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DIRECT MEASUREMENT OF NEUTRON DETECTOR EFFICIENCIES

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Using the d(d, ^{3}He)n reaction, neutron detector efficiencies for an NE102 organic scintillator have been measured for neutron energies between 25 and 60 MeV.

The determination of neutron detector efficiencies is essential in obtaining absolute cross sections for neutron-producing reactions. Although various techniques have been used to measure efficiencies, the associated particle technique is probably the most inherently complete and accurate method. The associated particle technique has been used extensively in other neutron measurements. For example, neutron flux from the t(d, n)α reaction has been monitored by detecting the associated α-particles[1–4]), and neutron energies have been measured in ^{3}He gas detectors using the ^{3}He(n, p)t reaction[5]). We report here initial measurements of neutron detector efficiencies for a single NE102 organic scintillator using the d(d, n)^{3}He reaction.

The experiment consisted of a measurement of the ratio of the ^{3}He–n coincidence rate to the ^{3}He singles rate, which provides a direct measurement of the neutron detector efficiency. By measuring this ratio at various kinematically allowed detector angles, a wide range of neutron energies can be obtained for a fixed incident deuteron energy. The experiment is greatly facilitated by the relatively high deuteron energies available from the University of Maryland cyclotron.

There are at least two distinct advantages in this associated particle measurement. First, the simultaneous storage of both singles and coincident events removes many of the systematic errors which arise in other techniques. Second, the storage of the coincident neutron pulse height spectrum allows one to obtain in one measurement the neutron detector efficiency for a number of pulse height thresholds.

Deuteron beams of 70.15 and 79.7 MeV from the University of Maryland cyclotron were used to bombard deuterated polyethylene (CD$_2$) targets placed at the center of a 5′ diameter scattering chamber. Two target thicknesses (1.2×10^{-3} and 5×10^{-3} inch) were used, depending on the energy of the outgoing ^{3}He particle. Additional measurements were made with polystyrene targets (CH) in order to obtain the ^{12}C background yields. The beam intensity was limited to 20 nA due to the high counting rates in the neutron detector.

The ^{3}He particle was detected in a counter telescope, consisting of a 200 μm Si surface barrier ΔE detector and a 4 mm Si(Li) E detector, placed on a remotely controlled arm in the scattering chamber. Particle identification was performed electronically, primarily to remove the singly charged particles from the spectrum. The angular resolution of the ^{3}He detector slit system was approximately 0.5°, which when combined with the beam divergence and the multiple scattering in the target led to an angular resolution somewhat better than 1.0°. The zero angle of the scattering chamber and the incident deuteron energy were measured kinematically by comparing the position of the ^{3}He peak from deuterium to those

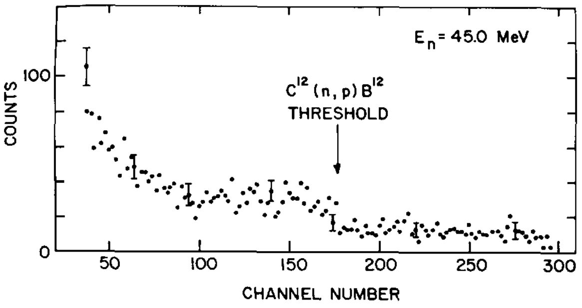

Fig. 1. Pulse height spectrum of 45 MeV neutrons observed in 3″ thick NE102 scintillator, showing ^{12}C(n,p)^{12}B threshold.

from ^{12}C at several angles on either side of the incident beam.

The neutron detector was located outside the scattering chamber and its angle changed manually. The detector consisted of a seven inch diameter, three inch thick NE102 scintillator coupled by a conical light pipe to a 2″ diameter RCA 8575 phototube. The scintillator and light pipe were tightly wrapped with aluminum foil. The experimental geometry was such that the coincident neutrons only illuminated approximately a two inch diameter area in the center of the neutron detector. Thus, due to the large diameter of the detector, accurate positioning of the neutron detector was not essential and edge effects were unimportant in the efficiency measurements.

To obtain a particular neutron energy, the ^{3}He and neutron detector angles were set according to two-body kinematics. The data were recorded event by event using ADCs interfaced to an IBM 360/44 on-line computer. Each event consisted of the total ^{3}He energy, the neutron pulse height, and the output of a time-to-amplitude converter (TAC) which measured the time difference between the ^{3}He and neutron signals. The time information was obtained using fast pickoff units on both detectors. The range and timing of the TAC were adjusted in order to obtain both the real coincidence beam burst and one accidental beam burst (separated by ≈ 85 ns) for subtraction. In addition, if no neutron detector stop signal was obtained within 150 ns, the TAC was stopped with the ^{3}He start signal, thus allowing the simultaneous storage of singles events.

Two types of neutron pulse height thresholds were used in the experiment. First, low pulse height electronic threshold of one light unit (LU) was set using the half height of the Compton edge of the ^{22}Na gamma ray (1.28 MeV). This threshold was accurately set and monitored throughout the run. Secondly, in replaying the data it was possible to calibrate the pulse height spectra using the ^{12}C(n, p)^{12}B and the n–p end points (see figs. 1 and 2). Although these end points were not particularly sharp they were sufficient for the present calibrations. Further details of the experiment can be found in ref. 6.

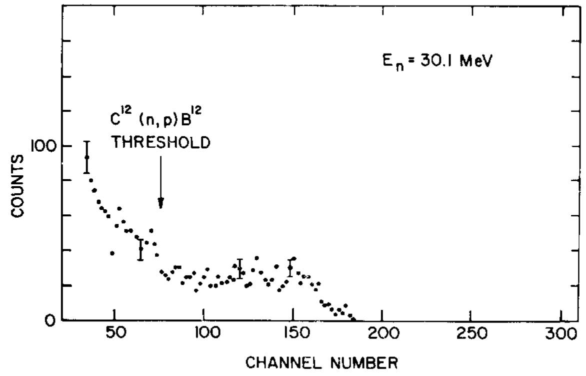

Fig. 2. Pulse height spectrum of 30.1 MeV neutrons observed in 3″ thick NE102 scintillator, showing ^{12}C(n,p)^{12}B threshold.

The neutron efficiencies for several pulse height thresholds are presented in fig. 3. The error bars in neutron energy reflect the kinematic spread introduced by the finite solid angle of the ^{3}He detector. Although there were variations in this spread with angle, they can be reduced somewhat by setting windows on the ^{3}He peak. The uncertainty in neutron energy for the data presented in fig. 2 is typically ± 2 MeV.

The major sources of the error in efficiency were (1) the uncertainty from counting statistics, including background subtraction for the singles spectra, (2) the uncertainty in the pulse height calibration, and (3) the uncertainty due to the scattering chamber wall (estimated to be approximately 2%). Combining these uncertainties the errors in efficiencies typically range from 5% to 6%.

In fig. 2 the measured neutron efficiencies are compared to predictions obtained with the widely used Kurz program[7]). Taking into account the 10% uncertainty generally assumed for this calculation,

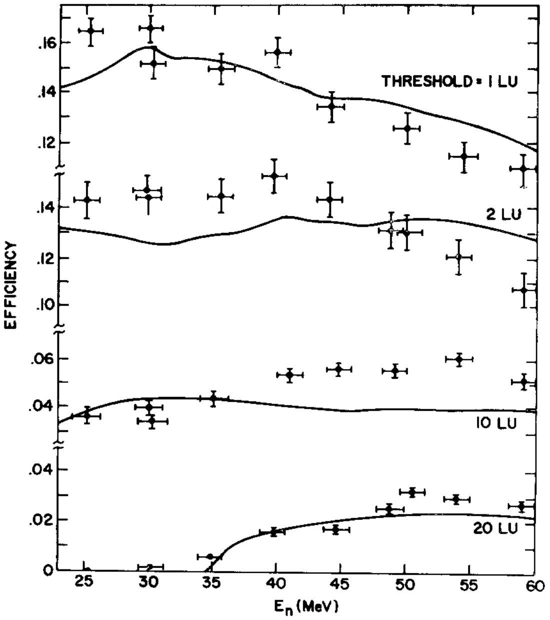

Fig. 3. Measured neutron detector efficiencies at four pulse height thresholds. The curves are theoretical predictions of the Kurz program.

there is fairly good overall agreement with the present results. The worst discrepancies occur for a threshold of ten LU, where differences of up to 50% are observed. Presumably these discrepancies arise primarily from an improper treatment of the $n+{}^{12}C$ reactions in the program.

The present work clearly demonstrates the usefulness of the associated particle technique as a means of measuring neutron detector efficiencies over a wide range of neutron energies for a number of different thresholds. Improvements in the present data can be made by using a deuterium gas target and reducing the ^{3}He solid angle. In addition this work shows the difficulties which can arise when using calculated neutron efficiencies in the analysis of experimental data.

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