Search for a New Shape Isomer in ^{239}U

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Shape isomers in actinide nuclei can be described as states in the (superdeformed) second minimum of the potential energy surface. They may exhibit two alternative decay modes: delayed fission and the γ back decay into the normal-deformed first well (see Fig. 2). Among the island of fission isomers identified so far in the actinides, half-lives ranging from *ps* to *ms* have been observed [1]. For ^{239}U the γ back decay is expected to dominate according to the expected structure of the fission barrier.

Our search efforts for a new shape isomer in ^{239}U were motivated by evidence from γ-γ coincidence spectroscopy following ^{238}U(n,f) reactions [2]. γ rays were studied from the decay of the 721.6 eV resonance, which had been identified before as a pure class-II state. 'Additional' γ transitions were observed in excess of those transitions expected from decays in the first minimum. Thus they were assigned as transitions from excited states in the second minimum. A tentative level scheme was deduced, resulting in a surprisingly low ground state excitation energy of the shape isomer E_{II} = 1.700 or 1.850 MeV, depending on the significance of two weak transitions potentially populating the isomeric ground state. An estimate of the half-life yielded a lower limit of $t_{1/2} > 250$ ns, while estimates based on fission isomer systematics predict even much larger values of up to 1 ms with a dominant γ back decay. Thus it is tempting to reach for a direct identification of this potential new shape isomer via in-beam γ-ray spectroscopy.

Using the ^{238}U(d,p) reaction the experimental approach is based on the complete detection of prompt and delayed γ rays. Fig. 1 gives a schematical view of the detector setup. The beam (E_d = 11 MeV) passes through the 4 mm hole of an annular Si surface barrier detector (300μm thick, active area 450 mm^2). The detector is protected from the direct beam by a Ta shield covering the rear side and the central hole. The target is placed about 15 mm in front of the detector surface.

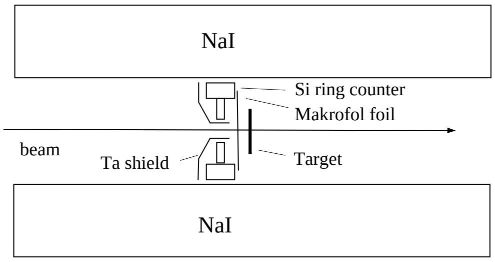

Fig. 1: Schematical view of the detector setup.

A special experimental problem is the handling of the highly-oxidizing, metallic ^{238}U target ($\sim$ 8mg/cm^2) that has to be mounted without contact to air. Proton reaction products are detected under backward angles in the Si counter with a solid angle coverage of 9%, while the detector is shielded by a 40μm Makrofol foil against (prompt) fission fragments. Prompt and delayed γ rays are detected with high efficiency in a cylindrical, sixfold radially segmented NaI detector array (length 32 cm, diameter 44 cm) surrounding the beamline (80 mm diameter, 2 mm Aluminum wall thickness) that houses the proton counter and the target. Fig. 3 shows a photograph of the experimental setup. From the detection of the protons in the Si ring counter the excitation energy E* can be deduced as the starting point of the decay process according to the relation $E^* = E_d + Q - E_p - E_R$. Here E_d and E_p denote the energy of the deuteron beam and the proton energy, respectively, while E_R is the ^{239}U recoil energy (Q: Q-value).

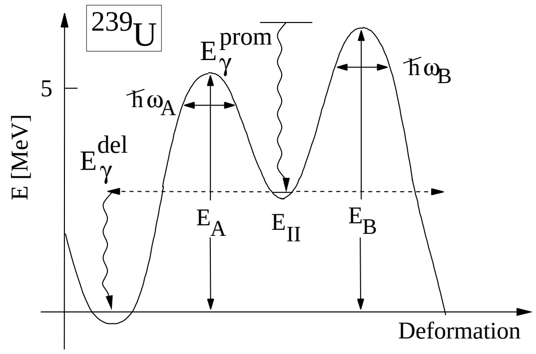

Fig. 2: De-excitation scheme following the ^{238}U(d,p) reaction. The fission barrier parameters for ^{239}U are: $E_A \approx 5.3$ MeV, $E_B \approx 6.2$ MeV, $\hbar\omega_A$ =1.0 MeV, $\hbar\omega_B$ =0.6 MeV, $E_{II} \approx$1.85 MeV.

The γ rays populating the ground state of the shape isomer will be detected as prompt sum energy $E^{sum}_{\gamma,prom}$, while the γ back decay of the shape isomer can be observed in the delayed γ sum energy $E^{sum}_{\gamma,del}$. Thus the relation $E^* = E^{sum}_{\gamma,prom} + E^{sum}_{\gamma,del}$ can be exploited to extract the isomeric ground state excitation energy E_{II}. This situation is illustrated by Fig. 2. Without having clear evidence for the expected half-life of the shape isomer, this first experiment was designed to cover the lifetime region below 2 μs. Therefore the repetition rate of the pulsed deuteron beam was set to 1.6 μs.

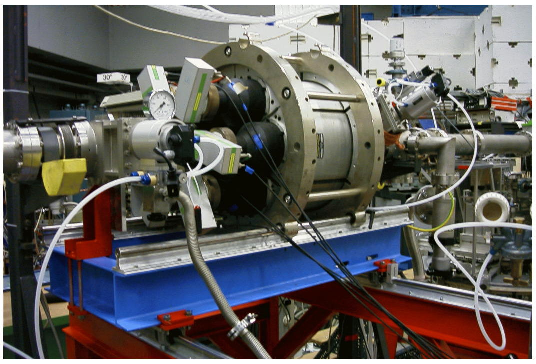

Fig. 3: Experimental setup, mainly consisting of a large cylindrical, sixfold radially segmented NaI detector array.

During the experiment the deuteron beam current was limited to about 100 pA by the counting rate of the NaI detectors of about 350 kHz, while the proton counter registered a count rate of $\sim$40 kHz. The goal of the ongoing analysis is to extract information on the isomer population cross section and the half-life of the fission isomer as well to consolidate the value of its ground state excitation energy.

References

[1] P.G. Thirolf and D. Habs, Prog. Part. Nucl.Phys. **49** (2002) 325
[2] S. Oberstedt and F. Gunsing, Nucl.Phys. **A636** (1998) 129 and references therein