Critical Reflector Thicknesses for Spherical \( {\text{U}}^{233} \) and \( {\text{Pu}}^{239} \) Systems*

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Received June 6, 1960

The thickness of reflectors required for critical configurations with spheres of \( {\text{U}}^{233} \) and \( {\text{Pu}}^{239} \) have been estimated from multiplication measurements of nearly critical assemblies. Reflectors employed were uranium enriched in \( {\text{U}}^{233} \), 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 \( {\text{U}}^{233} \), and 8.5 kg \( {\text{Pu}}^{239} \)—were employed in conjunction with \( {\text{U}}^{(93)} \), 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 \( {\text{Pu}}^{239} \) and \( {\text{U}}^{233} \) pieces are completely clad in 0.005-in. thick nickel. In addition, because of the gamma buildup in the \( {\text{U}}^{233} \), 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 sec-

* Work performed under the auspices of the U. S. Atomic Energy Commission.

1 The symbol \( {\text{U}}^{(93)} \) refers to uranium enriched to 93 \( \% \) by weight in the isotope \( {\text{U}}^{233} \).
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.,

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

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-

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**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.

$^{239}$ Pu Cores

The same general procedure as described above for the Pu core was employed in correcting the experimental results of the $^{235}$ U cores to give the critical reflector dimensions of solid spherical con-

![Graph](image1)

**Fig. 3.** Corrected reciprocal multiplications for the reflected 3.622-in. diameter $^{239}$ U core

![Graph](image2)

**Fig. 4.** Corrected reciprocal multiplications for the reflected 3.972 in. diameter $^{235}$ U core
TABLE I
CRITICAL CORE-REFLECTOR CONFIGURATIONS

| Material | Diameter (in.) | Weight (Kg) | Density | Enrichment | Critical reflector thickness
<table>
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<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>U(233)  p = 18.80  Be(98 w/o)  p = 1.53  Natural uranium  p = 18.92  W alloy 91.1 w/o  p = 17.21</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.601</td>
</tr>
<tr>
<td>U(233)</td>
<td>3.622</td>
<td>7.601</td>
<td>18.62</td>
<td>98.25 w/o</td>
<td>0.780</td>
</tr>
<tr>
<td>U(233)</td>
<td>3.972</td>
<td>10.012</td>
<td>18.62</td>
<td>98.25 w/o</td>
<td>0.478</td>
</tr>
<tr>
<td>Pu(239)</td>
<td>3.070</td>
<td>8.386 Pu</td>
<td>15.62</td>
<td></td>
<td>0.052</td>
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</tbody>
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* Probable error is 1% for these critical reflector thicknesses.

The Pu(239) used in this experiment contains 4.90 atomic % Pu(238), 0.31 atomic % Pu(239), and a minor amount of inert diluent.

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.

SOURCE 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 non-ideal 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 $S_\alpha$ cross sections which describe the neutronic properties of the appropriate reactor materials.

REFERENCES
