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FAST FISSIONS IN NATURAL URANIUM RODS

by

Samuel Untermyer
Laboratory Director's Office

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FAST FISSIONS IN NATURAL URANIUM RODS

by

S. Untermeyer

Abstract

The ratio (δ) of fast fissions to thermal fissions has been measured for rods up to 4 inches in diameter. Measurements were made with a 1/4" diameter fission ion current chamber, placed at various positions within the rods. The following data were obtained:

<u>Equivalent Diameter (inches)</u>	<u>Equivalent Radius (cm)</u>	<u>Fast Fissions Thermal Fissions</u>
0.96	1.22	0.039
1.46	1.85	0.065
1.96	2.48	0.090
2.96	3.76	0.123
3.88	5.00	0.158

These values are in good agreement with the measurements of D. L. Hill, as reported in CF-1548.

The value of the fast effect (ϵ) is approximately $1 + \frac{\delta}{2}$.

Introduction

Previous information regarding fast fissions in uranium rods stems from an experiment by D. L. Hill (CF-1548). This measurement depended upon corrections for the differences between U^{235} and U^{238} fission product decay schemes. It was felt that a more direct experimental approach would be desirable. At the same time, a knowledge of fast and thermal fission rate distributions throughout the rod would be advantageous for theoretical analysis.

Thus, measurements were made at various radii in the rod using a miniature gamma-compensated ion current chamber. Ionization currents from thick U^{238} and natural uranium foils were directly compared. A theoretical analysis indicated that a large variation in fission product energy distribution would not materially affect relative chamber efficiency for U^{238} and U^{235} fission fragments.

The study was extended to include larger and smaller rods than those measured by Hill.

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Experimental Procedure

A miniature ion chamber was developed. The chambers were contained in a 0.260 inch outer diameter stainless steel tube. This chamber consisted of three identical chambers which had identical plates as follows:

Natural uranium
Depleted uranium
Steel.

The depleted uranium used in this experiment contained 10 ppm of U^{235} . The chamber containing this material was used to measure U^{238} fission rate. The natural uranium chamber measured U^{235} fission plus U^{238} fissions in natural material, while the steel plate chamber was used to correct the other chambers for gamma background. A drawing of this ion chamber is shown in Figure 1.

Current from the chamber was measured with a sensitive meter. The circuit for this meter is shown on Figure 2. The switches on the meter were arranged to apply 300 volts to any one of the three chambers, while at the same time the other two chambers were connected to ground. The other chamber collecting leads were grounded to reduce extraneous gamma pickup.

In measurements, the chamber was placed at a fixed position at the mid-length of the rod. For surface measurements, the chamber was attached to the surface of the rod with tape. For all other measurements, the chamber was inserted into blind holes drilled axially into the rods. Holes not in use were filled with uranium plugs.

Measurements were made in the center of CP-2 (Argonne Graphite Pile). The uranium rods were irradiated in graphite or sheet metal "boats" in the T-23 removable sample stringer.

Measurements were made at two different powers, since readings of the U^{238} chamber were much lower than readings with the natural uranium chamber. By this procedure, possible errors due to non-linearity of chambers were minimized since all readings were made at approximately the same ion current. Generally, natural uranium readings were made at 5 KW, while depleted uranium was measured at 50 KW.

Supplementary readings indicated that the U^{238} fission background in the pile was negligible, and that the U^{235} fissions in the impurity of the U^{238} plate were also negligible. Similarity of the three chambers was checked by loading the chamber with three natural uranium plates. Readings were then identical within one percent.

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Results

Figures 2 through 8 show results of the measurements. These data have been normalized so that the thermal fission rate is one at the center of the rod. Furthermore, the U^{238} fission rate measured at the surface of the rod has been increased by a factor $\frac{R + 1/8 \text{ inch}}{R}$ to allow for geometric diminution of U^{238} flux from rod surface to point of measurement. No correction was applied to the U^{235} flux.

These curves have been integrated with respect to radius to obtain the ratio:

$$\delta = \frac{\int_0^R (U^{238} \text{ fission rate}) (R) dR}{\int_0^R (U^{235} \text{ fission rate in natural U}) (R) dR}$$

For purposes of comparison, rod diameters were reduced slightly to allow for the substitution of the ion chamber for uranium metal. This was accomplished by calculating the radius of the rod which would have the same mass as the actual rod with a hole for the ion chamber.

Calculated results are listed below:

Equivalent Radius (cm)	Rod Length (cm)	$\frac{\text{Fast Fissions}}{\text{Thermal Fissions}}$ δ
1.22	15.3	0.039
1.85	15.3	0.065
2.48	15.3	0.090
3.76	20.3	0.123
5.00	20.3	0.158

As reported in CF-1548, Hill measured a 1.71 cm cylinder and spheres of 3.22 and 3.96 cm radii. If we take these spheres as equivalent to cylinders of two-thirds their radius, then Hill's results could be reduced to the following table:

Equivalent Cylinder Radius (cm)	$\frac{\text{Fast Fissions}}{\text{Thermal Fissions}}$
1.71	0.064
2.15	0.085
2.64	0.096

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Discussion

As pointed out in CP-644, δ can be calculated from various nuclear constants. Specifically, in the notation of CP-644, δ is given by:

$$\delta = \frac{\nu_s P}{\frac{\sigma_T}{\sigma_f} - P' \left(\frac{\sigma_{el}}{\sigma_f} + \nu_f - 1 \right)}$$

If the following constants are used:

$$\nu_s = \nu_f = 2.5$$

$$\sigma_f = 0.3$$

$$\sigma_T = 6$$

$$\sigma_{el} = 3.6$$

Then

$$\delta = \frac{P}{8 - 5.4 P'}$$

Our experiments substantiate the usual assumption that fast fissions are uniformly distributed throughout the rod.

In our experiments, the distribution of thermal fissions can be approximately described by taking:

$$\frac{\kappa}{\Sigma T} = 2$$

With these assumptions, P and P' can be obtained using the curves in CP-644, and δ can be calculated. Results of this calculation are shown on Figure 9, and it can be seen that calculations are in general agreement with the experiment.

Unfortunately, such calculations are relatively insensitive to σ_{in} and ν_f so that reliable estimates of these constants cannot be obtained from these data. Furthermore, it seems likely that back-scattering of fast neutrons from the graphite may have contributed to the fast fissions in the case of the larger rods.

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Symbols Used in this Report

$$\delta = \frac{\text{Fast fissions}}{\text{Thermal fissions}} \text{ or approximately } \frac{\text{U}^{238} \text{ fissions}}{\text{U}^{235} \text{ fissions}}$$

$$\nu_s = \frac{\text{Neutrons emitted}}{\text{Thermal fission}}$$

$$\nu_f = \frac{\text{Neutrons emitted}}{\text{Fast fission}}$$

σ_T = Total fast cross section of uranium

σ_f = Fast fission cross section of uranium

σ_{el} = Elastic collision cross section of uranium

$$\epsilon = \frac{\text{Neutrons emitted from rod}}{\text{Neutrons emitted in thermal fission}}$$

P = Probability of a neutron emitted in thermal fission
experiencing a collision in rod

P' = Probability of a neutron emitted in fast fission
experiencing a collision in rod

κ = Reciprocal thermal diffusion length in uranium metal

Σ_T = Macroscopic total fast cross-section of uranium.

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FIG. 1
MINIATURE ION CHAMBER

RE-7-11148-A

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SWITCH CONNECTIONS

FIG. 2
ION CHAMBER AMPLIFIER

RE-7-11149-A

RE-7-11150-A

FIG. 3

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FIG. 4

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FIG. 5

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