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Average neutron detection efficiency for DEMON detectors

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The neutron detection efficiency of a DEMON detector, averaged over the whole volume, was calculated using GEANT and applied to determine neutron multiplicities in an intermediate heavy ion reaction. When a neutron source is set at a distance of about 1 m from the front surface of the detector, the average efficiency, ϵ_{av}, is found to be significantly lower (20–30%) than the efficiency measured at the center of the detector, ϵ_0. In the GEANT simulation the ratio $R=\epsilon_{av}/\epsilon_0$ was calculated as a function of neutron energy. The experimental central efficiency multiplied by R was then used to determine the average efficiency. The results were applied to a study of the ^{64}Zn+^{112}Sn reaction at 40 A MeV which employed 16 DEMON detectors. The neutron multiplicity was extracted using a moving source fit. The derived multiplicities are compared well with those determined using the neutron ball in the NIMROD detector array in a separate experiment. Both are in good agreement with multiplicities predicted by a transport model calculation using an antisymmetric molecular dynamics (AMD) model code.

1. Introduction

Efficiency calibration of neutron detectors used to measure neutron energy spectra and to determine absolute cross-sections are generally difficult. Detectors with large volumes are often used for such experiments, because the detectors must be set at large distances from the target to allow the determination of neutron energies by time of flight measurements. The efficiencies used in many experiments have been determined essentially for neutrons traversing the center of the detector. However the position dependence of the efficiency is one of the crucial parameters for a precise measurement of neutron spectra. Efficiency evaluations for the DEMON (DEtecteur MOdulaire de Neutrons) detector were previously performed in a wide energy range, from below 10 MeV to above 1 GeV [1–4]. Using a high accuracy tagging technique in which recoil protons were measured by a stack of three drift chambers, Thun et al. performed an accurate measurement for the position dependence of DEMON detector efficiencies in the energy range of 21–100 MeV [4]. They used the p(n,p)n reaction and the angle and energy of the ejected neutron were precisely determined by measuring the recoil proton. Unfortunately in most neutron measurements, a significant portion of the neutron yield is in the energy range below 21 MeV. In order to allow more precise neutron energy measurements over the whole energy range, we have made a simulation to obtain the average efficiency of a DEMON detector for neutrons of energy below 20 MeV over the whole volume. The efficiency calculation cades, such as SCINFUL [5] and CECIL [6], are widely used in this energy region for both central and average efficiency calculations. In this paper, we use a simulation code, GEANT [7] along with our previous simulation for the neutron ball efficiency calculation [8]. In the simulation, the ratio, $R=\epsilon_{av}/\epsilon_0$, is calculated, where ϵ_{av} and ϵ_0 are, respectively, the average efficiency over the whole volume and the central efficiency. In an actual application, the experimentally measured central efficiency combined with the newly extracted ratio R (efficiency $=\epsilon_0 * R$) was then applied for analysis of neutron multiplicities in an intermediate heavy ion reaction. The efficiency corrected energy spectra of neutrons were determined and neutron multiplicities were extracted, using a moving source fit. The extracted neutron multiplicities were compared with those obtained from a separate neutron ball measurement. The results were also compared with those of a transportmodel simulation.

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2. GEANT simulation

The radial position dependence of the neutron efficiency of a large detector is sensitive to the distance between the target (or neutron source) and the detector, because the injection angle deviates from the parallel line relative to the center line of the detector. When the detector–target distance becomes shorter, more neutrons emerge through the side wall, instead of going out through the back surface of the detector, and therefore the effective thickness of the detector is decreased. In Ref. [8], we calculated the neutron efficiency for a 4π detector array, NIMROD (Neutron Ion Multidetector for Reaction Oriented Dynamics), using GEANT3. In that simulation, the scattering, absorption and generation of neutrons were treated in the subroutine GCOLOR, which are designed for low energy neutrons. It makes use of the latest compilation of cross-section data. A more detailed description of the simulation is given in Ref. [8].

The DEMON neutron detectors use a NE213 organic scintillator, which is coupled to a XP4512B photomultiplier tube. The effective diameter of the scintillator cell is 16 cm and the length is 20 cm. The effective diameter of the photo-cathode of the photomultiplier tube is 11 cm. A thick layer of aluminum tube (2 cm thick) is added between the cell and the outside housing of a 20 cm diameter steel tube in order to minimize the cross talk between detectors. A plastic scintillator detector, often placed in front of the DEMON detector to veto charged particles, was not used in either the simulation or the experiment discussed later. Efficiency calibration measurements of the DEMON detectors have typically been performed at a distance of about 1 m [1,4]. Therefore for the simulation we explore at the distance around 1 m.

One of the important parameters for the efficiency calculation is the detection threshold. In the experiments, the detection threshold is set to a selected energy using gamma sources. In the simulation the total energy deposition of the recoiling charged particles in the scintillator is converted to the total light output in units of gamma-equivalent energy, keVee, using the built-in subroutine GBIRK. This subroutine is written based on the works of Birks and Chou [9,10]. In the subroutine a function with three parameters is used for each charged particle, and these parameters are taken from Ref. [11]. The calculated and experimental results for the central and average efficiency are shown in Fig. 1. All data shown were taken at the energy threshold of 500 keVee, which is also used for the calculated efficiencies. The calculated efficiency is overestimated in the energy range of 5–20 MeV. In this energy region there are significant contributions of the alpha particles from the different carbon break up channels, although these alpha particles are properly taken care of in GBIRK. In Fig. 2 the calculated efficiencies are given as a function of the radial distance, ρ, from the center of the front surface. The dashed line shows the calculated efficiency and symbols are from the experiment [4]. As one can see, the calculated efficiency is significantly overestimated near the edge ($6\text{ cm} \le \rho \le 8\text{ cm}$) of the detector. The small contribution outside the scintillator cell wall ($\rho > 8$ cm) originates from the neutrons scattering in the 2 cm thick aluminum outer tube, which is installed to minimize the cross talk between the detectors. The result of the SCINFUL calculation is also shown by the dash-dotted line (no aluminum shield is used). The result is essentially the same as that of the GEANT calculation. Since the area with $6\text{ cm} \le \rho \le 8\text{ cm}$ covers about a half of the front surface, this discrepancy causes a significant deviation of the average efficiency from those of the experimental data as shown in the bottom panel of Fig. 1. In order to improve the light response in this area, an empirical light collection efficiency, L_{eff}, is employed, even though the inside of the scintillator cell is coated by a reflective paint. L_{eff} is only

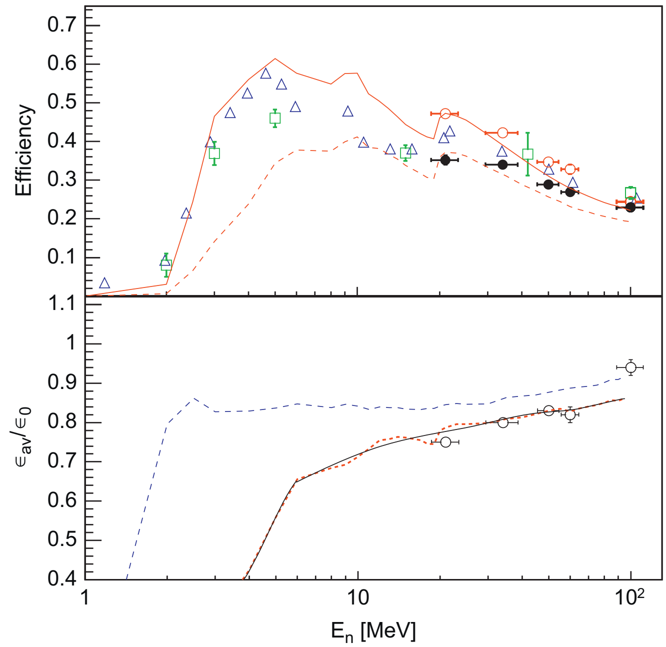

Fig. 1. (top) Neutron detection efficiency. For the calculation of the central efficiency neutrons are injected into a circle of 2 cm radius centered along the center line of the detector (solid line). The dashed line shows the calculated efficiency averaged over the whole front surface with an empirical light collection efficiency (see in the text). Symbols indicate experimental results and are taken from Ref. [1] (triangles), Ref. [2] (squares) and Ref. [4] (circles and dots). Open symbols are for the central efficiency and dots are the average efficiency. (bottom) The ratio of the average efficiency over the central efficiency with (dotted) and without (dashed) light collection efficiency. Solid line is the smoothed efficiency used in the actual calculation. Data (circles) are ratios from those in Ref. [4].

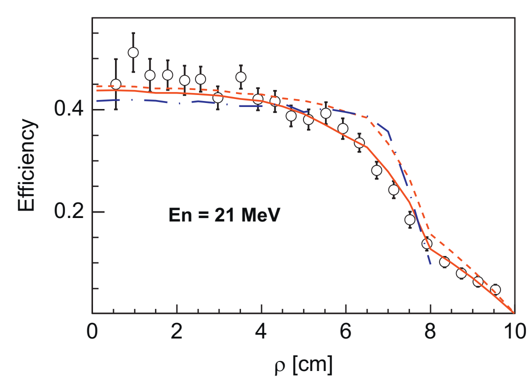

Fig. 2. Neutron efficiency as a function of radius ρ at the neutron energy of 21 MeV. Solid and dashed lines show results of calculations with and without the light collection efficiency correction, respectively. Dash-dotted line is the result of the SCINFUL calculation. Symbols represent the experimental data taken from Ref. [4].

effective near the side wall and given by $L_{eff} = (r_0/r_\perp)^2$ for $r_\perp > r_0$ and $L_{eff} = 1$ for $r_\perp \le r_0$. $r_\perp$ is the perpendicular distance from the center line of the detector to the energy deposition point.

To identify the origin of the light efficiency collection factor, L_{eff}, several attempts were made, converting the energy loss of each recoiled particles to photons in each segmented flight path, following the work of Verbinski et al. [12]. The effects of the reflection index on the wall of the scintillator cell, attenuation length, the size of the effective diameter of the phototubes and photon–electron conversion efficiency in the photomultiplier tubes were studied. The effects are significant concerning to the number of photons which go into the photomultiplier tube and the number of converted electrons at the cathode surface, but