PHOTOFISSION OF ^{238}U INDUCED BY A QUASI-MONOCHROMATIC, COMPTON BACKSCATTERED γ BEAM*

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The photofission cross-section of ^{238}U was measured in the sub-barrier energy region as a function of the γ energy using, for the first time, a monochromatic, high-brilliance, Compton backscattered γ beam. This prototype experiment was performed at the HIγS gamma beam facility of the Duke University at Durham (North Carolina, US) using the ^{238}U(γ, f) reaction at a beam energy varied between $E_\gamma = 4.7$–6.0 MeV and with an energy resolution of $\Delta E = 150$–200 keV ($\Delta E/E \approx 3\%$). The photofission cross-section was determined down to $E^* = 4.7$ MeV. Indications of transmission resonances have been observed at excitation energies of $E^* = 5.1$ and 5.6 MeV with moderate amplitudes.

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1. Introduction and motivation

Using highly-brilliant γ beams, which will be soon available at the MEGa-Ray facility (Livermore, United States) [1] and at ELI-NP (Bucharest, Romania) [2], a new experimental campaign on photofission studies can be envisaged to investigate extremely deformed nuclear states of the light

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actinides and their multiple-humped potential energy surface (PES) in a highly-selective way. Our experimental technique is based on the observation of transmission fission resonances in the prompt fission cross-section. Transmission resonances appear, when directly populated states in the 1st minimum energetically coincide with states in the 2nd or in the 3rd potential minimum [3, 4]. The fission decay channel thus can be expressed as a tunneling process of these gateway states through the multiple-humped fission barrier. So far, mainly light-particle induced nuclear reactions have been performed to study the transmission resonances with charged particle spectroscopy, resulting in a statistical population of the states in the (superdeformed, SD) 2nd and (hyperdeformed, HD) 3rd minimum with a probability of 10^{-4}–10^{-5}, leading to typical isomer intensities of ≈ 1/sec. Moreover, these measurements suffered from a dominating background from prompt fission. In contrast, by using the upcoming monochromatic ($\Delta E \approx 1$ keV), highly-intense γ beams providing a spectral flux of about $10^6\gamma/(\mathrm{eV\,s})$, the states in the higher-lying minima can be populated directly with considerably increased probabilities, leading to a much suppressed background and due to the strong spin-selectivity very clean spectra could be measured.

Until now, sub-barrier photofission experiments have been performed with bremsstrahlung photons, where the integrated fission yield was measured. In these experiments, a plateau ("isomeric shelf") was observed [5] in the fission cross-section, resulting from a competition between prompt and delayed photofission. The unique properties of the new γ beams will allow, for the first time, to resolve the fine structure of the isomeric shelf.

2. Photofission of ^{238}U

Photofission of ^{238}U, so far, has only been studied with intense bremsstrahlung, where sub-barrier resonances could not be resolved, and with tagged-photon beams, in which, due to the very moderate flux, a very low statistics was reported [6]. On the other hand, a previous $^{236}\mathrm{U}(p,t)$ measurement [7] showed pronounced resonance structures at $E = 5.6$–5.8 MeV and at 5.15 MeV, as well as a weaker resonance at 4.9 MeV. A whole sequence of further transmission resonances at lower energies is expected to explain the isomeric shelf [8], but such resonances have never been observed.

The aim of the present, exploratory study was to measure the $^{238}\mathrm{U}(\gamma,f)$ cross-section at deep sub-barrier energies and to search for transmission resonances. The experiment was performed at the HIγS facility (Durham, US) with its Compton backscattered γ beam, having a bandwidth of $\Delta E =$ 150–200 keV and a spectral flux of about $10^2\gamma/(\mathrm{keV\,s})$. An array of Parallel Plate Avalanche Counters (PPACs), consisting 23 electrolytically deposited $^{238}\mathrm{UO}_2$ (2 mg/cm^2) targets [9], was used to measure the photofission cross-section using the coincident detection of both fission fragments in order to suppress the α background to an extremely low level, which is needed by the particularly low counting rates (typically 0.1–1 Hz at $E_\gamma = 5$ MeV).

Figure 1 shows the experimental photofission cross-section of ^{238}U as a function of the γ energy. The result of our present experiment and the experimental data of Ref. [6] is indicated by full squares and open triangles, respectively. The continuous line is only for guiding the eye. Near the top of the barrier the two data sets are in a fair agreement. With the present experiment the cross-section data could be extended by about an order of magnitude in cross-section to the deep sub-barrier region down to $E =$ 4.7 MeV. A clear transmission resonance has been observed at $E_\gamma = 5.6$ MeV which is consistent with the observation of Ref. [6] and believed to be a SD resonance. A slight deviation from the exponential slope of the cross-section indicates a further resonance at $E_\gamma = 5.1$ MeV, however, with a very limited amplitude due to the moderate bandwidth of the γ beam. Considering a triple-humped fission barrier and its position, this resonance could be assigned to HD state(s). Further investigation is needed to support this interpretation at high-resolution γ sources, like at ELI-NP and at the MEGa-Ray facility. Using the measured cross-sections of the present experiment,

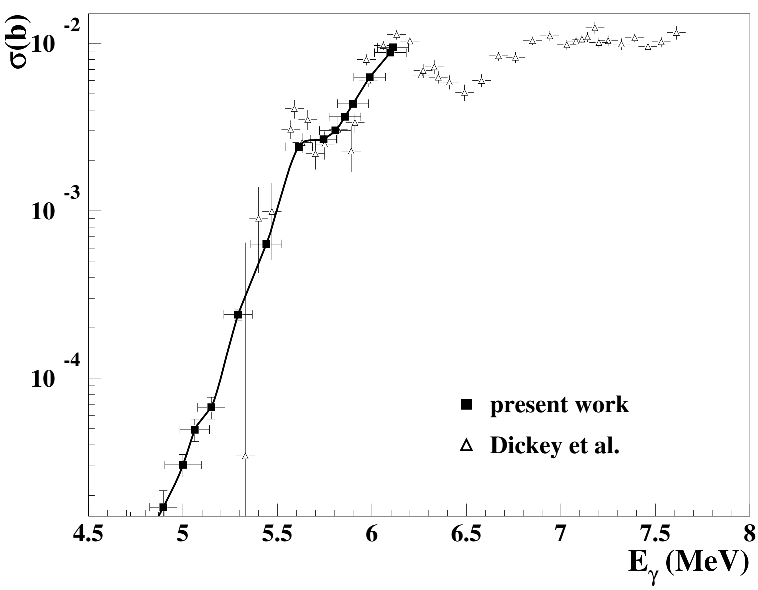

Fig. 1. The measured photofission cross-section of ^{238}U in the excitation energy range of $E^* = 4.7$–6.0 MeV. The result of our present experiment and the experimental data of Ref. [6] is indicated by full squares and open triangles, respectively. The solid line was added to guide the eye.

the triple-humped fission barrier parameters of ^{238}U can be extracted by performing nuclear reaction code calculations (EMPIRE3.1) and comparing it to the experimental data. Such calculations are in progress and will be published in a forthcoming paper.

Based on our experience of the present experiment, we currently develop a state-of-the-art position-sensitive fission detector array to exploit the unprecedented properties of the γ beams (*e.g.* very small beam spot) at Compton backscattered γ beam facilities. The new array will consist of 12 units of a gaseous proportional chamber with a size of 100 cm^2 and based on the recently developed Thick-GEM technology [10]. The detectors will be assembled with segmented anode boards, having either delay-line and charge-division readout. The targeted 2 mm position resolution together with the small (1 mm) diameter of the γ beam spot will allow for the determination of the angular distribution with a very high accuracy, thus, the spin assignments of the resonances will be possible. The testing of a prototype detector unit is currently in progress.

3. Conclusion

In summary, we measured the photofission cross-section of ^{238}U in the excitation energy region of $E = 4.7$–6.0 MeV with a monochromatic, high-brilliance, Compton backscattered γ beam. With the significantly higher intensity of the beam, when comparing to a tagged photon facility, the cross-section could be measured at deep sub-barrier energies. Clear indications of predicted resonance structures have also been observed, however, with moderate amplitudes. This work was partly supported by the DFG Cluster of Excellence 'Origin and Structure of the Universe'.

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