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Development of a Gas Filled Magnet spectrometer within the FIPPS project

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ABSTRACT

The Fission Product Prompt γ-ray Spectrometer, FIPPS, is under development to enable prompt γ-ray spectroscopy correlated with fission fragment identification. This will open new possibilities in the study of fission and of nuclear structure of neutron rich nuclei. FIPPS will consist of an array of γ and neutron detectors coupled with a fission fragment filter. The chosen solution for the filter is a Gas Filled Magnet (GFM). Both experimental and modeling work was performed in order to extract the key parameters of such a device and design the future GFM of the FIPPS project. Experiments performed with a GFM behind the LOHENGRIN spectrometer demonstrated the capability of additional beam purification.

1. Introduction

Even seven decades after discovery of nuclear fission, some of its features are still poorly understood [1]. The mechanism of angular momentum population of fission fragments is one of them. Today, this quantity is fundamental for the determination of the prompt γ spectra which in turn is essential in the calculation of γ heating and damage of nuclear reactor components [2]. A new instrument is needed to assess the prompt γ spectra per fission fragment.

The FIPPS (Fission Product Prompt γ-ray Spectrometer) project of the Institut Laue-Langevin (ILL), is under development to respond to these issues. Besides, one of the objectives of this future instrument is to study the nuclear structure of neutron rich nuclei in order to better describe the nuclear force (spin orbit interaction, pairing) and bring new information to better understand the nucleosynthesis. FIPPS is the combination of a fission fragment filter with a large array of γ and neutron detectors around a fissile target placed in a well collimated neutron beam. When fission occurs, one fragment is stopped in the target backing while the other one is flying towards the fission fragment filter. Prompt γ-rays and neutrons from both fragments are recorded by the detector array. A time coincidence between both devices allows the determination of fission fragment nuclear charge, mass and related properties.

The chosen solution for the fission fragment filter is a Gas Filled Magnet (GFM) [3,4]. This type of spectrometer is a good compromise between a large acceptance and a good mass separation. In this article, experimental results achieved at the already existing LOHENGRIN spectrometer of the ILL demonstrate the properties of such a device. A Monte Carlo simulation was done in order to shed light on the important physical parameters. A validation of this simulation with our experimental data will be shown. Finally the feasibility of a GFM as a fission fragment filter will be discussed.

2. Materials and methods

The LOHENGRIN recoil separator for fission products [5] is located at the high-flux reactor of ILL in Grenoble, France. The fission target is placed close to the reactor core in an evacuated beam tube, at a thermal neutron flux of: $\approx 5 \cdot 10^{14}$ n $\cdot$ cm^{-2} $\cdot$ s^{-1}.

This separated field parabola spectrometer is made up of a horizontal magnetic deflection followed by a vertical electrostatic deflection. This combination allows the separation of fission

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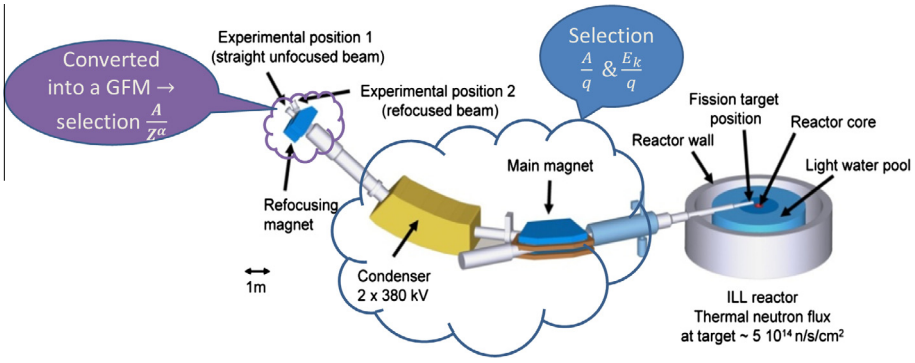

Fig. 1. Scheme of the LOHENGRIN spectrometer. The RED magnet was converted to a GFM by filling it with gas.

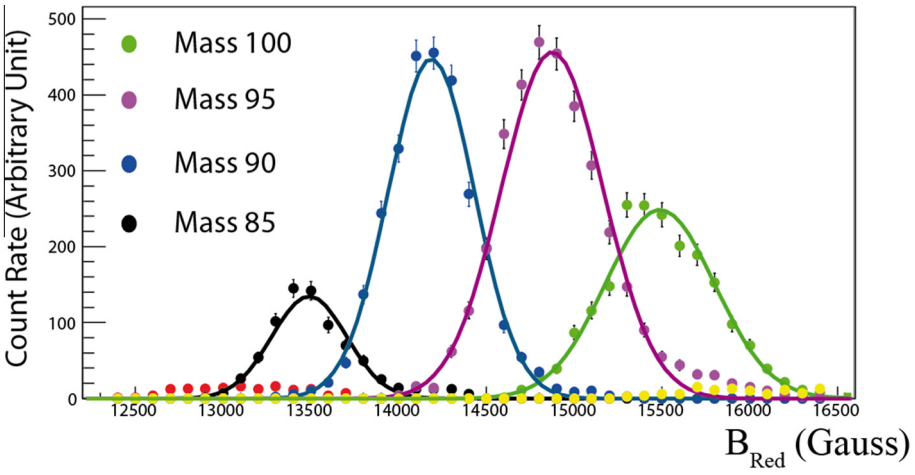

Fig. 2. Separation of the beam made up of fission products with different mass but equal velocity. Variation of the GFM magnetic field is equivalent to a spatial displacement of the detectors.

fragments according to the ratios of their kinetic energy (E_k) over their ionic charge (q) and their mass (A) over their ionic charge. In other words, for a same setting of magnetic and electric field, several masses have the same trajectory even with different kinetic energies. A focusing magnet, the Reverse Energy Dispersion (RED) magnet, placed at the end of the separator, increases the particle density at the focal position without changing the beam composition [6].

To identify the fission products an ionization chamber (IC) surrounded by two clovers consisting of four high purity germanium (HPGe) crystals each is placed at the RED exit. The IC is used to measure the kinetic energy of the fragments and consequently to identify their mass. The γ detectors (HPGe) permit precise identification of the nuclear charge of the fission product. In this work, only isotopes with μs isomeric states were considered. A time coincidence between the signals of IC and γ detectors enables the extraction of the unique decay signatures of these isotopes.

For the purpose of this study, the RED magnet was converted to a Gas Filled Magnet (GFM) by filling it with different gases. The total length of the fission fragment trajectory inside this device is around 1 meter with a deflection angle of 65°. The GFM was separated from the condenser with a 50 $\mu g \cdot cm^{-2}$ thick polypropylene foil. Fig. 1 shows the different parts of the LOHENGRIN spectrometer. In this configuration, the LOHENGRIN spectrometer was used as a parallel fission product beam source. Inside the GFM, the fission products are separated according to their mass A:

$$B\langle\rho\rangle = A\left\langle\frac{v}{q}\right\rangle \quad (1)$$

with B the RED magnetic field, $\langle\rho\rangle$ the mean radius of curvature, v and q the velocity and ionic charge of the fission fragment. We remind that the mass resolution of a GFM is intrinsically worse compared to a vacuum recoil spectrometer such as LOHENGRIN.

3. Experimental outcome

3.1. Separation power

As expected, a spatial dispersion of the initial fission product beam was observed using the combination of the LOHENGRIN spectrometer and the GFM. Fig. 2 shows the spatial separation of the different fission products with a pressure of 40 mbar of He. Since the detectors could not be moved along the focal plan, a variation of the magnetic field inside the GFM replaced the spatial displacement of the detectors. In this example, only fission products with a ratio $\frac{A}{q} = 5$ were selected by the LOHENGRIN spectrometer before going through the GFM.

Different studies on the characteristics of the GFM were achieved. Most of the results were done with N_2 gas because of important leaks appeared in the polypropylene foil at the entrance of the GFM when He was used at higher pressures. Moreover, to access heavier masses, a decrease of the mean magnetic rigidity was needed, which was achieved by using a heavier gas such as nitrogen. The global dependence of the mean magnetic field with the mass and nuclear charge of the fission fragment was deduced:

$$\overline{B\rho} \propto \frac{A}{Z^{\alpha}} \rightarrow \alpha = 0.64 \pm 0.02 \quad (2)$$