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PRECISION CRITICAL-MASS DETERMINATIONS

FOR ORALLOY AND PLUTONIUM IN SPHERICAL TUBALLOY TAMPERS

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ABSTRACT

This report gives the results of precision delayed-critical-mass measurements on high density and high U-235 concentration oralloy cores close tamped in spherical tuballoy shells. The six critical-mass points obtained enable one to plot a reliable M_c vs Tu tamper thickness curve. The results for Oy (93.9%), ρ = 18.75 gms/cm^3 are:

Tu thickness (in):	0	0.695	1.76	3.525	3.925	9.0
Oy critical mass (kg):	51.9	36.2	26.5	20.5	19.75	17.35

In addition, the M_c of plutonium in a Tu tamper thickness of 4.603" was measured and found to be ~ 6.28 kg.

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PRECISION CRITICAL-MASS DETERMINATIONS FOR ORALLOY[(1)] AND PLUTONIUM IN SPHERICAL TUBALLOY TAMPERS

I. INTRODUCTION

A series of delayed-critical-mass measurements, completed recently at the Pajarito remote control laboratory, were performed on both oralloy-tuballoy and plutonium-tuballoy assemblies. Previous measurements on Oy-Tu configurations have been reported in LA-1114. However, accuracy of results was limited by (1) pseudospherical tamper assemblies, and (2) safety limit of hand stacking for the thin tampers. The aim of the present Oy-Tu measurements was to obtain a precision curve of M_c vs Tu tamper thickness for a given density and U-235 concentration of the oralloy cores. The critical mass of an untamped Oy sphere had been established quite accurately from experiments preliminary to the Lady Godiva[(2)] assembly at Pajarito. These measurements indicated an M_c of 51.6± .2 kg for an untamped Oy sphere of 93.86% concentration and density of 18.81 gms/cm^3. Previous data obtained on the Topsy critical assembly gave a critical mass of 17.30± .07 kg for Oy (94.1%, ρ = 18.72 gms/cm^3) in nine inches of tuballoy tamper, after corrections for non-spherical geometry.

[(1)] Oralloy: (Oy) "Oak Ridge alloy," i.e., enriched uranium.

[(2)] Untamped Oy (93.9%) critical assembly.

These results served as the basis for estimating the sizes of Tu tamper shells required for a variety of nearly critical Oy masses.

All measurements were performed on the Comet, a machine consisting of an hydraulic ram above which is supported an "A" frame (Fig. 1). The lower tamper shell(s) containing the sphere of active material was placed on an aluminum cylinder attached to the ram. The "A" frame supported a threaded rod from which the upper tamper hemisphere(s) was suspended. This device permitted the stacking of quantities of active material which when assembled would be near critical.

The counting system consisted of three boron-lined neutron chambers placed in long counter geometry and mounted on a lift situated several feet from the tamper surface. The counters were checked periodically for consistency by placing a mock-fission source in a fixed position from the three counters and observing the consistency of counting rates.

In all neutron multiplication measurements, the desired assembly was mocked-up identically as to geometry and dimensions using tuballoy in place of the Oy or Pu with a mock-fission source centrally located. An unmultiplied count was then taken. Next, tuballoy was replaced by the active material and a multiplied count obtained. The ratio of the multiplied count to the unmultiplied count gives the multiplication of the assembly (more explicitly, the "net central source multiplication").

Three neutron monitors placed at varying distances from the assembly were set such that any one would drop the ram if the neutron flux exceeded a predetermined level.

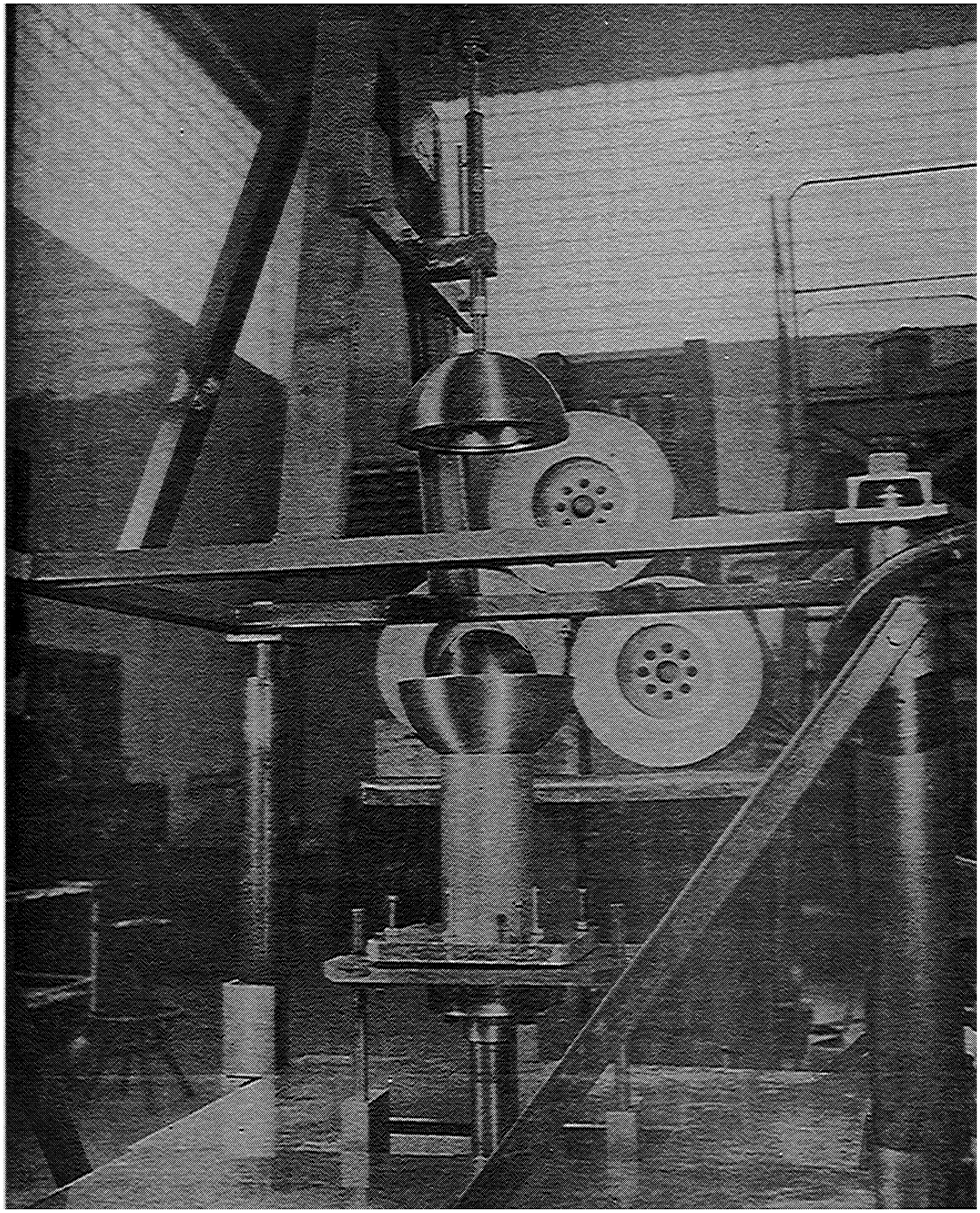

FIG. 1. Comet Machine with one tamper hemisphere suspended from the "A" frame and the other seated on the aluminum cylinder.

II. TU-OY CONFIGURATIONS

Neutron multiplication measurements were obtained with Oy cores in Tu tampers of 7.50" O.D., 9.00" O.D., 12.00" O.D., and 12.80" O.D. The data and extrapolated critical values from these measurements are listed in Tables I through IV. However, before turning to the results, some of the experimental terms and techniques used should be clarified. The term "filler" refers to two different Oy masses used to reduce a central source cavity (0.83" O.D.) to a smaller size. The first filler was in the form of a sphere, mass = 70.4 grams, with a cavity which could contain a cylindrical source. The second was in the form of two hemispheres, mass = 84.0 grams, with a very small source cavity ~ 0.34". By measuring the multiplication of the various assemblies with and without the filler, it was possible to determine the reactivity contribution of the filler and thus extrapolate to a solid Oy core.

The term "shim" as used in the Tables refers to aluminum shims of various thicknesses which were placed on the lower hemisphere to regulate the degree of closure of the system. A plot of reciprocal multiplication versus separation distance between mating surfaces of the tamper hemispheres enabled one to monitor the closing of the assembly. The shims also provided a very useful means for determining the multiplication of assemblies which were too reactive to close; for example, the 7.50" O.D. system. Data for this assembly minus the filler were plotted (Fig. 2) for various separation distances and the value of reciprocal multiplication at complete closure determined by extrapolation. The Oy filler was then added and this assembly was closed until a suitable multiplication was reached, in this specific case, with a separation of 130 mils. This determined the reactivity contribution of the Oy filler and thence the value of 1/M of the corresponding close tamped solid Oy core.

With the 9.00" O.D. assembly, the critical mass was determined by a linear extrapolation of reciprocal multiplication (1/M) against Oy radius. With the other three assemblies, the delayed critical configurations were determined by means of the Serber relation $S = \frac{\delta 1/M}{\delta r/r_0}$ where r_0 is the critical radius and S is a constant. From the bare sphere measurements S = 1.14 whereas for thick-tamper measurements on Topsy S = 1.16. Review of previous measurements on intermediate tamper thicknesses in LA-1114 and LA-1155 has indicated that here also $S \cong 1.15$.

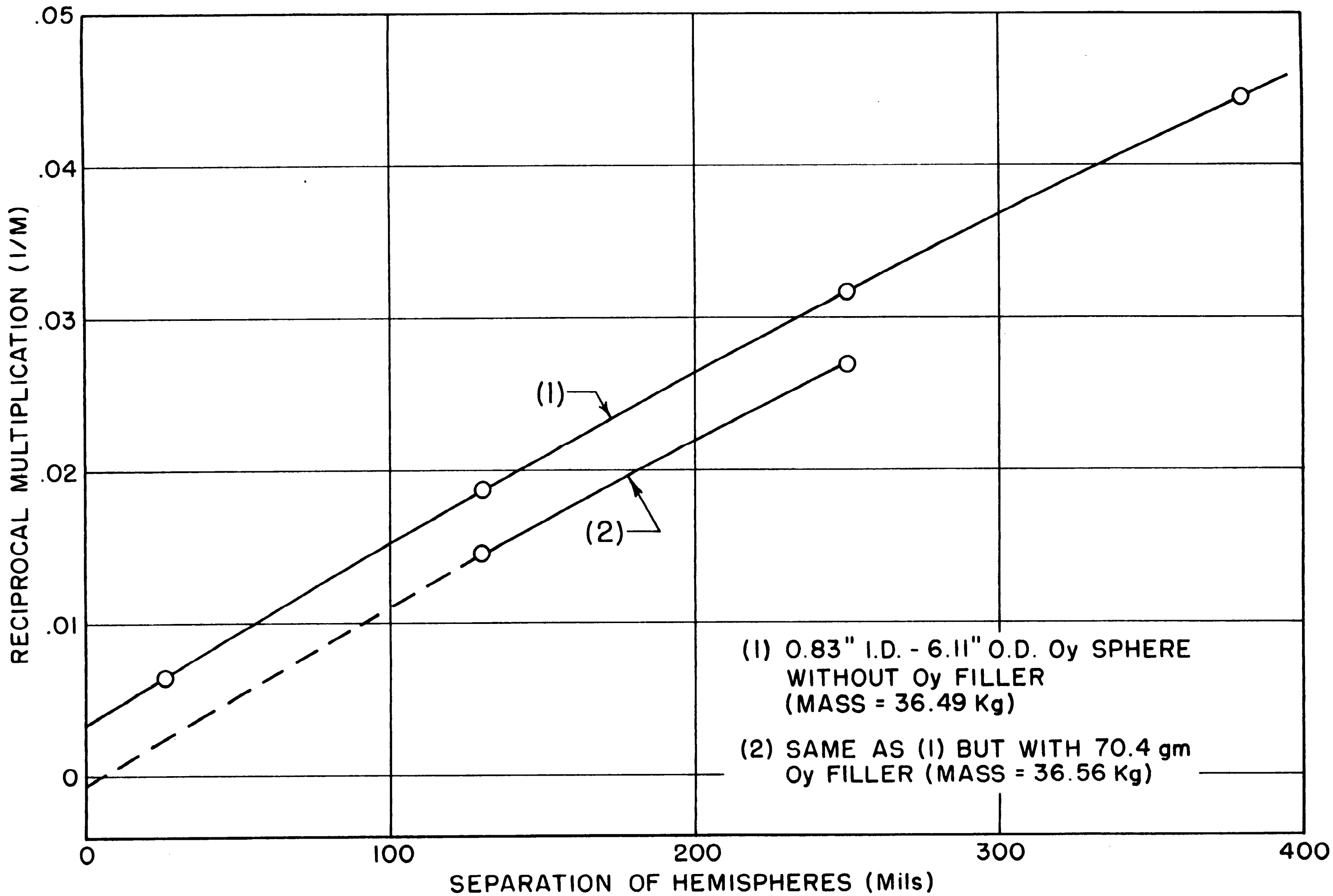

FIG. 2. Shim technique to determine reactivity of a supercritical assembly.

TABLE I. 7.50" O.D. assembly (Tu tamper thickness = 0.695")

Oy O.D.	Filler	Shim	Mass (Oy) (kg)	ρ (Oy) gms/cm^3	Concen-tration U-235	Reciprocal multipli-cation 1/M	Critical-mass M_c
6.11"	No	.380"	36.49	--	93.91%	.0444	
"	"	.250"	"	--	"	.0316	
"	"	.130"	"	--	"	.0188	
"	"	.026"	"	--	"	.0064	
"	"	None	"	--	"	.0034[(1)]	
"	70.4 gms	.250"	36.56	--	"	.0269	
"	70.4 gms	.130"	"	--	"	.0145	
"	Solid	None	36.58	18.69	"	-.0018[(2)]	
"	Solid	None	--	18.69	93.91	--	36.4_1 kg

[(1)] Extrapolated to zero shim.

[(2)] Extrapolated to zero shim, and to a solid core based on a contribution by the 70.4 gm filler of .0040 in units of reciprocal multiplication.

TABLE II. 9.00" O.D. assembly (Tu tamper thickness = 1.761")

Oy O.D.	Filler	Mass (Oy) (kg)	ρ (Oy) gms/cm^3	Concen- tration U-235	Reciprocal multipli- cation 1/M	Critical-mass M_c
4.95"	84 gms	19.510	--	93.90%	.0871	
4.95"	Solid	19.518	18.76	93.90	.0865 (1)	
5.44"	84 gms	25.874	--	93.98	.0071	
5.44"	Solid	25.882	18.74	93.98	.0065 (1)	
--	Solid	--	18.74	93.99	--	26.45 kg

(1) Extrapolated to solid core on the basis that the reactivity contribution of central Oy per gram is .00007 in units of reciprocal multiplication.

TABLE III. 12.00" O.D. assembly (Tu tamper thickness = 3.525")

Oy O.D.	Filler	Mass (Oy) (kg)	ρ (Oy) gms/cm^3	Concentration U-235	Reciprocal multiplication 1/M	Critical-mass M_c
4.68"	No	16.108	--	94.29%	.0948	
4.95"	No	19.108	--	94.04	.0404	
4.95"	84 gms	19.192	--	94.04	.0314	
4.95"	Solid	19.200	18.45	94.04	.0307 (1)	
4.95"	No	19.426	--	93.90	.0262	
4.95"	84 gms	19.510	--	93.90	.0188	
4.95"	Solid	19.518	18.76	93.90	.0181 (1)	
--	Solid	--	18.76	93.90	--	20.4_7 kg

(1) Extrapolated to solid core on the basis that the 84 gram Oy filler contributes .0074 in units of reciprocal multiplication.

TABLE IV. 12.8" O.D. assembly (Tu tamper thickness = 3.925")

Oy O.D.	Filler	Shim	Mass (Oy) (kg)	ρ (Oy) gms/cm^3	Concentration U-235	Reciprocal multiplication 1/M	Critical-mass M_c
4.95"	No	.380"	19.426	--	93.90%	.0502	
"	"	.250"	"	--	"	.0367	
"	"	.130"	"	--	"	.0244	
"	"	None	"	--	"	.0112	
"	70.4 gms	.380"	19.496	--	"	.0431	
"	"	.250"	"	--	"	.0302	
"	"	.130"	"	--	"	.0186	
"	"	None	"	--	"	.0060	
"	Solid	None	19.518	18.76	"	.0044[1]	
"	Solid	None	--	18.76	93.90	--	19.7_4 kg

[1] Extrapolated to solid core based on contribution by 70.4 gm Oy filler of .0052 in units of reciprocal multiplication.

In order to give a consistent plot of M_c (Oy) vs Tu tamper thickness (Fig. 3), it was necessary to correct the critical mass values to a single density and a single U-235 concentration. In Table V, the critical masses have been corrected (the small adjustments are based on the empirical relation $M_c \sim \rho^{-n} c^{-1.8}$ where the density exponent n varies from 2.0 for untamped Oy to 1.2 for thick Tu tamped Oy) to ρ (Oy) = 18.75 gms/cm^3, U-235 concentration = 93.9%, and a ρ (Tu) = 18.9 gms/cm^3. The initial slope of M_c vs Tu tamper thickness, $\frac{dM_c \text{ (Oy)}}{dt \text{ (Tu)}} = -32.2$ kg/inch at t = 0, was determined by reactivity measurements on tuballoy and oralloy samples located at the Oy-air interface of the Lady Godiva assembly. Analogous reactivity measurements on the Topsy Oy (9" thick Tu tamper) reactor have given $\frac{dM_c \text{ (Oy)}}{dt \text{ (Tu)}} = -0.12$ kg/inch at t = 9". These slopes have been utilized in Fig. 3 where a smooth curve has been drawn through the experimental M_c vs Tu tamper thickness points. For comparison only, previously determined M_c vs Tu tamper thickness values corresponding to the above concentration and density conditions are listed in Table VI.

TABLE V. M_c values corrected to ρ (Oy) = 18.75 gms/cm^3, U-235 concentration = 93.9%, and ρ (Tu) = 18.9 gms/cm^3.

Tu tamper thickness (inches)	Critical-mass M_c (kg) [(1)]
0	51.9
0.695	36.2_1
1.761	26.4_7
3.525	20.4_8
3.925	19.7_5
9.0	17.3_5

[(1)] Probable errors for these critical-mass values are estimated to be ~ 0.5%.

TABLE VI. Previously reported M_c values corrected to ρ(Oy) = 18.75 gms/cm^3, U-235 concentration = 93.9%, and ρ(Tu) = 18.9 gms/cm^3.

Tu tamper thickness (inches)	M_c (kg)	Reference
1.73	27.0	LA-1114 (1)
2.95	20.9	"
3.94	19.6	"
4.93	18.3	"
6.89	17.5	"
8.86	17.3_5	"
10.82	17.2_0	"
0.00	52.4	LA-1155 (2)
0.99	32.1	"
1.87	25.5	"

(1) Corrected from the assumed conditions ρ(Oy) = 18.72 gms/cm^3, U-235 concentration = 94.1%.

(2) Corrected from the assumed conditions ρ(Oy) = 18.5 gms/cm^3, U-235 concentration = 93.9%, and ρ(Tu) = 18.6 gms/cm^3.

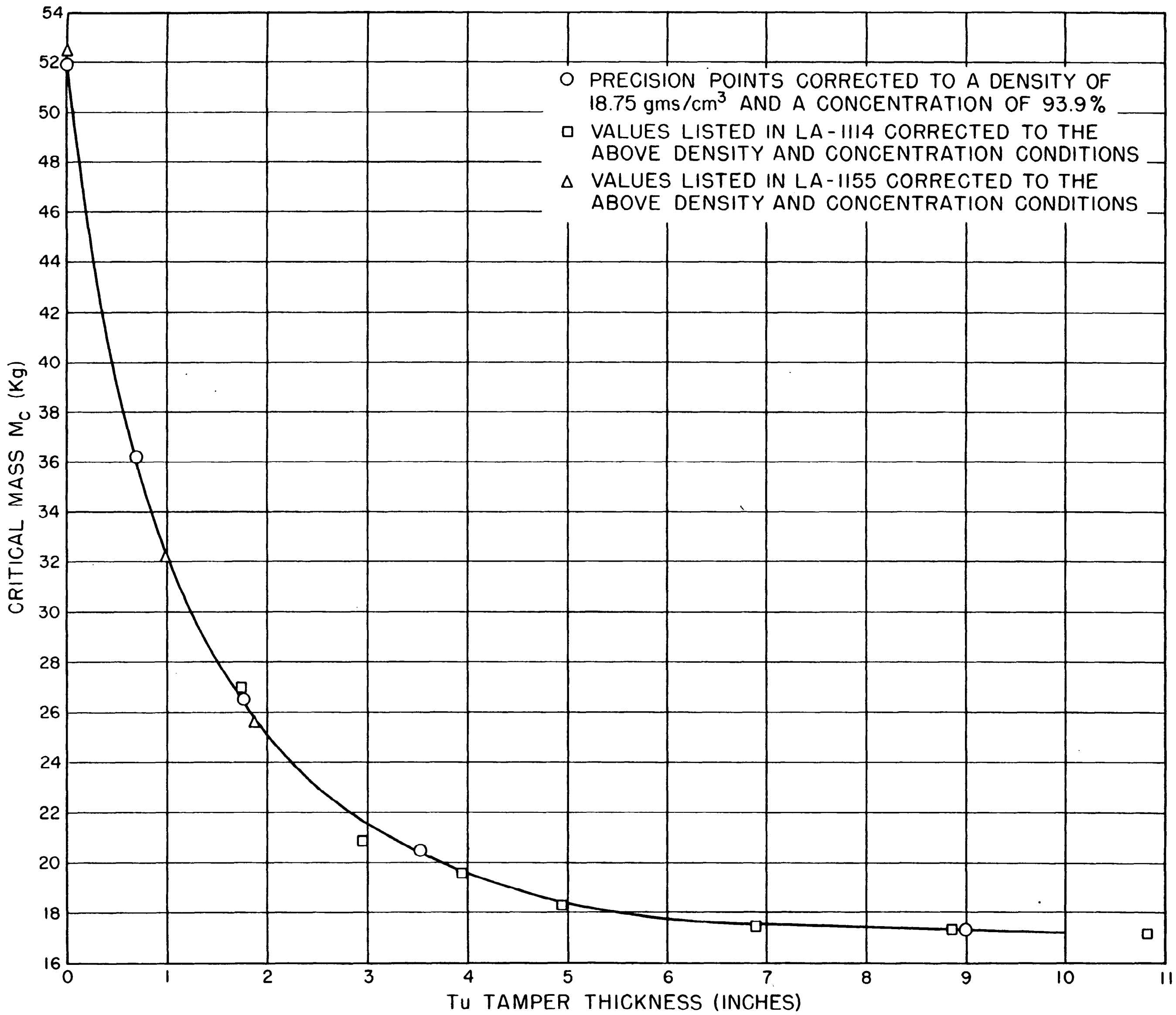

FIG. 3. Oy critical mass as a function of tamper thickness for Tu.

III. PU-TU CONFIGURATION

The purpose of the Pu-Tu measurements was to give a check point on plutonium versus Oy behavior and also to obtain design information for a critical Pu-Tu reactor now in the process of construction at Pajarito. The final assembly used consisted of a (3.60" O.D. ball of δ phase Pu alloy -- tamped by tuballoy to an outer diameter of 12.8". After it had been determined that this assembly could be closed, a 60 gram Pu filler was placed in the centre source cavity (0.83" O.D.) and the system was closed stepwise by means of the shim technique. A Serber constant of S = 1.16 was used for the M_c extrapolation. The data and results of these runs are listed in Table VII.

TABLE VII. 12.80" O.D. assembly (Tu tamper thickness = 4.603")

Pu O.D.	Filler	Shim	Mass (Pu) (gms)	ρ (Pu) gms/cm^3	Reciprocal multiplication 1/M	Critical-mass M_c
3.594"	No	None	6192.4	--	.0156	
"	60 gms	.380"	6252.4	--	.0233	
"	"	.250"	"	--	.0173	
"	"	.130"	"	--	.0106	
"	"	None	"	--	.0042[1]	
"	Solid	None	6269.7	15.74	.0009[2]	
"	Solid	None	--	15.74	--	6284 gms

(1) Extrapolated to zero shim.

(2) Extrapolated to solid core based on 60 gram Pu filler contributing .0114 in units of reciprocal multiplication.