Nuclear Data for Science and Technology (1988 MITO), 419- 421, Copyright © 1988 JAERI.

MONTE CARLO CALCULATED RESPONSE OF THE DUAL THIN SCINTILLATION DETECTOR IN THE SUM COINCIDENCE MODE

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ABSTRACT: The Dual Thin Scintillator (DTS) is a unique neutron detector that is being developed for improved fluence and spectrum measurement. Current attention has been directed towards understanding some details of the detector response in the sum coincidence mode of operation where a peaked pulse-height response is exhibited throughout the energy region of interest. As a result of the peaked distribution, the detector efficiency is a weak function of the pulse-height bias, allowing the number of recorded events above the bias to be determined with greater certainty. A Monte Carlo code has been used to calculate the sum coincidence pulse-height response at several energies within the 1 to 15 MeV region. The detector efficiency as a function of neutron energy has also been calculated. The results of the Monte Carlo calculations, which include the effect of multiple scattering on the shape of the response function and efficiency curve are presented.

(detector; efficiency; neutron; proton recoil; response function; scintillation)

Introduction

The difficult determination of absolute neutron fluence must be performed in neutron standard cross section measurements. The neutron fluence determination often contributes the largest uncertainty to the measurement error[1]. The development of new and improved neutron detection methods is recognized as an important means of achieving more accurate standard cross section data.

The development of the Dual Thin Scintillator (DTS) at the National Bureau of Standards (NBS) represents an effort to pioneer a new type of neutron detector with improved characteristics[2,3]. The detector utilizes a unique two scintillator detector geometry to produce a response that is calculated with a higher accuracy than normally achieved for thin organic scintillators. The detector, built at the NBS, is designed to operate in the 1 to 15 MeV energy range and is several orders of magnitude more sensitive than the standard geometry proton recoil telescope (PRT) detector which is widely used in the same energy region.

Currently, the DTS response characteristics are being examined for the case where the detector is operated in the sum coincidence mode[4]. In this mode, the detector exhibits a peaked response function for a given neutron energy. The peaked distribution, as opposed to the typical rectangular distribution obtained for a thin-scintillator response, provides a better determination of the fraction of detected events above a given pulse height bias and therefore a more accurate determination of neutron fluence. The peaked response is obtained without a large reduction in detection efficiency and can be calculated with good accuracy.

A general purpose Monte Carlo code has been modified to accommodate the characteristics of the DTS detector and its different modes of operation[2,3]. The calculation is used to study some of the details of the detector response in the sum coincidence mode, including the detector efficiency and pulse height distribution over the full energy range of interest. Results of the calculation show that there are effects from multiple neutron scattering on the shape of the pulse-height response and detector efficiency particularly at the lower end of the 1 to 15-MeV range, although the peaked distribution is maintained throughout. Some of these results are presented along with a brief description of the detector and its operation in the sum coincidence mode.

Detector Description and Operation

The DTS detector consists of two thin organic scintillators, positioned back to back and optically separated. Each scintillator is coupled through appropriate light guides to a separate set of photomultiplier tubes. The pulses from each photomultiplier tube set are combined electronically according to the mode of operation used. The detector configuration is illustrated in Figure 1. The detector can be operated in the rectangular or sum coincidence mode.

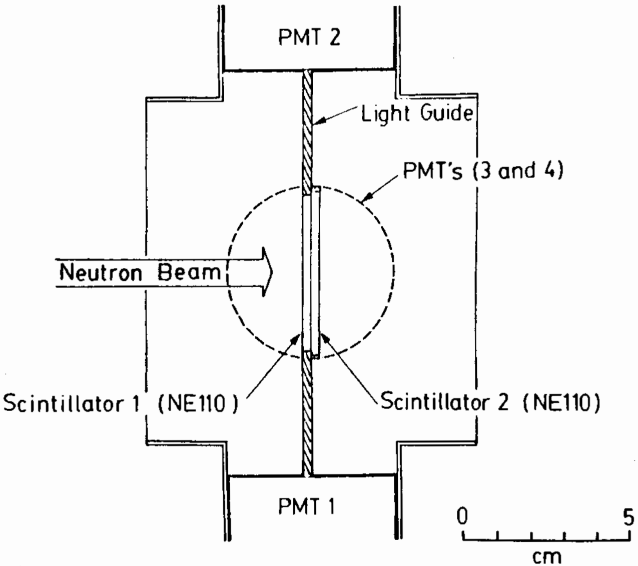

Fig. 1. Detector geometry.

The detector is generally positioned in a collimated neutron beam where the neutrons are incident on the first scintillator face and interact primarily through hydrogen scattering. Recoil protons created in the first scintillator are emitted into the forward hemisphere and either stop in the first scintillator or pass into the second scintillator. The fraction of recoil energy deposited in each scintillator is registered separately so that the total recoil energy can be reconstructed from the sum.

When the detector is operated in the sum coincidence mode, only pulses from each scintillator that arrive in coincidence are summed and recorded. The sum coincidence events correspond to proton recoils that originate in the first scintillator and pass into the second. The energy distribution of these protons is restricted by those recoil angles for which the pathlength to the second scintillator is shorter than the range. Large angle, lower energy proton recoils generally have larger pathlengths in the first scintillator and, because of their shorter ranges, have difficulty reaching the second scintillator. The detector response therefore consists of the more forward scattered, higher energy proton recoil events. These recoil events have energies more strongly correlated with the incident neutron energy and are less likely to fall below or in the region of a pulse height bias.

Calculated Pulse Height Response

The primary response of the DTS detector in the sum coincidence mode can be calculated analytically by considering the angular distribution of recoil protons, range-energy relationships, and the geometry of the detector. Using $E^{3/2}$ as an approximation for the energy dependence of the proton range, the energy distribution of recoil protons that contribute to the sum coincidence responce is obtained analytically as $(E/E_0)^2$, where E_0 is the incident neutron energy. The distribution is peaked at the incident neutron energy. The calculation indicates that at the maximum energy of 15 MeV, 1/3 of the proton recoils produced in the first scintillator are recorded in the sum coincidence. The peaked energy distribution is also shown to be unchanged throughout the 1 to 15 MeV range considered. The analytic calculation has been helpful in illuminating some conceptual aspects of the detection mechanism employed.

A Monte Carlo calculation has been carried out to check the results of the analytic calculation and to include the important details associated with multiple scattering, neutron interactions with carbon, non-uniformity in light collection, and the effect of lost coincidences. The effect of multiple neutron scattering on the sum coincidence response is substantial and is mainly due to neutrons that scatter once in the first scintillator and again in the second scintillator to create a coincidence event. A significant distortion of the peaked energy distribution is observed at the lower energy end of the 1-15 MeV range. However, most multiple scattering events remain above the pulse height bias and can be calculated with reasonably good accuracy. Due to the relatively short range of heavier particles, neutron interactions with carbon contribute to the sum coincidence response only through multiple interactions involving both scintillators and because of the small signals produced, the contribution can be removed by properly choosing the pulse height bias. The effect of lost coincidences due to the finite lower level electronic biases used for each scintillator is important and is carefully calculated by the Monte Carlo code. Response functions obtained from the Monte Carlo calculation at several neutron energies within the 1 to 15 MeV range are shown in Figures 2a through 2d. The peaked distribution is observed to be maintained throughout the 1-15 MeV region.

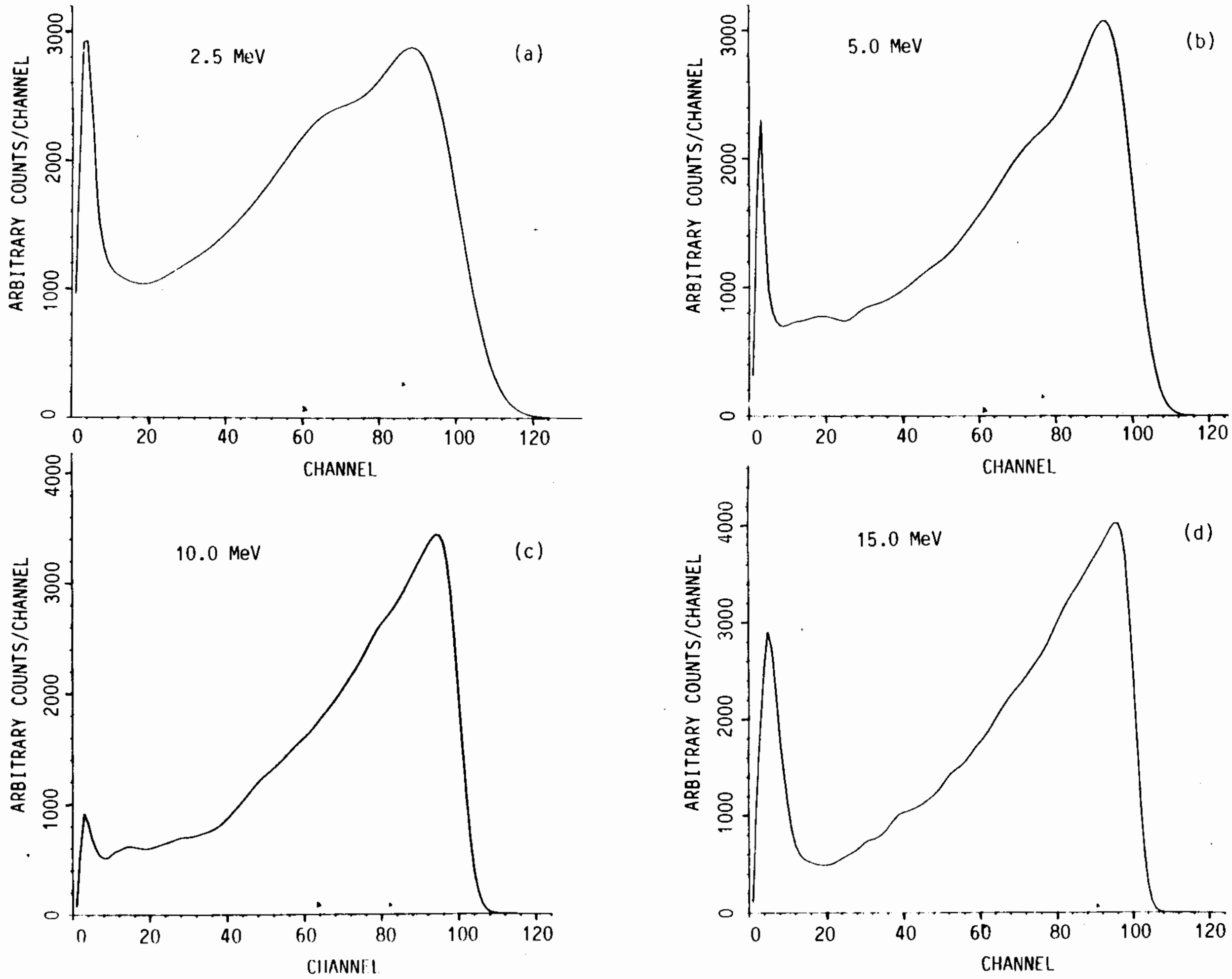

Figure 2. Monte Carlo calculated pulse height distributions for neutron energies of (a) 2.5 MeV, (b) 5.0 MeV, (c) 10.0 MeV and (d)15.0 MeV.

Calculated Detector Efficiency

The DTS detector efficiency is based primarily on the H(n,p) cross section, the number density of hydrogen atoms, and the thickness L of the first scintillator. The second scintillator thickness does not contribute to the DTS efficiency. In the sum coincidence mode, the effective thickness of the first scintillator varies with the incident neutron energy and depends on the range R_0 of protons with maximum recoil energy. Regions of the first scintillator for which knock-on protons have insufficient range to reach the second scintillator are essentially dead to the detection process.

Results of the Monte Carlo calculation show that in the sum coincidence mode, multiple neutron scattering has a dramatic effect on the detector efficiency, particularly at the lower end of the specified energy range. The effective thickness of the first scintillator decreases with decreasing neutron energy as R_0/L, but the full two scintillator thickness remains active to multiple neutron scattering. The multiple scattering contribution to the sum coincidence dominates the rapidly decreasing primary response at the lower energies. A comparison of the detector efficiency as a function of neutron energy is shown in Figure 3 for the cases where the multiple scattering contribution is turned on and then off in the calculation.

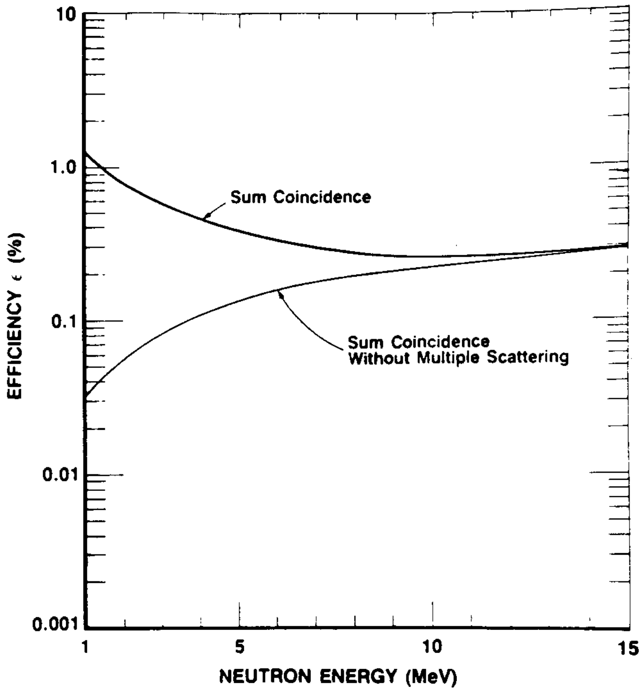

Fig. 3. Monte Carlo calculated detector efficiences with a 15% fractional bias for neutron energies in the 1-15 MeV range. Two cases are shown where the sum coincidence response and the sum coincidence response with multiple neutron scattering neglected are calculated.

Conclusion

The DTS detector is a unique neutron detector developed for absolute fluence determinations in the 1-15 MeV energy range. When operated in the sum coincidence mode, the detector exhibits a peaked pulse height distribution for a given neutron energy. The peaked distribution is obtained without a large reduction in detection sensitivity or accuracy.

A Monte Carlo code has been used to calculate the DTS response for the sum coincidence mode of operation. The results show that the pulse height distribution and detection efficiency for some energies in the 1-15 MeV range are significantly distorted by the multiple neutron scattering contribution to the response. However, the peaked shape of the pulse height distribution is maintained throughout the energy range of interest.

As a result of the peaked shape, a smaller fraction of the pulse height distribution is recorded below a selected bias allowing the absolute number of detected events to be determined with greater certainty. The detector efficiency is therefore a weak function of the bias and is less sensitive to variations in the bias positioning. The sum coincidence response calculated by the Monte Carlo code is on the average a factor of five less sensitive to variations in the bias positioning than expected with a typical rectangular pulse height response.

Acknowledgements

The authors wish to acknowledge J.B. Czirr for the initial suggestion to build the detector. We are also indebted to M.S. Dias, who developed the Monte Carlo code used in this work, was instrumental in building the DTS detector at the NBS, and who gave valuable advice on possible uses for the sum coincidence mode. We thank O.A. Wasson for his advice and guidance in the development of this work.

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