g/l SOLUTION

1 1/2" EDGE TO EDGE

(Plates 7/8" from bottom of vessel)

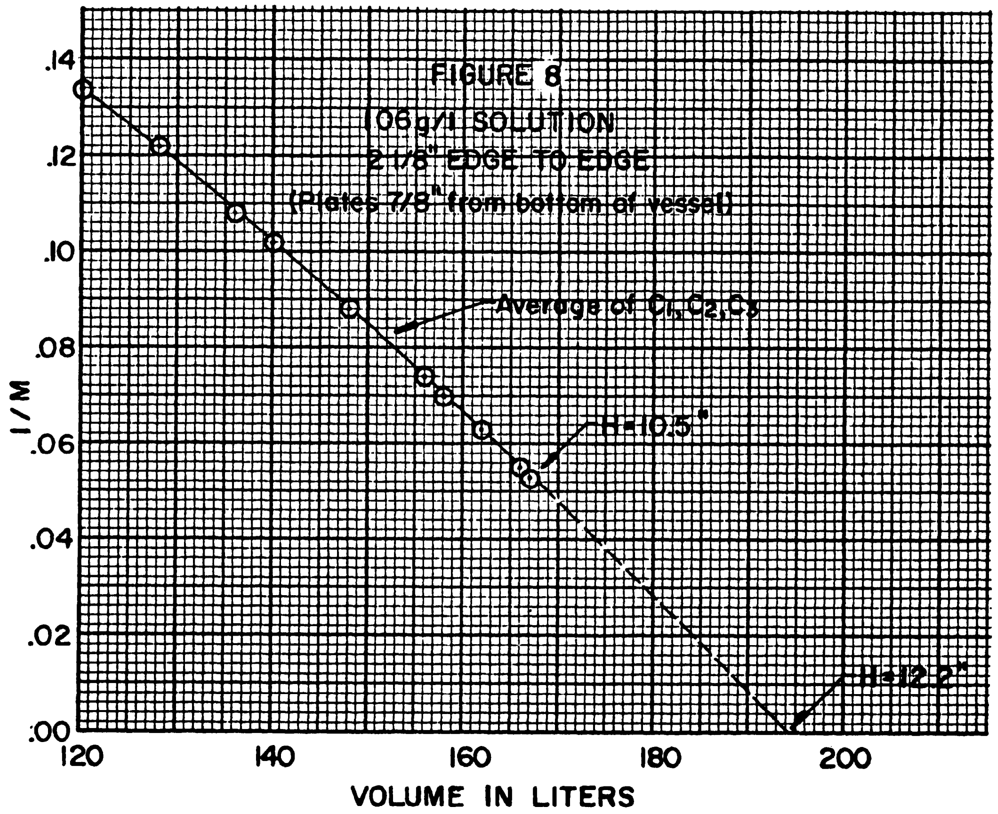


FIGURE 8
106 g/l SOLUTION
2 1/8" EDGE TO EDGE
(Plates 7/8" from bottom of vessel)

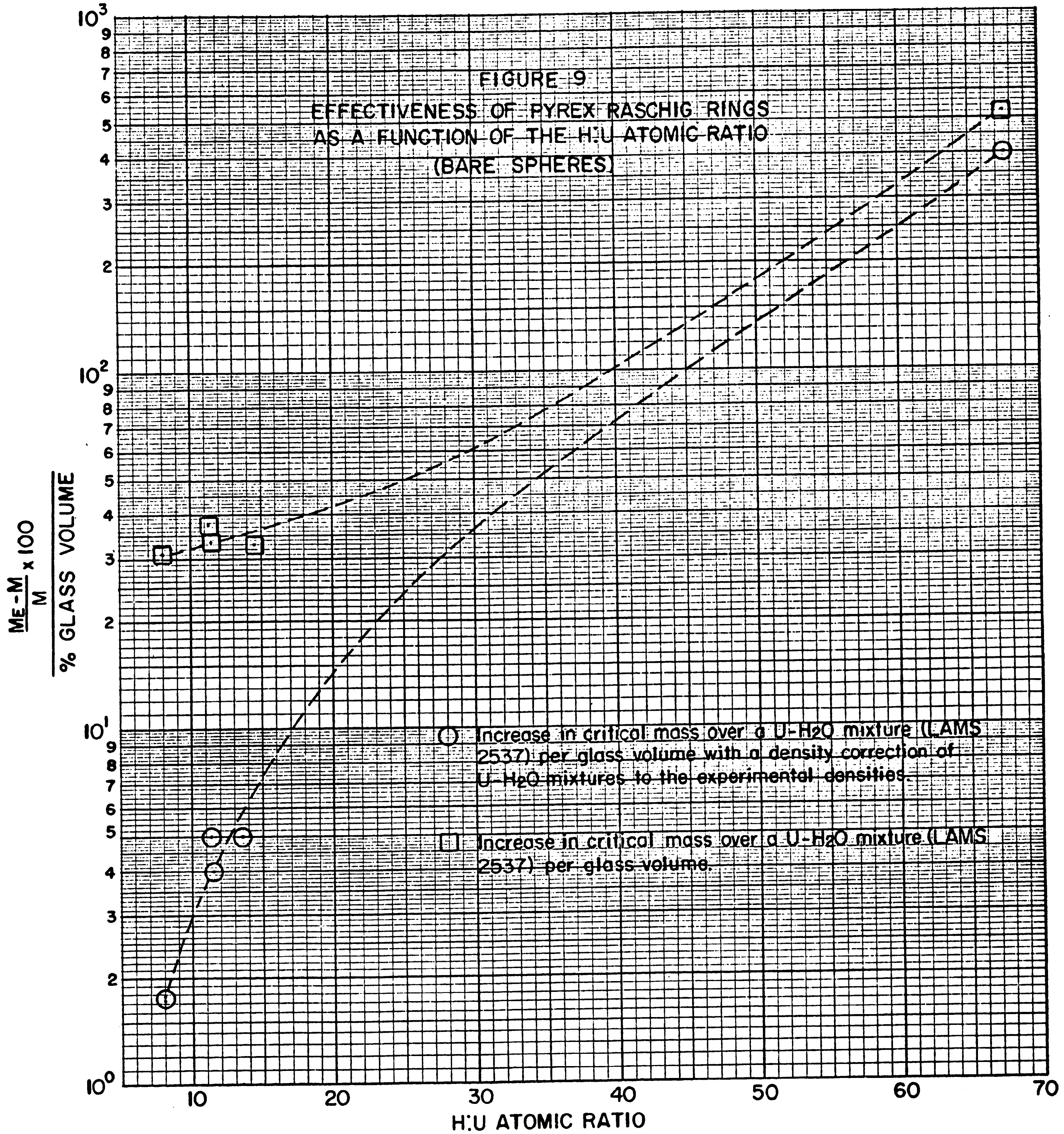


FIGURE 9

EFFECTIVENESS OF PYREX RASCHIG RINGS AS A FUNCTION OF THE H:U ATOMIC RATIO (BARE SPHERES)

○ Increase in critical mass over a U-H_2O mixture (LAMS 2537) per glass volume with a density correction of U-H_2O mixtures to the experimental densities.

□ Increase in critical mass over a U-H_2O mixture (LAMS 2537) per glass volume.

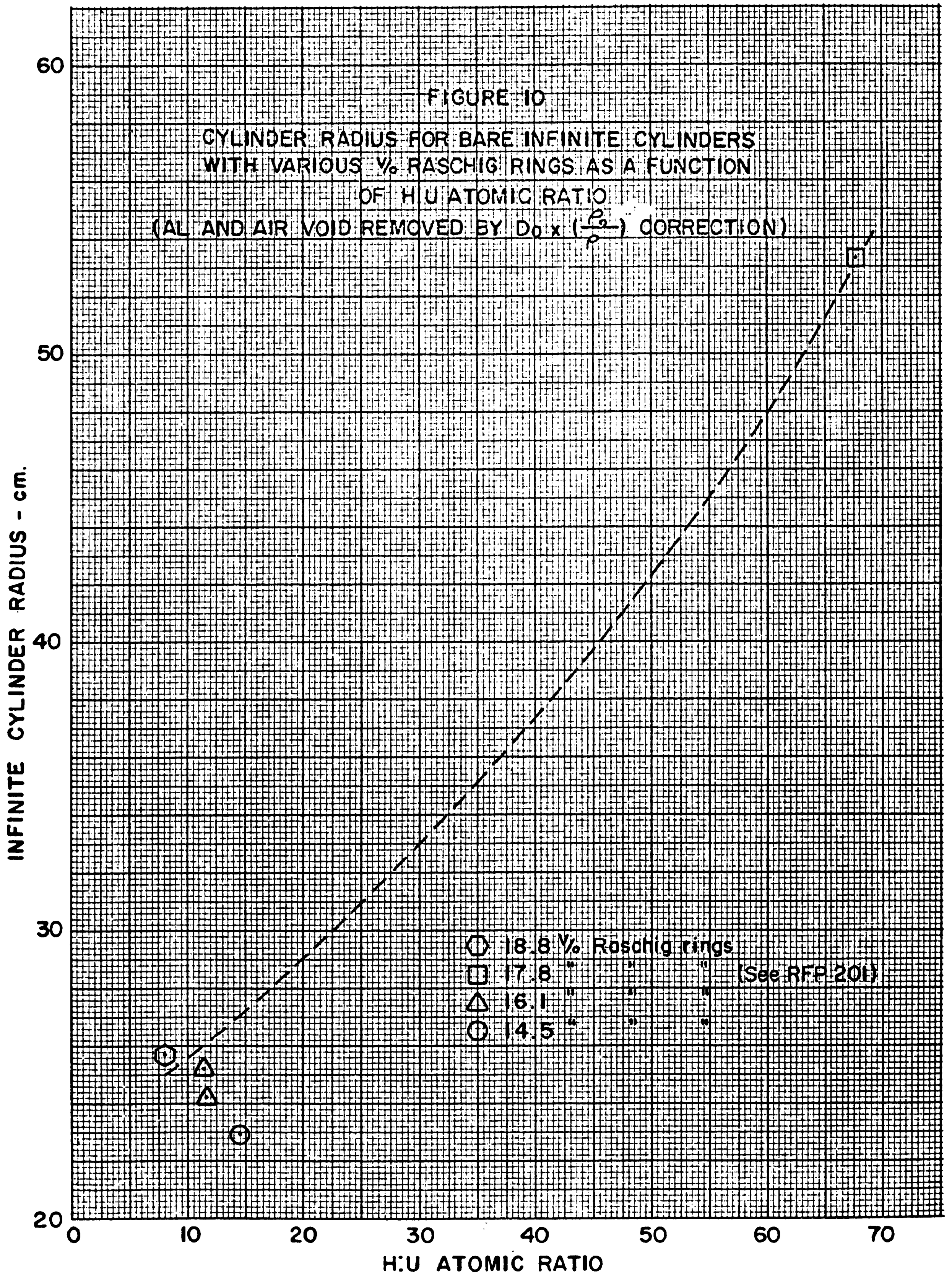


FIGURE 10

CYLINDER RADIUS FOR BARE INFINITE CYLINDERS WITH VARIOUS % RASCHIG RINGS AS A FUNCTION OF H:U ATOMIC RATIO (AL AND AIR VOID REMOVED BY $D_0 \times (\frac{\rho_0}{\rho})$ CORRECTION)

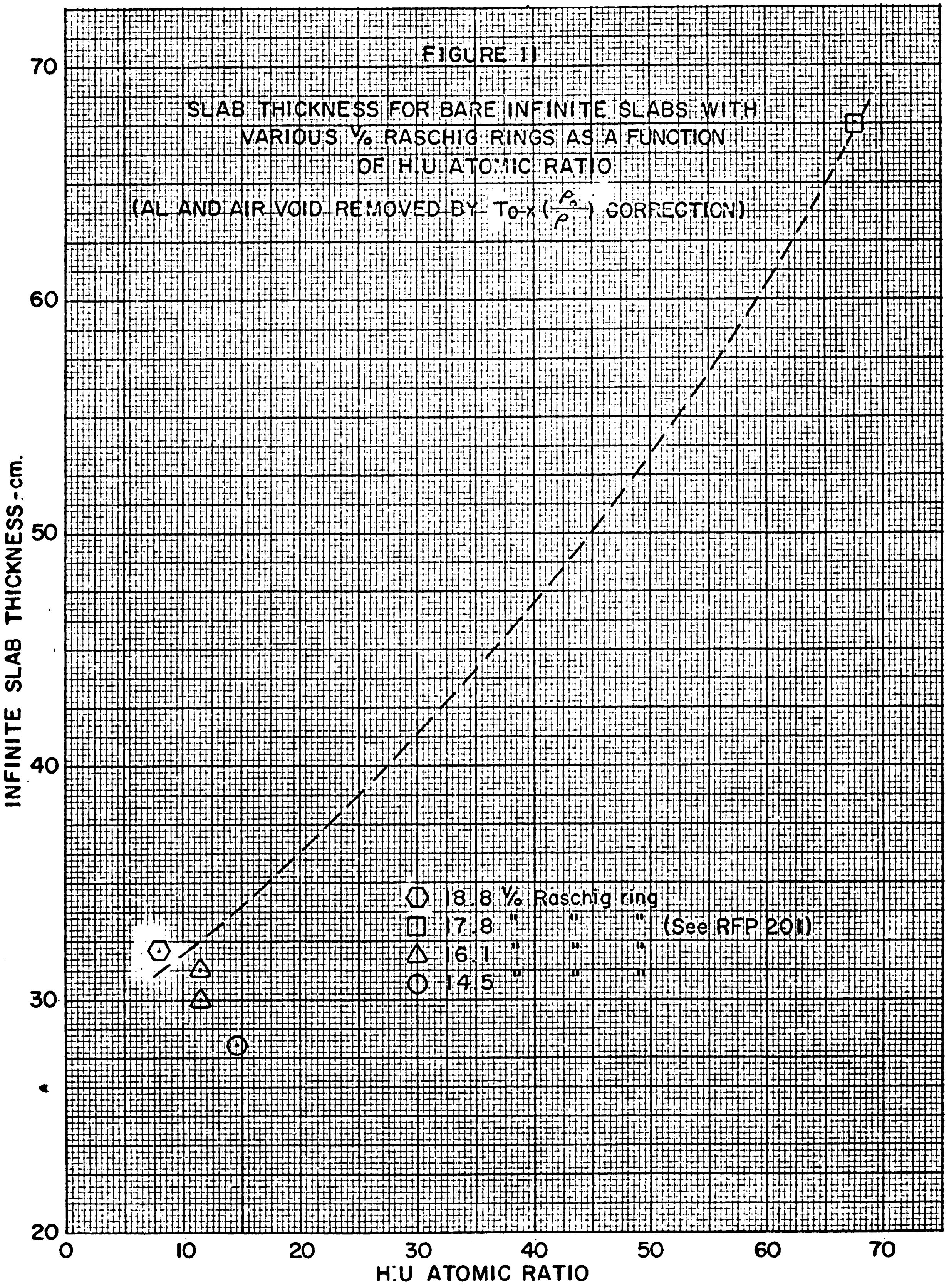


FIGURE 11

SLAB THICKNESS FOR BARE INFINITE SLABS WITH VARIOUS % RASCHIG RINGS AS A FUNCTION OF H:U ATOMIC RATIO

(AL AND AIR VOID REMOVED BY $T_0 \times (\frac{\rho_0}{\rho})$ CORRECTION)

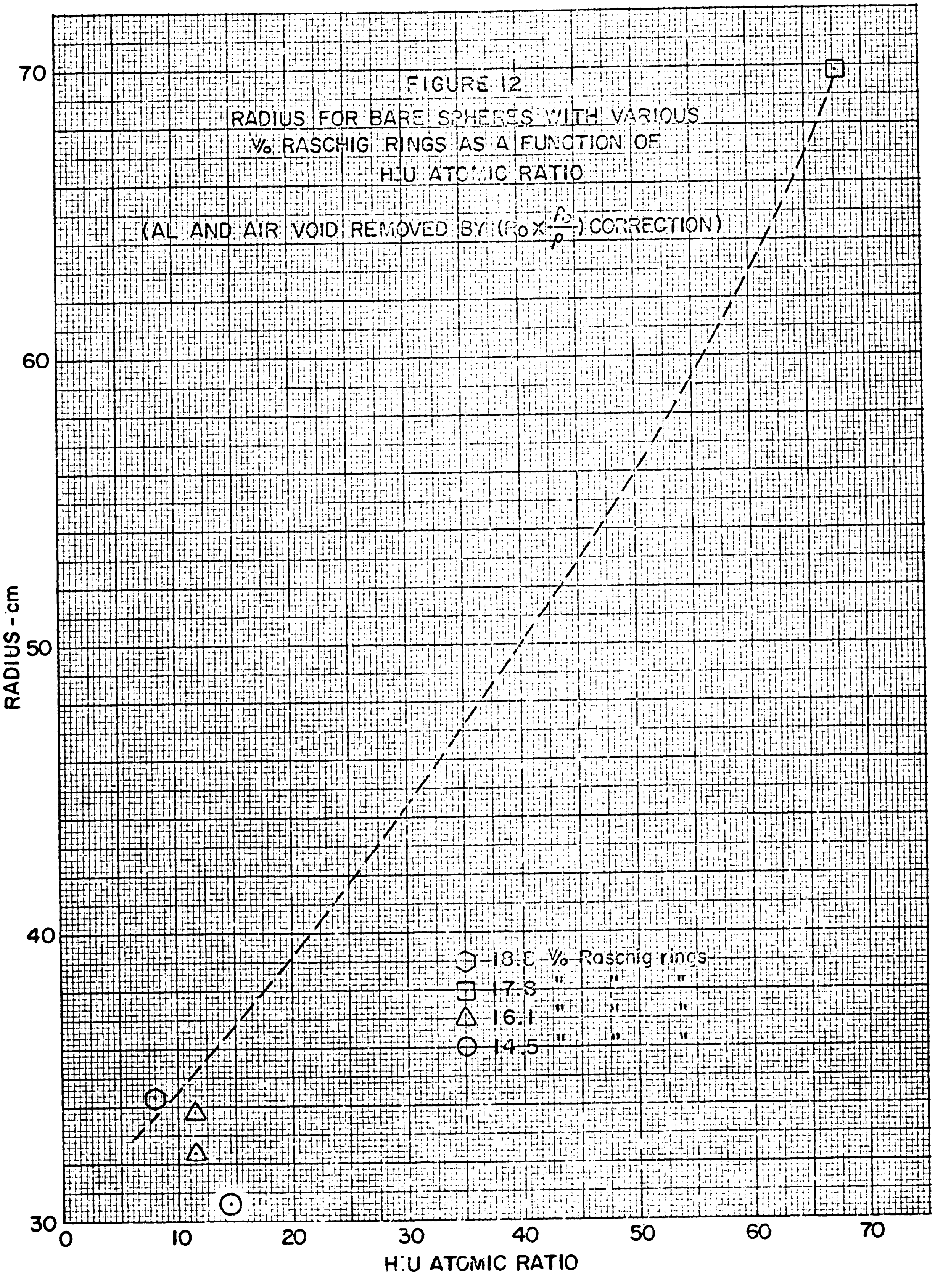


FIGURE 12

RADIUS FOR BARE SPHERES WITH VARIOUS % RASCHIG RINGS AS A FUNCTION OF H:U ATOMIC RATIO

(AL AND AIR VOID REMOVED BY ($R_0 \times \frac{\rho_0}{\rho}$) CORRECTION)