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CRITICAL PARAMETERS OF SPHERICAL SYSTEMS OF ALPHA-PHASE PLUTONIUM REFLECTED BY BERYLLIUM

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ABSTRACT

The critical thicknesses of beryllium reflectors were determined for five alpha-phase plutonium spheres with masses of 2.472, 3.217, 3.933, 4.664, and 5.426 kg. A description of the measuring techniques and experimental apparatus is given.

INTRODUCTION

The critical thickness of beryllium reflector was determined for five alpha-phase plutonium spheres with masses of 2.472, 3.217, 3.933, 4.664, and 5.426 kg, with average density of 19.25 g/cc.

Plutonium

The two smallest plutonium parts were made as complete spheres and were coated with 0.005 inch of nickel. The three larger spheres were made up of two hemispheres each. They were encased in a nickel coating 0.005 inch thick on the curved surfaces and 0.003 inch on the flat surfaces. The nickel coating thus produced a gap of 0.006 inch on the equatorial plane of the three larger spheres. (See Fig. 1) A gap of this sort will lead to a slight error in the determination of critical parameters. This type of error is discussed in the body of this report. Care was taken to minimize other effects, such as poor mechanical fits in the reflector and perturbing support structures.

Reflector

The reflector consisted of two matching sets of nesting hemispherical beryllium shells which could be expanded from a fixed inner radius to an outer radius that varied in approximately 0.25-inch steps (Fig. 1).

A series of four nesting Be "shim" shells was employed to adapt the larger reflector pieces to each of the plutonium spheres. The machining tolerances were held to close limits so that the gaps which resulted from the nesting construction were of the order of 0.001 inch.

The densities of various sets of shells and individual shells were determined by means of direct weighings and dimensions. The densities thus calculated had a mean value of 1.84 with a maximum spread of ± 2.5%.

The Be shells were held on the assembly machine by means of two 1/4-inch steel rods. These rods penetrated the shells and were secured to the inner shell by means of a head on the end of the rod which fitted into a counterbored portion of the hole. The reflector shells and core are shown in Fig. 2.

Assembly Machine

The assembly machine (Fig. 3) consisted of a remotely operated hydraulic ram. The assembly was divided into a lower reflector and plutonium core, and an upper reflector. The lower portion of the assembly was secured to the ram by means of the 1/4-inch steel rod. The upper portion of the reflector was suspended by a similar rod which was in turn supported from an upper structure of the frame of the machine (Fig. 1).

The assembly was accomplished by moving the lower portion upward until contact with the upper portion was effected. The upward motion could be stopped and reversed in approximately 0.1 second by means of a by-pass in the hydraulic system. This capability was used in conjunction with count-rate meters which operated from the neutron counters to provide a "scram" should the assembly exceed a predetermined multiplication.

An additional feature of the assembly machine was a set of three remotely variable spacers which could be inserted radially between the assembly halves. These spacers provided a positive and reproducible gap between the two reflector halves. The spacers were used when an assembly was being made with a configuration that would exceed the upper multiplication limit. The assembly was brought together in discrete steps and a plot of inverse multiplication vs the separation provided the desired multiplication (at closure) by extrapolation without necessitating complete closure. At small separations the steps could be controlled to increments of 0.025 inch.

Experimental Procedure

The beryllium reflector consisted of a series of nesting hemispherical shells which could be added in increments of approximately 0.20 to 0.25 inch. The critical thickness of beryllium for any sphere was determined by increasing the beryllium thickness until the inverse leakage multiplication plotted as a function of reflector thickness gave a reliable extrapolation to zero, at which point the assembly would have reached delayed critical. The measurements were limited by the control arrangements to a maximum multiplication of 100. The error of extrapolation from an assembly that had been taken to this point is of the order of 1%.

The leakage multiplication as used here is defined as the ratio of the multiplied neutron emission to the unmultiplied emission. The unmultiplied emission was determined by multiplying the neutrons produced per gram of plutonium per second (by spontaneous fission of the Pu^{240} contaminant) by the total mass of the plutonium core. The neutron leakage rate was influenced to some extent by the addition of reflecting material, but the low absorption cross section of beryllium made this effect negligible. The extrapolated critical reflector thickness is unaffected by slight systematic errors in individual multiplications, the only effect being a change in the slope of the inverse multiplication curve.

The counting equipment consisted of two BF_3 Hanson long counters and two CH_2-moderated LiI scintillation counters. The neutron emission of the plutonium was determined by comparing the counting rate of a non-multiplying (approximately 10-gram) sample of the material with the counting rate of a small calibrated mock-fission neutron source in a total geometry counter.

Results

The results are tabulated in Table I and shown graphically in Fig. 4. The probable errors are shown as a shaded portion of the plot. It will be noted that as an infinite reflector is approached, the uncertainties become great enough so that the minimum critical mass is poorly determined although it appears to be in the neighborhood of 2 kg.

Table I. Beryllium critical reflector thicknesses for various spherical alpha-phase plutonium cores.

Pu - ρ = 19.25 g/cc (kg)	Beryllium reflector thickness - ρ_{Be} = 1.84 g/cc (cm)
2.472	32.0 ± 4.0
3.217	21.0 ± 1.0
3.933	13.0 ± 0.1
4.664	8.17 ± 0.03
5.426	5.22 ± 0.02

A direct measurement was made to determine the effect of the 0.003-inch nickel coating of the plutonium on critical parameters. Specifically, a measurement was made of the expected change in critical reflector thickness should the nickel interfaces be removed from one of the larger plutonium spheres, thus presenting a solid sphere instead of two separated hemispheres. The 4.664-kg sphere was used with 7.630 cm of beryllium reflection. Varying amounts of nickel were placed between the plutonium halves and the change in multiplication was measured at each step. In order to provide room in an otherwise closely fitting reflector, the beryllium was used with a constant separation of 0.025 inch. The multiplication of the system was near 100, which is close enough to delayed critical so that the correction measured can be assumed to apply equally well to the critical configuration. The measured correction indicated that the critical beryllium thickness would be reduced by 0.25% for a solid plutonium core as compared to the core actually used.

The effect of the nickel coating which covered the periphery of the plutonium core was not measured. This coating created a 0.005-inch gap between the core and the reflector, a space which was in addition to that left by necessary clearance tolerances. The space in question is not entirely void since it is partially filled with the nickel, which has some effect as a reflector. The errors caused by this gap have been included in the errors quoted for the beryllium density, since the densities were computed using the actual plutonium surface as the inner reflector diameter.

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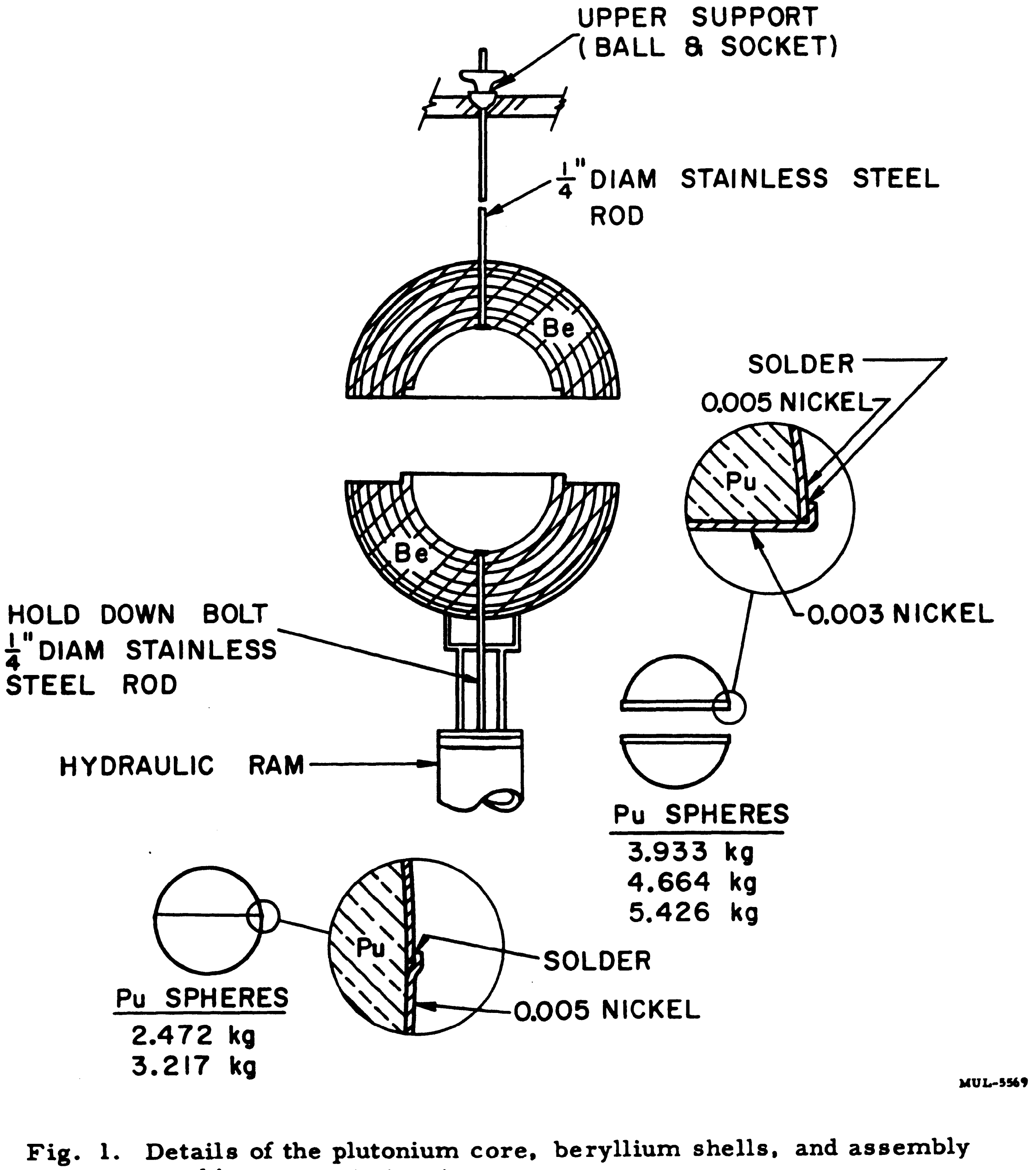

Fig. 1. Details of the plutonium core, beryllium shells, and assembly machine support structures.

Fig. 2. Reflector shells and core.

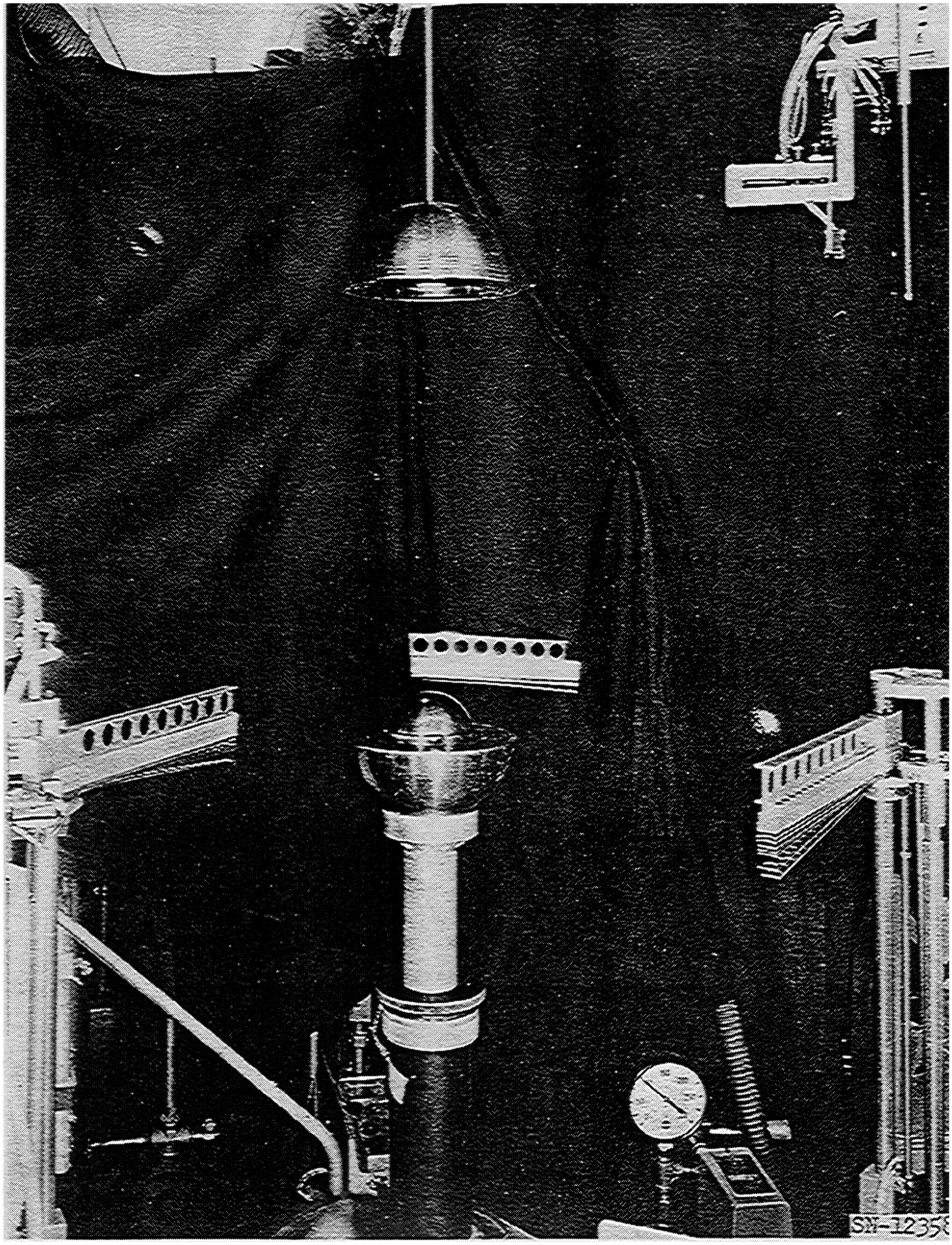

Fig. 3. Assembly machine.

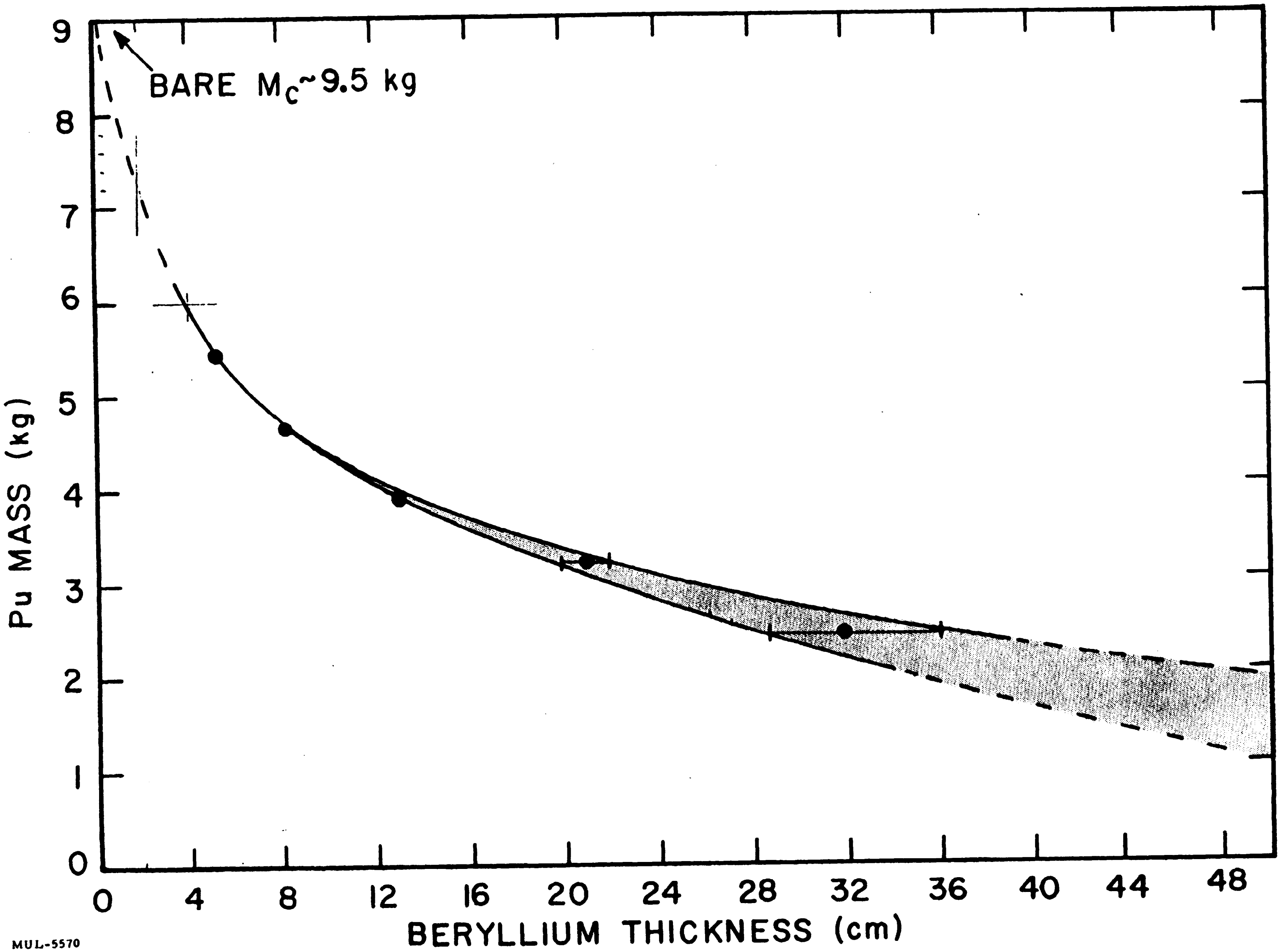

Fig. 4. Critical masses of spherical systems of alpha-phase plutonium reflected by beryllium.