

Neutron capture and fission reactions on ^{235}U : cross sections, α -ratios and prompt γ -ray emission from fission

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Abstract. According to the international benchmarks, and as it is mentioned in the NEA High Priority Request List, the $^{235}\text{U}(n,\gamma)$ cross section is of utmost importance for the operation and design of current and advanced nuclear reactors. The required accuracy in this energy region (100 eV to 2.25 keV) ranges between 5% and 7%, to be compared with the present differences of 20% between the α -ratios in different evaluations. At n_TOF we have measured this cross section during the summer of 2012 using a fission tagging capture set-up. This new set-up has been tested successfully in 2010 and combines the n_TOF 4π Total Absorption Calorimeter with a series of MicroMegs fission detectors. The experiment has provided as well very valuable information on the distribution of energies and multiplicities of the γ -rays emitted prompt after capture and fission reactions. The very fresh data from this experiment will be presented for the first time, and their quality and expected results will be discussed in detail

1 Introduction and Motivation

The measurement of capture reactions on fissile isotopes, of importance in the field of current and future nuclear reactors [1,2], presents serious difficulties and therefore the associated capture cross sections are not well known for most of the fissile actinides. In particular, the results from international benchmarks sponsored by the Nuclear Energy Agency (NEA) indicate that the case of ^{235}U is of special interest [3].

The comparison of the capture cross section of ^{235}U in the evaluated data libraries [4] and the available experiments shows that there are still sizable differences among them. This is illustrated for the experimental data found in EXFOR in Figure 1, where large differences (beyond 20%) between data all over the neutron energy range of interest are observed.

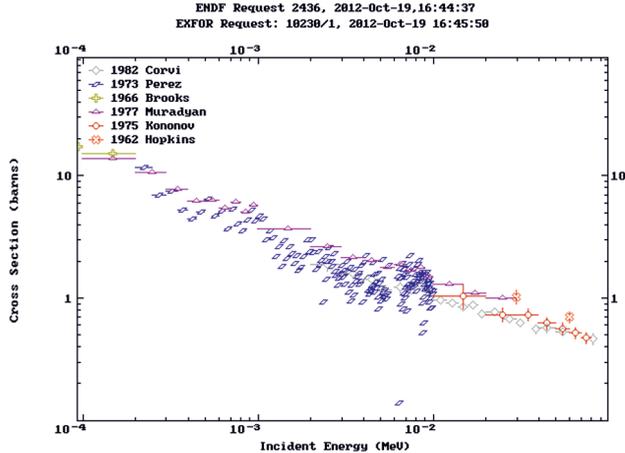


Fig. 1. Experimental values of the capture cross section of ^{235}U between 10 eV and 100 keV.

Furthermore, the comparison of the calculated and experimental results from the analysis of integral experiments show that the capture cross section of ^{235}U (in particular the region below 2.2.5 keV) plays a major role in the calculation of essential quantities such as the criticality of fast systems [5].

For these reasons, we have measured the capture and fission cross sections of ^{235}U at the CERN neutron time-of-flight n_TOF facility [5], combining the Total Absorption Calorimeter with a fission tagging device. This experiment will also provide data on prompt γ -ray emission following fission reactions (see Ref. [7] for full details), but this topic will be covered in a future publication.

2 Experimental set-up

The set-up consists in the combination of two types of detectors which have been used successfully in previous measurements at n_TOF: the Total Absorption Calorimeter (TAC) [8] and the MicroMegas (MGAS) [9]. These two detection systems were combined for the first time in 2010 in a test experiment which results have been recently published [10].

The TAC is a segmented 4π array made of 40 BaF_2 crystals forming a spherical shell of 20 cm and 50 cm inner and outer diameters, respectively. The combination of its segmentation, high geometric and intrinsic efficiencies and energy resolution make the TAC an excellent device for measuring capture reactions of small mass and radioactive samples. The MGAS, based in the microbulk principle, is a particular type of gas detector with its volume divided in two parts by a thin micromesh. As the ionization takes place in the first part, the produced electrons are multiplied and amplified by an avalanche process in the second part. In our case the electrons are generated by ionization of the gas produced by fission fragments from the ^{235}U samples. Several photographs of the MGAS assembly with 10 ^{235}U samples are displayed in Fig. 2.

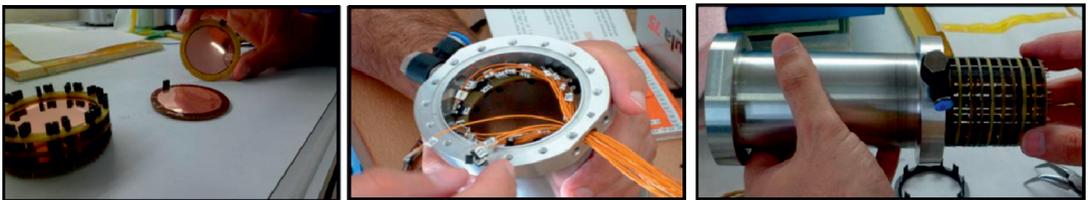


Fig. 2. Photographs of the stack of MGAS detectors and the gas chamber that is inserted in the center of the TAC.

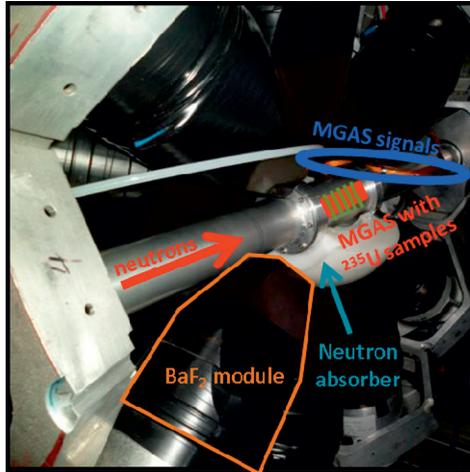


Fig. 3. Photograph of the experimental set-up showing the neutron beam line, the gas chamber loaded with the assemblies of ^{235}U samples and MGAS detectors, the neutron absorber (only half is shown) and the BaF_2 modules of the TAC.

A total of ten ^{235}U samples (42 mm in diameter and $300\ \mu\text{g}/\text{cm}^2$ in thickness, prepared at JRC-IRMM) have been placed in the inner hole of the TAC, as it is shown in Figure 3. Two configurations have been employed. In the first one only two samples are mounted inside MGAS detectors, while in the second one all samples were mounted in MGAS detectors. The advantage of the former is that all samples are placed exactly in the center of the TAC (i.e. similar detection efficiency) and the background from neutron-induced reactions in the MGAS detectors (mainly made of Copper and Kapton) is minimized. The advantage of the latter is that tagging capabilities are provided for all the samples simultaneously.

3 Measured E_{sum} and E_n distributions of events

The γ -rays signals detected in the individual TAC modules are transformed into detected events after combining them using a coincidence window of 20 ns. The combined analysis of the TAC events with the signals detected in the MGAS detectors provides information on which of the TAC events are associated to a fission reaction in any of the ^{235}U samples. In this way, and taking into account that the efficiency of the MGAS detector is $\sim 90\%$ [10], one can separate the TAC events into fission, capture and background, as it is illustrated in Figure 3.

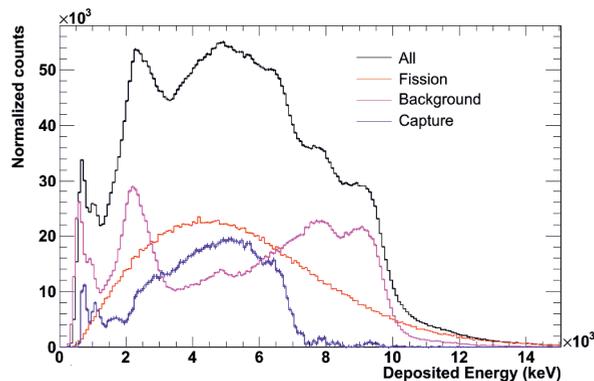


Fig. 3. Distributions of measured deposited energy in the TAC for different contributions.

When events detected as function of time-of-flight are transformed into the corresponding neutron energies one is able to observe the resonances of the neutron-induced capture and fission cross section of ^{235}U . These are displayed in the two panel of Figure 4, where the fission and capture contribution are separated thank to the fission tagging capabilities of the experimental set-up.

The good resolution of the n_TOF facility has allowed observing resonances all the way up to the beginning of the unresolved resonance region (URR) at 2.25 keV. Furthermore, there are also data available beyond this energy limit and up to 10 keV; however, this energy interval is largely dominated by background and it is not known yet the accuracy that will be reachable.

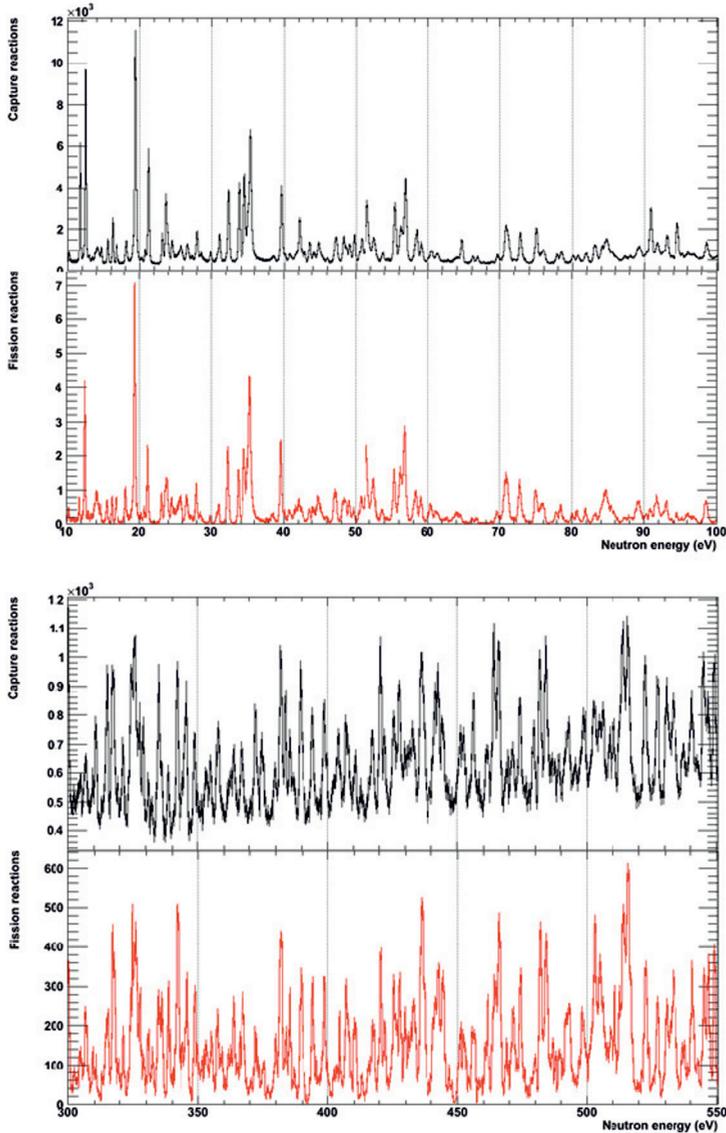


Fig. 4. Neutron energy distribution of events measured in the TAC corresponding to capture (black) and fission (red) in two different neutron energy ranges: 10-100 eV and 300-550 eV.

4 Outlook and Perspectives

The data taken in the experiment presented herein has finished on October 15th 2012. Now the detailed analysis shall begin, and this will certainly be very challenging. A combination of the measured data and a full simulation of the experimental set-up will serve to determine the different detection efficiencies of the two detectors for the two reactions under study: capture and fission. The background will be then determined from the measurements performed without samples inside the TAC in the two mentioned configurations: two and ten MGAS detectors measuring simultaneously. The data analysis shall provide a set of capture and fission cross section data between 0.3 eV and 10 keV as well as a direct measure of the α -ratio (see Fig. 1) for both individual resonances and averaged energy intervals. The latter will be then compared to previous measurements that did not reach the high resolution achieved at n_TOF.

Last, it shall be mentioned here that a new fission tagging set-up, this time combined C₆D₆ liquid scintillators, will be used in the new neutron beam line of n_TOF EAR-2 (20 m flight path with a corresponding increase of 25 in neutron flux) that shall become operative by summer 2014. In this new neutron beam line we will measure the capture cross sections of other fissile isotopes of interest for advanced nuclear reactors such as ²³³U, ²³⁹Pu, ²⁴¹Pu and ²⁴⁵Cm.

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