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Measurement of neutron energy from ^{252}Cf using the inverse time-of-flight technique with a VME-based DAQ system

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1. Introduction

Neutron-induced reactions are important not only in astrophysics but also in applications such as nuclear reactors and medical isotope production [1]. Therefore, accurately measuring neutron-induced reactions can play a crucial role in these fields. The time-of-flight (TOF) technique is often used to precisely measure the energy of neutrons. In this work, we measured the energy of neutrons using the TOF method with a BC501 liquid scintillator. Cf-252 was used as the neutron source, and a data acquisition (DAQ) system was constructed using NIM and VME modules.

2. Methods and Results

2.1 Experimental Setup

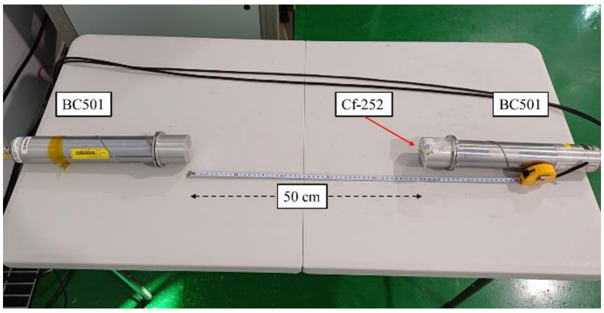

Fig. 1. Experimental setup for neutron TOF

For the neutron TOF experiment using a Cf-252 neutron source, the experimental setup was configured as shown in Fig. 1. To measure T0 and T1, two 2-inch BC501 liquid scintillators with identical specifications were used, and the Cf-252 source was positioned at the right detector (T0 detector) in Fig. 1. The distance between the two detectors, corresponding to the neutron flight path, was set at 50 cm. For the TOF experiment, the time it takes for gammas or neutrons generated by fission reactions to reach the T0 detector was used as the trigger signal. The time it takes for neutrons to reach the detector, which is 50 cm away from the source, was used as the T1 signal. Due to the Cf-252 source being positioned directly in front of the T0 detector, it generates a significant number of trigger signals. Consequently, this may lead to an increase in dead time or pile-up events. To mitigate these effects, the inverse TOF method was employed. In the inverse TOF approach, data acquisition only occurs when a signal is produced at the T1 detector. This technique can eliminate T0 signals that do not contribute to the neutron TOF measurement. To construct such a DAQ system, NIM and VME modules were used (Fig. 2).

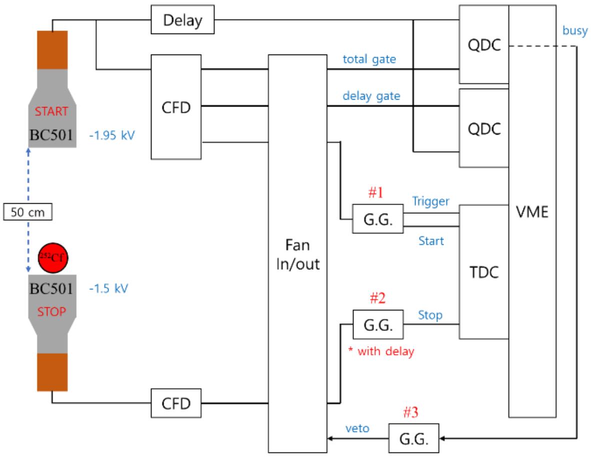

Fig. 2. The DAQ system for neutron TOF experiment consists of NIM and VME modules

2.2 Neutron Detection Efficiency

Neutrons incident on BC501 can interact with the materials of the detector, resulting in the production of charged particles such as proton and alpha. Subsequently, photons are generated by the electrons produced through ionization reactions, which are then converted into electrical signals through the photocathode and PMT. To calculate the response function and detection efficiency as a function of neutron energy, the SCINFUL-QMD code was employed. The SCINFUL-QMD code utilizes the Quantum Molecular Dynamics (QMD) model and the Statistical Decay Model (SDM) to compute the response function and detection efficiency for incident neutrons with energies up to 3 GeV [2]. To calculate the neutron detection efficiency, it is necessary to calibrate light-output of BC501. For the calibration of light-output, Co, Ba, and Cs sources were utilized.

2.3 Pulse Shape Discrimination

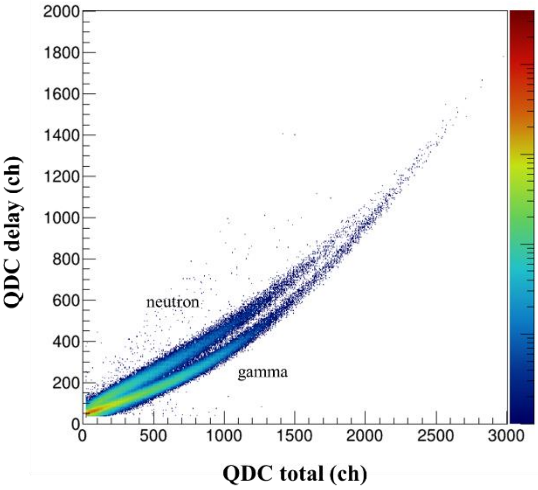

Fig. 3. The measured neutrons and gammas by using PSD method

To distinguish neutrons from gammas, the Pulse Shape Discrimination (PSD) method [3] was employed. Fig. 3 shows the QDC output for neutrons and gammas measured in BC501. The signals produced by neutrons have a longer pulse tail compared to those generated by gammas, resulting in a higher delay/total ratio for neutrons. Therefore, events located on the upper line in Fig. 3 can be considered neutron signals. In the low QDC total channel, there is an indistinguishable region between neutrons and gammas, which is removed using 2D-cutting. The neutron detection efficiency changes depending on the threshold of QDC channel, so it is necessary to apply the threshold value in the SCINFUL-QMD code to calculate the detection efficiency.

2.4 Neutron energy spectrum

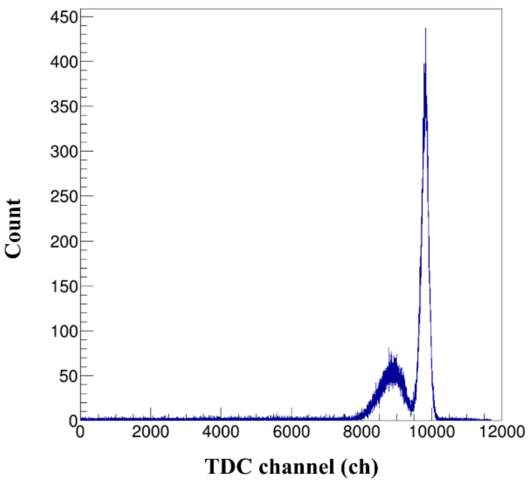

Fig. 4. The measured flight-time spectrum of neutrons and gammas by using inverse TOF method

The time difference between the detections at the T0 and T1 detectors was recorded using a TDC, and the resulting spectrum is as shown in Fig. 4. The peak on the right corresponds to signals caused by gammas, while the peak on the left is due to neutrons. Because we employed the inverse TOF method, the signals from gamma, which arrive first, are positioned on the right side of the spectrum. The gamma peak is located at approximately 9800 channels. The utilized TDC module has a resolution of 25 ps/channel, approximately 9867 channels can be regarded as the time zero point in the inverse TOF method because gamma takes about 1.67 ns to travel 50 cm. Using the channel value difference of neutron events from the zero point, the flight time of the neutrons was measured. By eliminating all gamma events in Fig. 3, the events corresponding to the right peak in Fig. 4 disappear, allowing for the analysis of neutron events only.

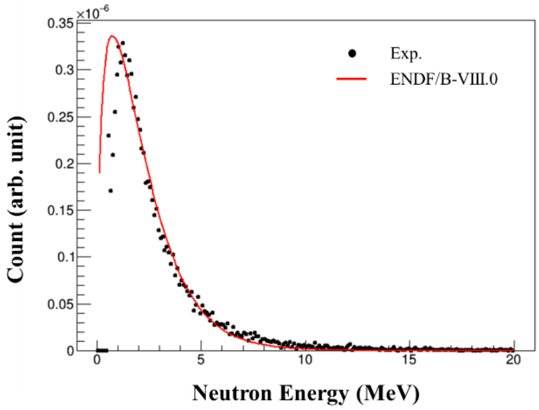

Fig. 5. The measured neutron energy distribution of Cf-252 source with ENDF/B-VIII.0 library

Figure 5 presents the neutron energy spectrum of Cf-252 measured using the TOF method. The data represented by solid line is from the ENDF/B-VIII.0 [4], while the dots indicate experimental data. In regions below 0.5 MeV, the neutron detection efficiency was reduced to zero due to the threshold, making data measurement impossible. From 0.5 MeV to 1 MeV, the experimental data were measured lower than ENDF. However, in the neutron energy range from 1 MeV to 20 MeV, the measured energy distribution showed good agreement with the ENDF data.

3. Summary

Accurate measurement of neutron energy is crucial to study neutron-induced reactions. In this work, the neutron energy spectrum of Cf-252 was measured using the inverse TOF method. The neutron detection efficiency was calculated using the SCINFUL-QMD code, and neutrons were distinguished from gamma signals using the PSD method. The DAQ system for inverse TOF consisted of NIM and VME modules. The measured neutron energy distribution of Cf-252 was compared with the ENDF library, and good agreement was found for energies above 1 MeV.

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