

## REFERENCE 111

**V. I. NEELEY, R. C. LLOYD, AND E. D. CLAYTON, "NEUTRON MULTIPLICATION MEASUREMENTS WITH PU-AL ALLOY RODS IN LIGHT WATER," HANFORD ATOMIC PRODUCTS OPERATION REPORT HW-70944 (AUGUST 1961).**

HW-70944

NEUTRON MULTIPLICATION MEASUREMENT WITH

Pu-Al ALLOY RODS IN LIGHT WATER

By

V. I. Neeley, R. C. Lloyd, and E. D. Clayton

Critical Mass Physics  
Physics and Instrument Research  
and Development  
HANFORD LABORATORIES OPERATION

August 29, 1961

ABSTRACT

Neutron multiplication and exponential measurements were conducted with Pu-Al alloy fuel elements in light water moderated lattices; a hexagonal pattern was used for the lattices which were fully water reflected. The critical mass was determined for 24-inch high cylinders by neutron multiplication measurements. The extrapolation length and bucklings for the lattices were determined by equating the buckling expression from the exponential measurements to the buckling expression for the critical size as determined from the neutron multiplication measurements. These equations were then solved for the extrapolation length and buckling. The critical mass for spherical geometry was calculated from the measured buckling and extrapolation length.

The minimum critical mass for the Al-5 weight percent plutonium alloy rods in light water was 1.5 Kg plutonium. The maximum buckling was,  $11,300 \times 10^{-6} \text{ cm.}^{-2}$ . The effect on the critical mass of the Pu-240 (~5%) was determined from calculations; the results indicate the critical mass (including all isotopes) would be reduced by about 8.2% in the absence of Pu-240, or to 1.38 Kg Pu-239.

A curve of the critical mass and buckling obtained from these experiments is shown. The various data are tabulated.

INTRODUCTION

Critical mass data were needed for Pu-Al alloy fuel elements in support of the Plutonium Recycle Program for use in the preparation of nuclear safety specifications concerning the handling and storage of this kind of fissile material. About one thousand fuel elements would have been required for critical mass studies with the enrichment to be used in the Plutonium Recycle Test Reactor (1.8 w/o alloy). In order to reduce the

number of fuel elements needed for the experiments and hence save on fabrication costs, fuel elements of higher enrichment were used in the experiments. Pu-Al fuel elements containing 5 w/o (260 elements) were thus fabricated for these studies. The data from the measurements with 5 w/o Pu alloy rods could then be used to correlate experiment and theory for this enrichment; the theory could then be extended to include the 1.8 w/o Pu alloy to be used in the PRTR.

These experiments represent the first work on heterogeneous Pu-Al water systems in the field of nuclear safety and hence provide data needed for the comparison of experiment with theory and for establishing basic nuclear safety parameters for these types of systems.

#### EXPERIMENTAL DISCUSSION

The experimental techniques and assemblies will be only briefly discussed here since they were fully discussed in other reports. (1,2,3,4,5)

The fuel elements were Pu-Al alloy rods with 5 w/o Pu enrichment. These rods were 24-inches long and 0.506-inch in diameter. They were clad in 0.030-inch Zircaloy-2 with 0.020-inch and 0.125-inch thick end caps. This gave a Zr/Pu atomic ratio of 31.92 and an Al/Pu atomic ratio of 168.20. Figure 1 shows a mock-up of a disassembled rod. The average rod contained 11.01 gms of Pu. The plutonium contained approximately five percent Pu-240.

The experiments were carried out in a four-foot diameter by five-foot deep tank of light water located in the Hanford Thermal Test Reactor reactor room. The lattices were hexagonal in shape and placed so as to provide effectively infinite water reflection on all sides. The lattice plates were constructed from lucite. Safety circuits, neutron sources, and BF<sub>3</sub> counters for monitoring the neutron flux were adapted from previous experiments of this type on 3.1% enriched uranium systems. (2) Figure 2 is

a picture of a typical lattice assembly.

The neutron multiplication measurements were carried to within 96% of the critical mass as determined from the inverse multiplication plots. The critical number of rods,  $N_c$ , was found from a least squares fit to the plot of the number of rods divided by the counting rate ( $N/\phi$ ) versus the number of rods in the region between 85 - 96% of criticality. It has been shown that a straight line fit to this section of the plot is a very good approximation. (5)

The exponential experiments were conducted after the assemblies had been reduced sufficiently in size, since in order to conduct the exponential experiments, it was necessary to reduce the pile size from the near critical condition.

Cylindrical geometry was approximated in the hexagonal lattice using the equation,

$$R_{\text{cylinder}}^2 = \frac{Nl^2\sqrt{3}}{2\pi}$$

where

$N$  = number of fuel rods, and

$l$  = center to center fuel rod spacing

The extrapolation length was determined by equating the buckling expression for the exponential measurements with the critical buckling as determined from neutron multiplication measurements,

$$B_{\text{critical buckling}}^2 = \left( \frac{2.4048}{R + \lambda_{\text{critical size}}} \right)^2 + \left( \frac{\pi}{h + 2\lambda} \right)^2 = \left( \frac{2.4048}{R_{\text{exponential}} + \lambda} \right)^2 - \left( \frac{1}{b_{11}} \right)^2$$

Figure 3 is a plot of the values of  $\lambda$  as determined from the above equation. The rather large errors in  $\lambda$  result from the uncertainty in the critical size as well as the error in the measured relaxation length ( $b_{11}$ ).

Figure 4 shows a curve of the critical mass and buckling determined from these experiments. Table 1 lists the various experimental data.

### THEORETICAL DISCUSSION

The purpose of these experiments was to obtain information on Pu-Al alloy systems which could be used to correlate experiment and theory and thus obtain nuclear safety specifications on Pu-Al alloy systems.

Theoretical calculations were performed using the "IDIOT" code on the Hanford IBM 7090 computer.<sup>(6)</sup> The results of these calculations are shown in Figure 5. The minimum critical mass is quite accurately predicted, however, the theoretical curve is slightly displaced toward a lower H/Pu ratio. For the higher H/Pu ratios, this displacement results in a non-conservative estimate of the critical mass, which from a nuclear safety point of view is undesirable.

A further effort to calculate the critical mass was made by "homogenizing" the heterogenous system by weighting the concentration of materials in the various regions by the relative flux in the region. The relative fluxes were obtained from "P<sub>3</sub>" (used as a sub-routine in IDIOT) calculations on the computer.<sup>(7)</sup> The critical mass of the "homogenized" system was then determined using the 18 group diffusion code "9-Zoom" (9-Zoom will not solve lattice problems) on the computer.<sup>(8)</sup> Figure 5 also shows the results of these calculations. In this case the calculations are always conservative and fairly accurate for low H/Pu ratios, but become excessively conservative for the higher H/Pu ratios.

The work to correlate the experimental and theoretical data will continue.

### CONCLUSIONS

The minimum critical mass for the five percent plutonium enriched Pu-Al alloy rods in spherical geometry was approximately 1.5 Kg of Pu. The maximum

buckling for these systems was approximately  $11,300 \times 10^{-6} \text{ cm}^{-2}$

Pu-240 tends to act as a poison for these thermal systems. Calculations were made using the IDIOT code to determine the effect of Pu-240 on the critical mass and buckling.<sup>(6)</sup> Although the critical mass and buckling values obtained from the calculations differ somewhat from the experimental results, the percentage changes, or differences in these quantities caused by the presence of Pu-240 should be nearly correct. Thus, the calculations show the minimum critical mass would be reduced by approximately 8.2% if no Pu-240 were present. Likewise, the maximum buckling would be increased approximately 2.5%. Hence, the minimum critical mass for a system containing no Pu-240 would be 1.38 Kg Pu-239 and the maximum buckling would be  $11,600 \times 10^{-6} \text{ cm}^{-2}$

#### REFERENCES

- 1) Lloyd, R. C., E. D. Clayton and H. E. Handler, "Criticality Parameters for Lattices with 1.6 Percent enriched Uranium Rod in Light Water", Nuclear Physics Research Quarterly Report, April, May, June, 1958, HW-57861.
- 2) Lloyd, R. C., R. B. Smith and E. D. Clayton, "Neutron Multiplication Measurements of Heterogeneous 3.1% Enriched Uranium-Water Systems", Trans. Amer. Nucl. Soc. 2-1, 62 (1959).
- 3) Neeley, V. I., R. C. Lloyd and E. D. Clayton, "Neutron Multiplication Measurements with Pu-Al Alloy Rods in Light Water", Trans. Amer. Nucl. Soc. 3-1, 1960.
- 4) Reardon, W. A. and R. C. Lloyd, "Shape Perturbations in Critical Experiments", Trans. Amer. Nucl. Soc. 3-1, 1960.
- 5) Neeley, V. I. and R. C. Lloyd, "Neutron Multiplication Measurements with Pu-Al Alloy Rods in Light Water", Nuclear Physics Research Quarterly Report January, February, March, 1960, HW-64866.
- 6) C. R. Richey, IDIOT --- A Lattice Parameter Code for the IBM-709, HW-63411, January 1960.
- 7) Matsumoto, D. D. and C. R. Richey, Program on the 709 Digital Computer of the P<sub>3</sub> Approximation to the Boltzman Transport Equation in Cylindrical Geometry, HW-60781.
- 8) Stone, S. P., et. al., 9-ZOOM - A One-Dimensional, Multigroup, Neutron Diffusion Theory Reactor Code for the IBM-709. UCRL-5682. 1959.

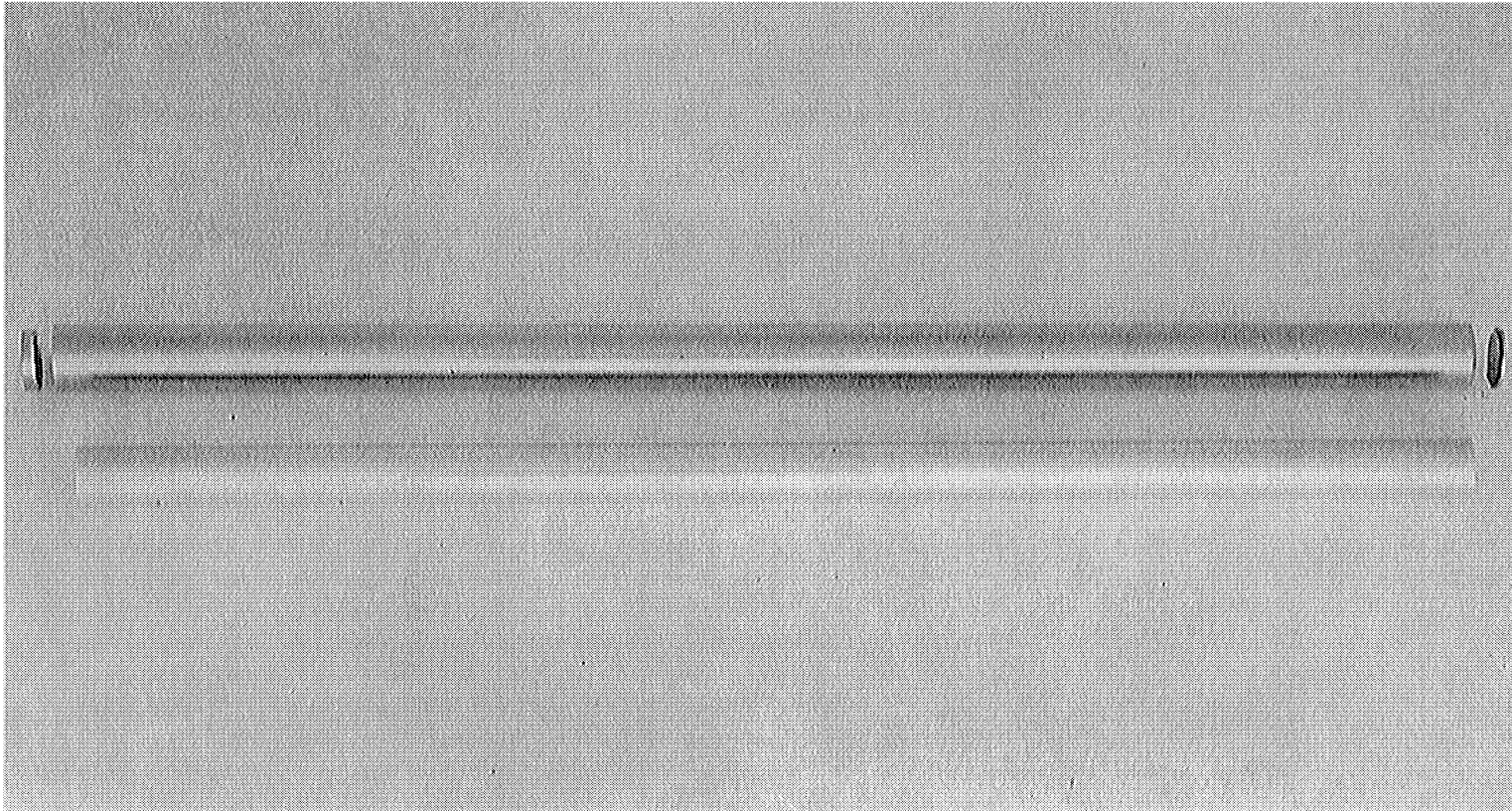


FIGURE 1

Mock-Up of Disassembled Pu-Al Rod and Zr-2 Cladding



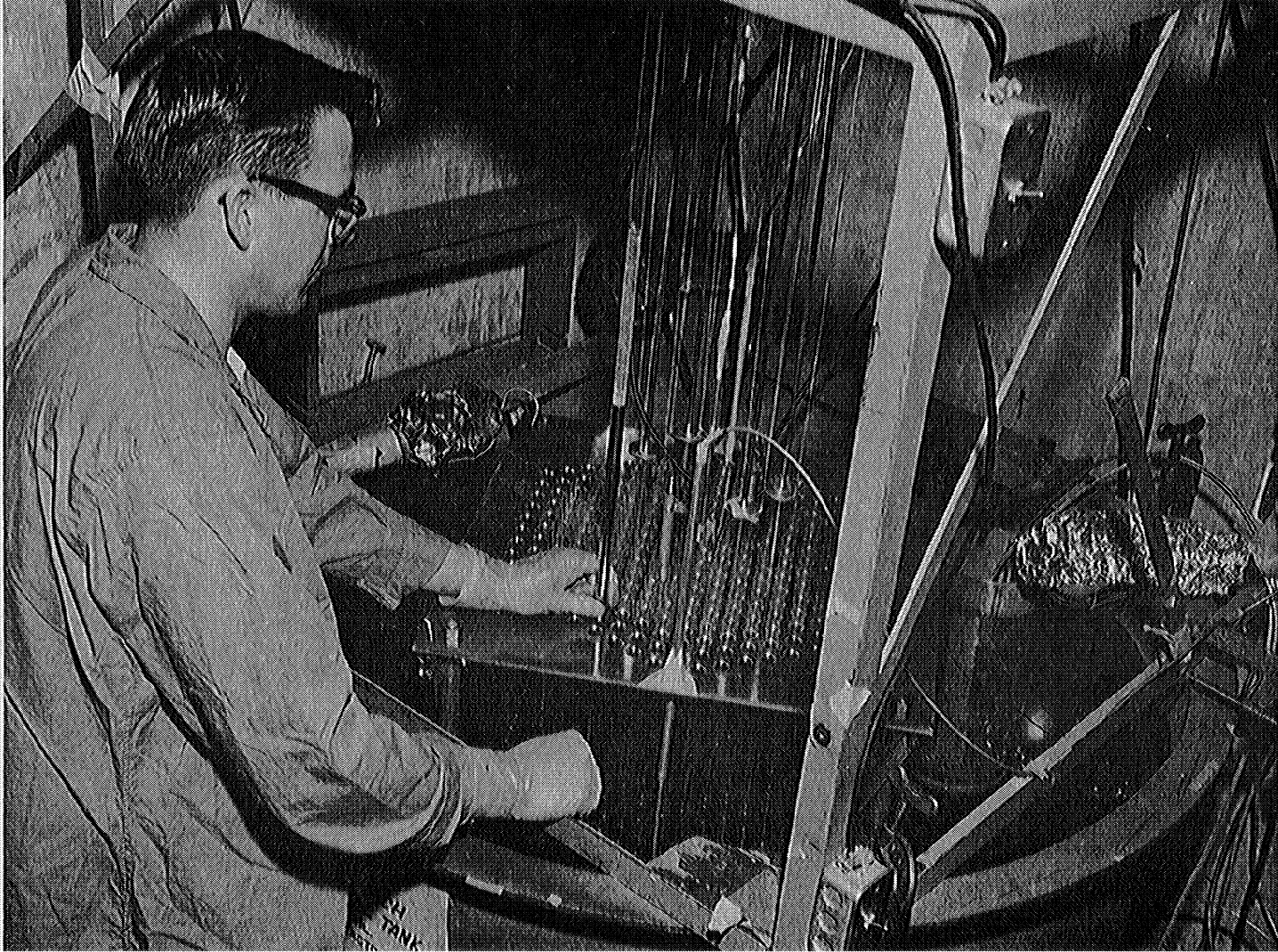


FIGURE 2

5% Pu Enriched Pu-Al Rod Hexagonal Lattice

EXTRAPOLATED LENGTH VS. H/PA ATOMIC RATIO (5% PA PERIODIC PA-AL  
RODS IN MOUNT WATER - FULLY REFLECTED LATTICES)

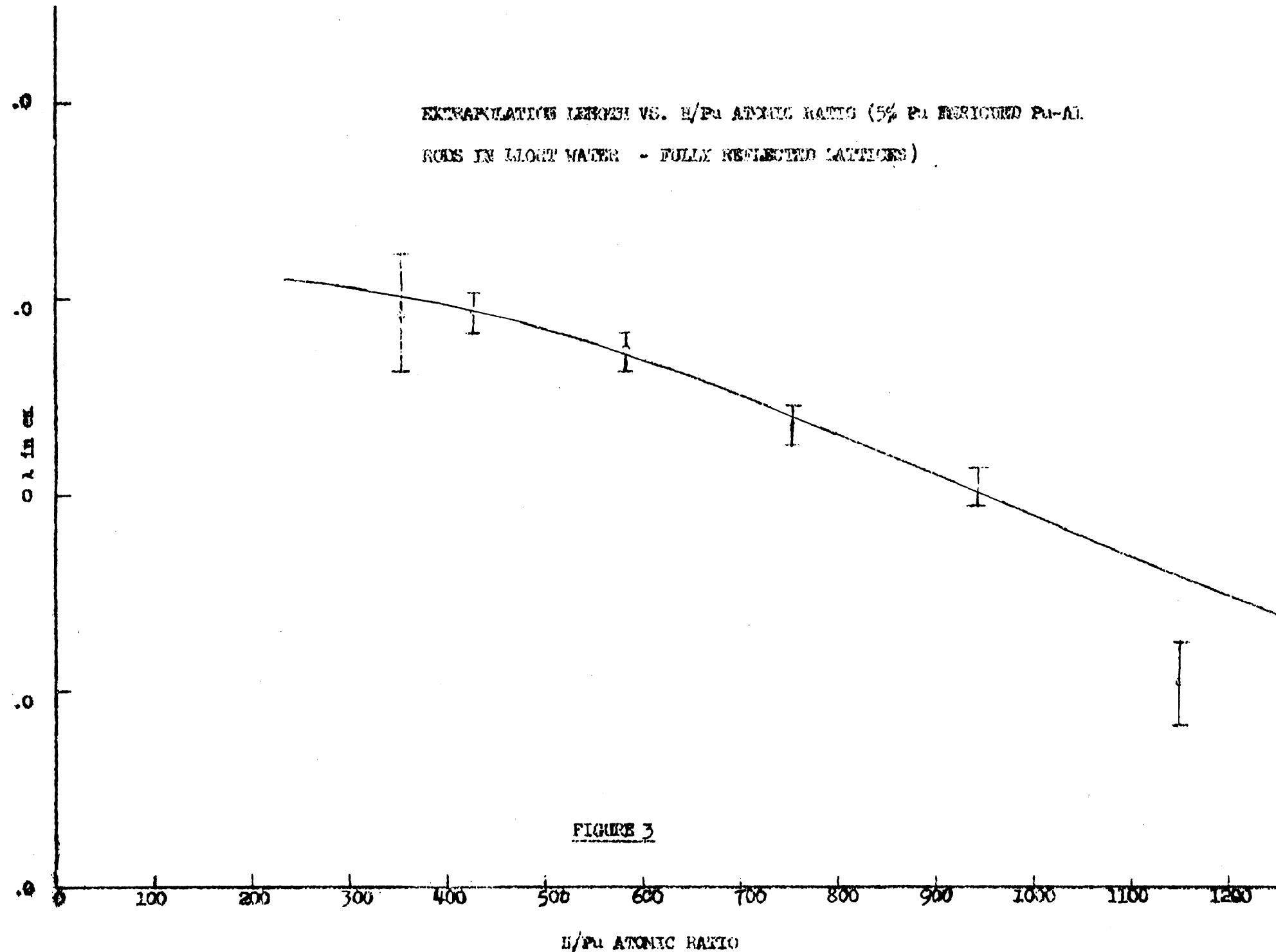


FIGURE 3

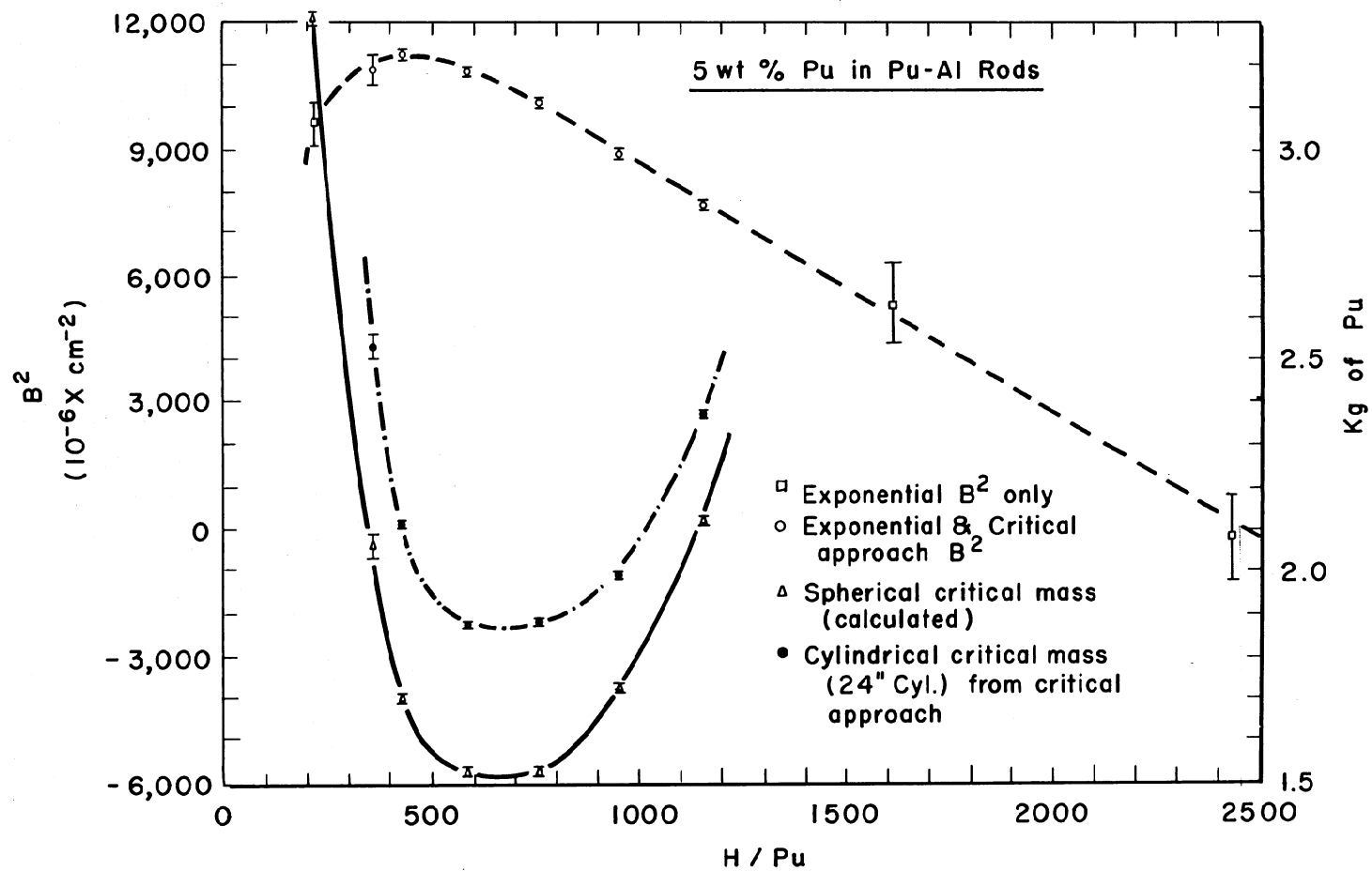


FIGURE 4

Buckling, Critical Mass for 24" High Cylinder and Critical Mass for Sphere vs. Hydrogen to Plutonium Atomic Ratio

TABLE 1

SUMMARY OF CRITICAL APPROACH AND EXPONENTIAL MEASUREMENTS  
WITH AL-5 Wt. % Pu ALLOY RODS IN LIGHT WATER

<u>Experiment</u>	<u>Lattice Spacing (inches)</u>	<u>H/Pu* (atom ratio)</u>	<u>H<sub>2</sub>O/V Pu-Al Alloy</u>	<u>Extrapolation Length (λ)</u>	<u>Critical No. of 24-in. rods (Cyl. Geometry)</u>	<u>Critical Mass (Spherical Geometry)</u>	<u>Buckling (10<sup>-6</sup> cm<sup>-2</sup>)</u>
Exp.	0.75	217.8	1.17	8.10 cm**	356.1 (3.92 Kg Pu*)	3.31 Kg Pu*	9,605
C.A. and Exp.	0.85	354.7	1.86	7.92 cm	230.2 (2.54 Kg Pu*)	2.07 Kg Pu*	10,839
C.A. and Exp.	0.90	426.8	2.23	7.93 cm	192.0 (2.11 Kg Pu*)	1.70 Kg Pu*	11,261
C.A. and Exp.	1.00	582.6	3.06	7.73 cm	170.1 (1.87 Kg Pu*)	1.53 Kg Pu*	10,853
C.A. and Exp.	1.10	755.1	3.96	7.34 cm	166.5 (1.88 Kg Pu*)	1.53 Kg Pu*	10,107
C.A. and Exp.	1.20	944.0	4.95	7.03 cm	181.1 (1.99 Kg Pu*)	1.73 Kg Pu*	8,840
C.A. and Exp.	1.30	1149.3	6.03	6.04 cm	215.5 (2.37 Kg Pu*)	2.12 Kg Pu*	7,681
Exp.	1.50	1609.2	8.44	5.80 cm**	307.8 (3.39 Kg Pu*)	3.10 Kg Pu*	5,332
Exp.	1.80	2422.3	12.70	5.20 cm**			- 197

Total Pu including all isotopes; the Pu contains approximately 5% Pu-240.

\*\* Assumed values of λ extrapolated from curve.

For those cases in which the exponential experiment (Exp.) only was conducted the critical number of rods and critical mass were calculated from the measured buckling.

HM-70944

EXPERIMENTAL AND THEORETICAL CURVE OF THE SPHERICAL CRITICAL  
MASS VERSUS THE H/Pt ATOMIC RATIO

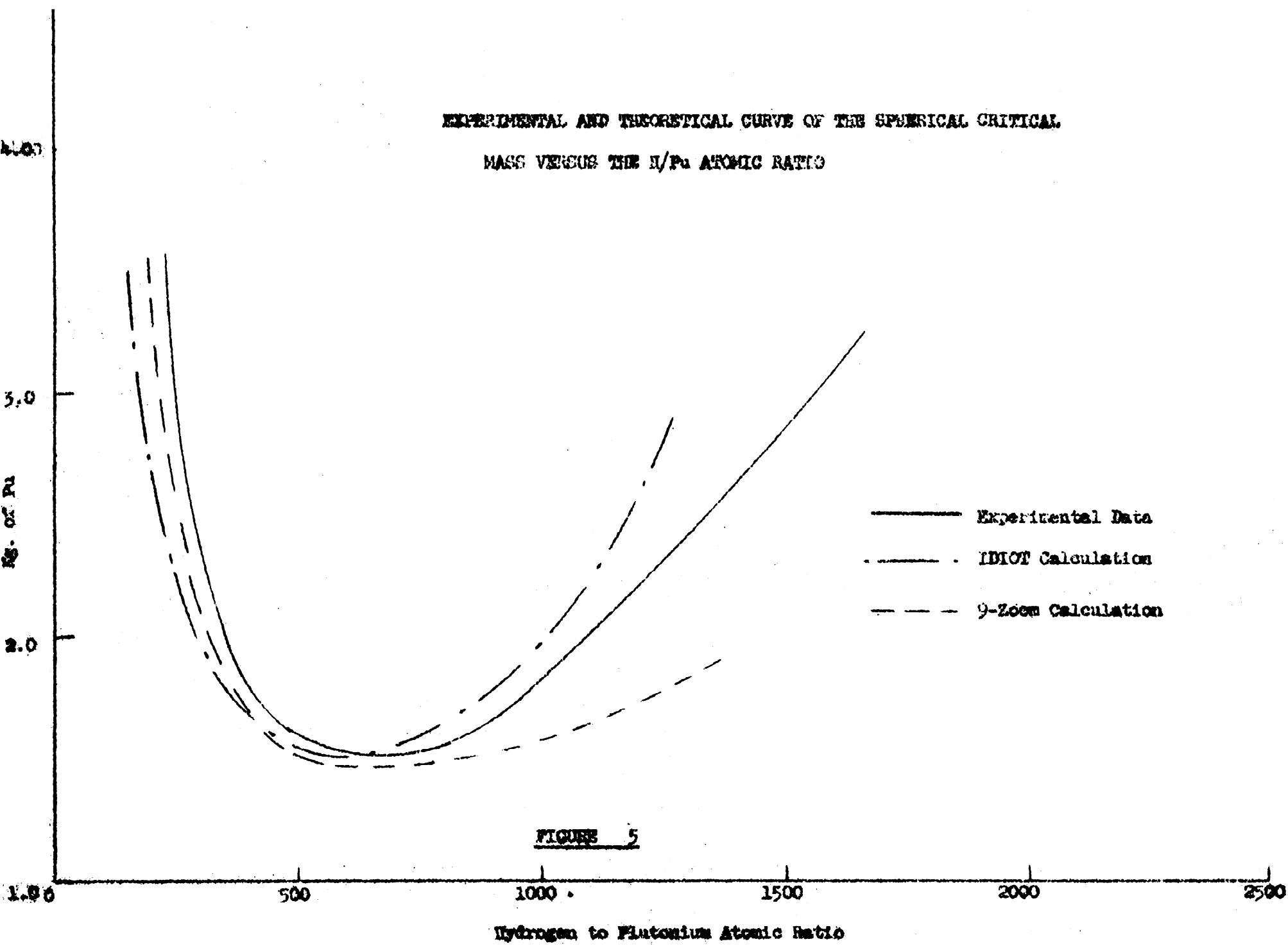


FIGURE 5