Fission-fragment anisotropy at the $^{238}U(n, 2nf)$ threshold*

R. Abegg
Institut für Physik, Universität Basel, Basel, Switzerland
and Department of Physics, University of Wisconsin-Madison, Madison, Wisconsin 53706

R. Wagner
Institut für Physik, Universität Basel, Basel, Switzerland
(Received 2 September 1976)

The angular distributions of fragments from neutron-induced fission of ^{238}U are measured by means of glass plates in the energy range $13.5 \le E_n(\text{MeV}) \le 17.5$. The behavior of the angular anisotropy in this energy region, where (n,f), (n,nf), and $(n,2nf)$ reactions are possible, shows a clear increase at the $^{238}U(n,2nf)$ threshold.

[NUCLEAR REACTIONS, FISSION $^{238}U(n,f)$ $E_n = 13.5$ to 17.5 MeV; measured fission-fragment anisotropy $A(E_n, \theta_{\text{fragment}})$.]

Neutron-induced fission of ^{238}U in the energy region $12 \le E_n(\text{MeV}) \le 18$ can occur by the reactions (n,f), (n,nf), and $(n,2nf)$ (Ref. 1). The expectation[2-6] that the anisotropy $A = W(0°) - 1$ increases at energies near the fission thresholds[1] is well confirmed by experimental results for the (n,f) and the (n,nf) reaction.[7-12] For $E_n > 12$ MeV, where the $(n,2nf)$ reaction becomes possible, no marked increase has been found.[7,10,13-19] The aim of this experiment was the measurement of the anisotropy in the energy range $13.5 \le E_n(\text{MeV}) \le 17.5$ in steps of 100–200 keV.

Neutrons in the energy range 13.5–14.8 MeV are produced by the $^3H(d,n)^4He$ reaction by means of a solid $CuTi^3H$-2 target and 150 keV deuterons (see Fig. 1). Higher energy neutrons ($E_n = 16.13$ and 17.47 MeV) have been produced with a tritium gas target[20] and deuterons of 1.0 and 1.8 MeV, respectively. Fragments from neutron-induced fission of a ^{238}U target (99.8% ^{238}U, 0.2% ^{235}U, 2.06 mg/cm^2) have been detected by means of glass plates.[21] The fission track detectors and

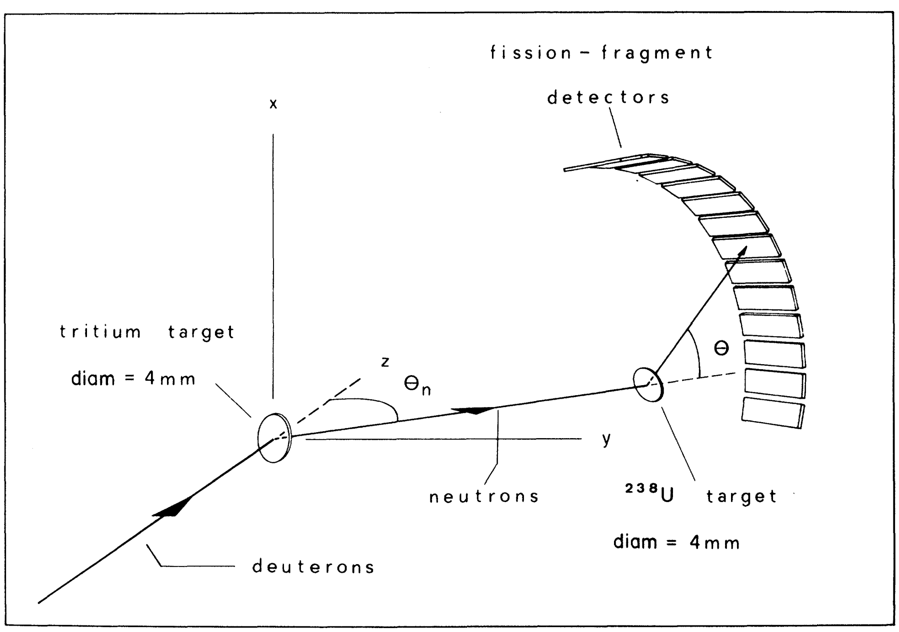

FIG. 1. Schematic drawing of the experimental arrangement.

the ^{238}U target were mounted in a scattering chamber connected to a Vacion pump. The distance of the ^{238}U target to the neutron source and the glass detectors was about 10 cm and 11.5 cm, respectively. After each irradiation the glass plates were etched for 300 s by 10% hydrofluoric acid at 20 °C. The tracks were observed by means of a travelling microscope.

The normalized experimental angular distributions $W(\theta)$ are reported in Fig. 2, where θ is the angle between the neutron axis and the direction of the fission fragments (see Fig. 1). To check if the ^{238}U target is sufficiently thin compared with the range of the fragments we measured the azimuthal angular distribution $W(\phi)$ (Fig. 3) which is assumed to be isotropic. In this way it was possible to determine the influence of the target

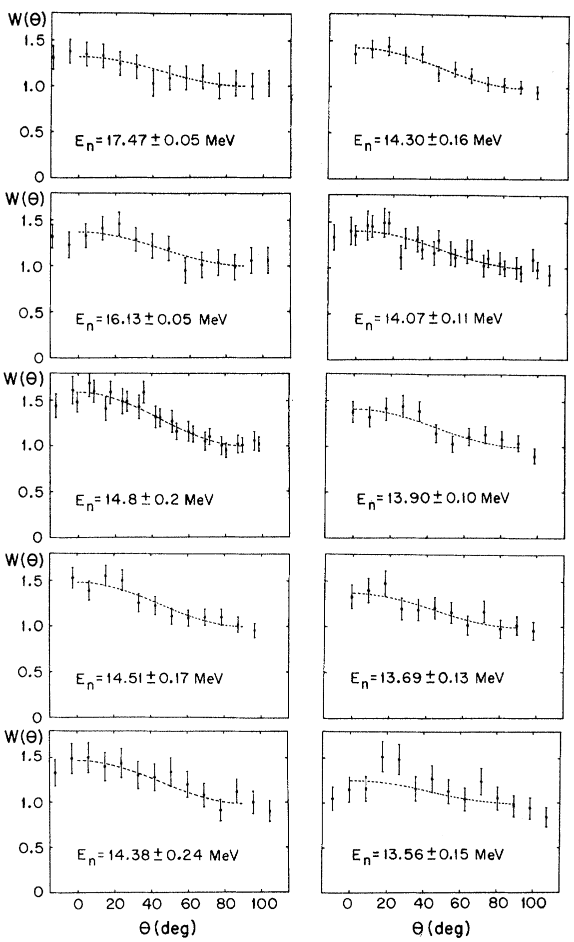

FIG. 2. Normalized fragment yield $W(\theta)$ for neutron-induced fission of ^{238}U. The dashed curves are least square fits to the experimental data using the function given in Eq. (1).

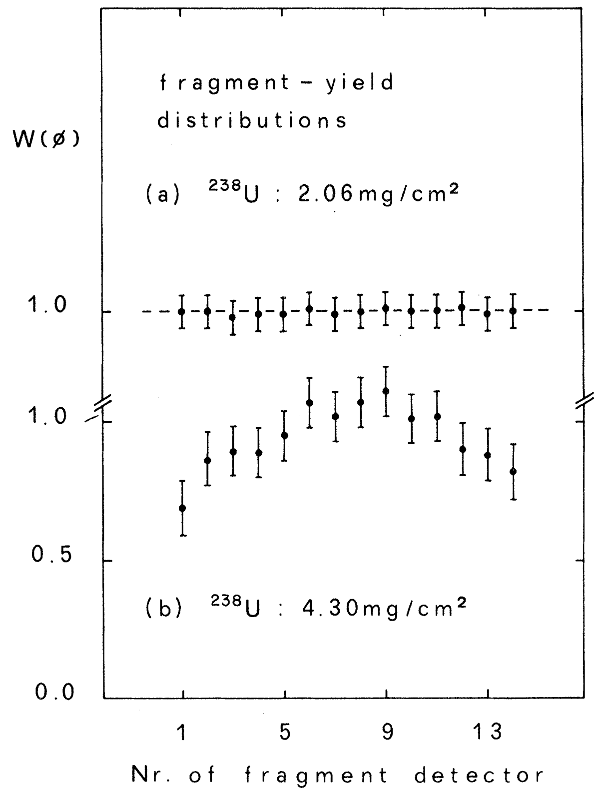

FIG. 3. The influence of the ^{238}U target thickness in the normalized yield $W(\phi)$ of each fragment detector. The actual measurements have been carried out using target(a).

thickness on the fragment yield $W(\phi)$ of each fragment detector.

The reported errors are only the statistical ones. The error of the distance of the ^{238}U target from the fragment detectors (1%) as well as the error of track counting under the microscope (1%) are small compared with the statistical ones (7%). The mean uncertainty of the emission angle $\theta(\pm 2.6°)$ is due to the uncertainty of the elevation angle of the scattering chamber ($\pm 0.5°$) and to the angular acceptance ($\pm 2.5°$) defined by the geometrical arrangement of the ^{238}U target and the counting area (0.5×1.86 cm) of the detectors. The neutron energy uncertainty ΔE_n is mainly given by the straggling ΔE_1 and the energy loss ΔE_2 of the deuterons in the tritium target. To minimize the sum of these contributions the measurements around $\theta_n = 90°$ have been made with a tritium target at 45° to the deuteron beam. At maximum ΔE_1 is 88 keV and ΔE_2 gives 195 keV.

The normalized experimental data (see Fig. 2) have been fitted with

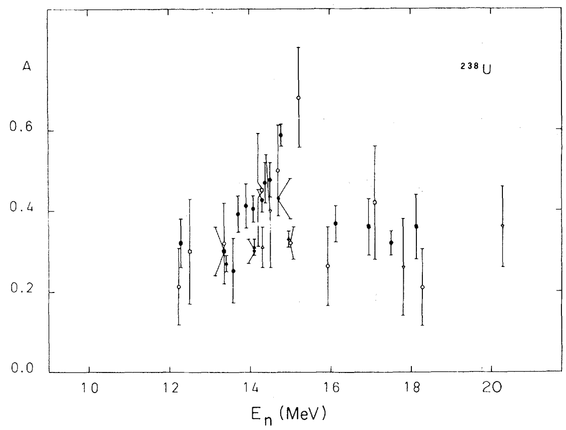

FIG. 4. Fission-fragment anisotropy A versus neutron energy E_n. (●, this work; ○, Ref. 22; ■, Ref. 19; △, Ref. 13; ▲, Ref. 10; ▽, Ref. 7; ◇, Ref. 17; ▼, Refs. 16 and 23; □, Ref. 14.)

$$W(\theta) = 1 + A\cos^2\theta \quad (1)$$

and lead to the anisotropy values A which are reported in Fig. 4 together with our previous experimental results[22] as well as with the data measured by other groups. Our measurements of the anisotropy A (Fig. 4) show the increase in the neighborhood of the fission threshold as expected from theories but not clearly shown so far by experimental results. Our attempt in explaining the angular momentum behavior of the fragments from the fissioning nucleus ^{237}U was inconclusive due to the complicated reactions leading to ^{237}U. The only conclusion which can be drawn from this attempt is that the statistical model cannot explain the behavior of the anisotropy in the vicinity of the fission threshold. Although the various parameters extracted from our BCS model calculations are reasonable they could be affected by large systematic errors and are therefore not reliable.

We wish to thank Professor Dr. E. von Gunten and P. Schmied (Eidgenössisches Institut für Reaktorforschung, Würenlingen) for the preparation of the ^{238}U targets. We are grateful to Dr. H. C. Britt (Los Alamos Scientific Laboratory, Los Alamos, New Mexico) for his interest in this work.

*This work has been supported in part by the Schweizerischer National Fond and in part by the U.S. E.R.D.A.

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