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(M-3679, 17th Ed.)

Criticality Measurements on Plutonium Metal Preliminary to the Design of a Melting Crucible

by

C. L. Schuske

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ROCKY FLATS PLANT DENVER, COLORADO

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CRITICALITY MEASUREMENTS ON PLUTONIUM METAL PRELIMINARY TO THE DESIGN OF A MELTING CRUCIBLE

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C. L. Schuske
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L. A. Matheson - Technical Director
John Epp - Assistant Technical Director

ABSTRACT

This report reviews a series of recent neutron multiplication measurements made on plutonium assemblies tamped with Plexiglas, graphite and aluminum.

Recommendations are presented for (1) a melting crucible involving charges up to 10 kilograms, and (2) two ingot sizes for rolling into sheet.

ACKNOWLEDGEMENTS:

These tests were made possible by the generous concurrence of Mr. I. B Venable and Staff. Special thanks are extended to W. M. Wright, J. F. Willging, and R D. Forest.

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INTRODUCTION

A series of neutron multiplication measurements were made on assemblies of plutonium metal (density 15.8 g/cm^3) in order that a safe melting crucible could be designed for charges of 10 kilograms or more.

It was also necessary to arrive at suitable ingot shapes and masses which could be rolled into sheet.

The recommendations presented here are used for preliminary design considerations only. The final charge limit will be determined by making in situ measurements with the actual production furnace when the furnace and crucible are completed.

RESULTS AND RECOMMENDATIONS

The results of these measurements are presented in Figures 1 through 5.

Figure 1 illustrates the effect of varying degrees of tamper on a 2 1/2 inch x 5 inch plutonium slab of thickness b. The dotted curve is an estimation of 4 inches of Plexiglas tamping, and was obtained by extrapolation of the 1-, 2-, and 3-inch tamping data. Figure 1 indicates that 4 inches of Plexiglas completely surrounding an assembly is near infinite tamping for the small plutonium systems presented here.

Figure 2 is a comparison of a 5/8-inch and 1-inch slab completely tamped with 4 inches of Plexiglas. The slab shape is illustrated pictorially above each experimental point.

Figure 3 gives the critical thickness of an assembly with a 5-inch square cross section.

Figure 4 provides a comparison of three tamper materials, aluminum, graphite, and Plexiglas. Plexiglas can be used conservatively for estimating tamper effectiveness (1 to 2 inches of tamper thickness) with exception of tungsten, uranium and tantalum, for the common materials used in production furnaces and crucibles such as steel, graphite, MgO, Al_2O_3, etc.

Figure 5 contains critical extrapolations of the data from Figures 1 through 3. Figure 5 was arrived at in the following manner:

It is desirable to express all of the 4-inch Plexiglas tamper data on a single curve if possible. The neutron measurements were made on assemblies made up of small plutonium slabs 1 inch x 2 1/2 inches x 5 inches and 5/8 inch x 2 1/2 inches x 5 inches stacked into various arrays (details are given in Figures 1 through 3). The parameters plotted in Figure 5 are critical thickness, t_c, of each array of slabs and the square root of the cross sectional area, $\sqrt{A}$, of the corresponding array. These parameters were found from extrapolating the data to a critical state in each case. Although the arrays were irregular in shape, i.e., four slabs 1-inch x 2 1/2 inches x 5 inches side by side as shown in Figure 2, it was assumed that the degree of irregularity for these experimental points did not alter the critical mass appreciably from what would be expected from more symmetrical arrays of material. This assumption is somewhat born out by the results of these experiments and some experiments performed at LASL[1] on Oralloy, heavily tamped by a hydrogenous material.

Extrapolations to critical were made for the experiments reported in Figures 1 through 3 and these values were then plotted in Figure 5 as indicated above. Plotting $\sqrt{A}$ as a function of critical thickness results in a smooth curve. The critical masses for these rectangular assemblies were then calculated for points on the curve. A minimum critical mass of 8.5 kilograms results from a $t_c/\sqrt{A}$ of 0.8. No significance is attached to the ratio of 0.8 because of the crude approximations used in drawing Figure 5.

Good empirical fits of the data were made by means of the following two equations:

(1) $(\sqrt{A} - 1.7)\ t_c - 0.25) = 4.3$

and

(1) Paxton, H. C., Critical Masses of Fissionable Metals As Basic Nuclear Safety Data. LA-1958, Los Alamos Scientific Laboratory, January, 1955.

$$(2) \quad 0.0590 = \frac{2}{(\sqrt{A} + 3.9)^2} + \frac{1}{(t_c + 3.9)^2} \quad \text{where}$$

$\sqrt{A}$ and t_c are expressed in inches.

Neither equation should be used for wide extrapolations unless used with caution.

Equation No. 1 was used for a preliminary crucible design where the total tamper thickness was assumed to be equivalent to 1 inch of Plexiglas rather than 4 inches as recorded in Figure 5.

The recommended crucible cavity dimensions are 3/4 inch x 10 inches x 10 inches for a 10-kilogram charge. Final recommendations will be made when the crucible has been installed into a production furnace.

A safe ingot dimension for 10 kilograms of metal is either a square or elongated slab 1/2-inch thick. The reduced dimension for the ingot is necessary since the rolling mill will be built massively of steel. A safe thickness for a 6-kilogram ingot is 1 inch.

EXPERIMENTAL

Equipment:

The neutron flux measurements were made with General Electric B^{10}-lined neutron counters and associated decade scalers. The counters were encased in cylindrical polystryene moderators located on the floor approximately three feet beneath the plutonium arrays.

The neutron source consisted of a polonium-beryllium unit having a strength of 4×10^6 neutrons/second.

Materials:

a. Active Material - Delta phase plutonium metal.

Density: 15.8 g/cm^3

Size: 4 each - 5/8 x 2-1/2 x 5 inches.

4 each - 1 x 2-1/2 x 5 inches.

Average Mass: 5/8-inch pieces - 2011 grams each.

1-inch pieces - 3236 grams each.

b. Tamper Materials:

Alumimun (density = 2.7 g/cm^3)

Graphite (density = 1.7 g/cm^3)

Plexiglas (density = 1.16 g/cm^3)

Contamination from the plutonium metal was prevented by total enclosure of the individual pieces. Each plutonium piece was first given a thin plastic coating ($\sim$ 0.001 inch) from an Amercoat plastic spray bomb. Then it was wrapped tightly with a single layer of 0.002 inch thick Scotch-type 853 plastic tape[(1)], with a 1/4-inch overlap at the seams. These precautions against contamination proved to be quite adequate in spite of considerable handling of the pieces during the four day tests. However, as a precaution against thermal effects leading to a possible subsequent failure of the coatings, the pieces were placed in an ice chest over night and during lulls in the experiments.

(1) Type 853 is a Mylar base tape having a very low neutron absorption cross section.

The tamper materials were cut into slabs having thicknesses ranging from 1/4 inch to 1 inch, and lateral sizes ranging from 2-1/2 x 5 inches to 9 x 11-1/2 inches. In this way, plutonium arrays of various sizes and shapes could be enclosed in various thicknesses of tamper with reasonable uniformity in all directions. However, this arrangement resulted in somewhat greater corner tamping than side tamping of the smaller arrays.

Procedure:

The arrays were built up of various combinations of the 2-1/2 x 5-inch plutonium pieces. The 5/8-inch and 1-inch thick slabs were built up in the manner depicted by the pictorials included in Figure 2. The 2-1/2 x 5-inch slabs of various thicknesses were built up by stacking the plutonium pieces one upon the other. The 5 x 5-inch slabs were similarly constructed. In each case, the tamper material was placed around the plutonium pieces in such a way as to enclose them with maximum uniformity and minimum voids.

Each recorded measurement was corrected for the effect of neutrons from Pu^{240} by counting with and without the polonium-beryllium neutron source.

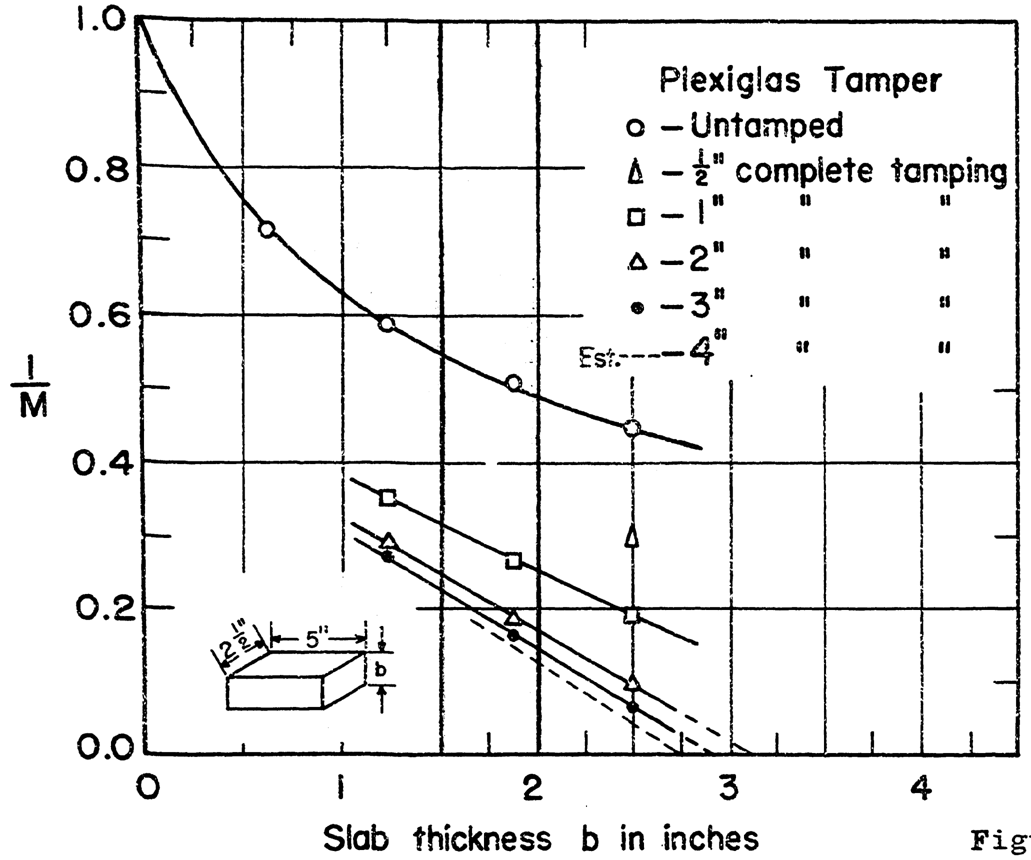

Figure 1

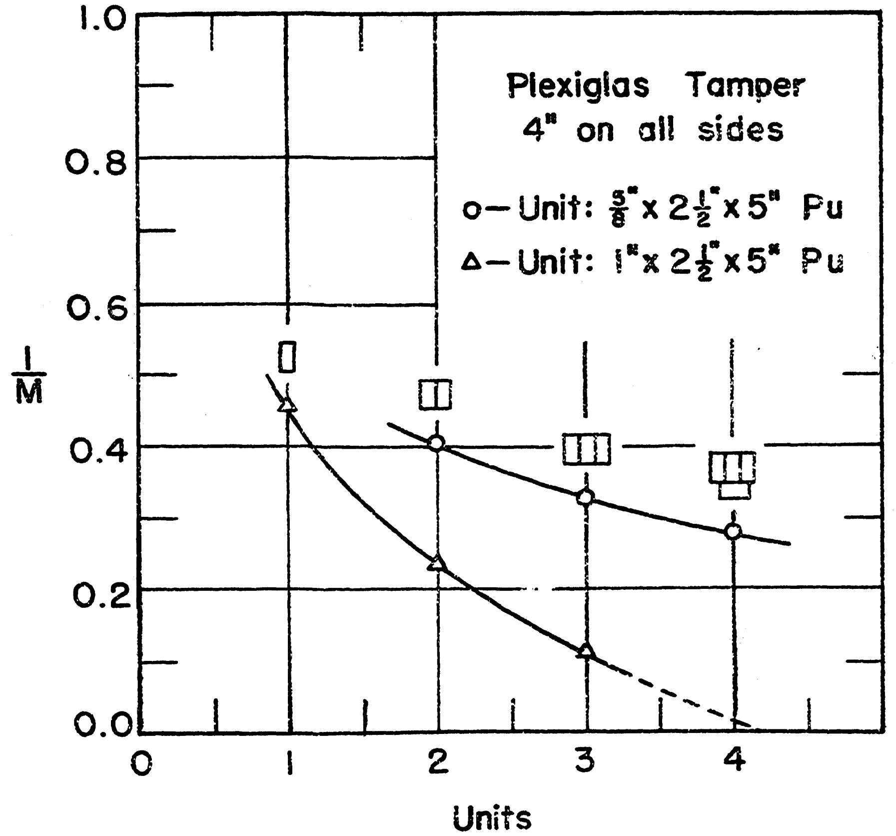

Figure 2

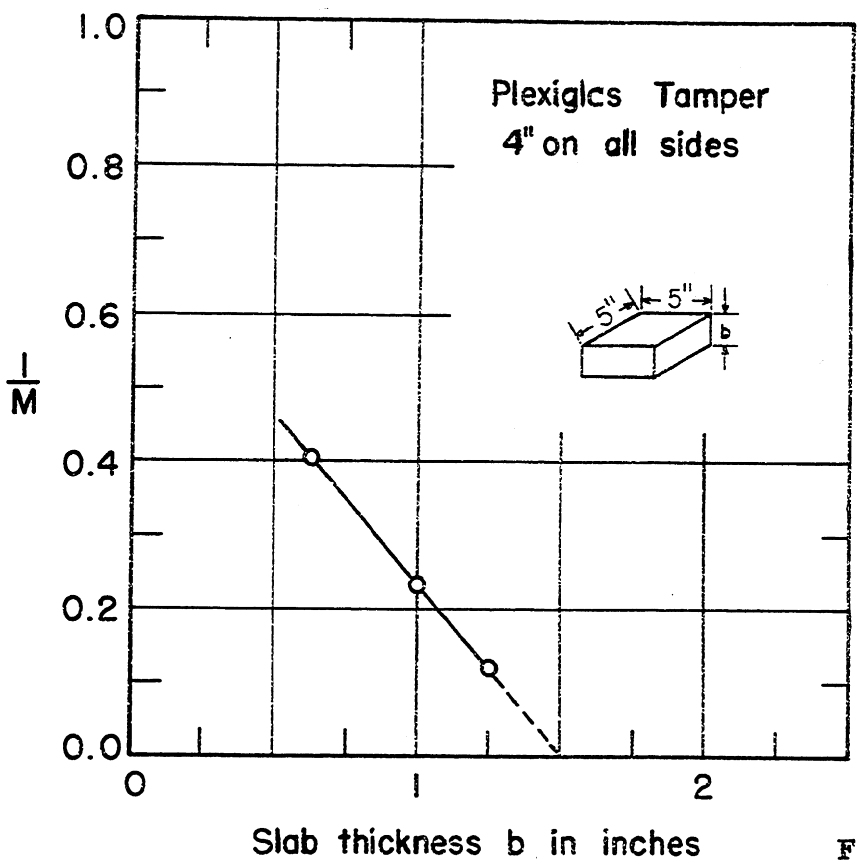

Figure 3

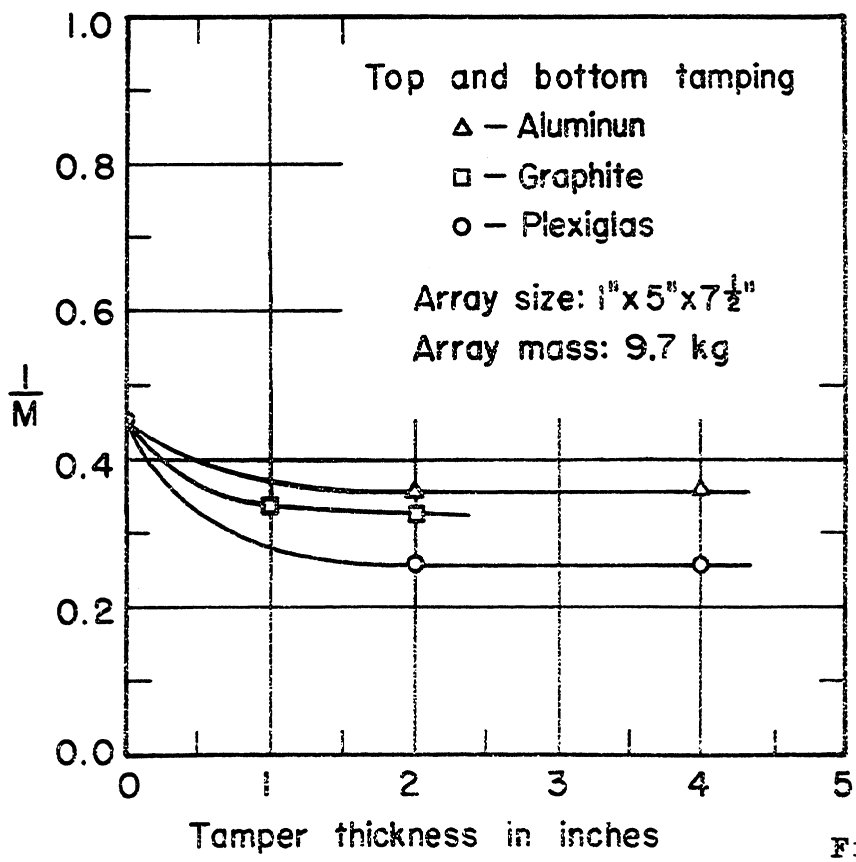

Figure 4

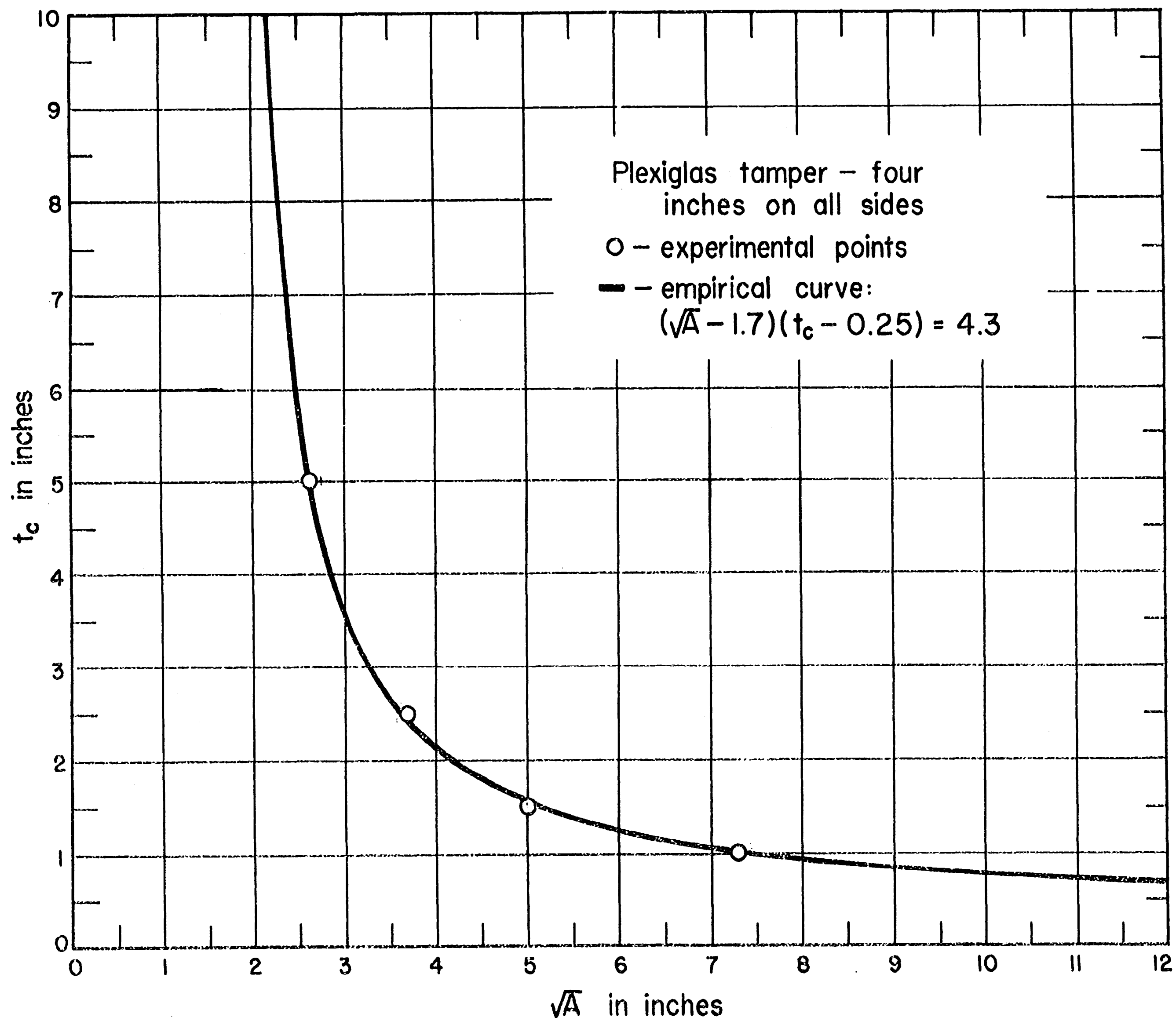
Plexiglas tamper – four inches on all sides
O – experimental points
– empirical curve:
(√A – 1.7)(t_c – 0.25) = 4.3
t_c in inches
√A in inches
0
1
2
3
4
5
6
7
8
9
10
11
12

Figure 5