Time-of-flight Measurement on the Neutron with a Maximum Energy in KOMAC

Dong-Hwan Kim [a,b], Soobin Lim [a], Jae-Hyung Park [a], Pilsoo Lee [b], Jeong-Jeung Dang [b*], Hyeok-Jung Kwon [b], Han-Sung Kim [b], Kyoung-Jae Chung[a] and Yong-Seok Hwang[a]
[a]*Dept. of Nucl. Engr., Seoul Nat'l Univ., 1 Kwanak-ro, Kwanak-ku, Seoul, Korea*
[b]*Korea Multi-Purpose Accelerator Complex, KAERI, 181 Mirae-ro, Geoncheon-eup, Gyeongju, Korea*
[*]*Corresponding author: jjdang@kaeri.re.kr*

1. Introduction

The radiation effects on semiconductor devices have increased as semiconductors, which are essential components of high-tech industries, have become thinner by nanometers. Accordingly, a soft error problem in which the entire system including semiconductors is threatened with even trace amounts of radiation are becoming important.

A particle accelerator capable of generating high-energy particles similar to those of nature may play a role in determining the frequency of occurrence of such a semiconductor soft error due to terrestrial cosmic radiation. Figure 1 shows lethargy representation of white neutron sources and terrestrial neutrons [1,2]. KOMAC is currently experimenting with generating neutrons with a white spectrum by reacting with a target composed of copper using a proton beam that can accelerate up to 100 MeV. In order to certify this facility as one of the global standard white neutron sources, a study is needed with measurements and calculations of the neutron flux and the energy spectrum in depth [3]. This paper presents the specific time-of-flight measurement on a maximum energy of proton-induced neutrons and comparison with Monte-Carlo simulation results.

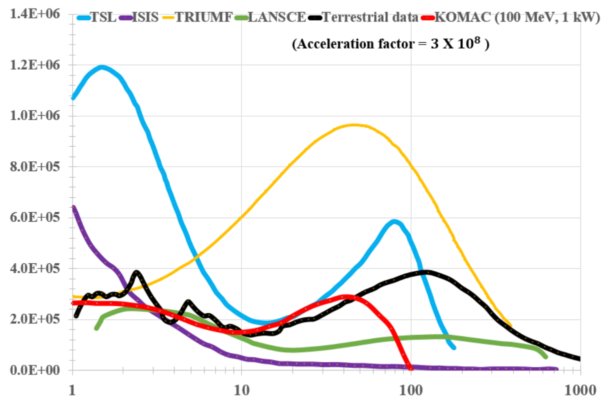

Fig. 1. Lethargy representation of white neutron sources and terrestrial neutrons [1,2].

2. Methods and Results

As measuring methods of the neutron energy spectrum, there is a passive method, a multi-foil activation method, and an active method, a time-of-flight method. Among them, in order to produce a real-time measurement with good energy resolution through the time-of-flight method, both a short beam pulse width and a fast detection system are required. Since KOMAC is currently developing a short pulse beam extraction system, it was necessary to devise a method that can measure neutron energy using a long pulse beam of 20 microseconds or more. The gamma-flash detector is used to tag the timing at which the beam-target reaction occurs, and the fastest, that is, the energy of the neutron with the highest energy is measured using only the earliest part of the beam pulse. Through this gamma-flash tagging neutron time-of-flight method, we were able to successfully measure neutrons with maximum energy close to 69 MeV and 100 MeV, respectively. Also, the experimental results could be compared with the Monte-Carlo calculation results.

2.1 Experimental Setups

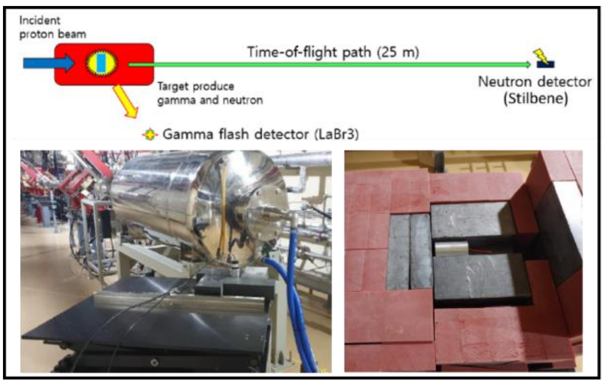

Fig. 2. Overview of gamma-flash tagging neutron time-of-flight measurement.

Neutrons are generated by proton-copper reaction at the beam dump. Gamma-flash detector plays a role of tagging the timing of beam-target reaction. Gamma scintillator LaBr3(Ce) was adapted as a gamma-flash detector and installed at 1 m away from the beam dump because of its fast responsibility. Stilbene neutron scintillator was selected as a neutron time-of-flight detector due to its fast response and superior neutron/gamma discrimination ability by a difference in pulse shapes. To achieve good energy resolution for the fast neutrons up to 100 MeV, stilbene detector was located 25 m away from the beam dump and enclosed by neutron/gamma shielding structures made up of borated polyethylene and lead.

2.2 Timing signal processing and time-energy conversion.

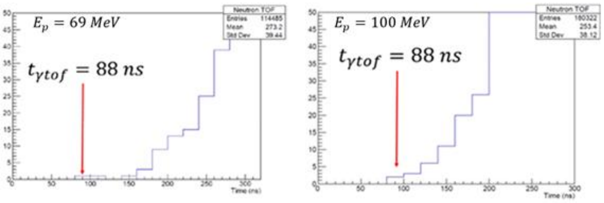

Fig. 3. Gamma time-of-flight histogram at 69 MeV and 100 MeV proton beam experiments.

Timing delays between the gamma-flash detector and neutron detector were recorded by 500 MS/s fast digitizer within preset coincidence windows. The windows are much narrower than the beam pulse width, such as 500 ns (TOF gate) and 20000 ns (pulse width). Figure 3 shows that stilbene detector have the same gamma TOF delay of 88 ns to the different proton beam energy; 69 MeV and 100 MeV. This result supported the consistency of the timing delay with the preceding gamma flash detector.

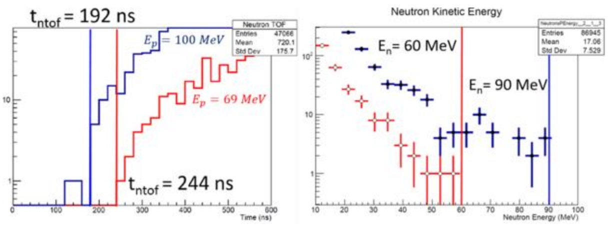

Fig. 4. Neutron time-of-flight histogram and processed energy histogram at 69 MeV and 100 MeV proton beam experiments

Coincidence delays were accumulated during repetitive beam pulses, and converted into the kinetic energies of neutrons in the post processing. Figure 4 showed neutron TOF delays and estimated neutron energy according the proton beam energy. Estimated neutron energy was a little lower than the incident proton beam energy; 60 MeV for the 69 MeV proton and 90 MeV for the 100 MeV proton.

2.3 Comparison with Monte-Carlo simulation results

Monte-Carlo simulation codes – Geant4 and MCNP6 were utilized to numerically calculate neutron energy spectra at the detector [4,5]. Figure 5 shows steep drop in partial neutron fluxes nearby 60 MeV and 90 MeV, respectively. Therefore, it can be inferred that there are little chances to measure the corresponding incident proton beam energy within the limited number of beam pulses. To obtain more accuracy, repetition rates of experiment needed to be drastically increased by introducing additional beam chopping system before the beam dump.

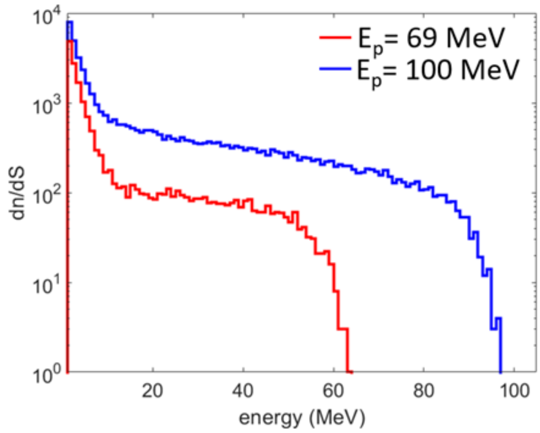

Fig. 5. Neutron energy spectra calculated by Monte-Carlo simulation.

3. Conclusions

Time-of-flight measurement of a maximum on the neutron with a maximum energy was performed by using gamma-flash time-tagging method. Neutron energy up to 60 MeV and 90 MeV was estimated for the 69 MeV and 100 MeV long-pulsed proton beam. The discrepancy could be comprehended with Monte-Carlo simulation results.

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