# Optimizing Simulation of Polyethylene Thickness for Applying a GEM-based Fast Neutron Detector

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## 1. Introduction

A gas electron multiplier (GEM) is a type of gaseous ionization detector used in nuclear and particle physics, and radiation detection. All gaseous ionization detectors are able to collect the electrons released by ionizing radiation, guiding them to a region with a large electric field, and thereby initiating an electron avalanche. The avalanche is able to produce enough electrons to create a current or charge large enough to be detected by electronics. In most ionization detectors, the large field comes from a thin wire with a positive high-voltage potential; this same thin wire collect the electrons from the avalanche and guides them towards the readout electronics. The GEM creates the large electric field in small holes in a thin polymer sheet; the avalanche occurs inside of these holes. The resulting electrons are ejected from the sheet, and a separate system must be used to collect the electrons and guide them towards the readout [1, 2]. The GEM have many advantages such as very high rate capability, milli-metric space resolution, radiation hardness, and low sensitivity to gamma rays. For these advantages, the GEM is especially used to detect fast neutrons which are occurred by D-D and D-T reactions in nuclear fusion device or neutron generator. In this study, the optimizing simulation of polyethylene thickness for applying the GEM-based fast neutron detector was conducted to study neutron detection efficiency.

## 2. MCNPX Simulation

### *2.1 Principle of GEM Detector*

A GEM detector consists of multi-layer structure. Fig. 1 shows a layout of the GEM-based detector. The first layer is a proton recoil neutron converter made of polyethylene by (n,p) reaction. The thickness of the converter needs to optimize respectively to maximize the proton production rate at 2.5 MeV neutron source, in this study. The second layer is constituted by an amplifying structure in which the recoil protons produce a detectable electron signal through ionization of gas atoms such as Ar/$CO_2$ mixture, consisting of a drift gap where the primary ionization is produced, one transfer gap and an induction gap for the charge collection. The GEM foils are stacked between a cathode and a segmented anode connected to the electronic system. Thus, it is necessary to calculate the optimal thickness of the converter to obtain high detection efficiency of the fast neutron because it requires more protons to generate more electrons.

### *2.2 Production of Recoil Protons by Fast Neutrons*

Neutrons, having no charge and with a mass slightly higher than that of a proton, do not interact directly with electrons but are confined to direct nuclear effects (elastic and inelastic scattering) and nuclear reactions (the absorption of a neutron by the nucleus and the emission of electromagnetic radiation or an energetic particle). The elastic collisions are billiard ball collisions which result in sharing of kinetic energy of the neutron between the target nucleus and the impacting neutron; thus, leaving a less energetic neutron and highly energized recoil nucleus. The recoil nuclei quickly become ion pairs and loose energy through excitation and ionization as the pass through the reaction material. The energy of the recoil nucleus is below:

$$E_{recoil\ proton} = E_{neutron}\frac{4A}{(1+A)^2}(\cos\theta)^2 \quad (1)$$

where A is a mass number of the recoil nucleus, and ϴ is a scattering angle. From above equation we can see that the energy is a function of scattering angle. Thus, the energy spectrum of the recoil proton is indicated for various values (0 to maximum neutron energy) of the recoil emission angle.

### *2.3 MCNPX Modelling*

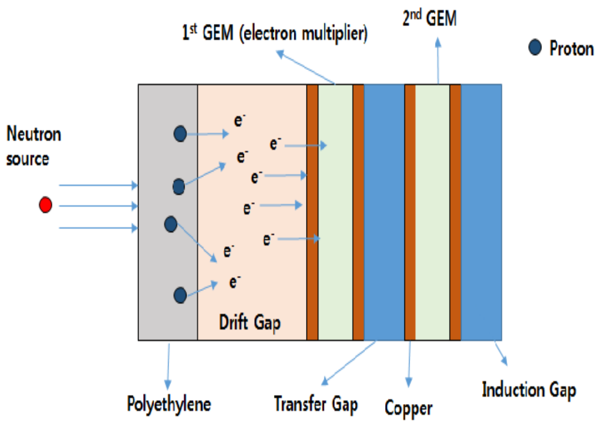


Fig. 1. Schematics of the modelled GEM detector design. The neutron is a beam type source. The recoil protons inject a drift gap region.

A neutron conversion material such as polyethylene is needed to measure the fast neutron using the GEM. The polyethylene layer serves as the neutron converter. The neutrons are converted in protons through elastic scattering on hydrogen. Energy spectrum and number of the recoil proton generated by (n,p) reaction were calculated for studying an optimal thickness of the polyethylene and changed neutron energy with respect to 1 mm polyethylene thickness to obtain the highest fast neutron detection efficiency using the MCNPX [3]. The basic structure which was modelled by the MCNPX consist of four component: (1) Neutron source, (2) Polyethylene as a neutron converter, (3) Fiber glass as a case, (4) region for proton detection (second layer). The 2.5 MeV neutron source as a beam source type for varying the polyethylene thickness was selected to evaluate the neutron produced by D-D reaction in the neutron generation devices. The fiber glass was used to prevent a leaving proton. The proton region was selected to a vacuum status. A distance was 1 mm between the polyethylene and the neutron source. The simulation parameters are as below:

- Neutron energy : 2.5, 5, 10, 14 MeV (beam type)
- Polyethylene thickness
  : 0.01 to 0.1 mm ($\Delta t$ = 0.01 mm)
  : 0.1 to 0.5 mm ($\Delta t$ = 0.1 mm)
  : 1.0, 1.5, 2.0, 5.0, 10.0 mm
- Neutron number : $10^7$@each simulation
- Proton energy cutoff : 0.1 keV (selected)
- Cross-section library : 1001.24h, 6012.24h

### *2.4 Energy Spectrum and Number of Recoil Proton*

As mentioned above, the proton detection region consist of a thin polyethylene radiator coupled to the second layer which is sealed by a fiber glass. Fig. 2 shows energy spectrum of the recoil protons emitted from the polyethylene foil vs. the energy of the incident neutron energy. The layer with density 0.94 g/cm$^3$ at room temperature, was placed between mono-directional neutron beams. The detection region was in close contact to the polyethylene layer and the simulation was performed for a wide range (2.5 – 14 MeV) neutron energies. As can be observed from Fig. 2, the spectrum of the recoil protons emitted by the converter does not have the characteristic rectangular shape [4] as one might expect from a hydrogen-rich material; due to the fact that protons lose energy along their path inside the converter because of interaction with the atoms of the converter.

A parameter which is associated with the neutron detection efficiency of the GEM detector is a number of the recoil protons generated by the converter into the detection region. The total number of the protons was calculated for the converter thickness change. The thickness was set in the range 10 to 100 μm and 0.1 to 10 mm in order to divide into very thin and thick region. The F4 tally was used to calculate the total number of the protons in the MCNPX, it was multiplied by the number of neutron particles and the total area for the unit conversion to the resulting value. The energy of the neutron source was set to 2.5 MeV emitted from the D-D neutron generator. Table I indicates reaction probability for the converter thickness. The thicker the thickness of the converter increases the probability. Because of an energy range of the proton, it is necessary to confirm the energy distribution and total number of the protons actually reaching the second layer. Fig. 3 and 4 shows the proton energy spectrum and the total number injected to the detection region (second layer) for the converter thickness change. When the thickness of the converter was set to 0.1 mm, the most proton reaches the second layer and the total number of the proton was the highest (6310 with standard error 1.25%). But, the converter thickness with 1 mm will be applied to fabricate a GEM detector because of the ease of fabrication and the small difference of the results (6120 with standard error 1.26%).

Table I. (n,p) reaction probability for polyethylene thickness

| Thickness (mm) | Reaction probability (%) |
|---|---|
| 0.01 | 2.728 |
| 0.05 | 2.839 |
| 0.1 | 3.000 |
| 0.5 | 4.225 |
| 1.0 | 5.836 |
| 5.0 | 21.097 |
| 10.0 | 44.658 |

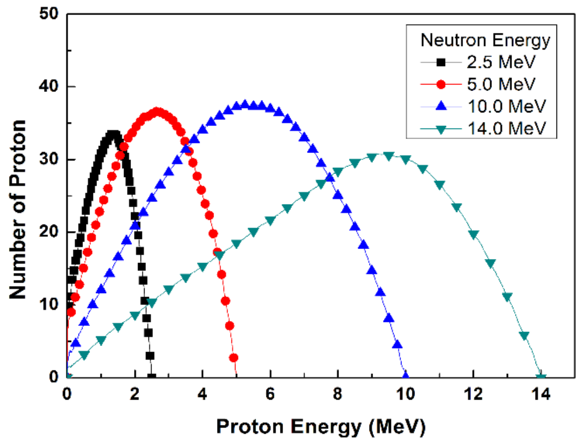


Fig. 2. Energy spectrum of recoil proton emitted from polyethylene foil by (n,p) nuclear reaction.

## 3. Conclusions

A gas electron multiplier (GEM) is a type of gaseous ionization detector used in nuclear and particle physics, and radiation detection. In this study, energy spectrum and total number of recoil protons emitted from (n,p) reaction caused by a neutron irradiation were calculated to apply for the GEM-based neutron detector by using the MCNPX code. In future works, neutron detection efficiency will be calculated for varying gas mixture ratio in the GEM chamber and a conceptual structure of the GEM detector will be designed and fabricated.

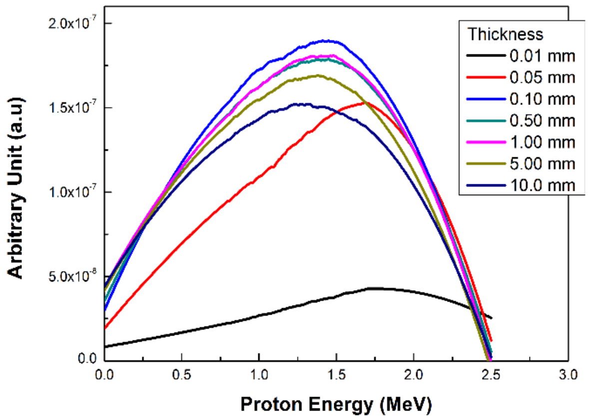


Fig. 3. Proton energy spectrum in second layer of GEM structure for polyethylene thickness using 2.5 MeV fast neutron

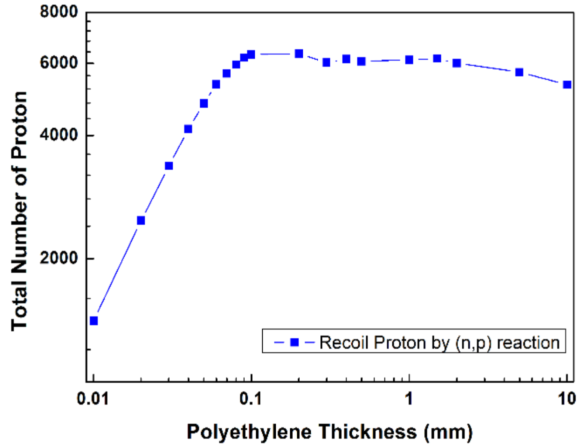


Fig. 4. Total number of proton injected to the detection region for the polyethylene thickness change. F4 tally was used to obtain the total number.

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