Fission Excitation Functions

J. JUNGERMAN AND S. C. WRIGHT
Department of Physics and Radiation Laboratory, University of California, Berkeley, California

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Excitation functions of the reactions U(α, fission), Th(α, fission), U(d, fission), Th(d, fission) were measured by use of alpha-particles and deuterons of maximum energies of 37.6 and 18.8 Mev, respectively. This was done using a stacked-foil technique. Recoil fission fragments were collected on aluminum "catchers" and their beta-activities formed a relative measure of the number of fissions occurring during a bombardment. An absolute calibration is described. If no competing processes are assumed, comparison with theory results in effective nuclear radii of 11.0×10^{-13} cm for the interaction of alpha-particles with uranium and 9.9×10^{-13} cm for the interaction of deuterons with uranium.

I. INTRODUCTION

FISSION induced in thorium and uranium of ordinary isotopic composition under alpha-particle, deuteron, and proton bombardment has been reported.[1] Measurements of the excitation functions of these reactions, using the higher energies available at the Berkeley sixty-inch cyclotron, have been attempted.

II. METHOD

Thorium or uranium coated aluminum foils placed alternately with aluminum "catchers" in a stack were bombarded with alpha-particles, deuterons, or protons. Later the beta-activities of the recoil fission fragments collected in these "catchers" foils were counted. If it is assumed for a particular reaction that the distribution of fission products is independent of the energy of the bombarding particle, then the measurement of these beta-activities at a given time after bombardment gives a relative excitation function. Evidence that this assumption is reasonable is presented under results. Absolute calibration of the cross sections was made possible by the measurements of E. Segrè. He used the Chicago pile to produce a known number of fissions in one of the foil stacks. The decay curve obtained from the beta-activity of one of these "catchers" provides an absolute cross-section scale assuming that counters of identical construction used in Berkeley and Chicago had the same efficiency for fragment activities when they had the same counting rates for a uranium glass standard. It must also be assumed that the complex of the fission products formed in the slow neutron and charged particle reactions have the same decay curves for a given number of fissions. It is fully realized that this last assumption is open to serious objections because of the probability of different composition of the product complexes in the various cases.

III. EXPERIMENTAL DETAILS

The thorium or uranium coated foils were prepared by being alternately painted with a solution of the nitrate on 0.001-in. aluminum and then baked at 550°C until the oxide was formed.[2] About 130 coats produced a 1 mg/cm^2 layer. Alpha-counting determined the amount of material per foil. Counting one foil with a mask in several positions showed the fissionable material on it to be uniform within 1.5 percent.

The collimating, energy, and current measuring equipment were similar to the apparatus used by Clark and Irvine[3] and will be described elsewhere.

The beta-activities of the fragments collected on the "catchers" were measured with cylindrical Geiger counters with 0.005-in. aluminum walls. Two bombardments were made for each of the following reactions: U(α, fission), U(d, fission), Th(α, fission), Th(d, fission), and one each with alpha-particles and deuterons on "catcher" aluminum.[4] The aluminum bombardments were

[1] G. Dessauer and E. M. Hafner, Phys. Rev. **59**, 840 (1941); E. Fermi and E. Segrè, Phys. Rev. **59**, 680 (1941); D. H. T. Gant, Nature **144**, 707 (1939); I. C. Jacobsen and N. O. Lassen, Phys. Rev. **58**, 867 (1940).

[2] T. Jorgenson, M.D.D.C. No. 467.

[3] E. T. Clark and J. W. Irvine, Phys. Rev. **66**, 213 (1944).

[4] We wish to thank Professor E. Segrè for the use of an unpublished Al(d; α, p) excitation function.

used to determine the "catcher" background activity. Bombardments were of 40 minutes to 90 minutes duration.

The beta-activity of the "catcher" foils was counted at standard times after bombardment, corrected for the aluminum background, and for counter coincidence when necessary. Then all counts were reduced to one microampere hour of particles incident upon a fixed number of uranium or thorium atoms. The initial beam energy was measured before and after each bombardment. Conversion to Mev from mg/cm^2 of aluminum was made using the range ratio of air to aluminum obtained by R. R. Wilson[5] and the range in air obtained by M. S. Livingston and H. A. Bethe.[6]

IV. RESULTS

Activities of the fission products in the various "catchers" of a foil stack remain in a constant ratio during the course of time within the limits of experimental error. This constant ratio indicates that the distribution of the fission products in the complex, for a given reaction, is independent of the energy of the particle causing the fission. This circumstance supports the use of the fragment activity as an indicator of the relative number of fissions occurring at different energies in a given reaction and also makes it possible to obtain a more accurate decay curve of the fragment complex of each reaction by averaging the activities of several of the associated "catchers."

Figure 1 shows the decay curves of the fission product complexes formed in the various reactions. To obtain these curves the activity of each of twenty or more "catchers" associated with a particular reaction was measured at a given time after bombardment. The average of these activities gives a point on the corresponding decay curve. All these curves are normalized to 100 c/m at 66 hours after the end of a bombardment.

Figure 2 shows the fission excitation functions measured. The absolute cross sections for the alpha-fission reactions were obtained by matching the recoil fragment decay curves directly to the slow neutron fission fragment decay curve at 2.75, 3.0, and 5.0 days and averaging. As a slow neutron fission fragment decay curve was not available beyond 5 days, the deuteron decay curves were matched to the thorium alpha-curve of Fig. 1 at 12, 28, and 42 days and averaged. The experimental probable error due to beta-counting, uniformity of foils, integrated current measurement, etc., is estimated to be about twenty percent.

This method was found inapplicable to proton-induced fission because the maximum proton energy (9.4 Mev) available was just above the fission threshold and therefore the aluminum background was prohibitive. This background activity was instead less than five percent of the fragment activity seven days after a short alpha-particle bombardment and twelve days after a short deuteron bombardment.

V. DISCUSSION

If no competing processes are assumed, a calculation of the cross section may be made by a method given by Bethe[7] and Bethe and

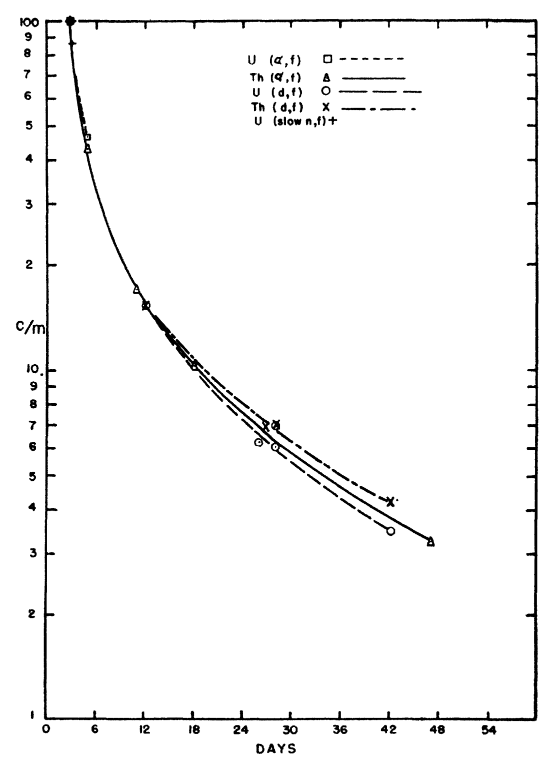

FIG. 1. Fission product decay curves.

[5] R. R. Wilson, Phys. Rev. **60**, 749 (1941).

[6] M. S. Livingston and H. A. Bethe, Rev. Mod. Phys. **9**, 261 (1937).

[7] H. A. Bethe, Rev. Mod. Phys. **9**, 177 (1937).

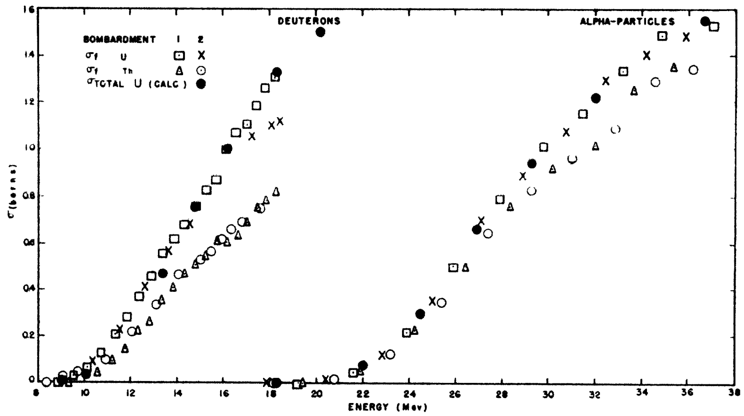

FIG. 2. Fission excitation functions.

Konopinski.[8] According to this treatment

$$\sigma_{\text{total}} = \pi\bar{\lambda}^2 \sum_l (2l+1)P_l. \qquad (1)$$

σ_{total} is the total cross section for formation of the compound nucleus. $\bar{\lambda}$ is the wave-length of the incident particle divided by 2π. P_l is the probability of penetration of the incoming wave having an angular momentum $l\hbar$ with respect to the nucleus. Using (1), an effective nuclear radius of 11.0×10^{-13} cm for the interaction of uranium and alpha-particles agrees with the U(α, fission) excitation function as shown in Fig. 2. Again, if no competing processes are assumed and Oppenheimer-Philips type interaction is neglected, the effective radius for uranium bombarded with deuterons is 9.9×10^{-13} cm in order to get agreement with the U(d, fission) excitation function. These nuclear radii correspond to $1.78\times 10^{-13}A^{1/3}$ cm and $1.60\times 10^{-13}A^{1/3}$ cm for the interaction of alpha-particles and deuterons, respectively. In each case, the theory predicts that bombardments on thorium should give higher total cross sections at a given energy than the same particle bombarding uranium. Since the opposite is observed, it appears that there is more competition with the fission process for bombardments on thorium than on uranium.

[8] H. A. Bethe and E. J. Konopinski, Phys. Rev. **54**, 130 (1938).

VI. ACKNOWLEDGMENT

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