AN ABSOLUTE NEUTRON FLUX DETECTOR FOR THE 1-20 MeV ENERGY REGION

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A neutron flux detector for use in the 1-20 MeV energy range is described. A dual thin scintillator configuration yields a proton recoil spectrum which approaches the ideal thin scintillator response. Corrections due to multiple neutron scattering and escape of recoil protons from the scintillator are small. The detector efficiency was experimentally calibrated at 2.47 and 14.1 MeV using the associated particle technique and was extended to other energies by means of a Monte Carlo calculation. The efficiency uncertainty is estimated to be 1-2% in the 1-20 MeV region.

[associated particle, detector calibration, flux detector, Monte Carlo, neutrons, scintillators, Van de Graaff]

Introduction

For fast neutron cross section measurements there is a need for absolute neutron flux detectors having a fast timing and a simple response with neutron energy. A detector with these characteristics has been built at the National Bureau of Standards to be used for cross section experiments with the NBS 150 MeV Electron Linac.

Organic scintillators have been extensively used as neutron flux monitors employing the proton recoil technique. In order to keep multiple scattering corrections small, thin scintillators are necessary. However, at neutron energy of several MeV, the escape of protons produces a large distortion in the proton recoil spectrum. For example, in a 2.5 mm thick scintillator and 14 MeV neutrons, the escape of protons is around 30%.

In the present work a detector is described where the escape of protons is eliminated experimentally, and the multiple scattering correction is low. The detector consists of two thin plastic scintillators optically separated from each other and independently coupled to phototubes. The protons which escape from the first scintillator are detected by the second scintillator which is placed behind the first one.

Because of the low multiple scattering and the spectrum discrimination, there is relatively little dependence on the carbon cross sections or angular distributions. Therefore the detector efficiency is essentially dependent on the hydrogen cross section, which is known with accuracies $\lesssim$ 1%, as well as on light tables and on the hydrogen areal density, which are parameters that can be checked experimentally.

The detector has been calibrated at 2.47 MeV and 14.1 MeV, using the associated particle technique with the NBS Positive Ion Van de Graaff as the neutron source. Details of the calibration are described later.

Theoretical calculations of the detector efficiency and pulse height distributions were performed using a Monte Carlo code in order to extend the detector efficiency to other energies between 1 and 20 MeV.

Detector Design

A schematic diagram of the detector is shown in Fig. 1. It consists of two cylindrical pieces of NE110 plastic scintillators 0.254 cm thick, and 4.70 and 4.90 cm in diameter, respectively. Each scintillator was coupled to a pair of RCA8850 phototubes in head-on geometry. Perspex light guides are used, with the same thickness as the scintillators. As a result, most of the light that reaches the photocathode is by total internal reflection. A small air gap was allowed between light guide and phototube because it was shown to result in a better light collection uniformity at different points on the scintillator.

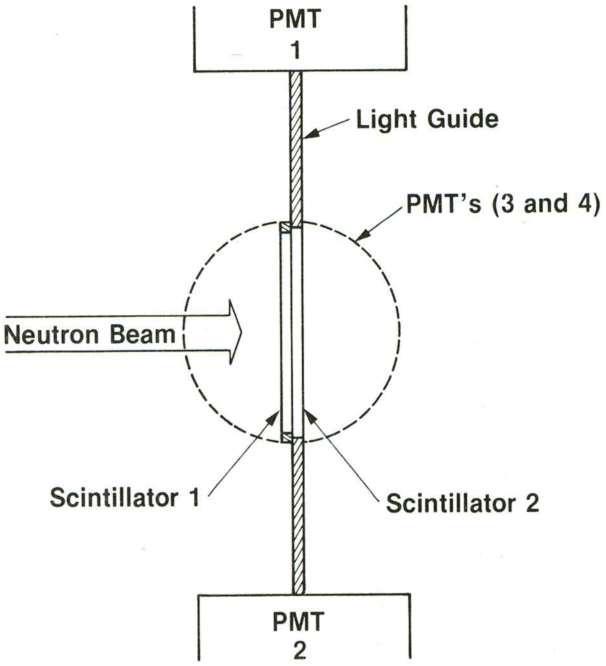

Fig. 1. Neutron flux detector.

Each scintillator was wrapped in a 6.6 μm thick aluminum foil, except at the interface between the two scintillators, where a 0.66 μm thick aluminum foil was used. The phototubes and scintillators were held together inside of a box which has a 54 μm thick aluminum window on each side, in order to make the system light tight.

Electronics

Figure 2 shows a simplified block diagram of the electronics for the flux detector. For each photomultiplier, both a time and linear signal is derived. The linear signals from the pair of phototubes of each scintillator are added and fed into a preamplifier and amplifier system. After adjusting the proper delays, the signals from each amplifier are joined into a sum amplifier. A linear gate placed in the second scintillator leg is triggered by the timing signal from the first scintillator, therefore

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K. H. Böckhoff (ed.), Nuclear Data for Science and Technology, 875–877.

all single events in the second scintillator are rejected. The pulses from the sum amplifier are single events from the scintillator 1 plus sum pulses produced by coincident events between the two scintillators.

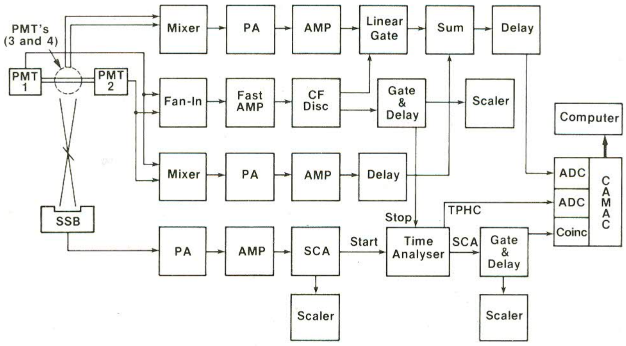

Fig. 2. Electronics for detector calibration.

Detector Calibration

Checks of the absolute efficiency of the detector have been performed by means of the associated particle technique at the NBS 3 MV Positive Ion Van de Graaff. For this purpose, a monoenergetic 500 keV molecular deuterium beam was utilized. The molecular deuterium dissociates upon impact with the target, allowing a 250 keV atomic beam to interact with the target nuclei. The $T(d,n)^4He$ reaction on a 3 mg/cm^2 copper backed TiT target was used to generate 14.1 MeV neutrons[1]. The associated ^4He particles were detected by a Silicon Surface Barrier detector located at 85 degrees with respect to the deuterium beam axis. The neutrons were detected at 90 degrees and 99% of the associated neutron flux was contained in a cone of 6.0 degrees half angle. The cone subtended by the neutron flux detector was 11.0 degrees half angle, which was large enough to account for variations in the beam profile due to deterioration of the tritiated titanium target.

The $D(d,n)^3He$ reaction on a 0.62 mg/cm^2 copper backed TiT target was used to generate 2.47 MeV neutrons. In this case, the associated ^3He particles were detected at 70 degrees with respect to the deuterium beam. The neutrons were again detected at 90 degrees and 99% of the associated neutron flux was contained in 10 degrees half angle. The profile was measured by a monitor consisting of a 2.5 cm diameter, 7.5 cm thick NE110 plastic scintillator. Corrections to the measured profile were applied due to target deterioration, and to the finite sizes of the monitor and target beam spot. The cone subtended by the neutron flux detector was 13.0 degrees half angle, and also considered sufficiently large to account for variations in the beam profile.

The electronics for the associated particle are also included in Fig. 2. The time distribution between the associated particles and proton recoil events was measured with a time analyzer. The analog signal from the sum amplifier of the neutron flux detector was fed into an analog to digital converter (ADC). Another ADC was used to receive the signals from the time analyzer. The data from both ADC's were then transferred through a CAMAC interface into a 32 x 128 work array in the computer for storage.

The experimental neutron detector efficiency is given by:

$$\varepsilon = \frac{Y_{coinc}}{Y_a} \cdot f$$

where	ε	is the efficiency
	Y_{coinc}	is the number of coincidences between the associated particle and the proton recoils.
	Y_a	is the number of associated particles detected.
	f	is the total correction factor including: neutron beam attenuation through the materials between the target and the neutron detector; dead-time losses; divergence of the neutron beam; associated particle background.

Calculated Efficiency

In order to extend the detector efficiency to broader energies, a Monte Carlo code is being developed to calculate the neutron detector efficiency and the expected pulse height distribution of proton recoils as a function of neutron energy. The computer code CARLO BLACK[2], originally written for use with the "Black Detector," has been modified to be compatible with the characteristics of the present detector. The main modifications are: a) dual scintillator configuration; b) up-dated cross sections using ENDF/B-V extended up to 20 MeV neutron energy range; c) use of forced first collision technique; d) effect of escape of protons; e) use of proton light table obtained experimentally.

The calculated pulse height distribution is fitted to the experimental spectrum by means of a code[3] which takes into account the Poisson statistics in the number of photoelectrons detected.

Results and Discussion

Figure 3 shows proton recoil spectra obtained with 14.1 MeV neutrons in an associated particle measurement. Spectrum A is the proton recoil spectrum for energy deposited in scintillator 1. Spectrum B is the proton recoil spectrum due to protons that lose a fraction of their energy inside each scintillator. Spectrum C is the observed spectrum including protons totally absorbed in scintillator 1 and pulses due to protons that lose a fraction of their energy inside each scintillator. Therefore, spectrum C approximates the thin scintillator response and it is the one used to calculate the efficiency. The solid curves are the theoretical spectra obtained with the Monte Carlo code.

Figure 4 shows the experimental efficiencies at 2.47 and 14.1 MeV. The calculated efficiency curve is also plotted as a function of the neutron energy and normalized at 2.47 MeV. The 14.1 MeV point agrees with the theory within 1.8%. The behavior of the calculated curve follows essentially the H(n,n)H cross section with some small irregularities due to C(n,n)C cross section. Therefore, the interpolation in the efficiency curve for the intermediate energy region may be obtained with good accuracy. Our present detector is optimized for energies up to 15 MeV. To measure above that, it is only necessary to replace the second scintillator by another one 4.5 mm thick. The slight increase in the efficiency is small and can be calculated.

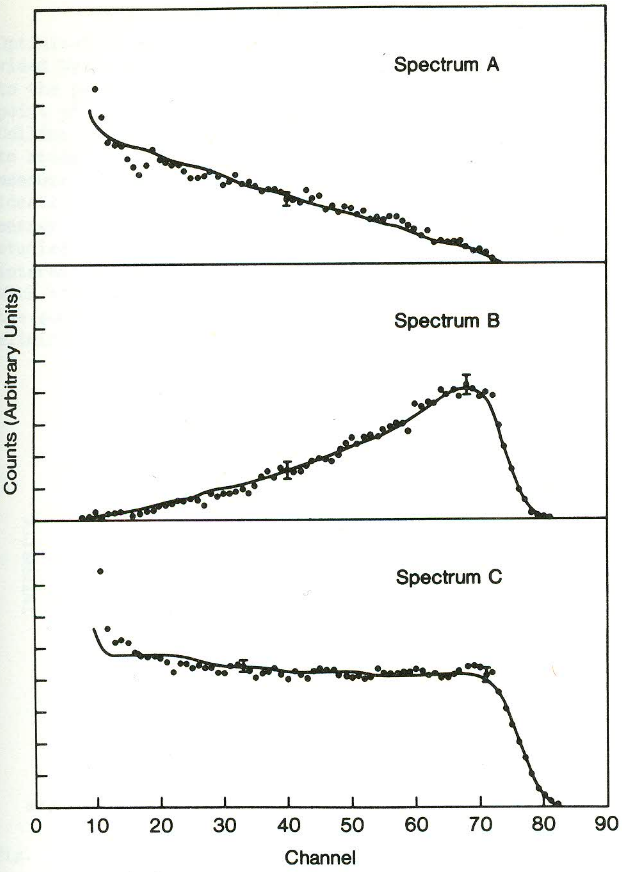

Fig. 3. Experimental proton recoil spectra. Solid curve is a Monte Carlo calculation.

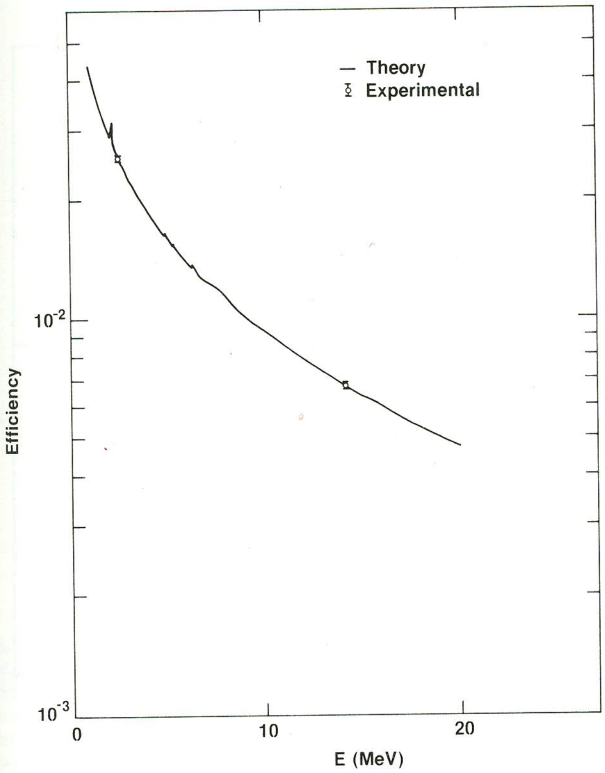

Fig. 4. Detector efficiency curve. The points at 2.47 and 14.1 MeV were obtained experimentally. The calculated curve is normalized at 2.47 MeV.

From these results it can be concluded that the detector can be used as a flux monitor in the 1-20 MeV range. The present accuracy at 2.47 and 14.1 MeV is 1.3%. Because the corrections involved in the calculation are relatively small and the proton recoil spectrum approximates the ideal scintillator response, it is expected that the estimated accuracy for the 1-20 MeV range is around 1-2%.

This detector is presently being used as a flux monitor to measure the ^{235}U(n,f) cross section in the 1-6 MeV range with the NBS Linac as the source of neutrons.

References

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3. M.M. Meier, NBS Internal Report, February 1978.