Singularities of the fissility of nuclei of medium-heavy elements

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We present experimental data on the fissility of nuclei from U to Sm, which reveal a singularity, in the region of the rare-earth elements, of the fissility as a function of the parameter Z^2/A of the target.

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It has been established experimentally that the fissility σ_f/σ_{in}, where σ_f and σ_{in} are the fission cross section and the total cross section of the inelastic interactions, decreases exponentially with decreasing parameter Z^2/A of the nuclei in the range of nuclei from U to W in accordance with Perfilov's systematics. Extrapolation of this empirical dependence into the region of lighter nuclei leads to vanishingly small values of the fissility. At the same time, a theoretical analysis based on the liquid-drop model predicts an increase of the fissility for nuclei with $A \lesssim 100$.[2]

Experimental investigations of the photofission cross sections,[3,4] using solid-state detectors, have revealed an appreciable increase of the fissility for nuclei of light elements. The fissility of Ni nuclei turned out to be comparable with the fissility of Au nuclei. Other measurements of the fissility of nuclei by α particles and nitrogen ions[5,6] did not confirm the results of[3,4] The reason for this disparity in the data is the ambiguity in the criteria used to distinguish between fission events and background tracks, and the presence of a mass threshold for the fragment registration. The latter can lead to a distortion of the measured cross sections, especially in the investigation of light nuclei, for which an increase in the widths of the mass distributions of the fragments has been suggested.[7,8]

Our present purpose was to investigate the fissility of the nuclei ^{238}U, ^{209}Bi, ^{197}Au, ^{184}W, ^{nat}Yb, ^{165}Ho, ^{159}Tb, and ^{nat}Sm using a 1-GeV proton beam and mosaics of semiconducting surface-barrier Si(Au) detectors. The use of semiconductor detectors makes it possible to introduce a larger number of selection criteria for the fission events in comparison with the solid-state detector procedure.[9] The reason is that semiconductor detectors can be used to register spectrometric and "fast" signals from paired fission fragments. In particular, our selection criteria were the following: 1) coincidence of the pulses

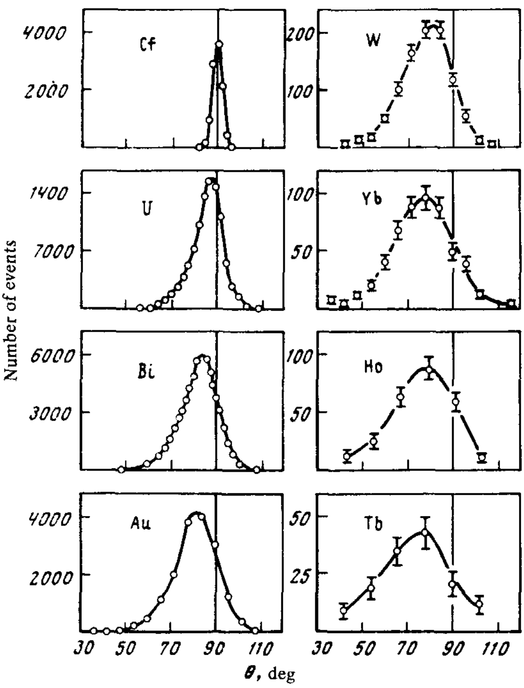

FIG. 1. Angular correlations of the fission fragments of nuclei in the proton-beam plane. The spectrum of the fragments of the spontaneous fission of ^{252}Cf nuclei provides the reference point for the angles.

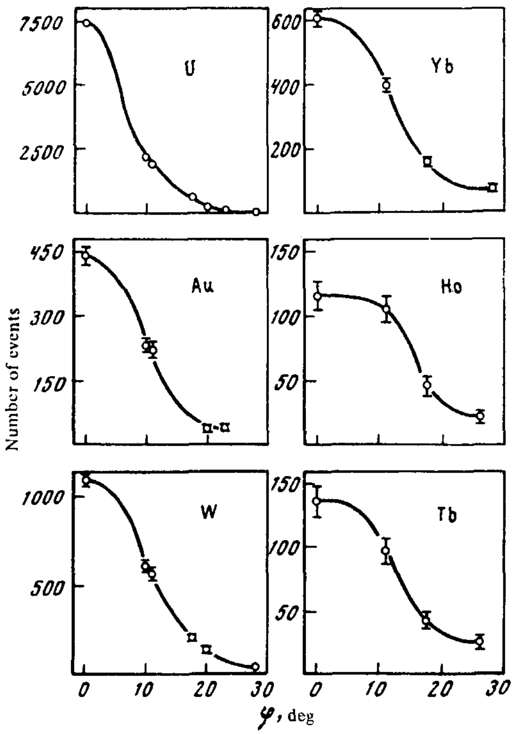

FIG. 2. Angular correlations of the fission fragments of nuclei in a plane perpendicular to the beam.

from the fragments in a given time interval; 2) minimal kinetic energy of the registered fragments; 3) registration of fragments in the mass-ratio range from 1 to 4. The foregoing fission-event selection criteria were obtained as a result of measurements of the energy and mass distributions of the fragments from the investigated targets.[10] The absence of heavy-nucleus impurities in the thin targets of medium-heavy element was verified with the aid of an activation analysis with reactor-neutron beams. An additional criterion of the purity of the targets was provided by the distributions of the fragments with respect to the total kinetic energy. To register the fragments we used 6 detectors in the horizontal plane of the beam and 3 detectors in the vertical plane. Such a geometry made it possible to measure the angular correlations of paired fragments both with respect to the angle θ in the plane of the beam, and with respect to the angle ϕ in a plane perpendicular to the proton-beam direction.

Figures 1 and 2 show the corresponding distributions. The relative nuclear fission cross sections were obtained by comparing, with suitable monitoring, the numbers of registered events obtained for the investigated target and for a ^{238}U target. The conversion to absolute values was the result of normalization to the independently-measured value of the total fission cross section of ^{238}U nuclei,[11] which turned out to be $\sigma_f = 1140 \pm 65$ mb. To determine the fissility σ_f/σ_{in}, the total cross section σ_{in} of the inelastic interactions was calculated

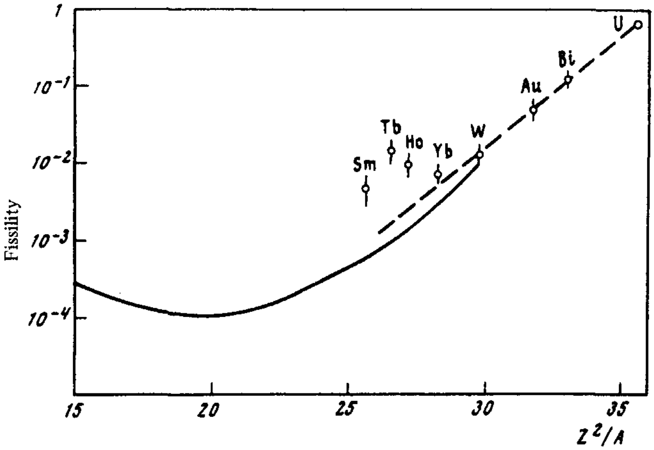

FIG. 3. Dependence of the fissility of the nuclei by protons of energy 1 GeV on the parameter Z^2/A of the target.

from the formula[1]:

$$\sigma_{in} = \pi(1.26\,A^{1/3} - 0.41)^2 \cdot 10^{-2}\ \text{b}.$$

The points in Fig. 3 are the experimental values of the measured fissilities. The dashed line represents Perfilov's systematics,[1] and the solid curve is a plot of one of the variants of the calculation of[2]. An appreciable increase of the fissility is observed for the nuclei of the rare-elements in comparison with both the systematics and the calculated dependence. This increase was first observed in[10]. Subsequently,[12] using stopped π^- mesons as the fission agent, some irregularity was observed in the behavior of the fissility in the region of the rare-earth elements; this irregularity, however, was attributed by the authors to a Th impurity in the targets.

Thus, our results point to the presence of a singularity in the dependence of the fissility on the parameter Z^2/A of targets, occurring in the region of rare-earth elements. At the same time, preliminary experimental estimates of the fissility of the nuclei Te and Ni, carried out in analogous geometry, allow us to state that no increase in fissility takes place on going to lighter nuclei: the fissilities of these nuclei turn out to be much lower than the fissility of Sm. Therefore the fissility growth observed in[3,4] calls for verification with the use of additional criteria for the selection of the fission events.

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