MEASUREMENT OF THE ^{236}U(n,f) CROSS SECTION WITH THE MICROMEGAS DETECTOR*

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The measurement of the ^{236}U(n,f) cross section was attempted with a new MicroMegas detector, based on the Microbulk technology. The incident quasi-monoenergetic neutron beams with energies in the range of 4–10 MeV were produced via the ^{2}H(d,n) reaction at the neutron beam facility of the Institute of Nuclear and Particle Physics at the NCSR "Demokritos" and first results of the analysis are presented.

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1. Introduction

The nucleus ^{236}U builds up in the equilibrium state of the Th/U fuel cycle and the corresponding fission cross section is required with 5% accuracy for the development of fast nuclear reactors and accelerator-driven systems. However the latest available evaluated libraries ENDF/B-VII.1 [1], JENDL-4.0 [2] and JEFF 3.2 [3] present differences above threshold that reach 8%, occurring from the few available discrepant data in this energy region [4].

New measurements with different techniques are, therefore, necessary in order to improve the accuracy of the evaluations and reduce the uncertainties of the new reactor design parameters. In this perspective, the ^{236}U(n,f) reaction was measured with the use of monoenergetic neutron beams at the neutron beam facility of the Institute of Nuclear and Particle Physics at the NCSR "Demokritos" in the neutron energy range of 4–10 MeV. The

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neutrons were produced via the ^{2}H(d,n) reaction and the ^{238}U(n,f) reaction was used as reference for the cross section calculation, since it is considered as a standard in this energy range and has a similar shape to the ^{236}U(n,f) one.

2. Details of the experiment

The experiment was performed at the 5.5 MV HV TN-11 Tandem accelerator laboratory at the NCSR "Demokritos". The quasi-monoenergetic neutron beams were produced via the ^{2}H$(d,n)^{3}$He reaction, by the bombardment of a deuterium gas target with deuteron beams of the appropriate energy from 2 to 7 MeV. The deuterium gas pressure was kept nearly constant at 1300 mbar and the produced neutron flux was about 10^{6} n/s/cm^{2}. The detection system consisted of a stack of ionisation gas cells based on the Microbulk technology [5] for the detection of the fission fragments (FF), each one containing one actinide target which served as the detector drift electrode. Each actinide target was covered by a 0.5 mm thick aluminium mask with a hole of 4 cm diameter. In total, 5 actinide targets were used and the target and Microbulk assembly are shown in Fig. 1. Two ^{236}U targets were put back-to-back and two ^{238}U targets before and after them for monitoring the neutron fluence. Finally, a ^{235}U target was used, as a very sensitive tool to low-energy neutron background, due to the high fission cross section at low energies. The assembly was put inside an aluminium chamber with thin kapton windows and filled with a mixture of 80% Ar and 20% CO_2 at approximately atmospheric pressure. More details about the detection system can be found in [6].

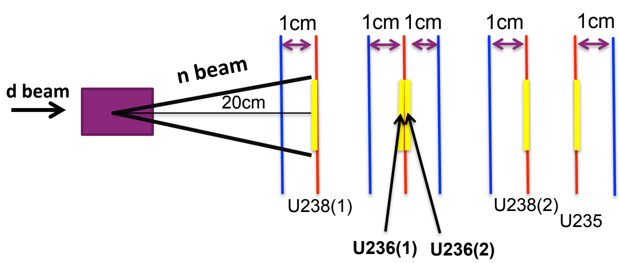

Fig. 1. (Color online) Schematic views of the gas cell, the target (light gray/yellow) and detector (dark gray/blue) assembly.

The data acquisition system consisted of low gain charge sensitive preamplifiers, energy amplifiers and ADCs, and the spectra obtained showed good discrimination of the heavy and light mass peaks of the fission fragments, and clean alpha–FF separation. A typical spectrum obtained from one of the ^{236}U targets is shown in Fig. 2.

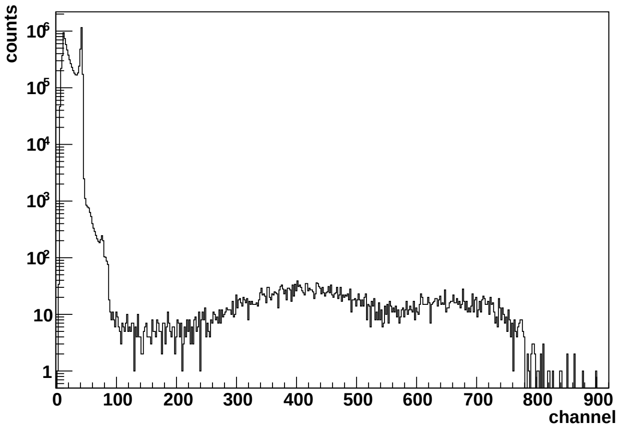

Fig. 2. A typical spectrum obtained for one of the ^{236}U targets at $E_n = 10$ MeV.

3. Details of the analysis

3.1. Cross section calculation

The cross section was calculated with use of the formula (1)

$$\sigma = \frac{CN'\Phi'\epsilon'}{C'N\Phi\epsilon}\sigma', \tag{1}$$

where C — the total fission fragment yield recorded in the MicroMegas detector for each target, Φ — the neutron fluence that enters the corresponding target, N — the total number of atoms of the corresponding target (estimated with α-spectroscopy), ϵ — the efficiency of each target assembly and σ' — the cross section of ^{238}U(n,f) used as reference. The primed values correspond to the reference target. Monte Carlo simulations with FLUKA [7] were performed in order to study the energy deposition of the fission fragments in the active area of the detector and accurately estimate the detection efficiency. The implementation of the geometry in the simulations was checked via the reproduction of the experimental spectra of α particles emitted from the actinide targets, and was very satisfactory, as can be seen in Fig. 3. The GEF code [8] was used for the realistic generation of the fission fragments (atomic and mass numbers, energies) from the different isotopes and for the different incident neutron energies. The FFs generated with GEF were used as source particles in the FLUKA simulations, distributed homogeneously in the volume of the targets, and their energy deposition was scored in the active gas of the detector. A simulated energy deposition histogram of FFs emitted from a ^{236}U target can be found in Fig. 3.

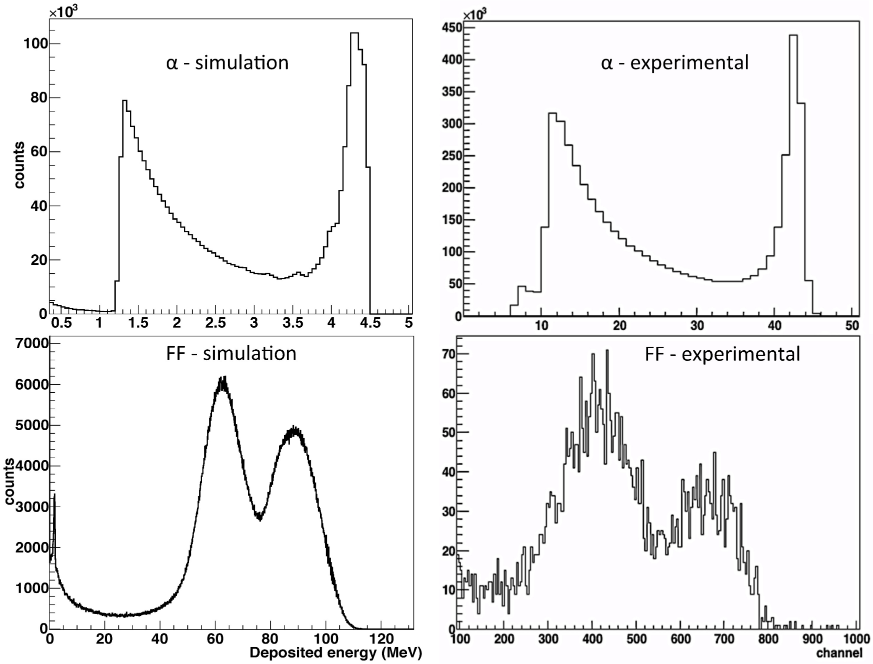

Fig. 3. Comparison of the simulated energy deposition histograms with the corresponding experimental spectra for α particles (upper figures) and FFs (lower figures).

3.2. Neutron beam characterisation

The neutron fluence was estimated with the use of the standard $^{238}\mathrm{U}(n,f)$ reaction. The neutron beam monochromaticity is affected by various factors, as: (1) the $^{2}\mathrm{H}(d,n)$ kinematics, which predict an angular dependence on the energy and fluence of the produced neutrons, which start decreasing smoothly for neutron emission angles $\geq 5^{\circ}$, (2) the deuteron beam energy and lateral straggling in the gas cell entrance foil and the deuteron gas, (3) the deuteron breakup ($^{2}\mathrm{H}(d,np)$) reaction which creates low-energy neutrons for $E_d \geq 4.45$ MeV, (4) parasitic deuteron-induced reactions with structural materials of the gas cell and the beam line producing neutrons of different energies than the main neutron beam, and (5) neutron scattering in the detector chamber. Due to the absence of a time-of-flight technique for the estimation of the neutron energies and the fact that fission has low thresholds, so parasitic fission reactions are induced in the targets by these neutrons, all these factors have to be carefully taken into account.

The study of the neutron beam energy and fluence produced from the bombardment of the gas cell by the deuteron beam was performed with the NeuSDesc code [9] developed at IRMM. The code takes into account the energy loss and the energy and lateral straggling of the deuteron beam in the gas cell materials using the SRIM-2008 program, the $^{2}\mathrm{H}(d,n)^{3}\mathrm{He}$ differential cross section and kinematics and the deuteron breakup as a competing reaction. An example of the neutron beam energy spectrum calculated with the NeuSDesc code for $E_n = 9.5$ MeV ($E_d = 6.65$ MeV) is shown in Fig. 4. The broadening of the main peak is mainly attributed to the energy straggling of the incident deuteron beam, while lower energy neutrons appear from the deuteron breakup reaction and the ratio of these parasitic neutrons to the main neutron beam increases with the incident deuteron energy as can be seen in Fig. 4.

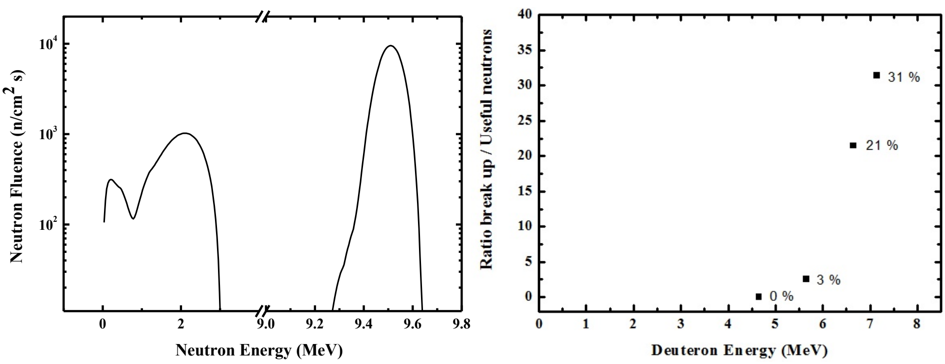

Fig. 4. (Left) The calculated neutron energy spectrum for 9.5 MeV. (Right) The ratio of parasitic neutrons produced from the breakup reaction to the neutrons produced from the $^{2}\mathrm{H}(d,n)$ reaction.

NeuSDesc offers the possibility to provide the neutron beam results in the form of a source file for the Monte Carlo simulation code MCNP5 [10, 11]. In the present work, MCNP5 simulations were performed based on the NeuSDesc results, in order to estimate the neutron energy spectrum and fluence at the targets, implementing the gas cell, the target assembly and the detector chamber. With these simulations, the scattering of the neutron beam at the exit widow of the gas cell (Pt foil of 1 mm) and at the detection setup was taken into account.

Finally, in order to correct for neutrons produced by parasitic deuteron-induced reactions with structural materials of the gas cell and the beam line after each run, the gas cell was emptied from the deuterium gas and bombarded with the deuteron beam under the same conditions. The fission events recorded with the empty gas cell were attributed to neutrons created from parasitic (d,n) reactions and subtracted from the events of the corresponding run, after normalisation to the same integrated incident deuteron charge.

4. First results and discussion

Preliminary cross section results are shown in Fig. 5.

The analysis is ongoing, mainly in the part of the neutron fluence and the resulting fission reaction rate for each target, based on the combined NeuSDesc and MCNP results and the corresponding fission cross section. However, the first results are very promising towards a reliable calculation of the fission cross section in neutron energies above 7 MeV, with neutron beams produced with the ^{2}H(d,n) reaction. At these energies, a strong contribution of low-energy parasitic neutrons is present, mainly due to the deuteron breakup, and induces parasitic fission reactions, making the extraction of reliable cross sections very difficult without of a time-of-flight technique.

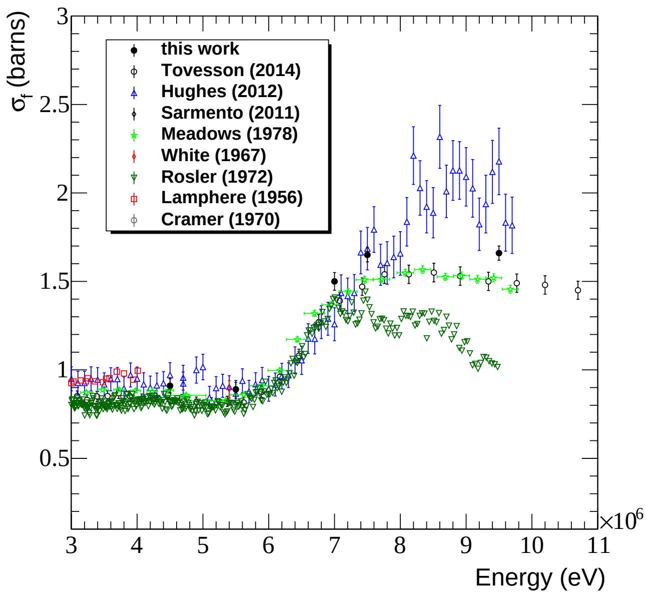

Fig. 5. (Color online) Preliminary results of the ^{236}U(n,f) from this work along with experimental data found in [4]. The statistical uncertainties are plotted.

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