Optimization of the Recoil-shadow Projection Method for the Investigation of Short-lived Fission Isomers [◇]

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The recoil-shadow projection method as described in [1], using solid state nuclear track detectors, has been optimized in order to continue with the experimental program to search for short-lived (ps) fission isomers in light actinides. While the projection method provides on the one hand an extremely simple experimental approach to very short isomeric halflives, avoiding any nuclear electronics and digital data acquisition techniques during the experiment, it however imposes challenging requirements on the target properties. A well defined sharp shadow edge and an optimum target flatness are the crucial points of this method: Any distortion of the target surface either from the mounting procedure or during the experiment via thermal effects caused by the energy loss of the ion beam in the target foil will lead to misinterpretations of isomeric fission fragments. Hence, one has to pay special attention to the target holder design. In the framework of a recent diploma thesis [2] the projection method was optimized. The target carrier material (1 μm Nickel foil) spans the top part of the newly-developed foil holder, being glued to it at the conical side surfaces (see Fig. 1). Pre-stretching of the foil is achieved by pushing a plunger mounted inside the target holder in order to counteract potential distorting forces from thermal stress. The outer diameter of the rim of the plunger, defining the shadow edge, is 4 mm, the spot diameter of the fissile target material (^{232}Th with 30 μg/cm^2) is 1.3 mm. In the middle of Fig. 1 the beam trace after an irradiation of about 31 hours with a 24 MeV α-particle beam can be seen. Unavoidable wrinkles at the conical sides of the target holder, where the Ni foil has to be glued at the holder, are irrelevant for the target quality, which is solely defined by the shadow edge and the front surface flatness.

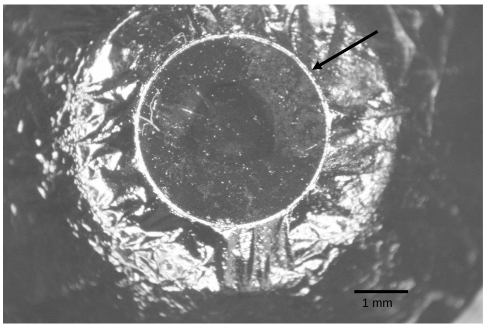

Fig. 1: Top view of the stretched 1 μm Nickel carrier foil with evaporated ^{232}Th (30 μg/cm^2, spot diameter 1.3 mm). The arrow marks the shadow edge. In the middle: beam trace after an irradiation of about 31 hours with a 24 MeV α-particle beam.

Three different targets have been tested during two beamtimes at the Garching Tandem accelerator, using the ^{232}Th(α,2n)^{234}U reaction at different beam energies between 23 and 26 MeV, searching for a potential new fission isomer in ^{234}U. Furthermore, a technique has been developed in order to monitor the target surface continuously via a capacitance measurement, similar to the technique used in plunger lifetime experiments [3]. This measurement follows the principle that the capacitance C of a plate capacitor is proportional to the reciprocal distance d between its two parallel conducting plates. The main idea used in our experimental setup is to monitor the distance between the target carrier foil and a reference electrode to identify possible thermal distortions of the target, while the ion beam is depositing energy. An electrode holder has been designed in order to center a ring electrode, pressed into an insulating plastic socket, in front of the target holder modifying the existing track detector support assembly. Since the ion beam has to pass through the setup, an annular counter electrode had to be used (inner diameter: 3 mm, outer diameter: 7 mm). The distance from the target is 0.2 mm in order to leave sufficient free space for the detection of fission fragments in the backward hemisphere of the track detectors. A pulsed signal (250 Hz exponential rise and decay, amplitude 10 V_{pp}) is permanently applied to the target holder. The resulting signal from the counter electrode is amplified and shaped with a conventional spectroscopy amplifier (ORTEC 452, shaping time 1 μs, gain 1000). During the experiment this signal is monitored continuously via an oscilloscope (for a later stage it is foreseen to digitize the signal in order to record it). Fig. 2 shows the resulting signal after its amplification.

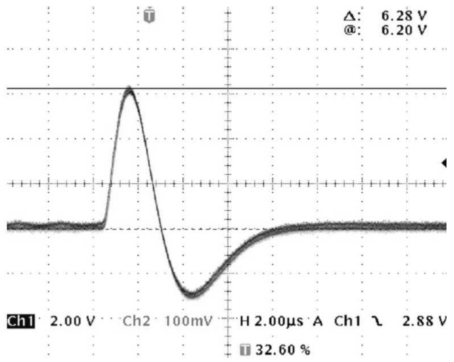

Fig. 2: Typical shape of the online monitoring capacitance signal after amplification. The signal applied to the target is an exponential pulse (rise time 50 ns, decay time 10 μs) with an amplitude of 10 V$_{pp}$ and a frequency of 250 Hz. The resulting signal at the counter electrode is amplified with a coarse gain of 1000 and a shaping time of 1μs leading to an amplitude of 6.28 V, while the beam current is about 100 nA (for an α beam with E=24 MeV).

It turned out that this method can be adapted successfully to our specific experimental conditions, while still leaving room for further improvements in order to gain a higher sensitivity. Furthermore the material properties of the used 1μm Ni foil together with the geometrical boundary conditions of the target holder do not allow to reach the required planarity of the target surface in the sub-μm regime. Therefore no detailed quantitative analysis of the

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data obtained from the experiments was performed.

However, the quantitative analysis of data obtained in an earlier experiment with targets based on thin silicon nitride membrane carrier foils (see [4] for details), shows a first promising evidence of a new fission isomer in ^{234}U, serving as a strong motivation to continue the experimental program searching for short-lived fission isomers. The tracks are analyzed with an automatized auto-focus microscope equipped with a high-precision positioning table (AXIOTRON with ZEISS optics) and a CCD camera with a special pattern recognition software [5]. Fig. 3 displays the distribution of the semi-minor axis length versus the central brightness of identified tracks for the ^{232}Th(α,2n)^{234}U reaction at 24 MeV beam energy, demonstrating the clear separation of fission fragment tracks (enclosed by the polygone).

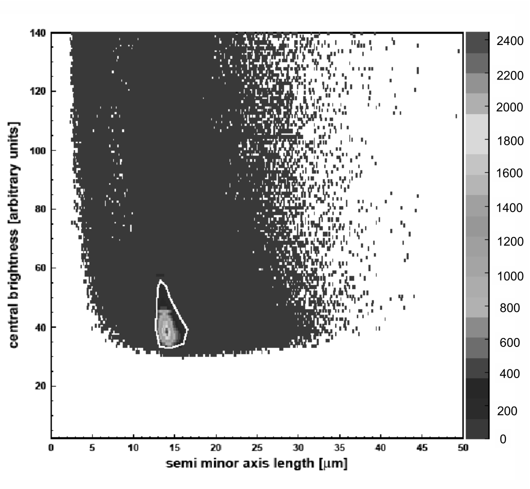

Fig. 3: Scan result from a track detector,showing the distribution of the semi-minor axis length versus the central brightness of identified tracks for the reaction ^{232}Th(α,2n) at 24 MeV. The area enclosed by the solid polygone contains the fission fragment tracks.

Fig. 4 shows the resulting fragment hit distribution around the prompt shadow edge projected onto the x axis of two track detectors. Data are shown for two of a complete set of 6 detector plates (irradiated with E_α= 24 MeV) and subdivided in each case into 3 regions along the azimuthal y axis. Thus potential anisotropies due to target distortions could be identified. As can be seen in Fig. 4, the kink in the slope of the prompt edge is visible in all areas of both track detectors (also visible in the x projections of the other 4 track detectors, not shown here) , thus supporting the experimental evidence of a new short-lived fission isomer in ^{234}U. Fig. 5 shows the summed projection in x direction of all six detector plates. The kink in the steep slope of the prompt shadow edge below the dashed line can be interpreted as evidence for a new fission isomer in ^{234}U. In order to derive the halflife of this potential new fission isomer, the slope of the decay curve has been determined by an exponential fit to the fission track distribution below 46.6 mm. A reference reaction leading to a known fission isomer was used in order to convert the slope of the track density distribution into a fission isomer halflife. In our case ^{240}Pu with a known isomeric halflife of 3.8 ns has been measured in previous experiments [6], a comparison of the decay slope obtained in these experiments with the one determined in Fig. 5 results in a lifetime of 38(5) ps for the potential new isomer in ^{234}U. Despite of the rather strong evidence for the existence of this new isomer, further experimental investigations will be required to confirm this finding.

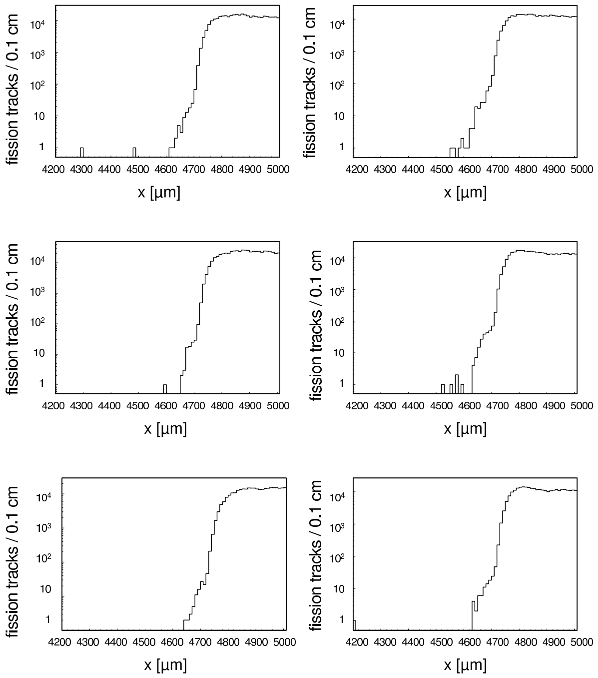

Fig. 4: Spatial distribution along the x axis of fragment tracks from two detector plates of one experimental run (irradiation time: 24 hours, beam energy 24 MeV, accumulated charge 10 mC), each subdivided into three azimuthal regions along the y axis.

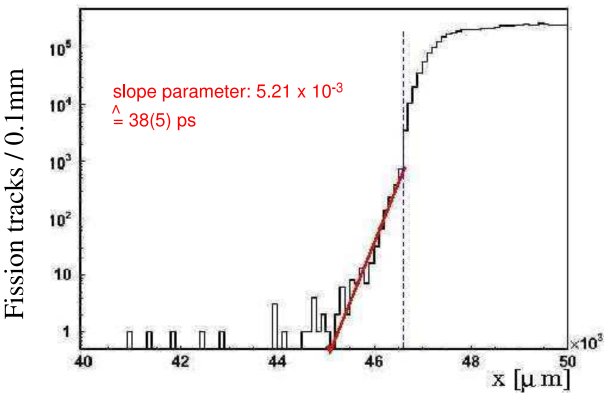

Fig. 5: Distribution of fragment hits around the prompt fission edge for the reaction ^{232}Th(α,2n) at 24 MeV. The kink in the steep slope of the prompt fission edge reveils the decay curve of a new short-lived fission isomer in ^{234}U with a halflife of 38(5) ps.

References

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