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Critical Reflector Thicknesses for Spherical U^{233} and Pu^{239} Systems*

E. A. PLASSMANN AND D. P. WOOD

University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico

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The thickness of reflectors required for critical configurations with spheres of U^{233} and Pu^{239} have been estimated from multiplication measurements of nearly critical assemblies. Reflector materials employed were uranium enriched in U^{235}, normal uranium, beryllium, and tungsten alloy. Correction of the experimental data has been attempted to give "idealized" dimensions, i.e., a solid core in intimate contact with its reflector material.

INTRODUCTION

Experimental determinations of simple critical configurations are considered as essential bits of information by the theorist as he is thus provided with definite check points for testing his analysis before proceeding to more complicated systems. In particular, for fast neutron work, a solid spherical configuration consisting of a fissionable core surrounded by effective reflector materials, lends itself most easily to calculational interpretation. In the present work, three different cores—7.5 kg, and 10 kg U^{233}, and 8.5 kg Pu^{239}—were employed in conjunction with U(93)[1], beryllium, natural uranium, and tungsten-alloy reflectors.

EXPERIMENTAL PROCEDURE

For each of these measurements, the fissionable core material is in the form of two hemispheres with a central void of 0.85 in. diameter. For the protection of personnel during setup procedures, all Pu^{239} and U^{233} pieces are completely clad in 0.005-in. thick nickel. In addition, because of the gamma buildup in the U^{233}, the precaution of a remote handling system is needed for this material.

Figure 1 is a photograph of the experimental setup. A stretched diaphragm of 0.015-in. thick stainless steel acts as a stationary platform on which one of the core hemispheres is centered. A mock fission source with a strength of some 10^5 neutrons/second, is positioned on the diaphragm under this top section. The second core hemisphere is supported above the platen of a hydraulic lift and can be raised by remote control. Assembly is achieved in a stepwise manner with the use of positive stops on the lift. Multiplication measurements, taken at each step in the assembly procedure, serve as a guide to predict the safety of the system before the separation distance is further narrowed.

The flux of leakage neutrons from the assembly is monitored by BF_3 counters in polyethylene geometry. Multiplication for these measurements is defined as the ratio of the neutron counting rate of the assembly with central source to that of the source (in identical position) alone.

A thin, close-fitting spherical shell of reflector material is placed around the core and the multiplication of the assembled system is measured. Similar multiplications of successively thicker shells of the same material are determined until a plot of reflector thickness versus reciprocal multiplication can be extrapolated to the critical thickness.

As an aid in the correction to solid sphere multiplications, the measurements are repeated with more core material added at the center of the configuration. This addition is a Pu^{239} (or U^{233}) filler piece which fits the void in the lower core hemisphere.

DISCUSSION OF RESULTS

As already indicated, a critical configuration was never attained in any of these assemblies. However, experimental multiplications of the order of 100 were obtained during the course of measurements for each reflector series. The reactivities of the systems

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[1] The symbol U(93) refers to uranium enriched to 93.2% by weight in the isotope U^{235}.

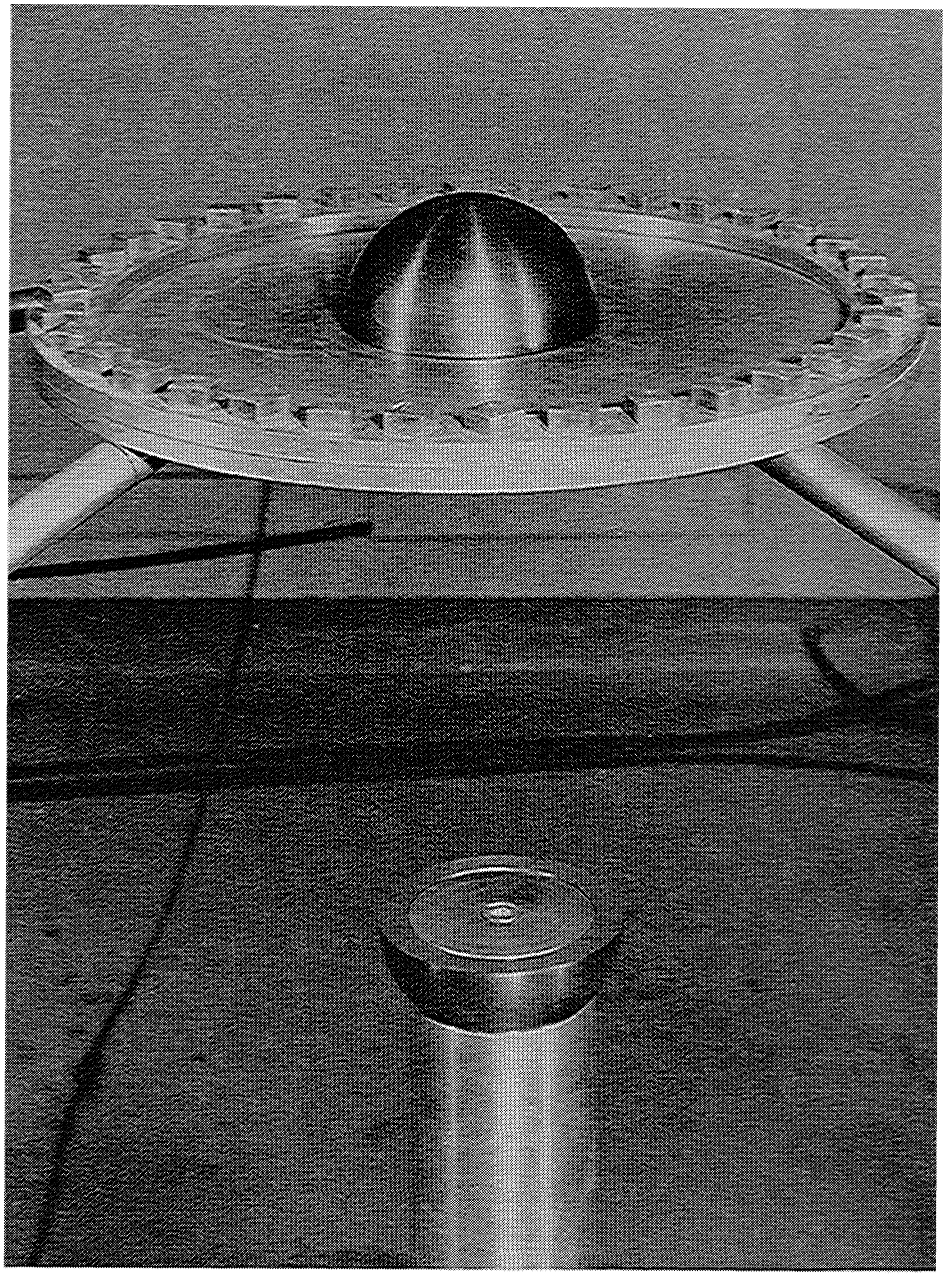

FIG. 1. Experimental setup for the multiplication measurements of spherical core-reflector configurations

were thus great enough to permit good extrapolations to critical. It is naturally desirable that the critical dimensions of solid spherical core-reflector configurations be determined and hence it is necessary to interpret the experimental measurements and correct out the modifications which are inherently present or built into the systems because of needed handling and assembling precautions.

Pu^{239} Core

In the experimental setup, a 0.015-in. thick stainless steel diaphragm supports one hemisphere, and is always present on the parting plane as the core-reflector combination is assembled. A plot of reciprocal multiplication ($1/M$) versus separation distance can be extrapolated for an additional 0.015 in. past the closure point to obtain the effect of the diaphragm on the multiplication of the system. The validity of this extrapolation was verified by increasing the thickness of the diaphragm with an additional 0.015-in. sheet of stainless steel. The multiplication thus obtained agreed with what could have been predicted from the $1/M$ closure curve above.

The change in multiplication which should be expected by filling the 0.85-in. diameter central void in the core, can be estimated by noting the increase in the multiplication of the system when a close fitting plutonium filler piece is added to the bottom half of the void.

One may also account for the effect of the 0.005-in. thick nickel cladding on the plutonium core hemispheres. The increase in the reactivity of the system to be expected if plutonium were substituted for nickel on the parting plane, and at the radius of the central void, was calculated using replacement measurements made in the Jezebel bare plutonium critical assembly (*1*). A similar calculation gives the reactivity gain associated with the addition of plutonium at the center of the core. The latter change corresponds to the experimentally measured $\Delta(1/M)$ for the addition of the central void Pu^{239} filler piece. Hence a $\Delta(1/M)$ value can be assigned for the nickel to plutonium substitution, viz.,

$$\left(\Delta \frac{1}{M} \text{ for Ni cladding replaced by Pu}\right) = \left(\text{experimental } \Delta \frac{1}{M} \text{ for Pu filler piece}\right) \cdot \left[\frac{\text{calculated } \Delta\text{¢ Pu for Ni}}{\text{calculated } \Delta\text{¢ Pu filler piece}}\right]$$

Based on replacement measurements made at the core surface of the Topsy critical assembly (*1*) [a heavily reflected U(93) system], the nickel coat at the outside radius of the core pieces is simply added to the reflector thicknesses of beryllium, natural uranium, and tungsten alloy, and must be reduced by a factor of two for a corresponding thickness of U(93) reflector.

A suitable correction for the clearance between the core and reflector material, which is necessarily present in the experimental setup, can be deduced from the slope of the measured curve of reciprocal multiplication versus reflector thickness. The slope at zero thickness is interpreted as giving the change in $1/M$ per unit thickness which would have occurred had the clearance void been filled with reflector. The external reflector radius can then be reduced to produce this same $\Delta(1/M)$ as indicated by the slope of the curve in this region.

Multiplications of the various plutonium core-reflector configurations with a centrally-located mock-fission source were measured over a period of about one year. The same source was always used, and because of the distributed multiplication of the core itself, the apparent multiplication of a given system depended on when it was measured. In the experiments reported here, all measurements with the several thicknesses of a given reflector material were taken on the same day, i.e., during a very short time interval in comparison with the source half-life ($t_{1/2}$ for Po^{210} is 138.4 days). Measurements on the different reflector materials, however, were per-

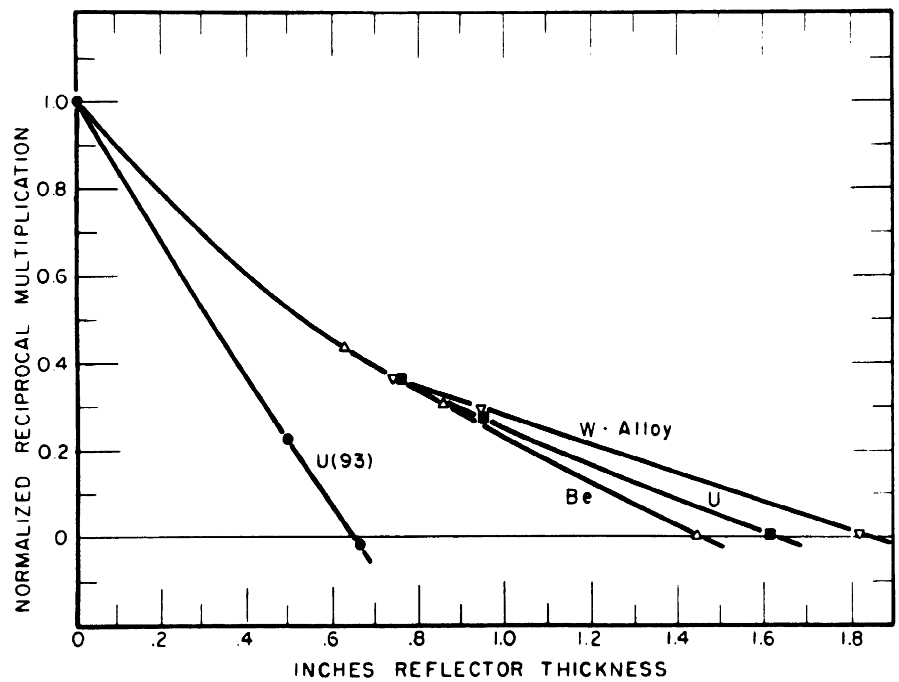

FIG. 2. Reciprocal multiplications for the reflected 3.970-in. diameter Pu^{239} core corrected to solid spherical core-reflector values.

formed on different days with as much as a few months separation. Hence, as a convenience in plotting, the corrected reciprocal multiplications have been normalized as shown in Fig. 2. Extrapolation to critical reflector thickness is made as shown.

In these corrected graphs, the reciprocal multiplication is sometimes negative. This occurs simply because the corrections had to be subtracted from the experimental $1/M$ measurements causing the plotted point to fall below the zero ordinate.

U^{233} Cores

The same general procedure as described above for the Pu core was employed in correcting the experimental results of the U^{233} cores to give the critical reflector dimensions of solid spherical con-

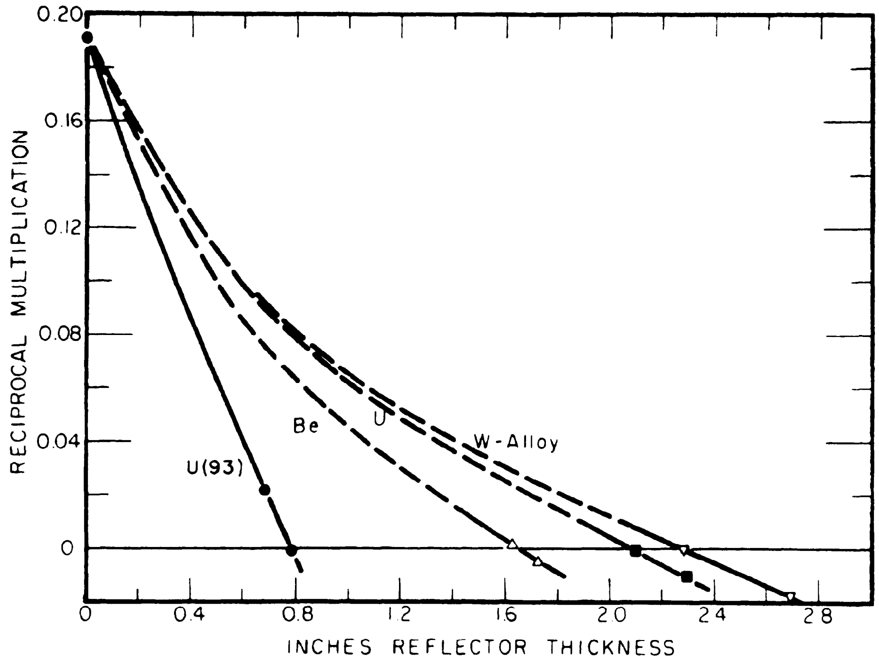

FIG. 3. Corrected reciprocal multiplications for the reflected 3.622-in. diameter U^{233} core

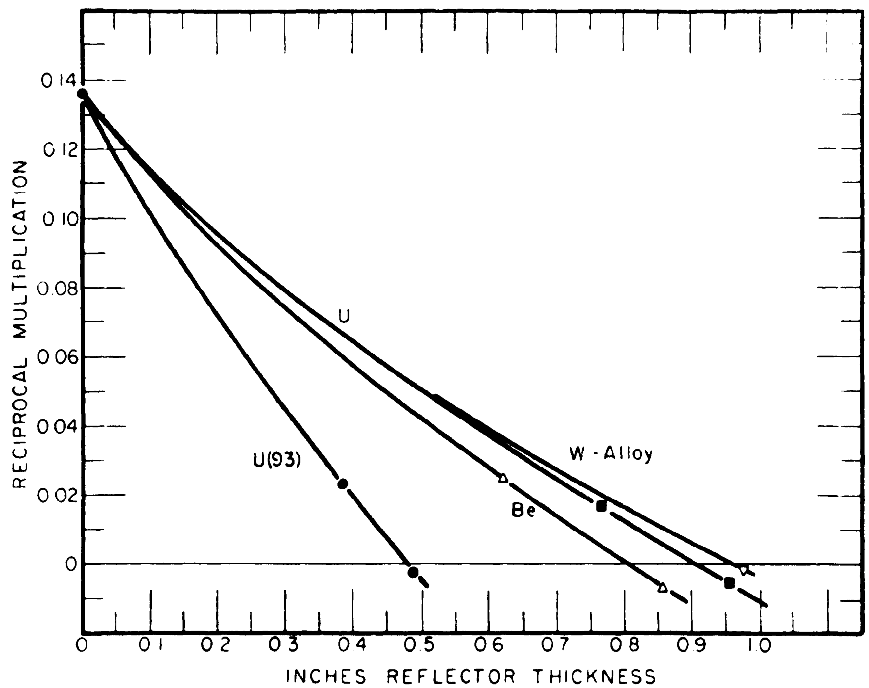

FIG. 4. Corrected reciprocal multiplications for the reflected 3.972-in. diameter U^{233} core

TABLE I

CRITICAL CORE-REFLECTOR CONFIGURATIONS

Core					Critical reflector thickness[a]			
Material	Diameter (in.)	Weight (Kg)	Density	Enrichment	U(93) ρ = 18.80 (in.)	Be(98 w/o) ρ = 1.83 (in.)	Natural uranium ρ = 18.92 (in.)	W alloy (91.3 w/o) ρ = 17.21 (in.)
U^{233}	3.622	7.601	18.62	98.25 w/o	0.780	1.652	2.090	2.280
U^{233}	3.972	10.012	18.62	98.25 w/o	0.478	0.805	0.906	0.960
Pu^{239}	3.970	8.386 Pu	15.62 Pu[b]		0.652	1.452	1.625	1.850

[a] Probable error is 1% for these critical reflector thicknesses.

[b] The Pu^{239} used in this experiment contains 4.90 atomic % Pu^{240}, 0.31 atomic % Pu^{241}, and a minor amount of inert diluent.

figurations. Since suitable replacement measurements for U^{233} do not exist, it was assumed that corrections for the Ni cladding would be approximated by the already known replacements at the same radius in the Jezebel critical assembly referred to above. The reactivity changes thus calculated are compared to the experimentally determined change in multiplication recorded when a U^{233} hemispherical filler piece of known weight and dimensions is added to the central void of the U^{233} core.

An example of the magnitudes of the corrections made as compared to the actual measured multiplications follows:

2.288-in. thick W reflector on the 7.5 kg U^{233} core with filler,

measured multiplication = 53.2 = 1/0.0188
measured $\Delta(1/M)$ for U^{233} filler = 0.0083

Corrections applied:

$\Delta(1/M)$ for stainless steel diaphragm	=	0.0044
$\Delta(1/M)$ to replace Ni cladding with U^{233} on parting plane and at radius of void	=	0.0043
$\Delta(1/M)$ to fill central void	=	0.0106
Total $1/M$ correction to be subtracted from experimental $1/M$ value of 0.0188 above	=	0.0193
For Ni cladding on outside of core	=	+0.005 in.
For 0.002 in. clearance between core and reflector	=	−0.006 in.
Total radius correction to be added to W reflector thickness	=	−0.001 in.

The corrected point to be plotted for this measurement is thus $1/M = -0.0005$ at a W reflector thickness of 2.287 in.

The corrected curves are drawn in Fig. 3 for the 7.5 kg and Fig. 4 for the 10 kg U^{233} cores. Interpolation to a reciprocal multiplication of zero then yields the proper critical reflector thickness.

SOURCES OF ERROR

Corrections to the solid spherical geometry are based on replacement measurements reported in (1) and on the change in multiplication observed when additional fissionable material is added to the center of the assembly. Of the former, plutonium replacement, which represents almost all of the correction involved, is quoted to 0.4% accuracy. The observed multiplication is the quotient of two counting rates, which in all cases, especially in the near critical configurations, were great enough to give statistical fluctuations of 0.5% or less.

The dimensions of the core pieces and reflector shells offer other possibilities for error. By actual sample measurements, these dimensional tolerances were of the order of ±0.003 in. which are averaged out over the entire spherical surface.

With consideration given to the accuracy of the experimental data and the methods in which corrections were applied, it is felt that the values of critical reflector thicknesses quoted in Table I are correct to within ±1%.

SUMMARY

The specifications of the cores used and the thicknesses of reflector materials required for critical configurations are listed in Table I. The dimensions given refer to solid spherical core-reflector systems. This implies that the actual experimental measurements have been modified to account for the nonideal configuration which is necessarily employed in the experimental set-up. Corrections attempt to offset the effects of the nickel cladding on the core pieces, the central void of the core, the stainless steel

diaphragm on the parting plane, and the clearance between the core and reflector materials.

The dimensions of these critical systems have been successfully used by Roach (*2*) as confirmation of sixteen group S_n cross sections which describe the neutronic properties of the appropriate reactor materials.

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