Search for a new Picosecond Fission Isomer in ^{234}U

P.G. Thirolf, D. Habs, R. Hertenberger, H.J. Maier, T. Morgan, O. Schaile, J. Schreiber, W. Schwerdtfeger, and J. Szerypo

Our experimental program to search for short-lived (ps) fission isomers in light actinides using the projection method as described in detail in last year's report [1] has been continued with BG24A phosphate glass track detectors (5x5 cm^2). In contrast to the CR-39 plastic detectors previously used, the detection threshold of Z≥6 for this material allows for an unambiguous identification of the fission fragments.

30 μg/cm^2 oxide targets of ^{232}Th and ^{238}U, evaporated onto 2μm thick stretched Titanium carrier foils were bombarded for typically 12-18 hours with 20-27 MeV α-particle beams (beam current about 200 nAmp). The (α,2n) reaction was used to populate the 3.8 ns fission isomer in ^{240}Pu and to search for a new isomer in ^{234}U. After the irradiation the BG24A detector plates were etched in 48% HF at 20^{o}C for 3 hours. An automated track counting system was used, consisting of a high-precision autofocus microscope, a positioning stage and a CCD-camera. The camera and the positioning stage are coupled to a computer with a pattern recognition software (SAMAICA [2]) which analyses the video images and searches for ion tracks. To each recognized track an ellipse is fitted and a number of parameters is stored such as position, semi-axes lenghts, enclosed area and central brightness. Afterwards the program moves the microscope by one image and the process is repeated until the whole track detector is scanned. For a 5 cm x 5 cm plate this typically takes 15 hours at a 50-fold optical magnification.

Fig. 1 displays the distribution of the semi minor axis length versus the central brightness of identified tracks for the reaction ^{238}U(α,2n) at 24 MeV beam energy, demonstrating the clear separation of fission fragment tracks (enclosed by the solid rectangle) from background contributions.

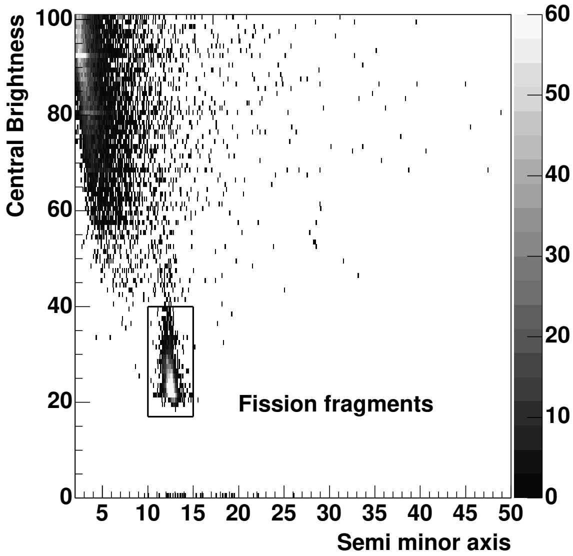

Fig. 1: Scan result from a BG24A track detector, showing the distribution of the semi minor axis length versus the central brightness of identified tracks for the reaction ^{238}U(α,2n) at 24 MeV. The area enclosed by the solid rectangle contains the fission fragment tracks.

The main experimental difficulty for these otherwise rather straightforward experiments originates from the requirement of a strictly planar target carrier foil surface together with a sharply defined shadow edge. Even smallest wrinkles at the shadow edge or deviations from surface planarity by more than 1 μm may distort the track distribution by producing artefacts that mimic the existence of short-lived isomers. Given the foil diameter of only 2.5 mm this turned out to be extremely difficult to achieve with thin, stretched metallic foils (Ni, Ti, Cu, V) in a reliable and reproducible way.

Therefore a new target technology was explored aiming at a generic solution for the planarity requirement. Si_3N_4 wafers (ca. 5 x 5 mm^2), etched in a central region of 0.7 x 0.7 mm^2 to a thickness of 300 nm, were used as an alternative to thin metallic carrier foils, thus inherently avoiding wrinkles near the shadow edge and providing a planar surface by the crystalline structure. While for the first exploratory experiment rather crudely-cut prototypes with a window size smaller than the actual beam diameter had to be used, in the future customized Si_3N_4 wafers with sharply-cut outside diameters of 5 x 5 mm^2 and a window size of 1.5 x 1.5 mm^2 will be used. In a first experiment these targets proved to be able to withstand the thermal load deposited by (α-)beam currents up to 250 nA. Nevertheless the same experimental difficulties as already observed with the metallic foil targets occurred, as shown in Fig. 2, where the azimuthal distribution of the fission fragment track density around the central target (corresponding to a set of six track detector plates) is shown.

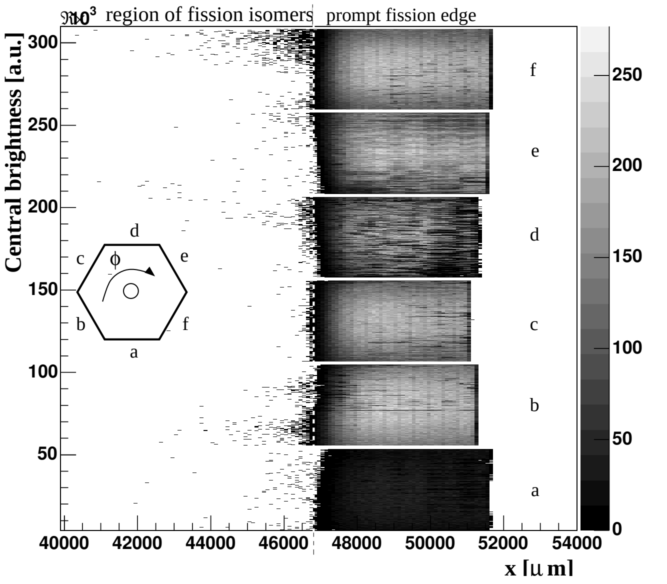

Fig. 2: Azimuthal distribution of the fission fragment track for a set of six track detector plates surrounding the central target in the reaction ^{232}Th(α,2n)^{234}U (24 MeV). Yet unexplained 'burst'-like structures beyond the steep prompt fission edge are visible.

Certain azimuthal regions exhibit deviations from the expected flat and sharply-defined prompt fission edge. 'Burst'-like structures of tracks in the region beyond the prompt shadow edge were observed which cannot be attributed to real fission isomers. Electrostatic charge-up of the track detector glass plates leading to perturbing electrical fields acting on the highly-charged fission fragments can be excluded, since the burst structures remained even after coating the glass plates with a thin (30 μg/cm^2) layer of Titanium. This yet unexplained effect is currently under investigation, potentially local thermal heating of the thin target foil by the beam current leads to a bulging of the target spot surface, thuis mimicing the occurrence of short-lived fission isomers. This will be systematically studied in a forthcoming experiment as a function of the beam current.

Nevertheless the present ^{234}U data were analyzed in potentially unperturbed azimuthal regions of the track detectors, while the ^{240}Pu were unaffected due to the much longer halflife of the 3.8 ns fission isomer. This well-known isomer served as a reference for the isomeric halflife as well as for absolute prompt and isomeric fission cross sections. Fig. 3 displays the track density along the detector plates for the ^{238}U(α,2n)^{240f}Pu reaction (upper panel, E$_\alpha$ =24 MeV) and for ^{232}Th(α,2n)^{234}U (E$_\alpha$ =23.5 MeV, bottom panel). A halflife of 140(25) ps for this new fission isomer in ^{234}U could be determinded in an unperturbed region of the track detectors from a fit to the exponential decrease of the isomeric track density identified behind the dominating prompt fission edge.

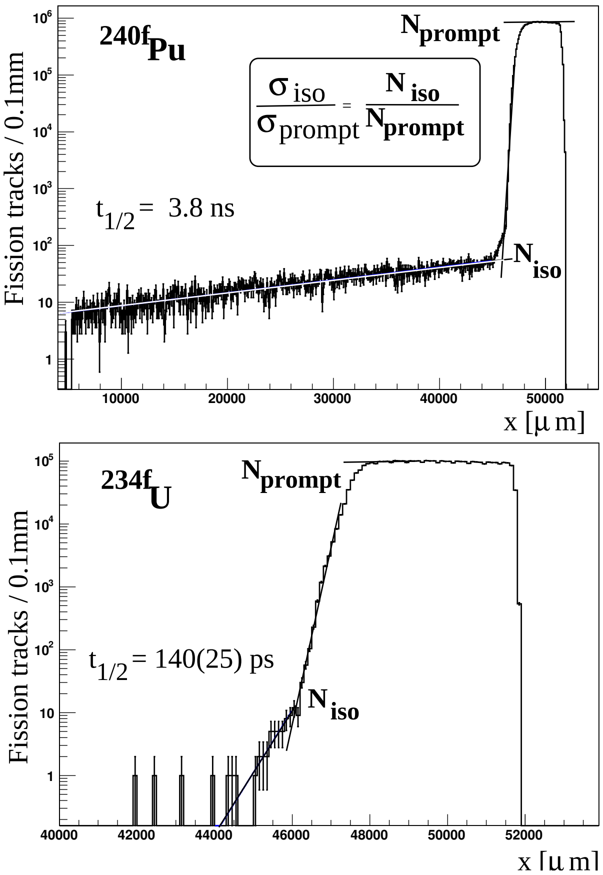

Fig. 3: Upper panel: decay curve of the 3.8 ns fission isomer in ^{240}Pu, following the reaction ^{238}U(α,2n)^{240f}Pu at E$_\alpha$ = 24 MeV as obtained with the projection method (see text). The bottom panel shows the same data for the reaction ^{232}Th(α,2n)^{234f}U at 23.5 MeV in an unperturbed region of the track detectors, reveiling a short-lived new fission isomer with t$_{1/2}$ = 140(25) ps.

In about 3 weeks of beamtime excitation functions were obtained in the energy region between 20 MeV and 27 MeV. The total integrated charge from the beam current was recorded in each case. Since all measurements were performed in direct comparison with ^{240f}Pu with a known production cross section [3], absolute isomeric and prompt fission cross section could be determined as shown in Fig. 4. The excitation function for the isomer in ^{240}Pu nicely follows the published curve (solid line) [3] with its maximum of 11μb at E$_\alpha$ =24 MeV. Scaling the reference reaction to the one leading to ^{234}U, the maximum isomeric cross section is obtained at 25 MeV with a maximum value of ca. 36 μb.

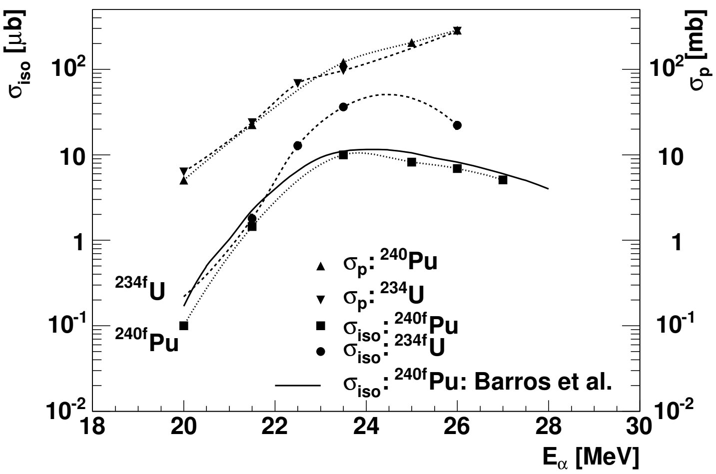

Fig. 4: Excitation functions for isomeric and prompt fission cross sections for the reactions ^{238}U(α,2n)^{240}Pu and ^{232}Th(α,2n)^{234}U, respectively. For ^{240f}Pu good agreement with the excitation function published by de Barros et al [3] can be proven.

In addition to the studies on ^{234}U presented here, a search for a fission isomer in ^{232}U was conducted using the ^{232}Th(^{3}He,3n) reaction. From the present status of the ongoing analysis no conclusive statement on the existence of a short-lived fission isomer can yet be inferred.
In the meanwhile the production of BG24A phosphate glass filters was stopped by the manufacturer (Schott/Mainz). Therefore first tests with a comparable material (UG5) as nuclear track detectors were successfully performed, proving that this material is equally suited to be used as track detector.

The identification of a picosecond fission isomer in ^{234}U would solve the the problem, that no nanosecond fission isomer could be identified so far in this nucleus, while well-known fission isomers exist in the neighbouring isotopes ^{236}U (116 ns) and ^{238}U (200 ns).

References

[1] P.G. Thirolf *et al.*, Annual report 2003, p. 22
[2] Samaica from ELBEK-Bildanalyse GmbH, D-57078 Siegen
[3] S. de Barros *et al.*, Z. Phys. **A323** (1986) 101