HORIZON 2020

HORIZON 2020 RESEARCH AND INNOVATION FRAMEWORK PROGRAMME OF THE EUROPEAN ATOMIC ENERGY COMMUNITY

Nuclear Fission and Radiation Protection 2018 (NFRP-2018-4)

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Dissemination Level: ***PU***

Reference:

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Comments: The finishing date was, originally, 31 August 2021 (M24). A delay was asked for due the COVID sanitary crisis and the impossibility to perform measurement tests during several months.

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The 1.1.1 Subtask project focus on the improvement of the ^{242}Pu(n,f) cross section in the [200keV;2MeV] neutron energy range. This cross section exhibits a fission threshold around 1 MeV, which correspond approximately to the peak energy in fast neutron reactors. Thus, the knowledge of this nuclear data is of peculiar interest for nuclear fuel in closed cycle scenarios as well as for precise flux measurements in nuclear reactor using ^{242}Pu fission chambers. The project is divided into (i) a ^{242}Pu(n,f) measurement in the [1MeV;2MeV] energy range, and (ii) the development of a specific device enabling a measurement in the [200keV;1MeV] energy range.
To obtain an accurate measurement of a cross section, one have to know precisely the neutron flux irradiating the studied target. The usual method is to use a secondary standard as a reference, by placing a ^{235}U or ^{238}U target in the same setup. The issue is a very strong correlation of many experimental measurements to these cross sections (especially ^{235}U), and an accuracy limited by the accuracy of these standard (1.3% to 10% between 200 keV and 20 MeV for ^{235}U [1]).
Another method is to use the proton recoil technique based on the primary standard ^{1}H(n,p). The use of another standard provide valuable "uncorrelated" measurements. Moreover, the ^{1}H(n,p) cross section is known with a very good accuracy (0.2 to 0.5% on a large energy range), and is structure-less, which prevent from introducing artificial structures to the results in the normalisation process. The proton recoil technique require to detect recoil protons, which is done easily with a Silicon detector (or a telescope) above 1 MeV. Below 1 MeV, an intense γ and e^- background generated by the neutron production target induce a very strong background in the detector, preventing an accurate measurement [2].

The aim of the point (ii) of the project is to develop a new proton recoil detector adapted for this energy range. Development of the Gaseous Proton Recoil Telescope (GPRT) prototype has begun during the CHANDA project. The GPRT consists in a H-rich foil located at the entrance of a double ionisation chamber (ΔE-E). A first collimator close to the H-rich foil precisely define the sample 'active' area. A second collimator between the two chambers enable a precise geometry definition. The detector is filled with a N_2/CO_2 (70/30) gas mixture, whose pressure is adapted to stop the recoiling protons in the second chamber. Figure 1 shows the GPRT prototype.

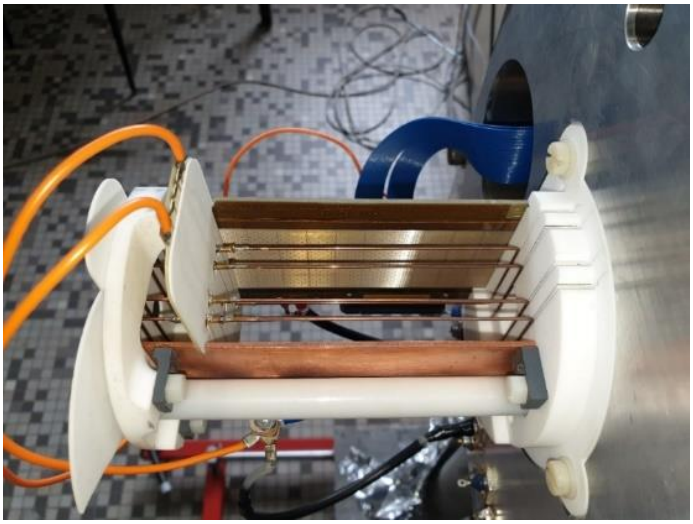

Figure 1: Picture of the GPRT. The ΔE chamber is the small space on the left, while the E chamber is the wide one. The segmentation of the micromégas detection plane is slightly visible.

The primary ionisation electrons created in the gas drift toward the anode. In order to ensure a proper electron drift, a field cage forces the electric field uniformity. The detection plane uses the Micromegas technology to amplify the signal: a polarized grid is located 125 µm above the anode, generating an intense electric field that enables electron multiplication. The detection plane is segmented in 64 pads, with a pattern shown on Figure 2.

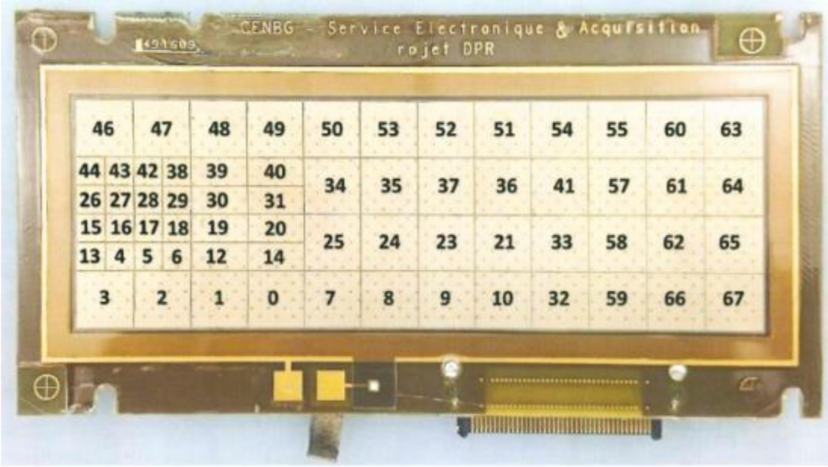

Figure 2: Segmented detection plane. Smaller pads are located in the front to have a better spatial resolution at the beginning of the particle track.

The pad segmentation allows to reconstruct the particle track. This ability is mandatory to discriminate the particle passing through the detector according to their origin, their direction, their range. For this purpose, the pads are smaller in the ΔE chamber (left side). The electron drift time can be taken into account to reconstruct the track in the third dimension, making the GPRT a small Time Projection Chamber.

Signals from the pads are collected and digitalized by the acquisition system developed at the LP2i from the AGET acquisition.

At the beginning of the SANDA project, the GPRT prototype was in its current physical form and many properties had been observed [3,4]:

- very low sensitivity on γ/e^-
- 3D track reconstruction
- good electric field behaviour (static and under irradiation)
- discrimination between direct and scattered neutrons.

Still, extensive studies remained to be carried out on the GPRT behaviour and performances, especially around the efficiency measurement [5,6] and the gas used.

1- Efficiency measurement

In order to determine a neutron flux with a good accuracy, it is of paramount importance to know precisely the detection efficiency. For that, the intrinsic efficiency has to be equal to 100% for every energies of interest.
Tests were carried out with an alpha source, whose activity was re-measured via long alpha spectrometry. Results obtained from the source was $\varepsilon_{intrinsic} = (99.2 \pm 3.7^{sys} \pm 1.1^{stat})$ in the most favourable conditions. The large systematic error comes from geometrical uncertainties because the experimental setup was not designed to hold such a source.
To overcome this and measure the intrinsic efficiency with a much better accuracy, a new experiment was designed. The aim was to send a proton micro-beam directly in the GPRT. With a low pressure and a Si detector downstream the GPRT, protons will go through it and be detected in the Si. The comparison of both counting rates enables to infer the GPRT detection efficiency.
The use of directional and mono-energetic particles also opens ways to better tests to characterize the performances of the GPRT.

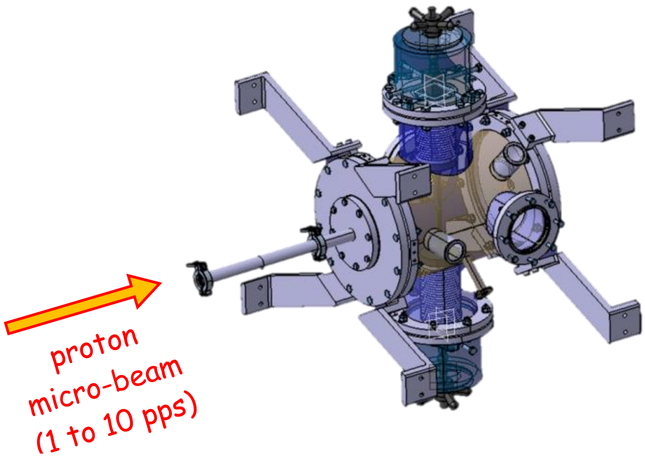

Figure 3: Sketch (left) and picture (right) of the
GPRT direct irradiation chamber.

A dedicated chamber was designed and used on the AIFIRA facility (see Figure 3). Several delays (accelerator breakdown and Covid-19) prevented us to carry out the experiment in 2020. Nevertheless, two test experiments were carried out in 2021 and 2022. The first one was dedicated to the efficiency measurement, and concluded the efficiency is 100% only at low counting rates. Above few particle per second, it drops quickly ($\varepsilon_{intrinsic}$ ~30% at 300 pps). This result was compatible with previous alpha tests since the source activity was quite low.
Investigations showed that the issue comes from the acquisition system. A complete review and overhaul of the system was required, and this project was added into the Electronic Service planning in 2022. A flaw was discovered in the communication between the hardware cards and the software program. A new test on the AIFIRA facility is planned by the end of 2022, to validate finally the efficiency of the GPRT.

The second experiment in 2022 aimed at characterizing the GPRT. Tests were carried out on:
- the lateral electron diffusion
- the electron recombination in the gas
- the energy resolution
- the electric field uniformity (loss of charge collection)

Analysis is ongoing to quantify these quantities.

2- Gas studies

First GPRT tests were done with Ar-CH_4 gas, as well as CF_4 gas (because of its high electron drift velocity). It appeared that such velocity was not required and a slower gas, namely N_2/CO_2 mixture (70/30) was used. Quantitative studies have been done during the SANDA project on the breakdown voltage and the amplification gain (i.e multiplication factor) using this gas.

The GPRT is difficult to operate at low gas pressure, at typically few 10 mbars (corresponding to neutrons energy below 500 keV): the breakdown voltage decreases due to the Paschen law, and the multiplication factor drops as there is less electrons to produce a cascade. Figure 4 illustrates this phenomena. At 30 mbar N_2/CO_2, the maximum operational multiplication factor is 40 times smaller than at 100-200 mbar.

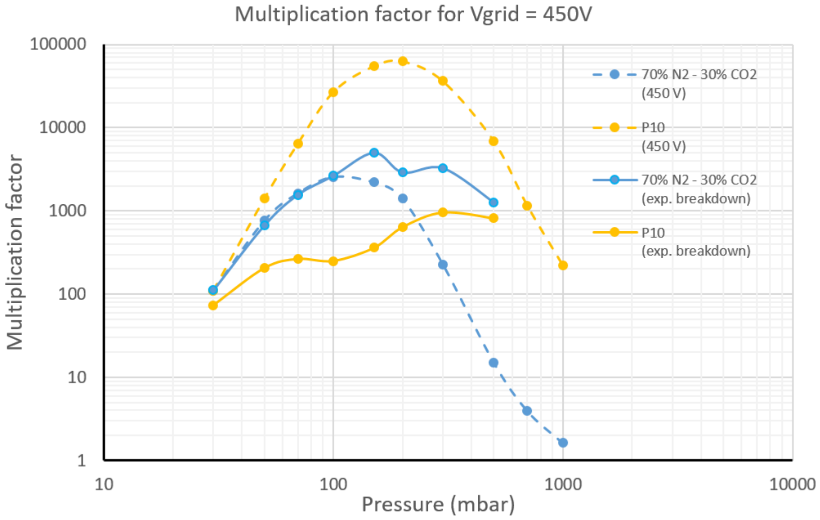

Figure 4: Calculation of the multiplication factor as a function of the gas pressure of the GPRT. The operation voltage is either 450V, or the experimental breakdown voltage.

In 2022, a new study has been undertaken to test different N_2/CO_2 ratio, in order to obtain better multiplication factors. Indeed, theoretical calculation showed that a CO_2 rich gas would have a higher breakdown voltage and a better gain. Such evolution would increase margins to operate the GPRT at low pressure.
Experimental multiplication factors for a pure CO_2 gas has been measured, and are one order of magnitude higher than with a 70/30 N_2/CO_2 gas mixture. This improvement is due to a significant increase of the breakdown voltage. Nevertheless, strong electronic card damages has been observed, probably due to stronger breakdowns. Other tests with an intermediate mixture will be done after the electronic card repair.

To conclude, the GPRT prototype is on the verge of being validated, since the next AIFIRA experiment at the end of 2022 should now confirm the 100% efficiency of this detector. Optimal working conditions are still to be investigated to improve the detector performances, but standard conditions (70/30 N_2/CO_2 gas mixture) have already shown satisfactory behaviour. These studies have been presented at the ND2022 conference and will be published.

Reference

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