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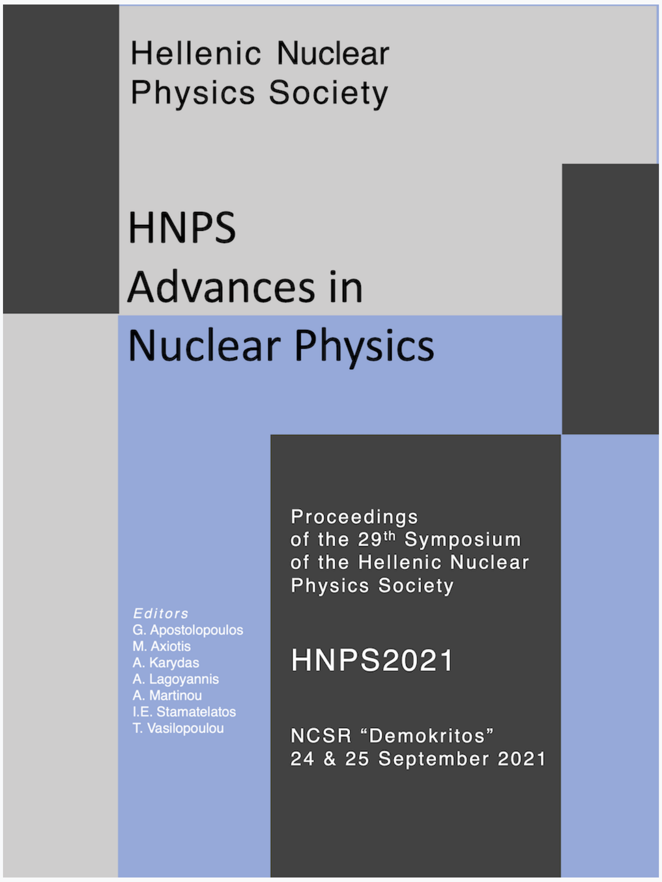

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Measurement of the ^{230}Th(n,f) cross-section at the CERN n_TOF facility

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Abstract The study of neutron induced reactions on actinides is of great importance both for the design of advanced nuclear systems and for fundamental research. The design of Generation IV reactors, Accelerator Driven Systems (ADS), as well as the study of alternative fuel cycles, such as the thorium fuel cycle, highlight the need for accurate cross-section data. In addition, fission cross-section data can assist in the study of the fission process and the fission barrier.

Specifically, ^{230}Th is produced from the alpha decay of ^{234}U in the thorium fuel cycle, thus its fission cross-section is required with high accuracy. In addition, in the fission cross-section of thorium isotopes narrow resonances and fine structures are present, which cannot be explained efficiently by the double-humped fission barrier. For ^{230}Th, previous measurements have shown a resonance at ~720 keV with additional fine structures. However, few discrepant experimental data exist in literature covering the energy region from the fission threshold up to 25 MeV.

For these reasons, the fission cross-section of ^{230}Th was measured at the CERN n_TOF facility, with the time-of-flight technique in order to cover the energy range of the previous measurements and extend the measurements to higher energies. The measurements were performed with Micromegas detectors, while the high purity ^{230}Th were produced at JRC-Geel in Belgium.

The analysis procedure for the cross-section results are on the final stages. In this work, a study on the angular distributions of ^{230}Th, performed for the first time with this kind of Micromegas detectors is presented.

Keywords fission, Micromegas, angular distributions

INTRODUCTION

The study of neutron induced reactions on actinides play an important role in the development of advanced nuclear systems, such as Accelerator-Driven Systems (ADS) and alternative fuel cycles, such as the thorium cycle. In addition, the observables related to the fission process are of great importance for the study of the fission mechanism. The neutron induced fission cross-section, combined with experimental data on angular distributions of the fission fragments, competing reactions, the mass distribution of the fission fragments, etc. can greatly assist to constrain and evolve the theoretical models.

Specifically, ^{230}Th is produced from the α-decay of ^{234}U in the thorium fuel cycle. In addition, its neutron induced fission cross-section is almost two times higher that ^{232}Th, contributing this way to the neutron balance of the cycle and assisting in the breeding of the fissile ^{233}U. Moreover, previous measurements of the ^{230}Th(n,f) have shown a large resonance in the fission threshold with additional fine structures. Narrow resonances and fine structures have been observed in the studies of various thorium nuclei, known as the "thorium

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anomaly". These structures have not yet been explained theoretically.

Up to now, few experimental data exist in literature for the neutron induced fission cross-section of ^{230}Th [1], which are presented in Fig. 1. As seen in the figure, the existing experimental datasets cover the energy range from the fission threshold up to 25 MeV, having discrepancies among them and high uncertainty values.

For this reason, the neutron induced fission cross-section measurements were planned and performed at the neutron time-of-flight facility n_TOF at CERN, with the scope to perform a high resolution and high accuracy measurement to resolve the existing discrepancies and extend the range of the existing data to higher energies. The analysis procedure to extract the final cross-section results is in its final stages. In this work, a very interesting aspect of the analysis procedure will be presented, concerning a qualitative study on the angular distributions of the ^{230}Th fission fragments, performed for the first time with this kind of Micromegas detectors.

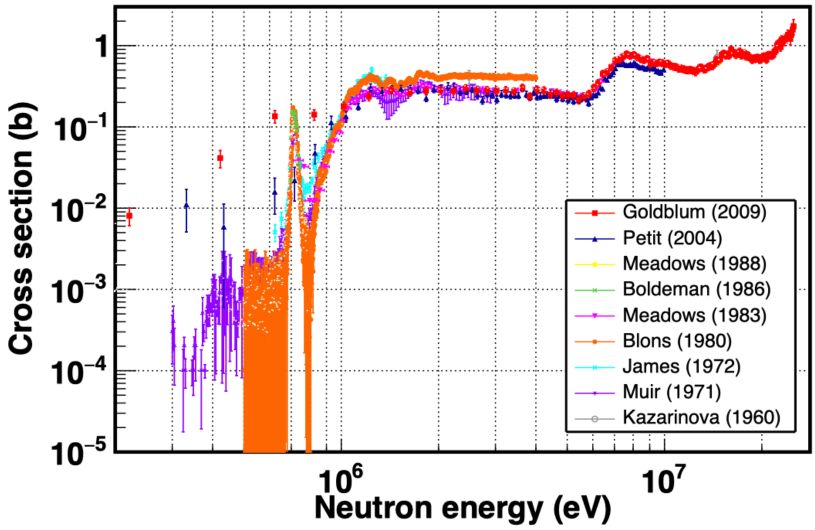

Fig. 1. *Experimental cross-section data for the ^{230}Th(n,f) reaction available in Experimental Nuclear Reaction Data Library EXFOR [1]*

EXPERIMENTAL DETAILS

The experiment was performed at the experimental area EAR-1 of the neutron time-of-flight facility n_TOF, located at CERN [2]. The white spectrum neutron source, ranging from the thermal region up to 1 GeV, was produced via spallation of high energy proton pulses impinging on a lead target. Then the neutrons travel a horizontal flight path of ~185 m to reach the experimental hall of experimental area EAR-1.

The energy of the neutron, which creates an event in the detection system, was estimated from its time-of-flight, since the distance from the spallation target to the detection setup is considered well known.

Seven high purity ^{230}Th targets, produced at JRC-Geel in Belgium, were used for the measurements, with a total mass of 27.14 mg and an activity ranging from 1.76 to 3.73 MBq. The samples were deposited on a thin 0.025 mm aluminum backing in 8 cm diameter. The characterization of the mass of the samples was performed via α-spectroscopy. One ^{235}U and one ^{238}U sample, with the same geometrical characteristics as the ^{230}Th samples, were used as references.

For the detection of the fission fragments a setup based on MicroBulk Micromegas (Micro-Mesh Gaseous Structure) was used [3]. The Micromegas detector is defined by three electrodes: the drift electrode, which is the actinide sample, the cathode electrode (micromesh), which is a 5 μm Cu foil with holes and the anode electrode, which is a Cu foil grounded via a 50 Ω resistance. The distance between the drift and the cathode is selected to fulfill the needs of each experiment, which in the present work was 6 mm, while the distance between the cathode and the anode is fixed at 50 μm. These distances, combined with the voltages applied to each electrode, result in the creation of a weak electric field between the drift and the cathode (~1 kV/cm) and a stronger one between the cathode and the anode (~50 kV/cm).

When a fission event occurs in the sample, two fission fragments are created moving to opposite directions due to the kinematics of the reaction, while only one of them enters the drift region. Upon entering the drift region, the fission fragment creates electron-hole pairs. The electric field applied in the region ensures that the electrons created move towards the cathode creating some secondary electrons on their path and are guided to pass through the holes of the micromesh. There the much stronger electric field assists in the multiplication of the electrons through the mechanism of avalanches. The signal was read from the cathode electrode and it is a result of induction from the movement of the charges.

The amplitude of the created signal is proportional to the energy deposition of the fission fragment in the drift region, which is not necessarily proportional to the kinetic energy of the fission fragment. The reason behind this is the fact that the emission angle of the fission fragment in the detector gas affects the portion of the initial kinetic energy that is deposited in the gas. On top of that, the emission angle of the fission fragment is related to the risetime of the recorded signal.

When a fission fragment enters the detector gas in parallel with the drift electrode (vertical to the direction of the neutron beam), it moves creating electrons in a very short time. Then the electrons drift towards the micromesh, where they arrive at almost the same time. In the opposite case, when the fission fragment enters the detector gas vertically to the drift electrode (parallel to the direction of the neutron beam) the electrons are created in the drift region almost simultaneously, but they arrive at the amplification region at different times, with the last electron created arriving first since it is created closer to the micromesh. This difference between the arrival times in these two cases, as well as the way the electrons move in all the in between angles, results in different risetimes of the fission fragment pulses.

Pulse shapes with different risetimes were observed during the analysis, while two of them are depicted in Fig. 2, normalized to the same amplitude. The low risetime pulse corresponds to fission fragment emitted in parallel to the drift electrode (blue line), while the high risetime pulse corresponds to fission fragments emitted vertical to the drift electrode. Another interesting difference between the two pulse shapes can be observed in Fig. 2: the positive polarity overshoot in the beginning of the pulse, which is much more significant in the low risetime pulses. This overshoot was observed mainly in high amplitude pulses, which correspond to higher energy deposition in the detector. However, higher amplitude pulses usually originate from fission fragments emitted at small angles with respect to the drift electrode, since in this case the available distance a fission fragment can travel inside the detector is considerably larger. So, this overshoot could be explained as the induction from the movement of the electrons in the drift region, which is lost in the background for lower amplitude pulses with higher risetimes.

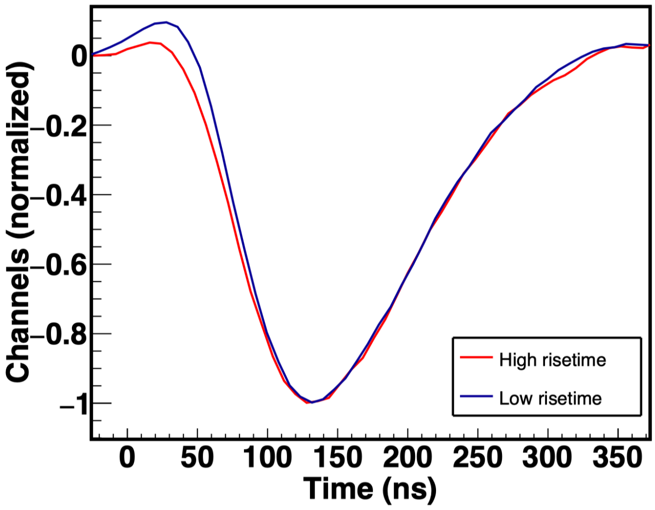

Fig. 2. *Fission fragment pulse shapes of the Micromegas detector*

RESULTS AND DISCUSSION

The difference in the risetimes of the Micromegas pulse shapes was taken into account in order to acquire a qualitative estimation of the angular distribution of the fission fragments. In order to do so, different pulse shapes where provided to the pulse shape analysis routine [4], while the routine selects via chi-square minimization the most suitable pulse shape for each signal. Then the ratio of the number of the pulse shapes with high risetimes (pulses around 0^o with respect to the neutron beam) versus the number of the pulses with low risetimes (pulses around 90^o with respect to the neutron beam) is estimated for neutron energies from the fission threshold up to 200 MeV.

Firstly, the methodology implemented for the estimation of the angular distributions is validated for the ^{235}U(n,f) reaction. The angular distributions of this work, namely a qualitative estimation of the asymmetry W(0^o) to W(90^o) ratio (Fig. 3a) are compared with previous measurements [5] (Fig. 3b). As seen from the comparison of Fig. 3a and Fig. 3b the results from this work manage to reproduce very well the shape of the angular distributions of ^{235}U.

Regarding the angular distributions for the ^{230}Th(n,f) reaction the results are presented in Fig. 4, namely the results of the resonance region of the reaction in Fig. 4a and the results of the higher energy region in Fig. 4b. As seen from the figures, a structure appears in the low energy region at the energy of the resonance (~700 keV), where an angular anisotropy is expected. In addition, an increase is observed in the anisotropy ratio at higher energies, which matches the second chance fission of ^{230}Th.

A few measurements of the angular distributions of the ^{230}Th(n,f) reaction are available in the Experimental Nuclear Reaction Data Library EXFOR [3], while only the oldest data of Simmons and Henkel [6] (Fig. 5) cover a wide energy range. Comparing the data of Simmons and Henkel with the data of the present work, a similar behavior can be observed, since both datasets appear to have an increase in the anisotropy ratio at ~2 MeV, which decreases at ~4 MeV reaching again a maximum value at ~7 MeV.

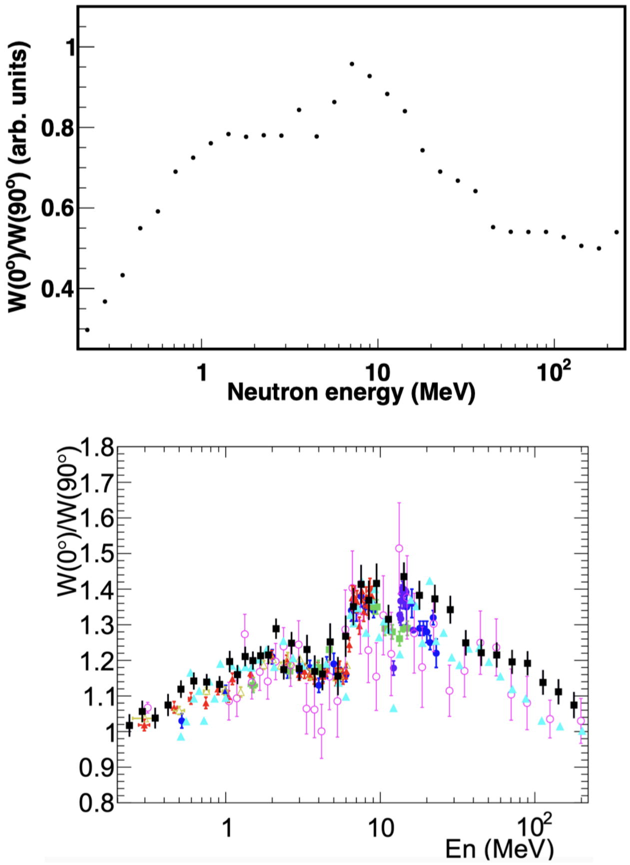

Fig. 3. Angular distribution of the ^{235}U(n,f) reaction from (a) this work and (b) previous measurements

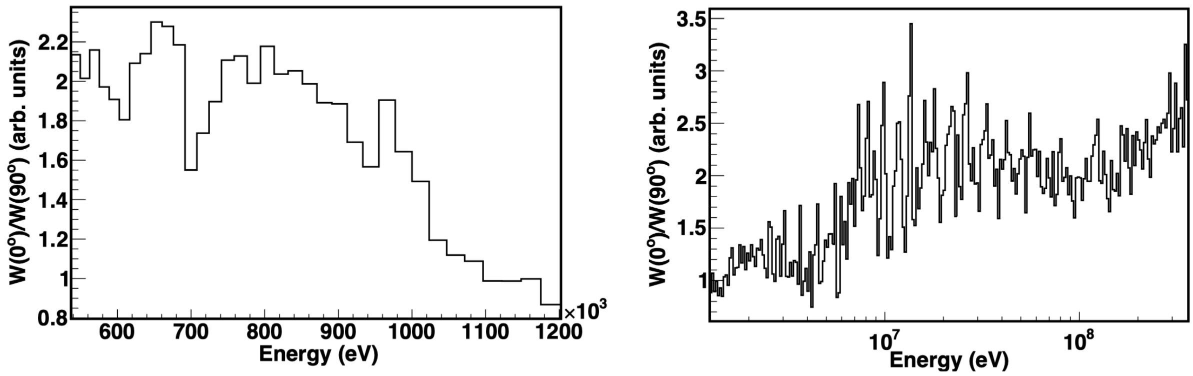

Fig. 4. *Angular distribution of the ^{230}Th(n,f) reaction for (a) the low energy region around the resonance and (b) previous measurements [5]*

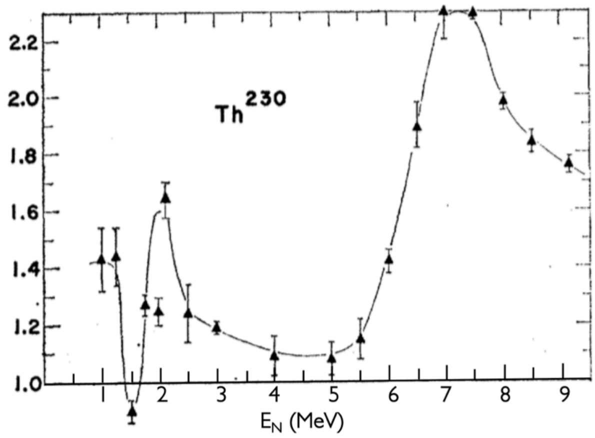

Fig. 5. *Angular distribution for the ^{230}Th(n,f) reaction from Simmons and Henkel [6].*

CONCLUSIONS

In this work, a methodology for a qualitative estimation of the angular distributions with MicroBulk Micromegas is presented. The methodology takes into advantage the pulse shapes of different risetimes, while it is used for the first time with this kind of Micromegas detectors and shows very promising results. Even though only a qualitative result is possible, this methodology can prove quite helpful in order to acquire a first estimation of the angular distributions in parallel with cross-section measurements and can assist in the design of future designated experiments.

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