Search for an isomer shelf in ^{232}Th photofission

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Measurements of the deep-tunneling yield of the reaction ^{232}Th (γ,f) during bombardment with bremsstrahlung γ rays with maximum energy E_{max} ranging from 3.3 to 4.8 MeV are reported. The angular distribution of the photofission fragments is anisotropic near the threshold energy, $E_{max} = 5.4$–6.8 MeV. Both of the experiments, which were carried out to test for effects due to an "isomer shelf," yield negative results.

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In above-barrier photofission the reaction yield falls off exponentially with the energy, by four or five orders of magnitude in an interval of 1 MeV, and then reaches a region of a much slower decrease, the "isomer shelf," where delayed fission is more important than prompt fission. The delayed fission results from the radiative decay of the fissile nucleus in a second well, the formation of a shape isomer, and its subsequent spontaneous fission,[1,2] The reason for the difference in the rates of change of the probabilities for prompt and delayed fission as functions of the energy is that the probability for the prompt fission is determined by the penetrability of both barriers, $T_A(E)T_B(E)$, while the probability for the delayed fission is determined by the penetrability of only the inner barrier, $\sim T_A(E)$. Observation of this feature in the total yield of the (γ,f) reaction is of physical interest in itself, as one of the most sensitive methods for studying low-probability reactions resulting in the production and decay of spontaneous-fission isomers. In particular, this effect has been linked to a possible detection of shape isomerism among light actinides such as ^{232}Th. At present, it is not possible to resolve this question, of some importance to the theory, because of the poor accuracy of, and contradictions among, the existing experimental data.[2–4] In the present letter we report an attempt to fill this gap by means of some new experiments. The measurements were carried out in the bremsstrahlung beam of the microtrons of the Institute of Physical Problems and the Physicoenergetics Institute.

In one experiment we measured the yields $Y(E_{max})$ of the reaction ^{232}Th (γ,f) in the range 3.3 MeV$\leqslant E_{max} \leqslant$4.8 MeV. In our previous measurements[3] at one end of this range, $E_{max} = 4.2$–4.8 MeV, we found a significant discrepancy with Ref. 4, but we were not able to move to lower energies because of the poor statistics of fission events. In order to go beyond the work in Ref. 3, we increased the number of thorium samples used and also the duration of the exposure, with the result that the number of detected events was increased by a factor of about 20. For a more comprehensive comparison with the results of the earlier measurements[3] we bombarded ^{236}U, ^{238}U, and ^{237}Np samples in addition to ^{232}Th. The experimental apparatus and procedure were otherwise the same (the mica detectors, the experimental geometry, the intensity of the electron beam, etc.).

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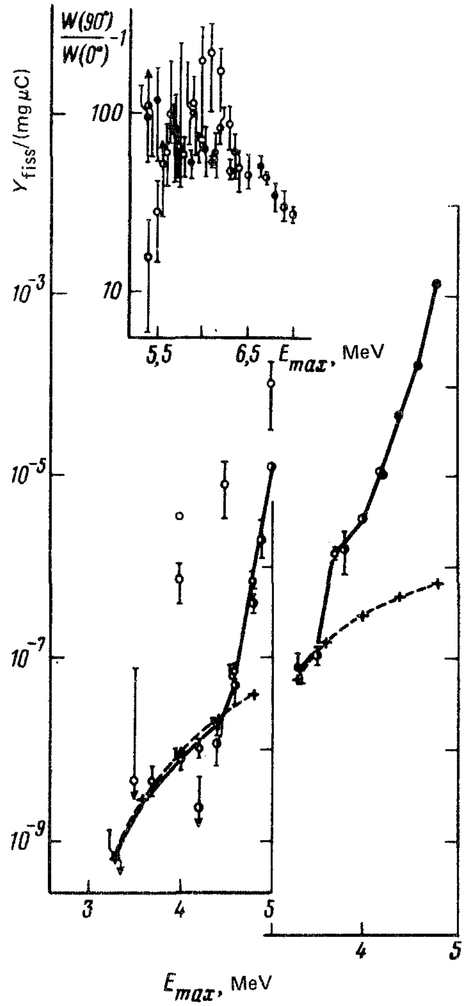

FIG. 1. Yield of the fission of ^{232}Th (at the left) and ^{236}U (at the right) induced by bremsstrahlung γ rays. ●—Present study; ◑—Ref. 30; ○—Ref. 4; dashed curve—background from neutrons from the reaction $Be(\gamma,n)$. Inset: Angular anisotropy of the fission of ^{232}Th by bremsstrahlung γ rays. ●—Present study; ◑—Ref. 10; ○—Ref. 9.

The main part of Fig. 1 compares the experimental results for ^{232}Th and ^{236}U with the data of Refs. 3 and 4. The new series of measurements, in the overlapping energy regions, agrees well with the measurements of Ref. 3 for all the nuclei, including ^{238}U and ^{237}Np (which we will not discuss here). This agreement confirms the pronounced discrepancy with Ref. 4 (see also Refs. 1 and 5). In the region of E_{max} which we had not studied previously the new results for both isotopes reveal a sharp decrease in the slope of the yields, dY/dE_{max}: At $E_{max} < 4.4$ MeV in the case of ^{232}Th and at $E_{max} < 3.5$ MeV in the case of ^{236}U. The behavior of $Y(E_{max})$ in the case of ^{232}Th is easily interpreted as an isomer shelf. At the same time, this behavior is very similar to the energy dependence of the background of fission events caused by neutrons from the photodisintegration of Be which was found in Ref. 3 and in the present measurements. Furthermore, if we assume that the decrease in the slope dY/dE_{max} in the case of ^{236}U is also caused by the background of neutrons from the reaction Be(γ,n), then we concluded that the yield of fission events caused by Be(γ,n) neutrons and the yield $Y(E_{\max})$ for ^{232}Th in the basic measurements are essentially the same, as shown in Fig. 1. Special experiments showed that the primary source of this background is beryllium in the mica of the detectors, at a concentration of a few micrograms per gram.

We can thus reject the interpretation offered in Ref. 4, according to which the isomer shelf for ^{232}Th is observed at yield values one or two orders of magnitude above the background level in our measurements. Whether the effect observed in Ref. 4 can also be attributed to neutrons from the photodisintegration of Be depends on both the Be concentration in the mica and the detector thickness (10–20 μm in our experiments). Data on the chemical composition of muscovite mica show that the Be concentration varies over an extremely broad range, 1–30 μg/g, depending on the origin of the material.

From a comparison of the experimental data on the yield $Y(E_{\max})$ we may conclude that the probability for the delayed fission of ^{232}Th is smaller by a factor of at least 10^3 than that in the cases of ^{236}U and ^{238}U. This estimate is in reasonable agreement with the theoretical results on fission barriers,[7] which predict a significant decrease in the height of the inner barrier as we go from U to Th and thus a sharp increase in the relative probability for the radiative discharge of the shape isomer into the first well.

We showed previously[3] that by making use of the isotropy of the delayed fission one can distinguish its contribution to the total yield of the photofission of even-even nuclei on the basis of the behavior of the angular anisotropy of the fragments, $W(90°)/W(0°)$, even in the energy range in which the prompt fission is predominant. Bellia *et al.*[9] have recently reported experimental observation of a decrease in the angular anisotropy of the ^{232}Th photofission as $E_{\max}$ was reduced from 6.1 to 5.4 MeV. Despite the near-threshold nature of the effect observed by them, Bellia *et al.*[9] attributed it to an isomer shelf. The important consequences that follow from these results, on the one hand, and the discrepancy between these results and our earlier data,[10] on the other, led us to repeat the measurements of the angular anisotropy of the ^{232}Th photofission near the threshold. The results of this experiment are compared with the experimental data of Refs. 9 and 10 in the inset in Fig. 1. Our data, both the new data and the data obtained previously,[10] fail to confirm the dependence observed in Ref. 9.

In summary, this search for the delayed photofission of ^{232}Th has yielded a negative result; this result corresponds to the present understanding of the fission barrier.

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