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Target thickness dependence of the Be(p,xn) neutron energy spectrum

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Abstract. We report on the current status of the analysis of an experiment performed at The Svedberg Laboratory, with the aim of investigating the produced neutron field by Be(p,xn) converters of three different thicknesses with a 30 MeV proton beam. The neutron energy spectra were measured with the Time of Flight technique using a BC-501 liquid scintillator with good n-γ Pulse Shape Discrimination properties, while the detected events were recorded simultaneously by two Data AcQuisition systems. In this paper, we present the experimental setup, the analysis technique and some preliminary results.

1 Introduction

High quality measurements of neutron-induced independent fission yields from key actinides are of importance in many aspects of the fission process. In fundamental physics, knowledge of the yield distribution is needed for studies of neutron rich nuclei far from the line of stability and for a better understanding of the fission process itself. For nuclear energy applications, good knowledge of the produced yields at various neutron energies is required in view of the possible use of fast neutrons in generation-IV reactors and in innovative cycles for the handling of spent nuclear fuel. For these reasons, a series of neutron-induced fission measurements is planned to be performed at the upgraded IGISOL-JYFLTRAP facility (University of Jyväskylä) [1, 2]. The aim is to create fast neutron spectra for studies of exotic nuclei far from stability, where a high neutron flux is desired, while for reactor applications neutron spectra resembling thermal and fast reactors are preferred [3]. In order to achieve these goals, the complete characterization and comparison of the various spectra produced by neutron converter targets are necessary [4]. The neutron energy fields considered here are created by Be(p,xn) converters of different thicknesses with a 30 MeV proton beam. As has been reported in Ref. [3] the two Monte Carlo (MC) simulation codes, MCNPX [5] and FLUKA [6, 7], used to estimate the produced neutron fields, show some discrepancies. Therefore, a direct measurement has been performed in order to characterize the neutron yield, and hopefully settle the disagreement. In

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addition, this measurement will try to add more data to the literature, which are relatively scarce in this energy range.

2 Experimental setup

The experiment was performed at The Svedberg Laboratory (TSL) where we employed a prototype of the target that will be used at the IGISOL-JYFLTRAP facility. The design of the target is similar to the LENS target [8], developed at Indiana University Cyclotron Facility. The assembly consists of a 5 mm thick Be target, a 10 mm thick cooling water layer and a 3 mm thick Al back plate. The target is thinner than the full stopping length of the 30 MeV protons so that they stop in the cooling water, instead of inside the target. In this way, the cooling requirements and the hydrogen build-up in the metal, which both could cause a major problem at high currents, are significantly reduced, at the cost of a small reduction of about 5% in the neutron yield.

The goal of the neutron converter target is to have a flexible design that can be adapted to different materials and thicknesses, in order to enable the use of neutron fields with different energy distributions. Hence, besides the aforementioned target, two more thicknesses (1 and 6 mm) were investigated. The assembly in these cases consists only of the Be target. In the former case, the thin target was used to produce a quasi-monoenergetic neutron field, and was also used as the reference measurement for the white neutron spectrum created by the other two targets (5 and 6 mm). In the latter case, the thickness of the target was sufficient for the protons to stop in the metal, so there was no need of the additional layers. Beryllium was selected as the target material due to the high neutron yield; in the studies of nuclides far from stability, the converter should deliver 10^{12} high energy neutrons (above 1 MeV) per second on the fission target in order to give competitive count rates with respect to the other experimental facilities.

The initial proton beam was 37.3 MeV while the main driver accelerator at IGISOL will be a high-intensity MCC30 light ion cyclotron with a maximum energy of 30 MeV. Therefore the proton beam was degraded to 30 MeV by letting it pass through a 1 mm thick aluminium tile followed by 2 m of air. To adjust the beam shape, two different collimators were used.

For the measurement, the Time Of Flight (TOF) technique was applied, using simultaneously two different Data AcQuisition (DAQ) systems. In this report, the results from the DAQ using a digitizer of the model ADQ412 (SP Devices) are presented. With the digitizer the whole pulse of each event was saved for off-line analysis and Pulse Shape Discrimination (PSD). The initial threshold was low, about 2 MeV, and could be adjusted as desired during the analysis. For the results of the other DAQ, see Ref. [9]. For the TOF setup, a 3.3 litre BC-501 liquid scintillator from the NORDBALL array was employed [10], placed at an angle of ten degrees with respect to the beam-line, at three different distances (1.2, 2.0 and 4.8 m) from the source. These distances were selected in order to obtain a good energy resolution over the whole energy interval and to minimize the wrap-around effect (i.e. when the slowest neutrons of one bunch arrive after the fastest neutrons of the next one), due to the time structure of the cyclotron, with a period of 44.25 ns.

3 Results

3.1 Pulse shape discrimination

The n-γ discrimination with liquid scintillators using digitizers is based on observable differences in the pulse shape. The total light output generated in the scintillators can be represented by the sum of the two exponential decays referred to as the fast and slow components. In general, the slow component is larger for heavier particles, i.e. the tails of the average neutron pulses are consistently larger than the tails of the γ-ray pulses. This difference in the tails between the slow neutron and γ-ray component serves as a basis for the PSD method used to identify and characterize pulses [11].

The method used in the present work for the PSD is the charge integration method that compares the total charge of the pulse with the charge obtained by the partial pulse integration. The full integration represents both the fast and the slow component (peak and tail) (A_1), while the partial range (A_2) covers the fast component. The difference between these corresponds to the integral of the tail. The integrals are given to in a unit of (V · ns). The optimal sample points for defining the start and the end of the integrals are depicted in **Fig.1**. The area ratio R is defined as:

$$R = (A_1 - A_2)/A_1 \quad (1)$$

Neutron pulses generally have a larger ratio R, as the magnitude of the slow component integral is larger for neutrons than for γ-rays. A classification point R_c must be chosen, in order to accurately classify the detected particles. Above this point, all pulses are classified as neutrons, while below all the pulses are classified as γ-rays. Some pulses, unavoidably, will be misclassified, especially the low energy neutrons. The preliminary results presented in the current work are based on the one dimensional discrimination shown in **Fig.2**, with $R_c = 0.248$.

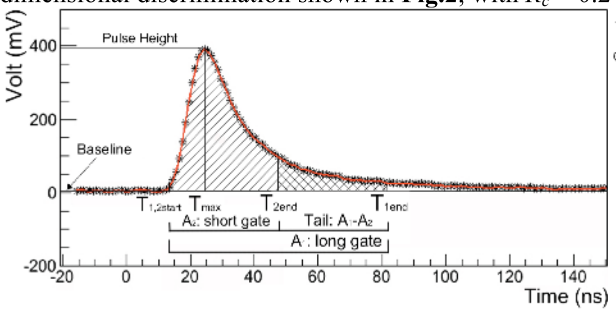

Figure 1: Integration of pulse over different time ranges.

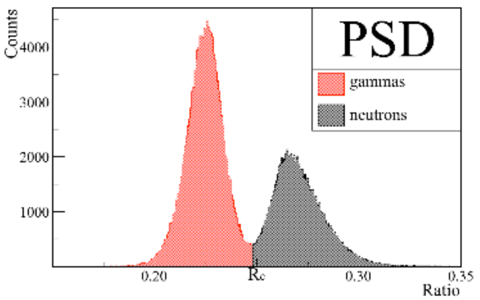

Figure 2: 1D-plot of the off-line PSD.

3.2 Energy spectrum

Using the PSD and having calculated the neutrons TOF, the energy spectra from the different target thicknesses could be calculated. **Fig.3** depicts the energy distribution of the produced neutron field over the whole range, for the various thicknesses of the target and for the detector located at 1.2 m distance from the target. In each case, the plots are scaled to the same number of events with respect to the data set with the most entries. The analysis of the other two positions of the detector is still ongoing. For the thicker targets (5 and 6 mm), the neutron yields from the (p,xn) reaction show a monotonic decrease with the neutron energy above 20 MeV. For intermediate energies, between 5 and 15 MeV, the thick targets produce a higher neutron flux, while the thinnest target produces a higher flux for the energy range above 24 MeV, as expected.

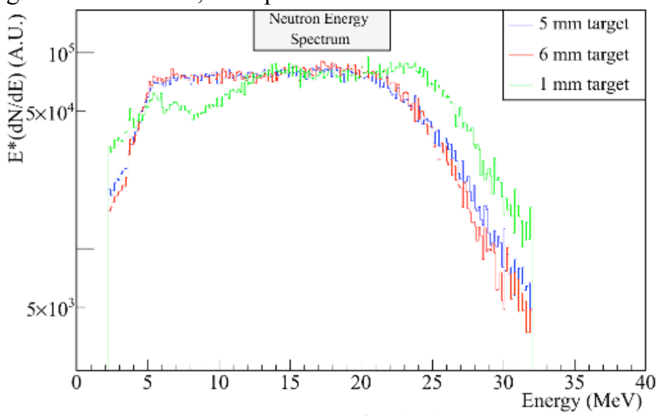

Figure 3: Neutron energy spectrum for the detector at 1.2 m distance.

Some peaks at the lower part of the spectra, especially for the thin target, may be due to misclassification of γ-rays and this has to be further investigated. The neutron background was mainly produced by the multiple scattering of neutrons in air or off the surrounding materials of the experimental hall. This contribution has been estimated by separate measurements with shadow cones that block the direct path between target and detector. The analysis of this setting is still ongoing; hence the spectrum in **Fig.3** shows the total neutron field without background subtraction.

4 Future work

The optimization of the PSD will be further investigated in order to improve the results of the n-γ separation. For this reason a 2D-plot similar to the one shown in **Fig.4** will be used. The red line represents the one dimensional cut, $R_c = 0.248$, of the present PSD. This shows that some pulses are inevitably misclassified and that applying a 2D gate will improve the discrimination.

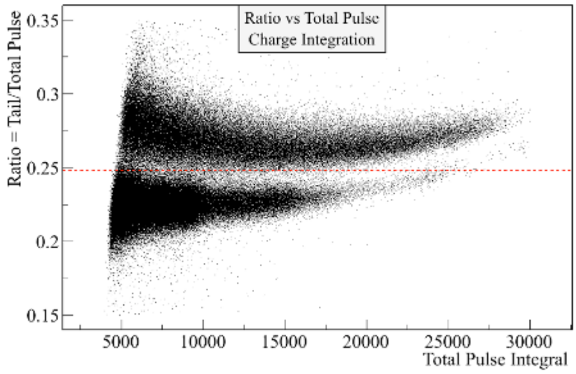

Figure 4: Example of the off-line n-γ PSD for the 5 mm target at 1.2 m distance.

Furthermore, Monte Carlo simulations with different codes (FLUKA, MCNPX and Geant4 [12, 13]) are being performed and the results will be compared with the experimental data. In addition, the detector response function will be extracted from the data and compared to simulations. Thereafter, this will be used as a correction in the energy spectrum (**Fig.3**).

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