Development of Proton Recoil Detector for Measurement of Ultrafast Neutron Spectrum with YAG:Ce Scintillator

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1. Introduction

Accelerator-based neutron source is actively under development at various facilities in South Korea. However, characterization technique for such neutron source is, though essential, not as much prepared. Energy of accelerator-based neutron source ranges from thermal (0.025 eV) to ultrafast (> 20 MeV). In particular, energy measurement of ultrafast neutron usually is usually implemented with neutron time-of-flight method [1], but it is often limited due to the flight path which requires vast space for its collimating tunnel. Therefore, a prototype proton recoil detector with scintillation detector is designed and tested for ultrafast neutron spectroscopy in limited space.

2. Detector Design

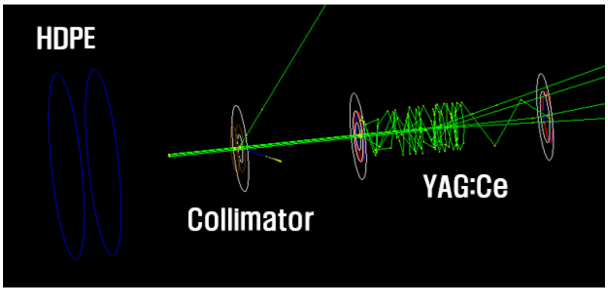

Figure 1. Simulation of the proton recoil detector.

Fig. 1 is Geant4 simulation [2] of a proton recoil detector for conceptual design. When an ultrafast neutron collides with hydrogen in HDPE, a recoil proton is produced with an angle-dependent energy. The recoil proton goes through collimator and deposit energy into the scintillator. the scintillator is composed of YAG:Ce crystal due to its relative insensitivity to neutrons and fast (~ 70 ns) decay time constant [3], for the measurement in high radiation environment.

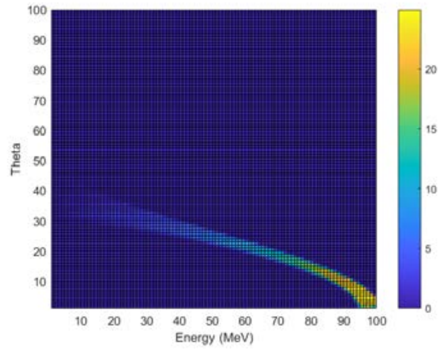

Figure 2. Energy-angle histogram in n-p conversion.

Fig. 2 shows energy dependency on the scattering angle when 3 mm HDPE is applied as the neutron-proton converter with 10 mm x 30 mm collimation path. 10% of systematical energy broadening and 8.5×10^{-6} of detection efficiency is expected for the detector.

3. Measurement and Result

3.1. Energy calibration

Scintillation light yield of YAG:Ce at high energy proton is rarely known and therefore need to be calibrated with a neutron source. 100 MeV proton accelerator in KOMAC [4] can produce ultrafast white neutrons with proton beam irradiated into a copper beam dump at the end of its beam line, and maximum energy of produced neutron is determined by the incoming proton energy. The scintillation light yield is calibrated with maximum light output per scintillation pulse with variable proton beam energy from approximately 33 MeV to 100 MeV. Fig. 3 is the maximum light yield of a pulse with different incoming proton energy.

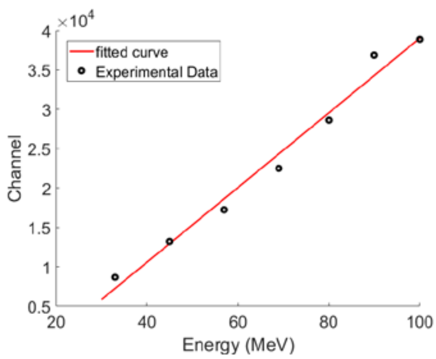

Figure 3. Detector light yield per incoming proton.

The elastic scattering cross section of neutron-proton is also dependent to the incoming neutron energy, which contributes the detection efficiency. The cross section is well studied and distributed in National Nuclear Data Center [5]. Fig. 4 is the cross section used as energy efficiency of the detector.

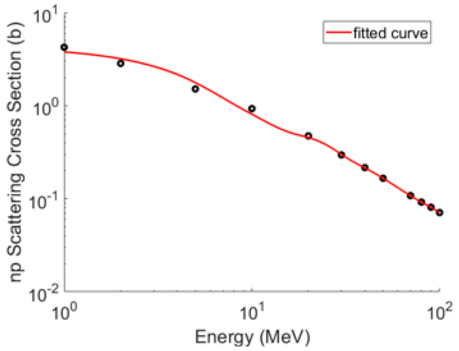

Figure 4. Neutron-proton elastic scattering cross section from 1 to 100 MeV with fitted curve.

3.2. 100 MeV neutron spectrum measurement

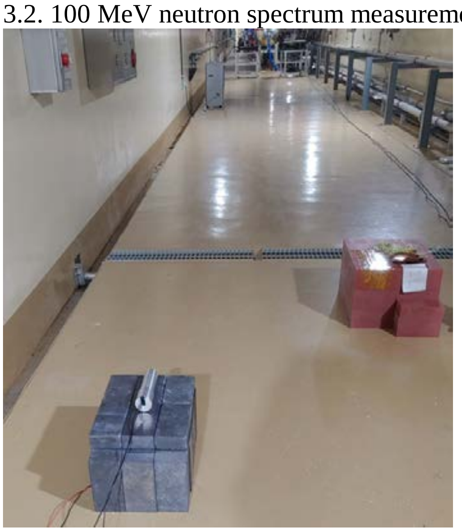

Figure 5. Picture of the neutron measurement in KOMAC.

Initial measurement of neutron spectrum is conducted with 100 MeV proton beam irradiated to the Cu beam dump. To measure only the n-p converted protons inside the detector, the energy histogram is obtained with and without n-p converter inside the detector. Distance from the detector to the beam dump is 25 m, and 7^{o} away from the beam irradiation axis. Fig. 6 is energy histograms with and without the HDPE converter.

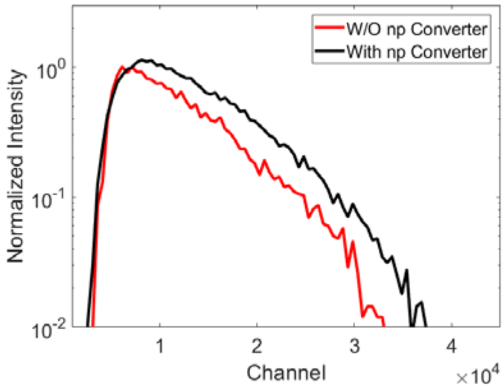

Figure 6. Detector energy histogram measured with and without HDPE converter.

Assuming that the difference between the histograms are converted recoil protons, spectrum unfolding is conducted with n-p elastic cross section and light yield calibration result. Fig. 7 is the result of neutron unfolding and comparison with Geant4 simulation result at the position of measurement [4]. Horizontal error bars are uncertainty expected from the collimator structure of the recoil detector, and vertical error bars are statistical standard deviation.

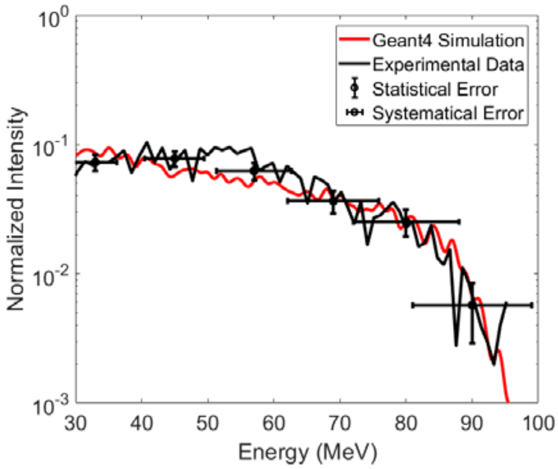

Figure 7. Unfolded neutron spectra from the measurement and comparison with Geant4 simulation

4. Conclusions

For characterization of accelerator-based ultrafast neutron sources in limited space, a proton recoil detector with YAG:Ce scintillator is designed. Preliminary measurement of neutron spectrum measurement with white neutron produced by 100 MeV proton irradiated to Cu beam dump is conducted. Unfolded neutron spectrum shows an agreement at approximately 30 to 100 MeV range, which confirms feasibility as an ultrafast neutron spectrometer. The recoil detector will be improved in the future with pulse shape discrimination (PSD) method, or addition of identical detector without HDPE converter so that it can directly obtain neutron spectrum without additional measurement.

Acknowledgment

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