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Micromegas detector response test at the new EAR2 neutron beam of n_TOF facility in view of the 243Am(n,f) measurement

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Micromegas detector response test at the new EAR2 neutron beam of n_TOF facility in view of the ^{243}Am(n,f) measurement

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Abstract   A key ingredient in the design of advanced nuclear systems, such as Generation IV reactors and accelerator driven systems, is the study of neutron induced fission reactions. Accurate cross-section data on key actinides is needed both for their operation and the handling of the nuclear waste. ^{243}Am is among the long-lived isotopes present in nuclear wastes, that contribute to the long-term radiotoxicity, and the respective fission cross-section data are needed with high accuracies. Consequently, an experiment was planned to measure the neutron induced fission cross section of ^{243}Am in experimental areas EAR1 and EAR2 of the n_TOF facility at CERN. However, due to the replacement of the lead spallation target of the n_TOF facility, which led to significant changes in the characteristics of the neutron beam of experimental area EAR2, as well as to the increased complexity of the detection setup compared to similar past experiments, a preliminary experiment to test the setup in the new conditions was deemed necessary. In this work, we will describe the experimental setup and examine the test results.

Keywords   n_TOF facility, Micromegas, fission

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INTRODUCTION

As part of the development and study of advanced nuclear reactor systems, a wide range of nuclear data is necessary, especially for certain key elements. One of those elements is Americium, produced in the normal operation of nuclear reactors and classified as high-level nuclear waste. Of the two main Am isotopes, ^{243}Am is the longest lived with a half-life of 7364 a and contributes to the long-term radiotoxicity of the waste through production of ^{239}Pu. In addition, ^{243}Am is an important candidate for use in future accelerator driven systems (ADS) as a burnable actinide. However, few datasets are present in literature and often highly discrepant and of poor energy resolution. Consequently, the ^{243}Am(n,f) is classified in the General Request List (GRL) of the NEA [1] relevant to advanced nuclear systems.

To this end, an experiment was proposed to measure the ^{243}Am(n,f) cross-section with high accuracy at the experimental areas, EAR1 and EAR2 of the n_TOF facility at CERN [2]. The experimental setup is based on the Micromegas detectors and includes 20 samples, including 11 ^{243}Am samples, reference samples of ^{235}U, ^{238}U, ^{10}B and dummy samples. The higher number of samples compared to similar previous fission cross-section experiments at n_TOF (e.g [3]-[5]) leads to an increased complexity, which requires more careful consideration of the details of the setup inside the experimental area. In addition, during the long shutdown 2 the lead spallation target was redesigned and replaced, being optimized for experimental area EAR2 [6]. The new target design features similar beam characteristics for experimental area EAR1 but an improved energy resolution and higher neutron flux in experimental area EAR2. In experimental area EAR2, the so-called "γ-flash" (γ-rays and other relativistic particles) is not significant, but the "γ-flash" tail, due to the neutron interactions with the detector materials, is important and significantly affects the neutron energies of few MeV. An increased neutron flux could affect the quality of the data at higher energies due to the Micromegas detector response mainly to the "γ-flash" tail. Thus, some optimization was deemed necessary.

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For these reasons, a preliminary experiment was carried out. The goal was to simulate the final experimental conditions and optimize the setup before the ^{243}Am was in place, so the configuration needed to be as close as possible to the final one. The main objectives were to test the response of the Micromegas detectors to the γ-flash with the increased flux after the change of the lead target and optimize the setup. Furthermore, the opportunity was provided to test the new detectors and preamplifiers prepared for the experiment and to evaluate different gas mixtures to identify the ideal one in terms of the pulse shape and γ-flash response. Finally, when using the ^{10}B reference sample, the detection of ^{10}B(n,α) signals require greater gain on the preamplifier, which leads to the creation of a huge amount of charge in the electronics from the γ-flash, causing saturation of the signal of the preamplifier. To avoid the saturation a switch circuit [7], that isolates the preamplifier from the detector during the γ-flash, was tested for use with the Micromegas detectors as will be discussed later on in the experimental details.

EXPERIMENTAL DETAILS

The setup was as close as possible to the final ^{243}Am(n,f) experimental setup. The reference samples, produced at the EC-JRC-Geel Target Preparation Laboratory (JRC.G.II.5) in Belgium, included a total of three ^{235}U samples with a mass of approximately 100 μg, one thicker ^{235}U of approximately 2100 μg, one ^{238}U, and one ^{10}B. These samples were electro-deposited on a thin aluminum backing (25 μm), forming a small disk of 6 cm diameter. In addition, 2 "dummy" samples were included, which consisted of the same aluminum backing without any deposit. For the detection of fission fragments, or charged particles in the case of ^{10}B, Micromegas detectors were used. The backing of the sample served as the cathode of each detector. Each sample detector pair was placed inside an aluminum cylindrical chamber. To accommodate the total number of detectors and samples, including their cabling, in the ^{243}Am experiment, two chambers will be needed. Therefore, the samples were split between the two chambers to better approximate this and test for the first time how the two chambers would be placed inside experimental area EAR2, as well as other technical details (gas circulation, preamplifier installation, detector and electronics grounding etc). To support the two chambers on top of the beam line and keep them at a minimum distance, they were mechanically coupled together.

To allow room for the cabling, the second chamber was flipped compared to the first one, which, due to the way the samples were mounted, meant that in the first chamber (lower chamber of Fig. 1) the neutrons would encounter the Micromegas detectors before the sample, while the opposite is true for the second chamber (upper chamber in Fig. 1), as schematically shown in Fig. 2.

Figure 1. *The experimental setup inside the bunker of experimental area EAR2. The neutron beam is coming from below.*
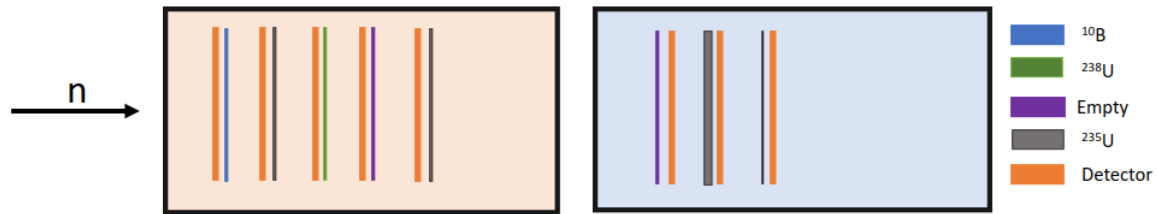
Figure 2. *The samples inside the chambers. Note that in the first chamber the detectors are first in the beam line, while the opposite is true for the second chamber.*
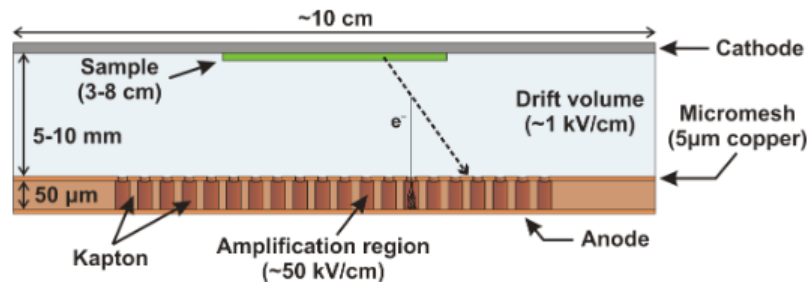
Figure 3. *Example of a fission Micromegas detector and basic operational principle*

The chambers were filled with two different gas mixtures that were switched during the experiment. The first was a gas mixture of $Ar:CF_4:_{iso}C_4H_{10}$ (88:10:2), which is the standard gas used in previous experiments, and the second was a mixture of $Ar:CF_4$ (90:10). The isobutane was removed to try to minimize the effect of potential scattering events from high energy neutrons from the γ-flash tail on hydrogen.

Preamplifiers constructed at INFN-Bari were used for the signal readout and the voltage supply to the detectors. Each preamplifier was housed in a separate aluminum box for better shielding and minimization of cross-talk. Due to the lower signal from the charged particles emitted from the $^{10}B(n,α)$ reaction, higher gain was needed to achieve a good signal-to-noise ratio. This, however, also causes a saturation of the detector signal at the γ-flash, limiting the neutron energies that we can measure with this setup. For this reason, a recently developed switch circuit [7] was included in the electronic chain associated with the ^{10}B sample. The signal from the detector passes first through the switch that would ground the charge before entering the preamplifier for a fixed amount of time, thus avoiding the saturation of the preamplifier. A time window that corresponds to the γ-flash was identified, allowing only the tail from the γ-flash to be recorded.
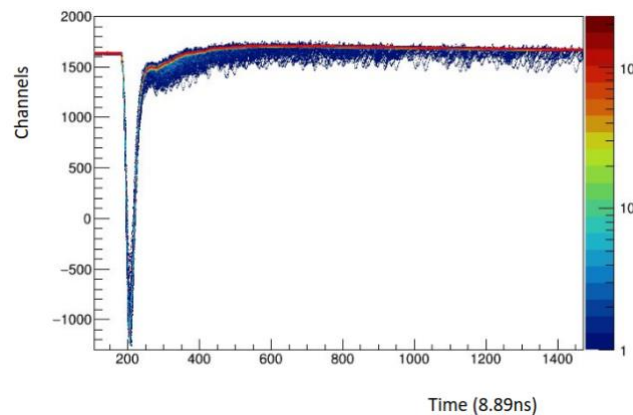
Figure 4. *A γ-flash stack from ^{235}U. The red line corresponds to the extracted average γ-flash.*

To measure the response of the detectors for each different configuration, an average γ-flash shape was extracted. That was done by stacking the first movie from each event in a 2D histogram (Fig. 4)

[5]. A cut is applied in the total counts for each point in the histogram to remove pulses other than the γ-flash that would lower the average value. Then the average is taken for each point of the x axis creating the average shape of the γ-flash (red line in Fig. 4), which can be used for the baseline subtraction during the raw data analysis.

## RESULTS AND DISCUSSION

In Fig. 4, we can see the stack of multiple γ-flash movies for a ^{235}U sample. Regarding the question of the response of our detectors to the higher γ-flash, we can see that we can maintain a high enough gain for our signals to be able to detect the fission fragments, while keeping the γ-flash non saturated. In addition, the tail of the γ-flash is relatively smooth, achieving a fast baseline restoration. However, a significant result occurred when comparing the γ-flash response for detectors in the two different orientations, meaning whether the sample or the detector is upstream with respect to the neutron beam. In Fig. 5, we can see the average γ-flash shape from two thin ^{235}U samples from the two different chambers. A bump occurs in the γ-flash shape in the case the detector is first, covering energies from about 1.0 MeV – 5.5 MeV, that is not seen in the second case. This result was consistent among all samples in the two chambers including the "dummy" ones. The explanation given here for this phenomenon is the following. The Micromegas detector based on the Microbulk technology (Fig. 3), used in this work, is made of a 5 μm copper layer with holes ("Micromesh"), a 50 μm Kapton layer with holes and a 5 of copper layer ("anode"). Neutrons in the MeV energy range scatter elastically with the protons of the kapton of the Micromegas, practically transferring their full energy to the protons at forward scattering. These MeV protons pass through the Micromesh and enter the gas, creating a signal that is then detected. To qualitatively test this explanation, SRIM simulations were performed, that included 5 μm of copper, 4mm of Argon gas and three different amount of kapton, 0 μm, 25μm and 50μm, corresponding to the edge, the middle and the start of the kapton layer, at three neutron energies of E_{n1} =1.1 MeV, E_{n2}= 2.3 MeV and E_{n3} = 5.5 MeV, corresponding approximately to the lower edge, peak and upper edge of the bump (Fig. 5). An average scattering angle of 20° was calculated based on the differential cross-section of the ^{1}H(n,el) reaction. From the kinematics of the reaction, the energy of the recoil proton was calculated, with E_{p1} = 0.971 MeV, E_{p2} = 2.031 MeV and E_{p3} = 4.855 MeV. The simulations showed that at E_{p1} the protons have just enough energy to pass through the copper and deposit their remaining energy in the Argon. At E_{p2} protons have enough energy to pass through all the kapton and deposit part of their energy, ~125 keV in the Argon. At higher energies protons deposit less energy, ~43 keV at E_{p3}. This effect, coupled with the downwards trend of both the ^{1}H(n,el) reaction and the experimental area EAR2 flux at higher energies explain the reduction of the effect until it is no longer observable.

Furthermore, the average γ-flash for the same ^{235}U sample at two separate times when the gases inside the chambers were switched are shown in Fig. 6, while two fission fragments pulses for the two different gases are shown in Fig. 7. As was foreseen, with the Ar:CF$_4$ gas, the detector has a slightly better response to the γ-flash, with a faster baseline restoration compared to the case of the Ar:CF$_4$:$_{iso}$C$_4$H$_{10}$ gas. By comparing the two fission fragment pulses we can see that there is no significant difference between the two. Since the goal is to have as clear a γ-flash tail as possible and there is no detrimental effect to the pulse shapes, the Ar:CF$_4$ gas was decided to be used for experimental area EAR2.

Finally, in Fig. 8 we can see the γ-flash stack for the case of ^{10}B without and with the switch to ground the charge of the detectors. In the first case, without the switch, we can see that the γ-flash is saturated with a long tail, with baseline restoration being achieved at neutron energies of about 10 keV, making it significantly harder to measure at higher energies. In the second case, where only the tail of
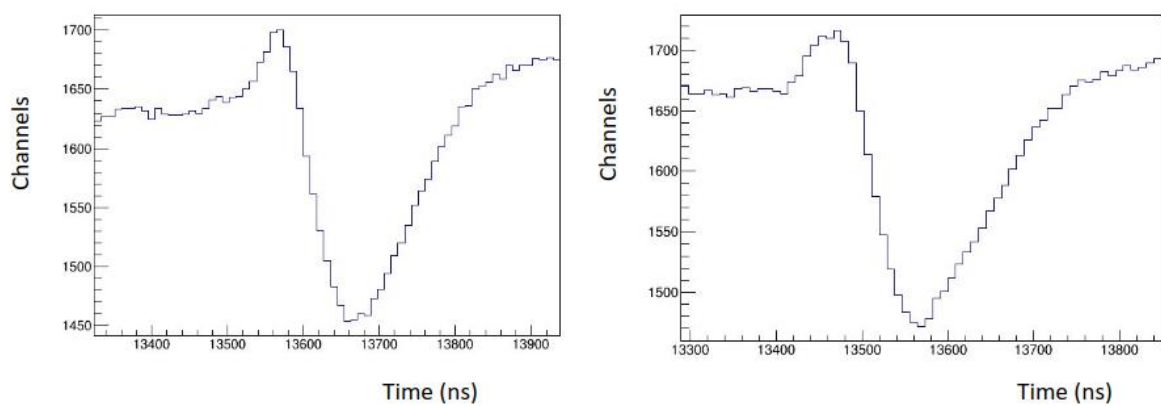
the γ-flash is kept, a much faster baseline restoration is achieved. Different timing settings were examined to find the optimum configuration.
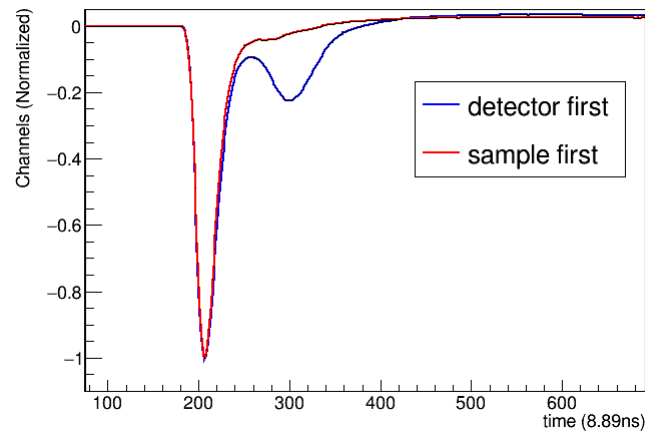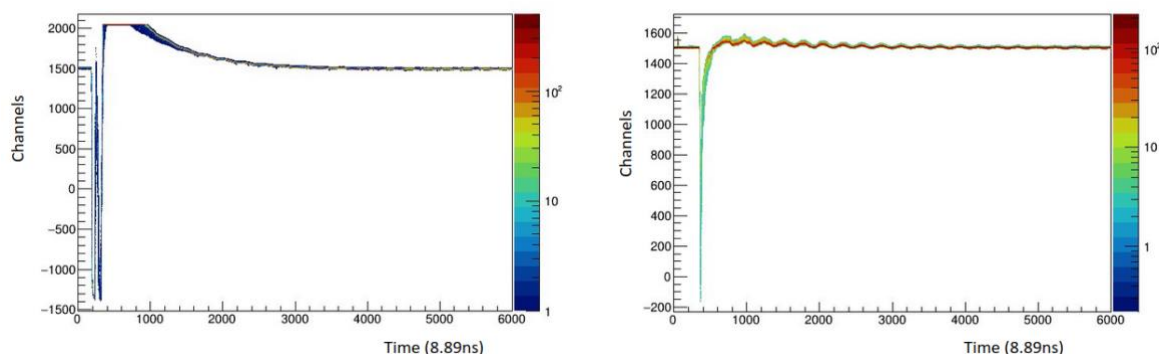

Figure 5. *Average γ-flash shape, for two detectors with different sample-detector order*
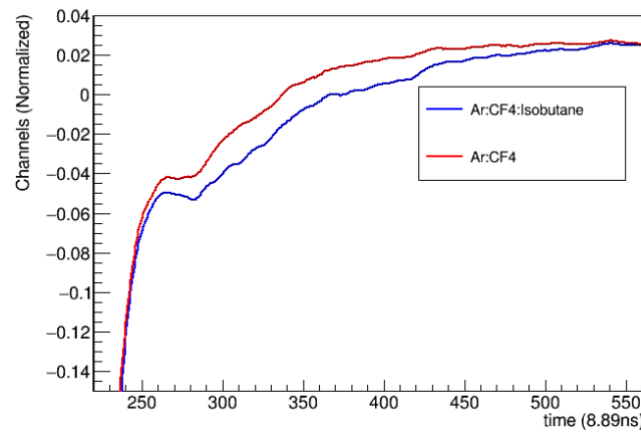
Figure 6. *Comparison of the average γ-flash on the same detector, using the two different gases*

Figure 7. *Pulse from a fission event from ^{235}U. With the Ar:CF$_4$:IsoC$_4$H$_{10}$ (left) and with Ar:CF$_4$ (right).*

Figure 8. *γ-flash stack for the ^{10}B sample. Left without using the switch, right when using it.*

CONCLUSIONS

In this work, various aspects of the setup of the ^{243}Am(n,f) cross-section measurement in experimental area EAR2 of n_TOF at CERN, as well as the Micromegas response to the increased neutron flux after the upgrade of the spallation target, were tested in a dedicated beam test with a setup as close as possible to the final one.

The response of the Micromegas detectors was found to be satisfactory despite the increased flux. Furthermore, it was shown that the order of the mounting of the samples inside the chambers has a strong effect on the result, and that the sample needs to be upstream with respect to the neutron beam. A new candidate gas, namely Ar:CF$_4$ (90:10) was tested, which showed some improvement compared to the standard Ar:CF$_4$:$_{iso}$C$_4$H$_{10}$ (88:10:2) one. Finally, the use of the switch circuit in the case of a saturated γ-flash was studied, optimized, and was found to present certain advantages. All these results will be subsequently incorporated in the ^{243}Am(n,f) cross-section measurement.

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