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# MULTIPLICATION OF A 2-1/2 INCH 25 SPHERE AS MEASURED WITH 28 AND 25 FISSION DETECTORS

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## ABSTRACT

Data are reported for the multiplication by a 2-1/2 inch sphere of 71-per cent 25, as measured by 28 and 25 fission chambers. Some data for a 2-inch sphere are also given. For the 2-1/2 inch sphere the multiplications are found to be:

$M_{28} = 1.13 \pm .02$ $M_{25} = 1.37 \pm .02$

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## MULTIPLICATION OF A 2-1/2 INCH 25 SPHERE AS MEASURED WITH 28 and 25 FISSION DETECTORS

### Introduction

If the multiplication of a sphere of active material is measured with a detector whose energy sensitivity is not flat, the result will depend upon inelastic scattering as well as upon $\nu$, $\alpha$, and $\sigma_f$. Such a measurement may thus be used as a check on the inelastic scattering cross section. In the experiment reported here, the multiplication of a 2-1/2 inch sphere of 71-per cent 25 was measured with 28 and 25 fission chambers.

### Theory

For the complete theory and calculations of this experiment, the reader is referred to a forthcoming report by Richman and Serber.

A first collision analysis is presented below, however, in order to give a semiquantitative picture of how various quantities affect the multiplication as measured with an energy-sensitive detector. This analysis also indicates the difficulties introduced by using a mock fission source rather than a true fission source.

We use the following notation:

$\overline{p_f}^s$ is the probability that a neutron from the source produces a fission in traversing the radius of the sphere. The bar indicates an average over neutron energies.

$\overline{p_i}^s$ and $\overline{p_a}^s$ are the corresponding probabilities for inelastic scattering and absorption of source neutrons.

$\overline{p_D}^X$, $\overline{p_D}^s$, $\overline{p_D}^i$ are the probabilities of detection (by detector D) of fission, source, and inelastically scattered neutrons, respectively.

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$S_o$ is the number of neutrons emitted per sec. by the source.

The multiplication after one collision, as it would be measured by the detector, may be written as follows:

$$M = \frac{1}{S_o \overline{p_D}^s} \left[ S_o \overline{p_D}^s + S_o \overline{p_f}^s \nu \overline{p_D}^X + S_o \overline{p_i}^s \; \overline{p_D}^i - S_o \left\{ \overline{p_f}^s (1 + a) + \overline{p_a}^s + \overline{p_i}^s \right\} \overline{p_D}^s \right]$$

$$M - 1 = \overline{p_f}^s \nu \; \overline{p_D}^X / \overline{p_D}^s + \overline{\sigma_i}^s \; \overline{p_D}^i / \overline{p_D}^s - \left[ \overline{p_f}^s (1 + a) + \overline{p_a}^s + \overline{p_i}^s \right]$$

This is simply the ratio of the total number of neutrons of the various types (fission, source, and inelastically scattered neutrons) detected with the sphere in place to the number (source neutrons only) detected without the sphere, according to an approximation which neglects multiple processes. Although this expression requires a number of corrections if it is to provide a completely accurate description of the experiment, it will serve to estimate the effect of various constants on the result. For example, we may consider the following cases:

1. Detector with flat response: $\overline{p_D}^X = \overline{p_D}^s = \overline{p_D}^i$

   $M = 1.25$

2. 28 detector with $\overline{p_i}^s = 2.0$ $\quad \overline{p_D}^i = 0$ and $\overline{p_D}^X = \overline{p_D}^s$

   $M = 0.98$

3. 28 detector with $\overline{p_i}^s = 1.5$, $\overline{p_D}^i = 0$, $\overline{p_D}^X = \overline{p_D}^s$

   $M = 1.05$

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4. 28 detector $\overline{p_i}^s = 2.0$, $\overline{p_D}^i = 0$ $\overline{p_D}^X = 0.9\, \overline{p_D}^s$

$$M = 0.93$$

5. 25 detector $\overline{p_D}^i = 1.1\, \overline{p_D}^s$, $\overline{p_D}^X = \overline{p_D}^s$

$$M = 1.26$$

The relative values for cases 2, 3, 4 compared with 1 indicate the sensitivity to inelastic cross section and to lack of duplication of the fission spectrum by the mock source. Unfortunately, $p_{28}^s$ has been measured only for mock source No. 1, and values sufficiently reliable for a precise evaluation of this effect are not yet known for the fission spectrum or for mock source No. 2. Case 5 illustrates the effect of a 10-per cent increase in $p_{25}^i$ which might arise if a sufficient number of inelastically scattered neutrons are in the region of increasing $\sigma_f(25)$.

## Experimental Arrangement

Fig. 1 shows the relative positions of the sphere and detectors. The latter were spiral fission chambers made by Bright and Hoogterp in which the fissionable material is spread over a cylindrical volume about 3/4" in diameter and 5/8" high. The 25 chamber contained 136 mg of 63-per cent material. Two 28 chambers were used at different times, one containing 360 mg and the other 203 mg of material.

The sphere was made up of three spherical shells as follows:

| Shell | O.D.<br>in. | I.D.<br>in. | Enrichment | Wt.<br>gm. |
|---|---|---|---|---|
| 1 | 1.500 | 0.314 | 73.0% | 525 |
| 2 | 1.999 | 1.503 | 72.0% | 749 |
| 3 | 2.500 | 2.040 | 70.0% | 1238 |

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The hole in the center was large enough to contain an 8-curie Po-$NaBF_4$ mock fission source (No. 2) emitting about $6 \times 10^5$ neutrons per sec.

Thirty-minute runs were taken with and without the sphere around the source, the ratio being the value of the multiplication obtained for one cycle. Once each cycle or once in two cycles, a fifteen-minute background was taken. Even with the high-efficiency spiral chambers, the counting rate was low, ranging from 9 to 25 counts per minute. This made it important to obtain as low a background as possible, whereas the necessity of working at low biases, due to the high capacity of the chambers, makes them quite susceptible to electrical distrubances.

During the first set of measurements, made in the technical area at the same time that Group R-2 was measuring the multiplication with their long counters, the electrical background was bad and very erratic. This made the results so uncertain that a second set of measurements was made outside the technical area where the background was steady and was only about 2 per cent of the counting rate.

Data: Table I gives the results of the two sets of measurements made on the 2-1/2 inch sphere. Also included are the results of a few measurements made in the technical area with a 2-inch sphere.

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TABLE I

| | 28 High Bias | 28 Low Bias | 25 High Bias | 25 Low Bias |
|---|---|---|---|---|
| (1) First measurement: | 1.09 ± .03 | 1.10 ± .03 | 1.39 ± .04 | 1.37 ± .04 |
| Average multiplication of 2-1/2 inch sphere | $M_{28}$ = 1.10 ± .03 | | $M_{25}$ = 1.38 ± .04 | |
| Multiplication of a 2-inch sphere | $M_{28}$ = 1.07 ± .05 | | $M_{25}$ = 1.28 ± .06 | |
| (2) Second measurement: Average multiplication, with error calculated from deviations of individual cycles | 1.128 ± .014 | 1.147 ± .014 | 1.335 ± .019 | 1.346 ± .015 |
| Total number of counts with source bare | 8160 | 8390 | 12,630 | 20,630 |
| Total counts with source in sphere | 9200 | 9600 | 16,870 | 27,710 |
| Multiplication from ratio of total counts, with standard deviation expected from this number of counts. | 1.127 ± .017 | 1.144 ± .017 | 1.330 ± .016 | 1.343 ± .012 |
| Average multiplication for second measurement | $M_{28}$ = 1.136 ± .017 | | $M_{25}$ = 1.338 ± .018 | |

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Due to the background troubles mentioned above, the first measurement is considered more uncertain than the second, and is weighted one third as much as the second in obtaining the averages:

$M_{28} = 1.13 \pm .02$ $\qquad$ $M_{25} = 1.35 \pm .02$

This value of $M_{25}$ should be corrected for the effect of the 28 present in the 25 chamber. This correction of 1.5 per cent raises the multiplication for a pure 25 chamber to

$M_{25} = 1.37 \pm .02$

Comparison with theory

In Table II are listed two different sets of assumptions used by Richman and Serber in calculating the multiplication, with the values of $M_{28}$ and $M_{25}$ obtained for each set.

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## TABLE II

| | First Set of Assumptions | Second Set of Assumptions |
|---|---|---|
| Source Spectrum | Richards' old fission spectrum (Handbook[1])<br>Calculated $\overline{\sigma_{28}}^{s}$ = .27 b | Spectrum as measured for mock source No.1 (mock source No. 2 used in this experiment contains some Be and probably contains some higher energy neutrons).<br>Calculated $\overline{\sigma_{28}}^{s}$ = .31 b<br>J. Williams reports a measured value of $\overline{\sigma_{28}}^{s}$ = .27 b for source No. 1 |
| Fission Spectrum | Richards' old fission spectrum. Average energy, 2.1 Mev. | Some new data of Richards' based on ~1250 tracks Average energy ~2.5 Mev.<br>Calculated $\overline{\sigma_{28}}^{x}$ ~ .39 b |
| $\sigma_f(25)$ | Hall-Koontz-Rossi data at low energy. Flat at 1.33 b for $0.6 \leq E \leq 3.0$ Mev. Dropped above 3 Mev to 0 at 7 Mev. | Same, except at high energy where it is taken to be flat at 1.33 b for $E \geq 0.6$ Mev. |
| Inelastic scattering to energies below 1 Mev | For $1.0 \leq E \leq$ Mev,<br>$\sigma_i(25)$ = 1.5 b, $\sigma_i(28) \sim 2.5$ b | For $1.0 \leq E \leq 11$ Mev.<br>$\sigma_i(25) \sim 1.8$ b, $\sigma_i(28) \sim 2.4$ b |
| Capture | $\alpha_{25} = (.16)\ (1 - E/2)$<br>$\sigma_a(28) = (.1)\ \sigma_f(25)$ | $\alpha_{25} = (.14)\ (1 - E/2)$<br>$\sigma_a(28)$ from Segre's measurements in Handbook[1], and interpolation |
| Calculated multiplication for 2" sphere | $M_{28} = 1.05$ $M_{25} = 1.24$ | $M_{28} = 1.11$ $M_{25} = 1.28$ |
| Calculated multiplication for 2-1/2" sphere | $M_{28} = 1.105$ $M_{25} = 1.35$ | $M_{28} = 1.185$ $M_{25} = 1.42$ |

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The large increase in the calculated value of $M_{28}$ for the second set of assumptions over that for the first set is due mainly to the change made in the fission spectrum. The sensitivity of a 28 detector to such a change is so great as to mask the effect of inelastic scattering as long as the relative values of $\overline{\sigma}_{28}^{s}$ and $\overline{\sigma}_{28}^{X}$ remain uncertain. It should be pointed out that these average cross sections do not tell everything, since the shape of the spectra is also of some importance. However, it is hoped that a significant comparison between theory and experiment can be made as soon as data are obtained on the average 28 cross sections for the fission spectrum and for the spectrum of mock source No. 2.

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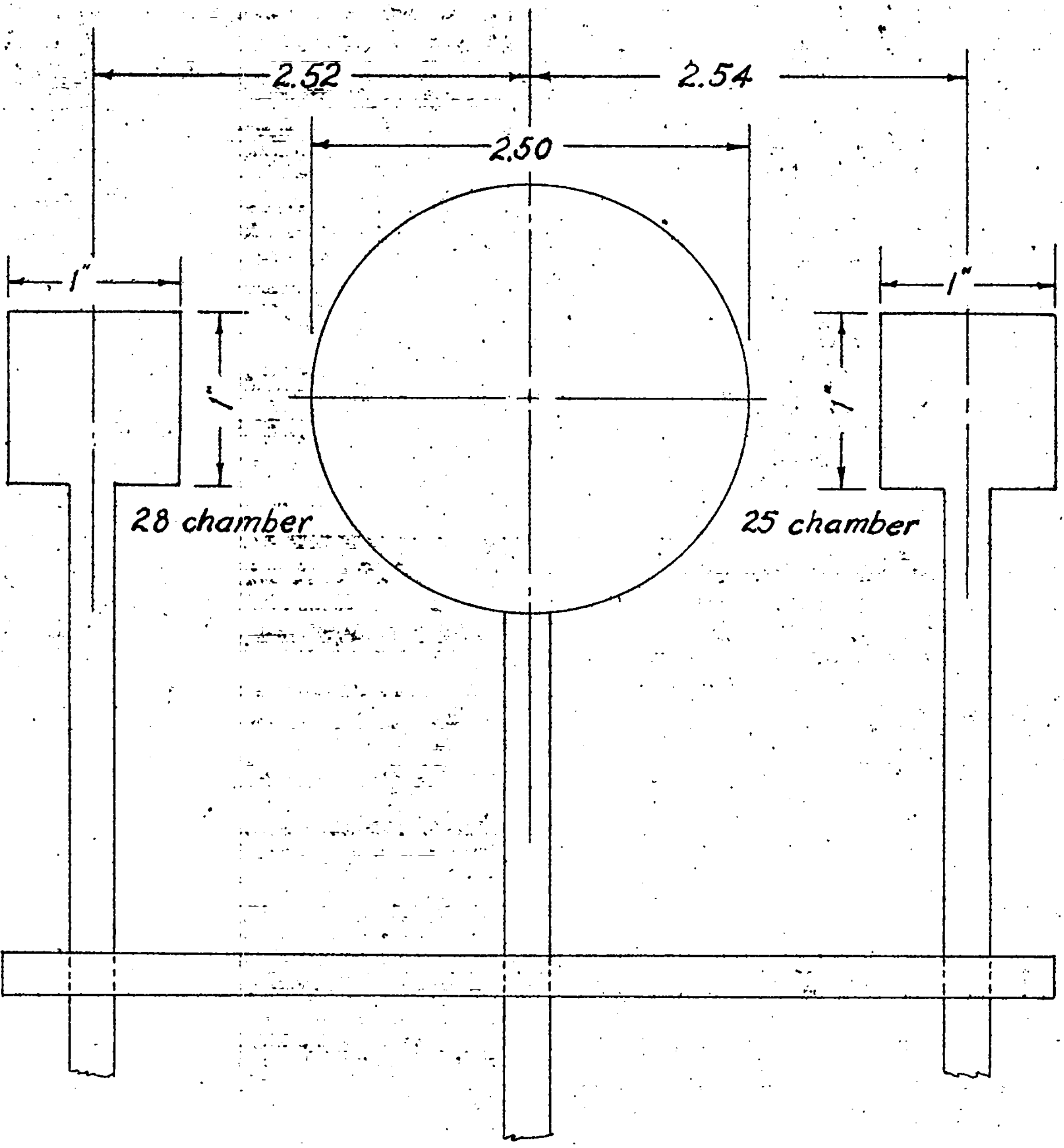
FIGURE 1



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