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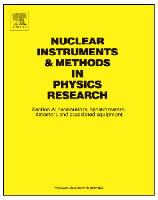

Measurement of the angular distribution of fission fragments using a PPAC assembly at CERN n_TOF

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ABSTRACT

A fission reaction chamber based on Parallel Plate Avalanche Counters (PPACs) was built for measuring angular distributions of fragments emitted in neutron-induced fission of actinides at the neutron beam available at the Neutron Time-Of-Flight (n_TOF) facility at CERN. The detectors and the samples were tilted 45° with respect to the neutron beam direction to cover all the possible values of the emission angle of the fission fragments. The main features of this setup are discussed and results on the fission fragment angular distribution are provided for the ^{232}Th(n,f) reaction around the fission threshold. The results are compared with the available data in the literature, demonstrating the good capabilities of this setup.

1. Introduction

Accurate data on neutron-induced fission cross-sections at intermediate energies are crucial for different fields in physics. In particular, thorough knowledge of the reactions involved in the so-called thorium cycle is important to improving the existing nuclear energy-related technologies.

An extensive experimental program [1] is being carried out at the Neutron Time-Of-Flight (n_TOF) facility at CERN in order to provide accurate values of the cross-sections of neutron-induced reactions, with particular reference to fission and radiative capture.

The fission fragment angular distribution (FFAD) is an important observable for understanding the fission mechanism; especially for studying the quantum properties of the levels of fissioning nuclei for a given J and K (total spin and its projection on the nuclear symmetry axis) when considering energies close to the thresholds of the different multiple-chance fission channels [2]. This makes it possible to describe the existence of a vibrational structure around the fission threshold for the light isotopes of Th, Pa and U [3]. Simultaneous reproduction of fission cross-section and fragment angular distribution is important for the determination of the best set of fission barrier parameters [4].

The anisotropy of the angular distribution of the fission fragments at high energies is also a controversial question. Some theoretical models indicate that fission above several tens of MeV should be isotropic and equal for both proton- and neutron-induced fission. However, a non-isotropic behavior was found for fission of ^{232}Th and ^{238}U with neutrons up to 100 MeV [5]. Therefore, new measurements of the angular distribution of fission fragments are needed to clarify this situation, and the n_TOF facility, with a neutron beam covering an energy range from thermal up to GeV, can supply new data with high accuracy.

Apart from the theoretical implications, the strong anisotropies observed at the thresholds of different chances of neutron emission before fission also affect the fission cross-section measurements due to the angular limitation of the detectors. One of the experimental setups used at CERN n_TOF for studying the fission process is a reaction chamber containing Parallel Plate Avalanche Counters (PPACs). During the Phase1 of the n_TOF project (2001–2004), the fission cross-sections of several nuclei were measured [6,7]. However, due to the limited angular acceptance exhibited by these detectors, only emission angles below ~60° were detectable, thus requiring a correction for fragments stopped in the material layers. These corrections were largely determined by the angular distribution of the emitted fragments, for which only incomplete data were available in the literature.

Therefore, a new setup based on a modified geometrical configuration was developed to overcome this difficulty and to obtain full coverage of the angular distribution of the emitted fragments. It was first used during the 2010 and 2011 campaigns (n_TOF-Phase2) to measure ^{232}Th(n,f) [8], following the procedure described in the present work.

2. Experimental setup

The experiment was performed at the CERN n_TOF facility, where a very intense neutron flux is produced by spallation reactions on a lead target using the 20 GeV/c proton beam from the Proton Synchrotron at CERN. The water surrounding the spallation target acts as a moderator to produce a neutron flux covering a wide neutron energy range, from thermal up to more than 1 GeV. The long (185 m) flight path between the spallation target and the experimental area makes it possible to perform high-resolution time-of-flight (TOF) measurements. A detailed description of the facility can be found in Ref. [9].

2.1. Parallel Plate Avalanche Counter

The PPACs used in this experiment have a central anode flanked by two cathodes. A low-pressure gas fills the 3.2 mm gaps between 1.7 μm aluminium coated Mylar foils, which act as electrodes. PPAC anode signals are very fast (9 ns FWHM), reducing the pile-up probabilities and making it possible to reach energies as high as 1 GeV, since these detectors are quite insensitive to the γ-flash created by high energy reactions at the spallation target [9].

The cathodes of each PPAC are segmented in 100 strips 1.9-mm wide and with a separation of 100 μm. The strips on the cathodes are arranged perpendicular to each other, so that the trajectory of the fission fragments (FF), and therefore their angular distribution, can be reconstructed. The anode is connected to a high voltage of around 540 V, while the cathodes are grounded.

The fission reaction chamber includes 10 PPACs with 9 samples in between, and fission events were identified by coincident anode signals of two consecutive PPACs. The chamber was operated with a forced flow of C_3F_8 at a constant pressure of 4 mbar.

2.2. Geometrical configurations

The main difference between the Phase1 and Phase2 setups is their geometrical configuration: in Phase2 the detectors and the samples were tilted 45° with respect to the neutron beam direction, as shown in Fig. 1. This modification was introduced to increase the range of the accessible $\cos\theta$ values, and it was used in the 2010, 2011 and 2012 campaigns to measure the angular distribution of emitted fragments in fission.

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