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Effect Evaluation of the Converter/Absorber for Measuring 14 MeV Fast Neutron

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1. Introduction

In controlled thermonuclear fusion devices the fusion power is assessed through the measurement of neutrons emitted from a plasma. The two reactions employed in fusion experiments (D-D and D-T) yield 2.5 and 14 MeV neutrons, respectively. These two neutron components must be measured separately in future fusion reactors such as ITER [1]. The development of new detection systems for the 14 MeV neutrons suitable to fusion reactors is still an open challenge, although liquid scintillators and diamond detectors already represent a viable chance [2]. Compact dimensions, high counting rate capability good detection efficiency, stability under electromagnetic fields, radiation resistance, and insensitivity to gamma-ray are key requirements. Possible good candidates for fast neutron detection in fusion devices are gas detectors concept. The gas chamber detectors have been successfully used for neutron detection [4] due to their high counting rate capability, they can play an important role also for neutron diagnostics in fusion devices. This paper describes the design and the optimization of a 14 MeV neutron detector based on the gas detector. In this study, Effects with respect to detection efficiency of polyethylene thickness as a converter and aluminum as an absorber were simulated using the MCNPX [3].

2. Methods and Results

The principle proposed in our study is very similar to the Bonner sphere, but instead of spheres we use a set of flat plates (finally cylinder type) with different thickness. The detector consists of a series of variable thickness layers made of converter, absorber (mainly polyethylene, aluminum) positioned in front of the gas chamber. The converter having a proper thickness is required to produce the recoil proton by (n,p) reaction. The idea of the addition of an absorber material is reduce the diffusion length of low energy neutron during the path inside the layer. Fig. 1 shows layout and basic structure applied to the gas detector.

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 lose energy through excitation and ionization as the pass through the reaction material. The energy of the recoil nucleus is below:

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

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.

2.1 Monte Carlo Calculations

A gas detector has been coupled to a proton-recoil converter (mainly polyethylene) and to an absorber (aluminum) in order to obtain a fast neutron detector sensitive to only 14 MeV neutron. The absorber foil has the proper thickness to set an energy threshold for the protons produced by low energy neutrons emitted by D-D reactions. The recoil protons generated by (n,p) reactions in the converter and having enough energy to cross the absorber foil, lose their energy by ionization of the gas atoms. The generated electrons are collected in the electronic system layer structure giving a detectable signal.

The design and the optimizations of the neutron detector have been performed using the MCNPX code. Also, evaluation for effects of the converter and absorber was conducted by calculating proton energy spectrum for the converter thickness. The proton-recoil converter, absorber, and several simulations with mono-energetic neutron beam (14 MeV) have been performed to optimize the thickness of the parameters.

2.2 Simulation Results

Fig. 2 shows the number of protons exiting from the polyethylene converter (and releasing energy in the detection region) versus neutron energy for different converter thickness. By increasing the polyethylene thickness, the number of protons to 14 MeV neutrons increases more than a factor 7 from 0.1 to 2 mm, while the number to 2.5 MeV neutrons slightly decreases. A further thickness increase (5 mm) is useless because the number tends to saturate since the thickness approaches the proton range in the material. Thus, a 2 mm thick converter was selected providing the number of recoil proton of 35,708 particles with standard error 1.26% for 14 MeV neutrons.

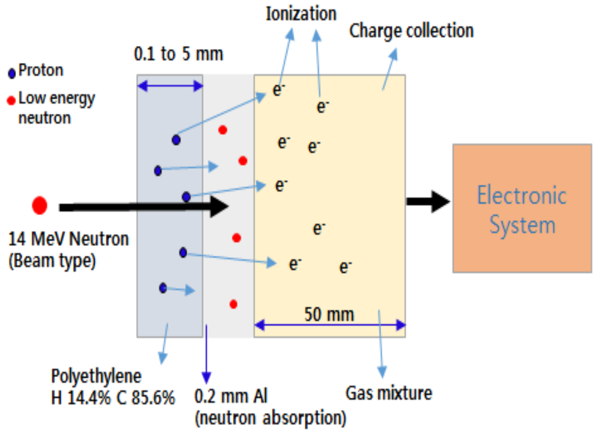

Fig. 1. Layout and basic structure applied to the MCNPX simulation for measuring 14 MeV fast neutron (dimensions are not in scale).

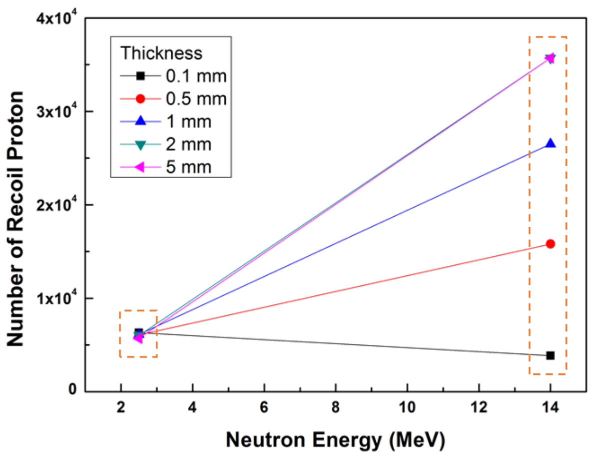

Fig. 2. Number of recoil protons exiting from a polyethylene converter versus neutron energy. The data refer to 0.1, 0.5, 1, 2, and 5 mm of converter thickness.

Because the proton-recoil converter is not energy-selective, a thin aluminum absorber is inserter in order to set a threshold at low neutron energy (to measure only 14 MeV neutrons). A thickness of 0.2 mm of aluminum [4] has been selected to suppress the signal due to protons generated by D-D neutrons in fusion reactor applications. Fig. 3 shows the energy spectrum of the recoil proton (entering proton detection region) produced by 14 MeV neutrons with and without 0.2 mm aluminum absorber. When the 0.2 mm aluminum absorber is coupled to the polyethylene, the production rate of high energy proton decreases approximately 32% because of energy loss and the low energy proton are absorbed before reaching the proton detection region and thus, they are not detected.

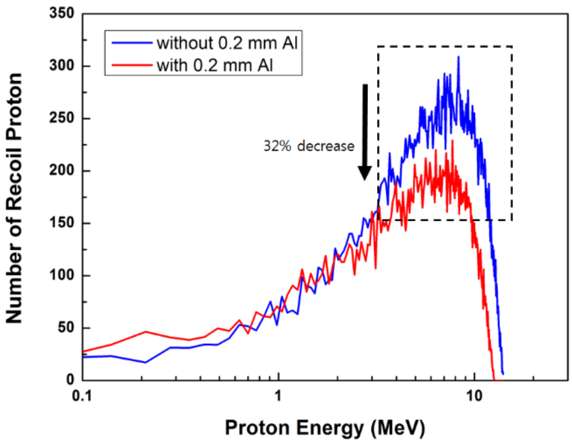

Fig. 3. Total number of proton injected to the detection region for the polyethylene thickness change. F4 tally was used to obtain the total number.

3. Conclusions

A gas chamber detector was designed to measure 14 MeV fast neutron for fusion applications. Polyethylene and thin aluminum sheet are used as a converter and an absorber. Using the MCNPX code, optimized thickness of the converter and effect of the absorber was calculated and evaluated to obtain the highest detection efficiency of recoil proton and effects of the absorber was confirmed. In future works, the designed neutron detector will be fabricated using these results and several experiments will be conducted to measure a fast neutron.

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