Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 27-28, 2016

Measurement of Neutron Energy Spectrum Emitted by Cf-252 Source Using Time-of-Flight Method

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1. Introduction

Neutrons can be considered to be analogs of the weakly interacting massive particles believed to constitute most of the dark matter in the universe. Such matter is thought to constitute more than 90% of the gravitational mass of the universe and its detection is the subject of major efforts throughout the world [1]. The techniques proposed to detect the neutrons usually require the detection of a secondary recoiling nucleus in a scintillator (or other type of detector) to indicate the rare collision of a neutron with a nucleus. This is the same basic technique, in this case detection of a recoil proton that was used by Chadwick in the 1930 s to discover and identify the neutron and determine its mass [2, 3]. It is primary technique still used today for detection of fast neutron, which typically involves the use of a hydrogen based organic plastic or liquid scintillator coupled to a photo-multiplier tube [4, 5]. The light output from such scintillators is a function of the cross section and nuclear kinematics of the n + nucleus collision. With the exception of deuterated scintillators, the scintillator signal does not necessarily produce a distinct peak in the scintillator spectrum directly related to the incident neutron energy. Instead neutron time-of-flight (TOF) often must be utilized to determine the neutron energy, which requires generation of a prompt start signal from the nuclear source emitting the neutrons [4, 5]. This method takes advantage of the high number of prompt gamma rays. Such gamma rays can be detected outside of a sealed source with a plastic scintillator and can serve to generate a suitable start signal for the TOF measurement of the neutron spectrum. In this study, we describe such an experiment (above mentioned) to measure incident neutron energy using the TOF method and details are as follows.

2. Methods and Results

2.1 Experimental Setup

In our experimental setup, a Cf-252 neutron source was used to measure neutron energy spectrum using the TOF method. The Cf-252 source usually includes both alpha and SF decay branches, with alpha decay comprising 97% of the activity and SF the remaining 3%. Approximately 4.4×10^3 neutrons are emitted per second per μCi of the Cf-252 source. In this experiment, the Cf-252 source with 8.7 μCi activity was located at the 70 cm distance to the BC-408 plastic scintillator (Saint-Gobain) for measuring a stop signal. Liquid scintillator (Saint-Gobain) to measure a start signal was placed close to the source. Primarily, lead bricks with 5 cm thickness were installed in order to block the radiation such as cosmic ray that is irradiated from the outside. Also, the bricks as a role in reducing the gamma-ray intensity were installed in order to prevent the excessive irradiation of the gamma-ray around the Cf-252 neutron source. Likewise, the source was placed to improve the accuracy of measured values at 5 cm distance from the start detector. Finally, experimental equipment were placed to block the external light and other radiations inside the 50 × 50 × 100 cm black box.

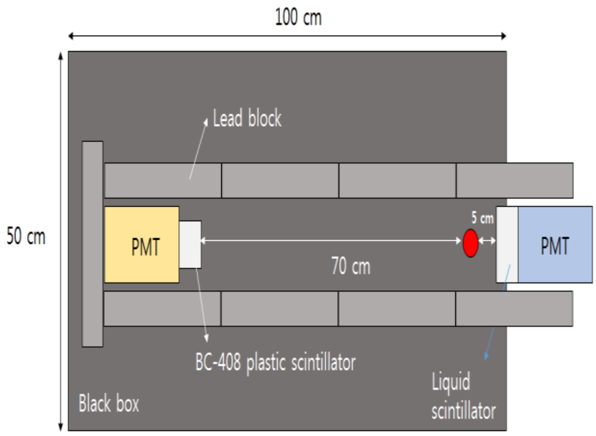

Fig. 1. Experimental setup for measuring TOF spectrum of the BC-408 plastic scintillator.

2.2 Electronics

Fig. 2 shows a conceptual schematic for measurement of the Cf-252 neutron spectrum using the TOF method. Specifications of modules used to measure the neutron spectrum are shown below:

a) Start signal : Liquid scintillator
b) Stop signal : BC-408 scintillator
c) PMT : Hamamatsu H6614-70 (1500 V)
d) H.V power supply : Ortec 556, CAEN N1470
e) CFD : Ortec Quad 935
f) Delay : Ortec 425A
g) TAC/SCA : Ortec 567
h) MCA : Ortec 919E

In the setup shown in Fig. 2, the timing spread, using constant-fraction discriminators (CFD) was 2 – 4 ns (FWHM) and somewhat worse (up to 2 times) when using other types of NIM timing discriminators. The CFD module has a property of 20% constant fraction and threshold value of the CFD module was adjusted to -20.12 mV (lowest value of the module in order to reduce the loss of particles) by a small driver and the value was confirmed using a 175 True RMS Multi-meter (Fluke). Any other values of variable were used the default value of the CFD. Table I indicates time of flight to reach the stop detector (BC-408 detector) for neutron energy change. In the case of gamma-ray, the time of flight to reach the stop detector was calculated 2.333 ns. Because of the resolution of the detector, peak of the gamma-ray at the 2.333 ns position on X-axis was not accurately shown. Thus, Delay module was used and adjusted with 48 ns in order to show the peak of the gamma-ray at 50.333 ns position. Finally, full scale time range of the TAC module was selected of 200 ns with dispersion of 0.1 – 1 ns per channel in the MCA, depending on the detector timing resolution. And then, the 512 channels in the MCA module were set to have a resolution of 0.39 ns/ch. The resolution of the 0.39 ns/ch indicates that it has a measurement error of about 0.2 MeV at 3 MeV neutron energy, depending on the neutron energy.

Table I. Time of flight to reach the stop detector for neutron energy change

Energy (MeV)	Time (ns)	Energy (MeV)	Time (ns)
0.5	71.567	4.5	23.932
1.0	50.626	5.0	22.713
1.5	41.352	5.5	21.664
2.0	35.826	6.0	20.750
2.5	32.057	6.5	19.944
3.0	29.275	7.0	19.226
3.5	27.115	7.5	18.582
4.0	25.373	8.0	17.999

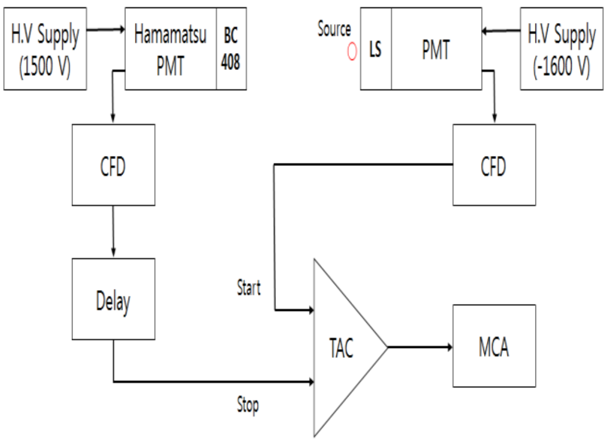

Fig. 2. Conceptual schematic for measurement of the Cf-252 neutron spectrum using the TOF method.

2.3 Neutron Spectrum

The TOF spectrum using the BC-408 plastic scintillator as a stop signal detector taken with the setup and electronics shown in Figs. 1 and 2 is shown in Fig. 3. The spectrum was measured for 5 hours. The large gamma-ray peak (50.333 ns peak position) seen in the TOF spectrum is due to the prompt fission gamma-rays detected by the TOF detector, which are delayed relative to the prompt gamma-ray detector (Liquid scintillator) signal by the difference in flight paths. Broad spectrum measured in the right position of the gamma-ray peak can be estimated neutron emitted by the Cf-252 source. Time scale was converted to neutron energy scale through calibration of the time-of-flight. Fig. 4 shows the Cf-252 fission neutron energy spectrum deduced from the measured TOF spectrum. The neutron energy more than 8.5 MeV cannot be shown the graph because of the influence of the 0.39 ns/ch resolution. The fission process of the Cf-252 typically produces two medium-mass fission fragments that are excited above their ground state and are neutron-rich relative to nearby stable nuclei. The fission fragments will then quickly emit on or more neutrons. Thus, one might expect that the neutron energy spectrum is similar to a Gaussian distribution and neutron energy spectrum equation of the Cf-252 source calculated by the Gaussian function fitting is below and Table II indicates calculated values for parameters in this study:

$$y = y_0 + \frac{A}{w\sqrt{\pi/2}} exp(-2\frac{(x-x_c)^2}{w^2}) \qquad (1)$$

Table II. Calculated values for each parameter through the Gaussian function fitting

y	Relative counts	
x	Neutron energy (0.5 – 8.5 MeV)	
Parameter	Value	Standard error
y_0	16.48223	0.82443
x_c	2.39486	0.13437
w	2.97584	0.34947
A	154.42528	15.33703

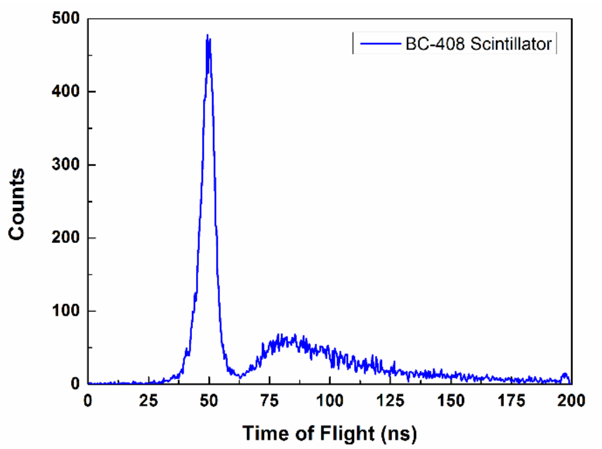

Fig. 3. The TOF spectrum of the BC-408 plastic scintillator that was measured using the experimental setup shown in Fig. 2. The Delay module was applied to the gamma ray peak position in 50.333 ns.

3. Conclusions

The Time-of-Flight method was used to measure neutron energy spectrum emitted by the Cf-252 neutron source. Plastic scintillator that has a superior discrimination ability of neutron and gamma-ray was used as a stop signal detector and liquid scintillator was used as a stat signal detector. In experiment, neutron and gamma-ray spectrum was firstly measured and discriminated using the TOF method. Secondly, neutron energy spectrum was obtained through spectrum analysis. Equation of neutron energy spectrum that was emitted by Cf-252 source using the Gaussian fitting was obtained. In future, the discrimination ability of the plastic scintillator was evaluated using the FOM analysis.

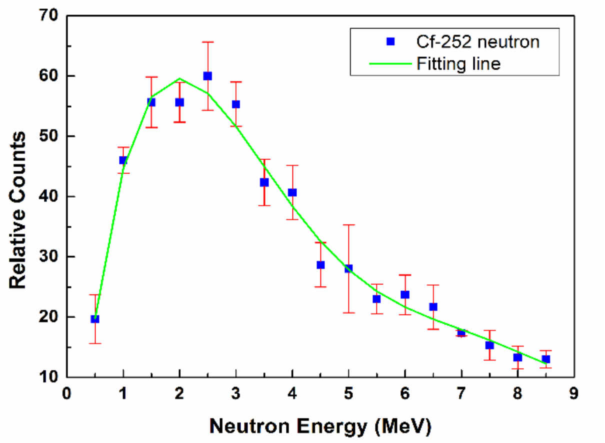

Fig. 4. The Cf-252 fission neutron energy spectrum deduced from the measured TOF spectrum.

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