NEUTRON DETECTION EFFICIENCY USING PASSIVE CONVERTERS

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The effect of passive iron converters on the detection efficiency of neutrons in a plastic scintillator was investigated at energies of 20 to 140 MeV. An enhanced detection efficiency for neutron energies above 70 MeV was found using iron converters of 2–3 cm thickness. The experimental results are compared to a simulation.

1 INTRODUCTION

Rare isotope beam facilities that use projectile fragmentation and in-flight separation to produce neutron-rich nuclei require neutron detection systems with a high detection efficiency at energies of above 50 MeV in order to investigate these nuclei. In many applications, the neutrons are reaction products that are detected under forward direction, and the time of flight is used to determine the neutron energy. This technique generally requires large-area detectors with high detection efficiencies and good time resolution.

With the experiment described here, we tried to determine the lower energy limit at which the detection efficiency of a plastic scintillator can be enhanced by adding a passive iron converter. Passive converters are widely applied in neutron calorimeters used for high energy physics experiments. Due to the shorter interaction length for neutrons in the denser converter material, more charged particles are generated, which then can be detected in the following detector material. The Large Area Neutron Detector (LAND) at GSI makes also use of passive iron converters [1]. This detector is a time-of-flight wall optimized for neutrons of energies up to 1 GeV. While the LAND group reported detection efficiencies for their detector setup at energies of 200 MeV and above, experimental data for an iron-plastic combination at energies around 100 MeV do not exist.

In order to gain information in this energy range, we undertook measurements of relative detection efficiencies for a combination of iron converter and plastic scintillator compared to a pure plastic scintillator detector for neutrons of 20–140 MeV. On of the main purposes of this experiment was to corroborate results from simulations that we had performed.

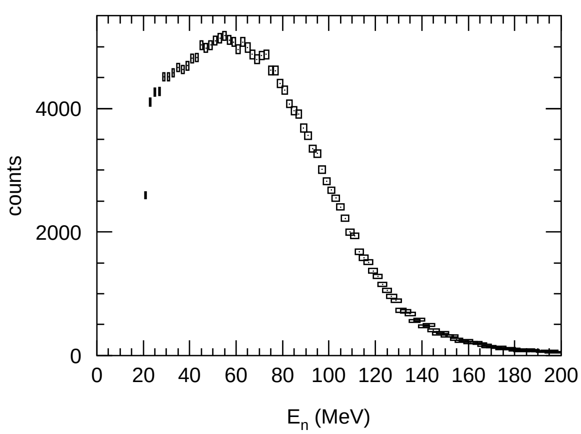

Figure 1: Measured neutron energy distribution. The rectangles indicate the error based on the time-of-flight measurement and the statistical error.

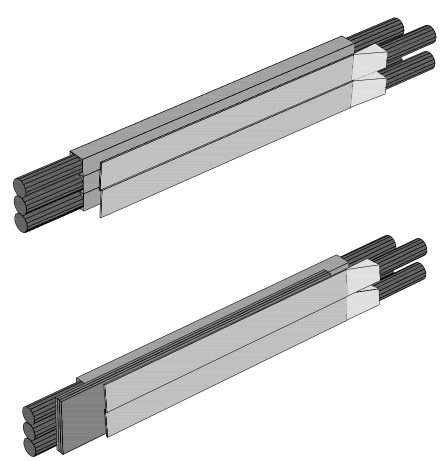

Figure 2: Neutron detector setup. The lower set of detectors contains iron sheets (dark grey) placed between the veto detectors and the neutron detectors.

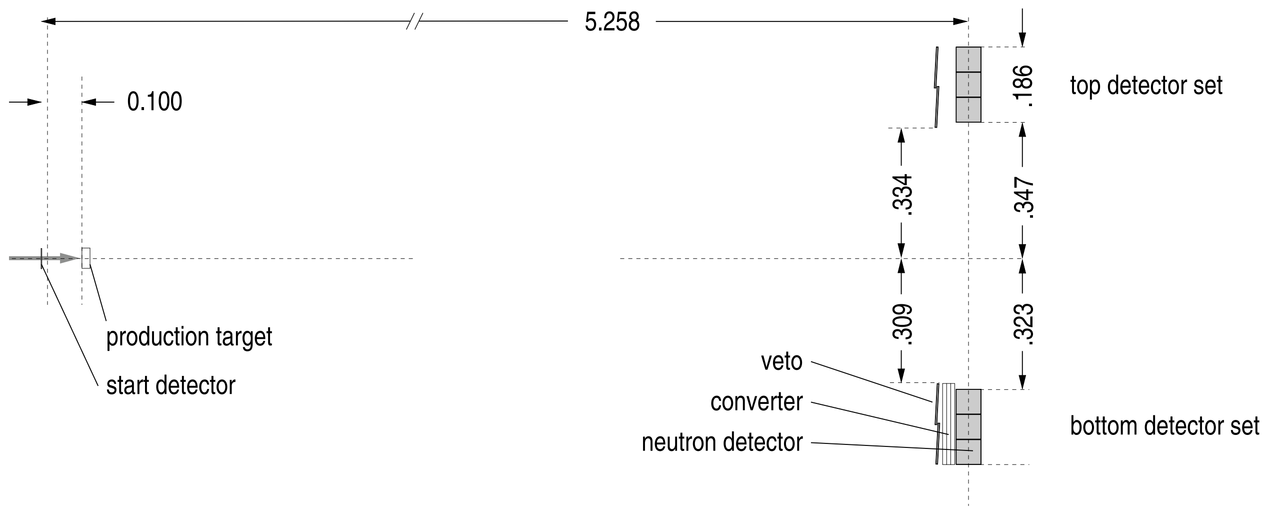

Figure 3: Schematic side view of the detector setup, dimensions are given in meters.

2 EXPERIMENTAL INVESTIGATION

The experiment was undertaken at the RIKEN Accelerator Research Facility (RARF) in Tokyo, Japan. Elements of RARF's neutron detector array NEUT were used for this measurement.

Neutrons of a broad energy range were produced using a 100 MeV/nucleon beam of ^{13}C from the RIKEN Ring Cyclotron impinging on a 2 cm thick aluminum target. The measured energy distribution of the neutrons is displayed in Fig. 1. The primary beam was stopped in the target, so that only lighter fragments and neutrons could reach the detector setup. A thin plastic start detector was placed in front of the production target, while the neutron detectors were mounted at a distance of about 5 m behind the target (see Fig. 3). This distance was needed in order to yield a sufficient energy resolution by a time-of-flight measurement. With a time resolution of 170 ps, we achieved an energy resolution of 1% in sigma at 100 MeV neutron energy.

The neutron detector setup consisted of 2 sets which were placed symmetrically with respect to the beam axis. Each set contained 3 blocks of $6 \times 6 \times 108$ cm^3 BC-408 plastic scintillators stacked vertically. Each scintillator block was read out by two photo-multiplier tubes mounted on either end. The front of each set was covered by plastic veto detectors of 5 mm thickness in order to discriminate charged reaction products. The two detector sets were mounted roughly 40 cm above and below the beam axis (see Figs. 2 & 3).

An iron converter of 2 cm or 3 cm thickness was added to one of the two detector sets, enabling a direct comparison of the number of detected neutrons in each of the two detector sets. One measurement without any iron converter yielded a normalization of the two detector sets with which any asymmetries between the two sets could be corrected.

Separation of beam-related gamma rays and neutrons was achieved by the time-of-flight measurement. A small background of cosmic gamma rays could not be discriminated because plastic scintillator does not have pulse shape discrimination capabilities. It was possible to subtract an extrapolated background in the analysis, although the final results of the analysis showed that the amount of background events was negligible.

3 EXPERIMENTAL RESULTS

The results of this experiment are the relative detection efficiencies of the iron-plastic combination as compared to the pure plastic scintillator detector. The absolute detection efficiencies of plastic scintillator materials has been measured many times and can be calculated with a good accuracy [2,3], therefore we aimed for the simpler measurement of relative efficiencies.

Figure 4 shows the efficiency ratios for the measurements using 2 cm (open circles) and 3 cm (filled

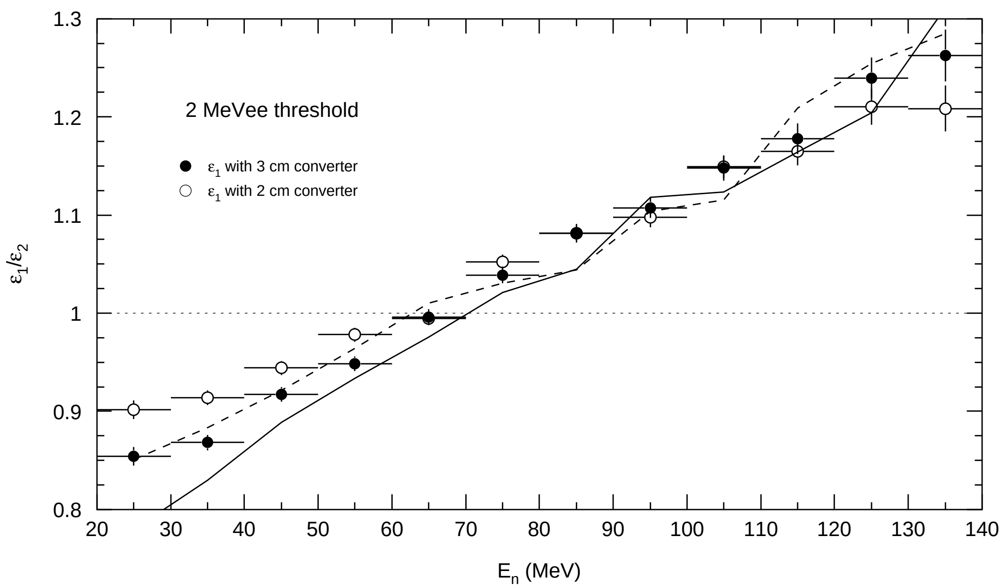

Figure 4: Detection efficiency ratios versus neutron energy for 2 cm (open symbols) and 3 cm (filled symbols) iron converter. The dashed (2 cm converter) and solid (3 cm converter) lines represent preliminary results from a GEANT/FLUKA simulation.

circles) iron converters plotted versus the neutron energy. A dotted line indicates the ratio of one, at which both detector sets detect the same number of neutrons. Ratios larger than one indicate a higher detection efficiency for the iron-plastic combination. The main result of these measurements is that already at energies above 70 MeV the detection efficiency can be enhanced by the use of relatively thick iron converters. The gain in detection efficiency is of the order of 10–20% in the 100–140 MeV energy range.

The fact that the cross over, i.e. the neutron energy above which the use of a converter enhances detection efficiency, occurs between 65 and 75 MeV confirms Monte Carlo simulations that were performed before this measurement. The solid and dashed lines in Fig. 4 indicate the preliminary results of GEANT/FLUKA [4–6] simulations that were done for this specific experimental setup.

4 CONCLUSION

The results of this measurement are valuable information for the design of the proposed large-area high-efficiency neutron detector at the NSCL. This detector will make use of the neutron rich rare isotope beams of the coupled cyclotron facility, and is optimized for the 100–200 MeV energy range. As the measurement presented here shows, the use of passive converters can significantly enhance detection efficiency at these energies.

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