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NUCLEAR SAFETY EXPERIMENTS ON PLUTONIUM AND ENRICHED URANIUM HYDROGEN MODERATED ASSEMBLIES CONTAINING BORON

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ABSTRACT

Neutron multiplication measurements were made on cylindrical assemblies containing layers of plutonium metal discs, Plexiglas discs, and boron carbide impregnated Epolene-n discs.

In addition to the above nuclear safety measurements, curves were drawn for a 42-in. diameter stainless steel tank containing an aqueous solution of $UO_2(NO_3)_2$ and poisoned with Pyrex Raschig rings.

Attempts were made to calculate sphere, infinite cylinder and slab shapes from the experimental finite cylindrical assemblies.

ACKNOWLEDGMENTS

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1. INTRODUCTION

Neutron multiplication measurements were made on bare 12.5-in. and 18.0-in. diameter cylindrical assemblies of alternate layers of plutonium metal discs, Plexiglas sheet, and Epolene-n discs loaded with B_4C (containing normal boron). An attempt was made to convert the extrapolated critical dimensions to sphere radii, infinite cylinder diameters, and infinite slab thicknesses.

In addition to the above measurements, neutron multiplication measurements were made on a 42-in. diameter cylindrical stainless steel tank loaded with 1-1/2-in. Pyrex Raschig rings and filled with 236 g/l and 360 g/l solutions of $UO_2(NO_3)_2$. The uranium enrichment was approximately 90% U^{235}. Attempts were also made in this case to estimate the infinite slab thickness and sphere radius for the 360 g/l case.

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 Li(Eu) scintillators.

2.1 Materials (for cylindrical assemblies of plutonium)

2.1.1 Fuel

Plutonium discs, average density 15.8 g/cm^3

Diameter (in.)	Thickness (in.)	Mass (g)
12.5	0.0576	1837.4
18.0	0.0158	535.1

2.1.2 Moderator

Plexiglas, Type R, average density ~1.2 g/cm^3

Diameter (in.)	Thickness (in.)
12.5	0.115
12.5	0.243
12.5	0.472
18.0	0.117
18.0	0.230
18.0	0.470

2.1.3 Boron Carbide Impregnated Epolene-n*

$(CH_2)\eta$ + boron carbide

Diameter (in.)	Thickness (in.)	Mass (CH_2) (g)	Mass B_4C (g)
12.5	~0.060	120.6	2.1
18.0	~0.090	284.1	21.4

Boron carbide ~82.8% boron (some elemental boron as inclusions)

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*Epolene-n - Eastman Chemical Products, Inc., Kingsport, Tennessee.

2.2 Materials (for Raschig ring tank experiment containing enriched uranium)

2.2.1 Fuel

Enriched ~90% U^{235}, $UO_2(NO_3)_2$ aqueous solution.

360 and 236 g uranium per liter of solution.

~0.75 normal HNO_3

2.2.2 Vessel

42-in. diameter stainless steel tank in square thick concrete vault with no top reflector.

Glass volume 17.8% of tank volume.

Boron content in core ~0.01536 g/cm^3.

2.2.3 Raschig Rings

1.5 x 1.5 x 0.078-in. rings.

12.5% B_2O_3

3. PROCEDURE AND RESULTS

Figure 1 is a schematic of the plutonium-Plexiglas assemblies. Tables I through III summarize the experimental data and results. The H:Pu atomic ratios were calculated on the basis that the metal, Plexiglas, and boron carbide impregnated Epolene were homogeneously mixed. The assemblies were untamped right cylinders having 12.5 and 18.0-in. diameters.

Figures 2, 3, and 4 contain plots of sphere radii, infinite cylinder diameters and infinite slab thicknesses as functions of the boron core density g/cm^3. This was done for a number of H:Pu atomic ratios.

The method employed in Table III to correct for inhomogeneity due to the thickness of the plutonium disks was discussed in RFP-178.[1]

The method of GAT-189[2] was used to convert the experimental finite cylinder parameters to those of spheres, infinite cylinders, and slabs.

This method consists of letting k = 1 in the equation $k = \eta f U_f U_t$ and solving for ηf for each experimental case. $\underline{U_f}$ and $\underline{U_t}$ are the non-escape probabilities for fast and thermal neutrons, $\underline{f}$ is the thermal utilization, and $\underline{\eta}$ is the neutrons per absorption. Thus ηf as used in this report includes the effect of inhomogeneity of the boron-plastic disks and the metal foil.

The method described in GAT-189 is employed merely to convert the finite cylindrical parameters to those of spheres, infinite cylinders, and slabs. These values are compiled in Tables I, II, and III.

Neutron multiplication measurements were also made on a 42-in. diameter tank filled with aqueous solutions of $UO_2(NO_3)_2$ and Pyrex Raschig rings. The experimental vessel

(1) C. L. Schuske, G. H. Bidinger, A. Goodwin, Jr., D. F. Smith, "Plutonium Plexiglas Assemblies", USAEC Report RFP-178, January 20, 1960. (Declassified)

(2) J. Pond, "Critical Geometries for Bare Cylinders", USAEC Report GAT-189, July 20, 1956. (Unclassified)

TABLE I

Experimental Values

Cylindrical Core Diameter (in.)	Extrapolated Critical Mass (kg)	Mass of Boron in the Core (g)	Calculated Critical Height (cm)	Density of Pu in Core (g/cm^3)	H:Pu Ratio	Density of Boron in Core (g/cm^3)
12.5	24.6	23.6	20.1	1.544	13.4	0.00148
12.5	19.3	18.5	27.2	0.897	24.1	0.00086
12.5	18.4	17.6	36.9	0.630	35.0	0.00060
12.5	33.8	32.4	92.4	0.462	48.2	0.00044
18.0	62.5	1011.2	33.8	1.126	18.9	0.01850
18.0	45.4	372.5	25.2	1.099	19.4	0.00900
18.0	38.9	638.6	52.0	0.456	48.8	0.00750
18.0	47.6	780.6	126.6	0.229	98.7	0.00380

TABLE II

Conversion of Experimental Data by Method of GAT-189

H:Pu*	Plutonium Core Density (g/cm^3)	Boron Core Density (g/cm^3)	Sphere Radius (in.)	Infinite Slab Thickness (in.)	Infinite Cylinder Diameter (in.)
13.4	1.544	0.00148	5.85	4.88	8.49
24.1	0.897	0.00086	6.59	5.63	9.63
35.0	0.630	0.00060	7.22	6.26	10.60
48.2	0.462	0.00044	8.19	7.20	12.10
18.9	1.126	0.01850	8.94	7.97	13.20
19.4	1.099	0.00900	7.80	6.88	11.50
48.8	0.456	0.00750	10.30	9.40	15.30
98.7	0.229	0.00380	11.70	10.80	17.40

*Ratios calculated from the equation $(H{:}Pu + 1.45)\ \rho_{Pu} = 22.94$

TABLE III

Calculated by Method of GAT-189
for Non-Boronated Homogeneous Cases

Diameter (in.)	H:Pu	Plutonium Density (g/cm^3)	Sphere Radius (in.)	Infinite Slab Thickness (in.)	Infinite Cylinder Diameter (in.)
12.5	20.3	1.046	6.5	5.3	9.2
12.5	47.6	0.464	6.2	5.1	8.9
12.5	92.9	0.241	6.5	5.3	9.1
18.0	19.4	1.092	6.5	5.3	9.2
18.0	48.5	0.456	6.2	5.1	8.9
18.0	94.1	0.238	6.5	5.3	9.2

Finite cylinder data extracted from RFP-190.[3]
(Plexiglas density assumed = 1.19 g/cm^3.)

TABLE IV

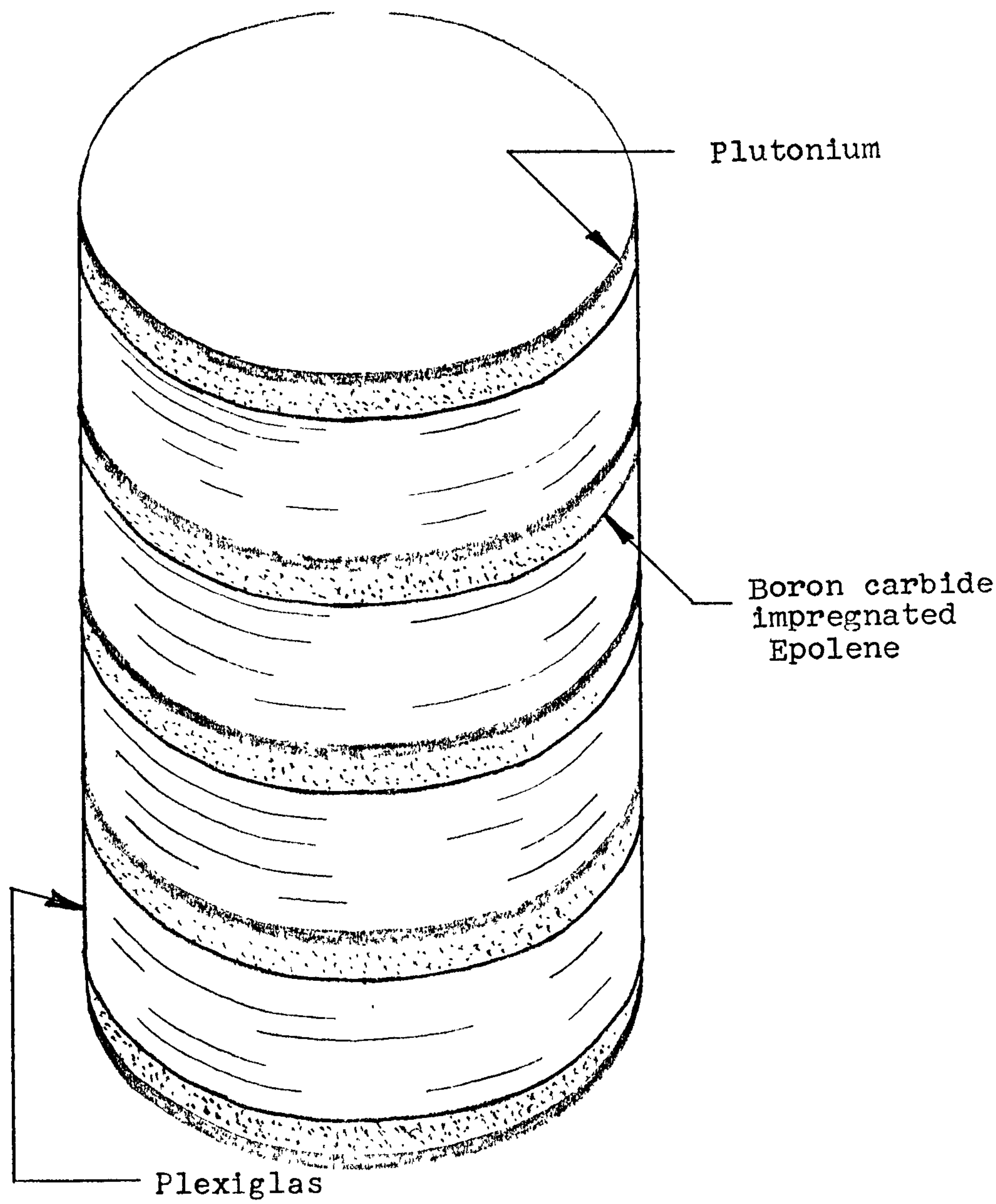
Conversion of Raschig Ring Filled Tank Dimensions
to Those of the Sphere and Infinite Slab
by the Method of GAT-189

Geometry	Dimensions (in.)	
Sphere	radius	27.5
Slab	thickness	26.6
* ∞ Cylinder	diameter	42.0

* Experimental value

(3) G. H. Bidinger, C. L. Schuske, D. F. Smith, "Plutonium Plexiglas Assemblies, Part II", USAEC Report RFP-190. (Unclassified)

Figure 1: Schematic of Experimental Assembly



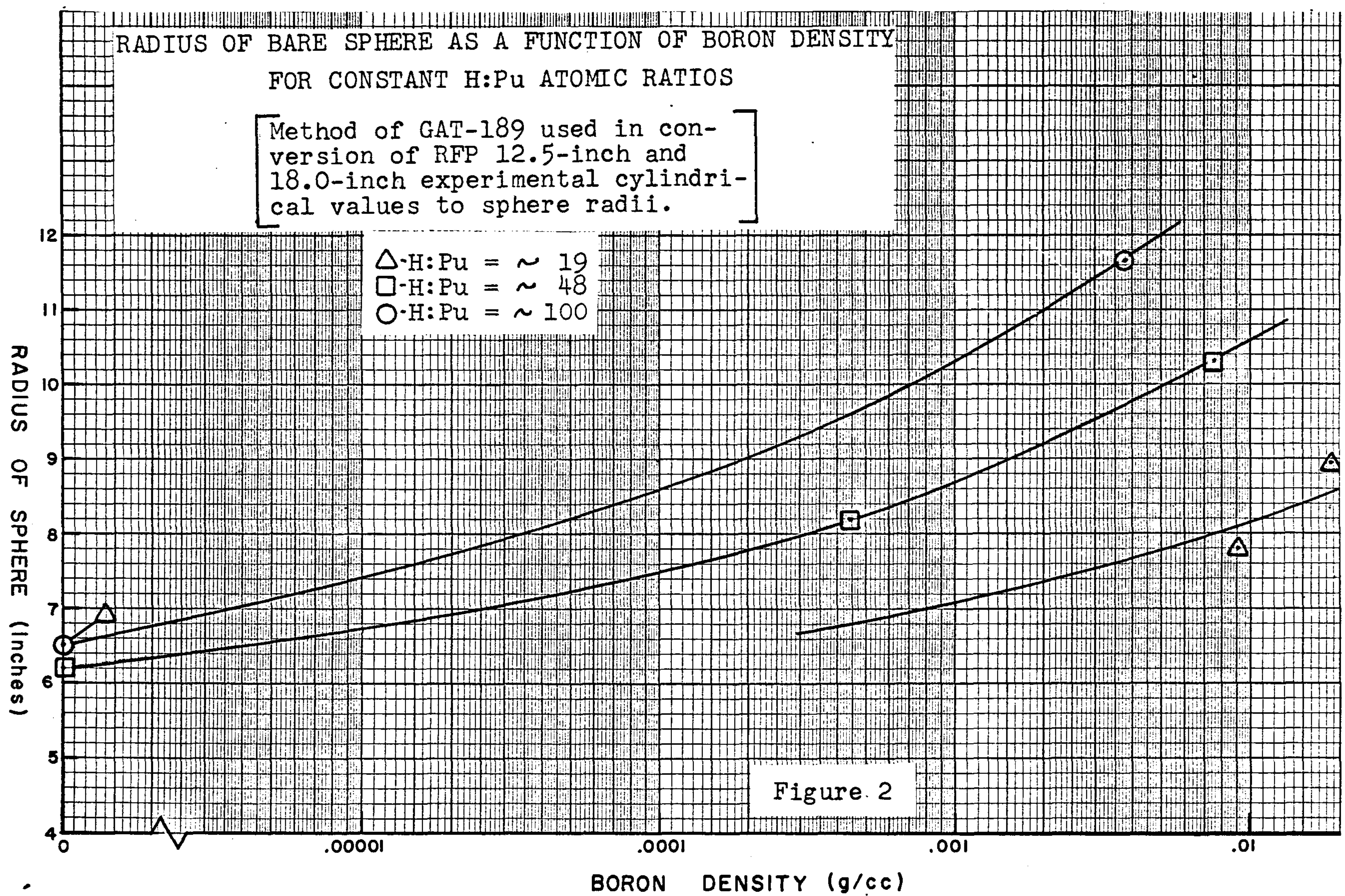

RADIUS OF BARE SPHERE AS A FUNCTION OF BORON DENSITY
FOR CONSTANT H:Pu ATOMIC RATIOS
Method of GAT-189 used in conversion of RFP 12.5-inch and 18.0-inch experimental cylindrical values to sphere radii.
△-H:Pu = ~ 19
□-H:Pu = ~ 48
○-H:Pu = ~ 100
RADIUS OF SPHERE (Inches)
12
11
10
9
8
7
6
5
4
0
.00001
.0001
.001
.01
BORON DENSITY (g/cc)

Figure 2

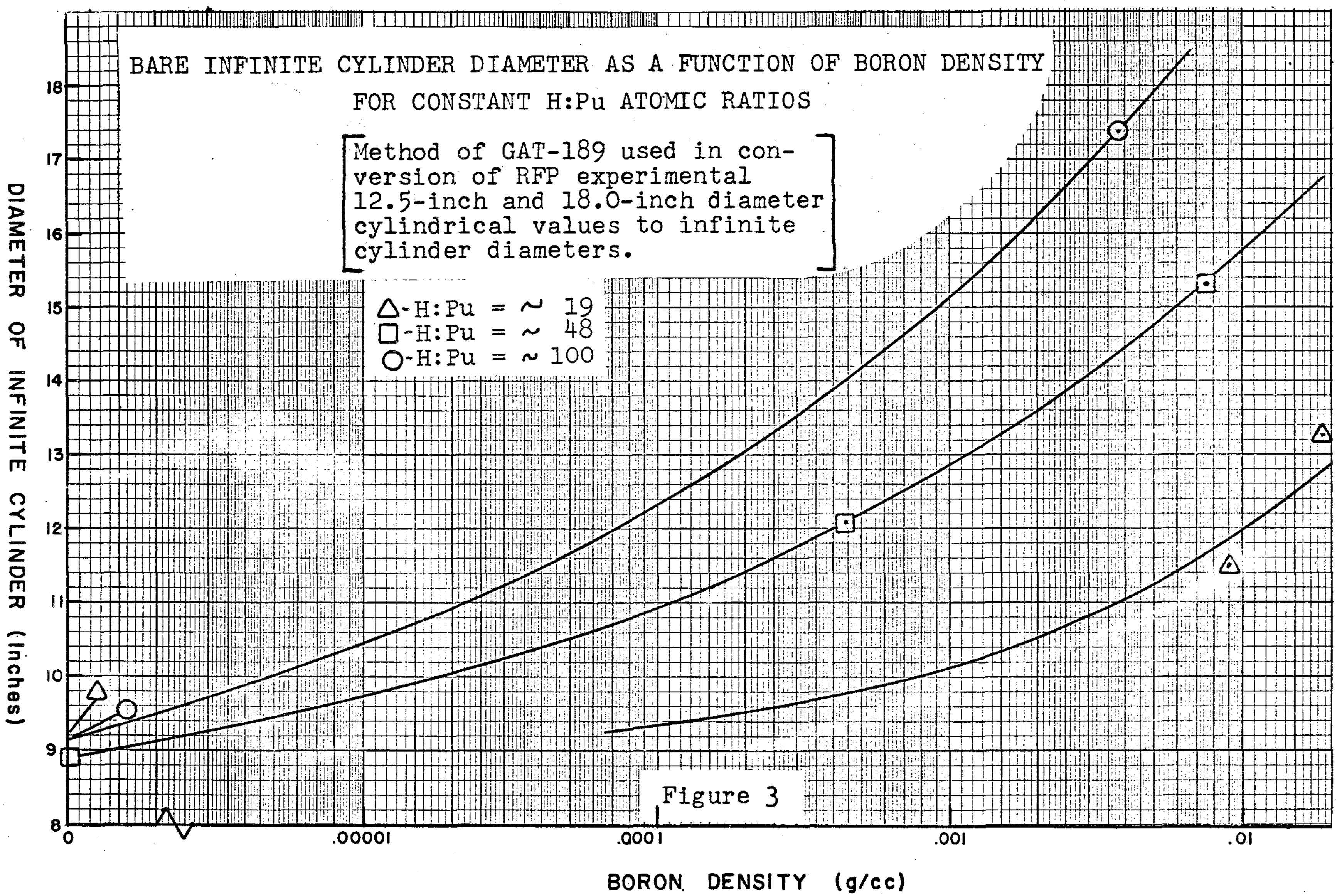

BARE INFINITE CYLINDER DIAMETER AS A FUNCTION OF BORON DENSITY
FOR CONSTANT H:Pu ATOMIC RATIOS
Method of GAT-189 used in conversion of RFP experimental 12.5-inch and 18.0-inch diameter cylindrical values to infinite cylinder diameters.
△-H:Pu = ~ 19
□-H:Pu = ~ 48
○-H:Pu = ~ 100
DIAMETER OF INFINITE CYLINDER (inches)
8
9
10
11
12
13
14
15
16
17
18
BORON DENSITY (g/cc)
0
.00001
.0001
.001
.01

Figure 3

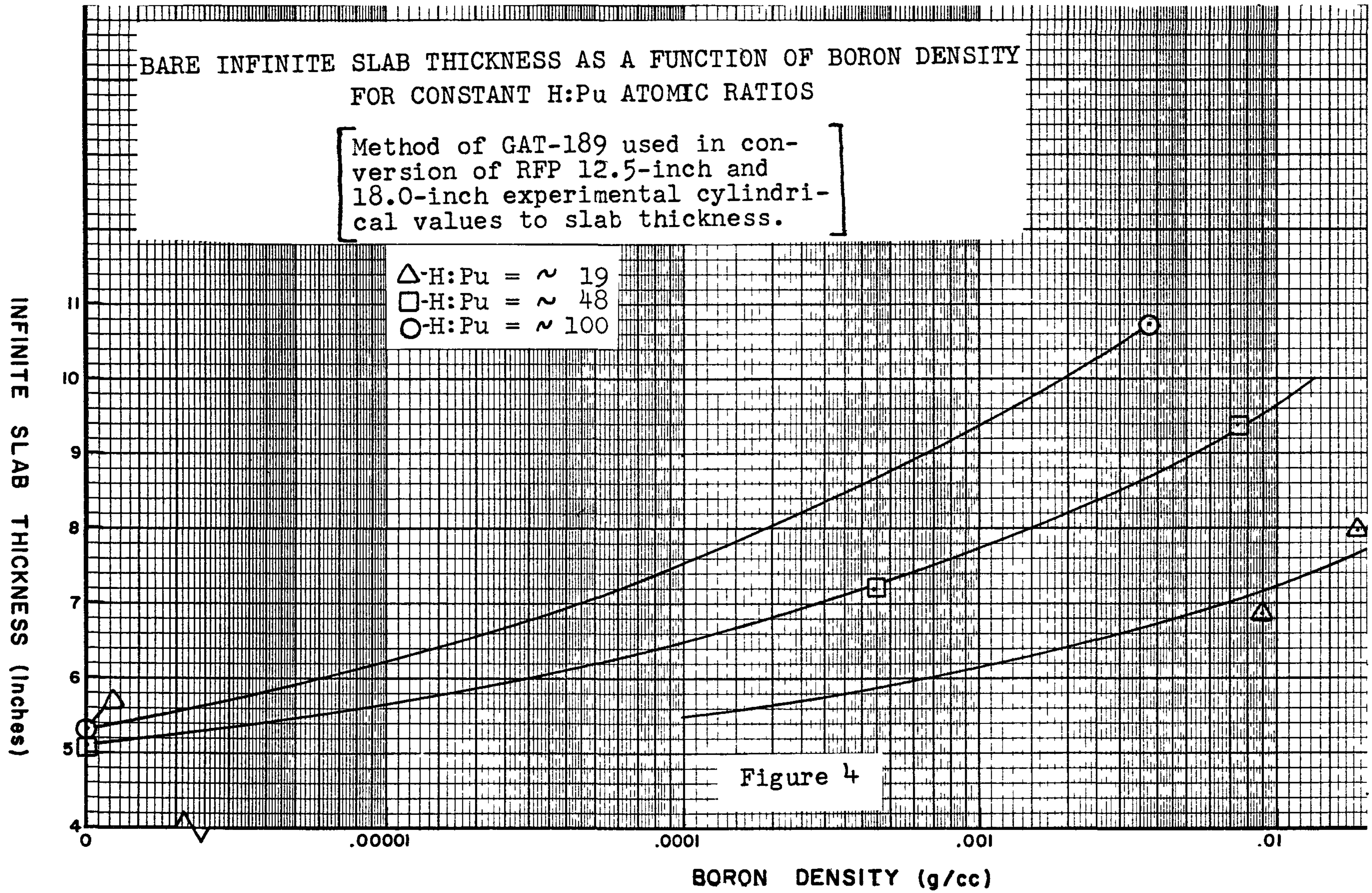

BARE INFINITE SLAB THICKNESS AS A FUNCTION OF BORON DENSITY
FOR CONSTANT H:Pu ATOMIC RATIOS
Method of GAT-189 used in conversion of RFP 12.5-inch and 18.0-inch experimental cylindrical values to slab thickness.
△-H:Pu = ~ 19
□-H:Pu = ~ 48
○-H:Pu = ~ 100
INFINITE SLAB THICKNESS (Inches)
11
10
9
8
7
6
5
4
0
.00001
.0001
.001
.01
BORON DENSITY (g/cc)

Figure 4

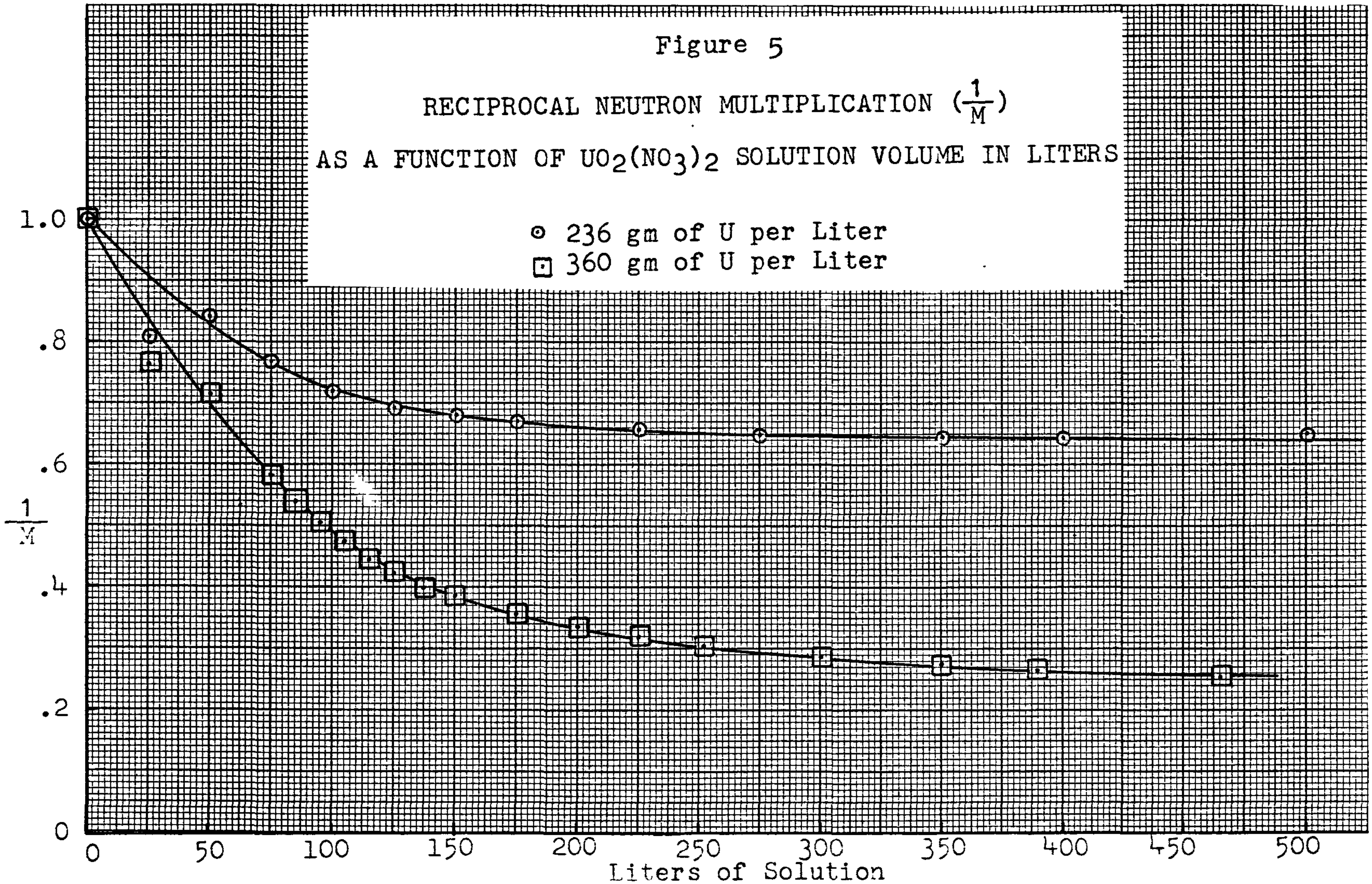


Figure 5

RECIPROCAL NEUTRON MULTIPLICATION ($\frac{1}{M}$)

AS A FUNCTION OF $UO_2(NO_3)_2$ SOLUTION VOLUME IN LITERS