Simulation of neutron yield comparison depending on proton energies and targets for BNCT

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1. Introduction

For neutron production in the accelerator-based Boron Neutron Capture Therapy (BNCT), Li and Be are widely used as targets [1]. But, the energy of neutrons produced by Li(p,n) and Be(p,n) reactions is high for BNCT, a moderator is needed to slow down their energy to the epithermal energy region (1 eV to 10 keV). A higher proton beam energy can increase the neutron flux, in which case a thicker moderator would be required. Therefore, the optimal incident proton energy should be investigated by considering the moderator thickness, which affects the neutron yield.

In this study, GEANT simulation [2] was performed to compare the epithermal neutron yield depending on proton energies and targets by considering a moderator.

2. Moderator test

Moderator materials and their length should be optimized to obtain a neutron beam with an appropriate energy and a suitable intensity. In this moderator test, widely used moderator materials were considered, such as Al_2O_3, AlF_3, ^7LiF, TiF_3, and MgF_2, and two ratios, namely $f_{epithermal}/f_{in}$ and $f_{epithermal}/f_{fast}$, were mainly considered to choose the best moderator material. The parameters of $f_{epithermal}$, fin and f_{fast} denote the epithermal neutron flux, incident neutron flux, and fast neutron flux, respectively.

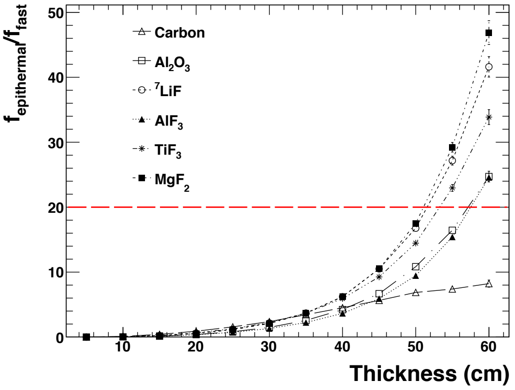

Fig. 1. The ratio of epithermal neutron flux divided by fast neutron flux. The red lines represent IAEA recommended condition for BNCT [3].

In the simulations, the moderator's shape was set to be cylindrical with a radius of 30 cm, and 5×10^6 neutrons with an energy of 4 MeV were incident at the center of the cylinder. We varied the moderator thickness from 5 cm to 60 cm and examined how the neutron energy spectrum varied at the end of the moderator. Fig. 1 shows the value obtained by dividing the number of epithermal neutrons exiting the moderator by the total number of neutrons incident on the moderator. MgF_2 showed the highest $f_{epithermal}/f_{fast}$ ratio for thicknesses exceeding 40 cm, and it showed about 20 $f_{epithermal}/f_{fast}$ at 52 cm.

The multilayer structure was found to be effective in reducing the moderator thickness [4]. Therefore, a multilayer structure was considered for the moderator, and it was examined whether the moderator's thickness could be reduced. To determine the optimal material and thickness of each layer, we performed simulations by varying the thickness of each of the layers of a bilayer structure. From the aforementioned five candidate materials, different pairs of materials were chosen, and each material of a pair was filled in a cylindrical moderator. We generated neutron at the center of the moderator and determined the combination of materials that minimized the thickness of the moderator whil maximizing the epithermal neutron flux. The neutron energy produced by the reaction of 4 MeV protons with Be target was used. We found that the combination of MgF_2 and TiF_3 showed the highest epithermal neutron flux among all combinations satisfying the condition $f_{epithermal}/f_{fast} > 20$.

When a combination of 40 cm MgF_2 and 5 cm TiF_3 was used, a thickness reduction of about 7 cm and an epithermal neutron increment of about 70 % could be achieved compared with the result for a single material. On the basis of the above results, MgF_2 was selected as the first layer and TiF_3 was selected as the second layer.

3. Neutron yield comparison of Li and Be targets by applying a moderator

The higher the proton energy, the higher the neutron yield. However, for a higher proton energy, a thicker moderator is required to reduce the neutron energy. Since the epithermal neutron flux decreases with an increase in the moderator thickness, it is necessary to determine an appropriate proton energy by considering the proton energy and the moderator thickness together. We performed simulations to compare the epithermal neutron flux for different proton energies. In the simulation, each neutron energy spectrum obtained for the Be(p,n) or Li(p,n) reaction with different proton energies was used as an incident beam. By varying the thickness of the first layer (MgF_2), we determined the moderator thickness that satisfied the condition $f_{epithermal}/f_{fast} > 20$, and we obtained the number of epithermal neutrons for that thickness. The epithermal neutron flux was obtained at the exit of the moderator.

Fig. 2 shows comparison results. The x-axis represents the energy of protons incident on the target, and the y-axis represents the relative epithermal neutron yield. The solid triangle are the simulation results for Li target. And the solid circle are the simulation results for Be target.

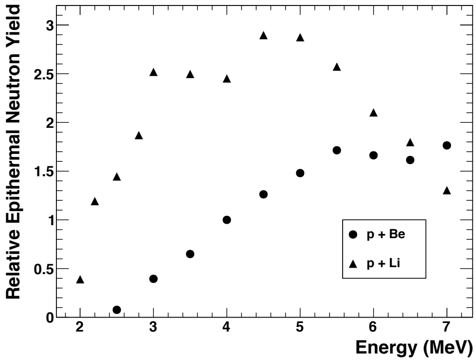

Fig. 2. Comparison of epithermal neutron yield as a function of incident proton energy. The solid triangle are the simulation results for Li target. And the solid circle are the simulation results for Be target.

Fig. 2 shows that for the Li target, epithermal neutron flux peaked at the proton energy of 4.5 MeV and decreased drastically. Because a thicker moderator caused the epithermal neutron flux to decrease, the epithermal neutron flux did not continue to increase with the proton energy.

4. Conclusions

To accurately compare the epithermal neutron flux according to proton energy, we used an MgF_2 + TiF_3 multilayer moderator. Fig. 2 has a different shape with the neutron production yield from the target [5]. When the proton energy exceeded a certain level, the epithermal neutron yield did not continue to increase. This implied that for target thicknesses above a certain value, the decrease in number of neutrons because of the moderator was greater than the increase in the number of neutrons generated from the target. Although the difference in the epithermal neutron yield between the targets decreased with an increase in the proton energy, the Li target remained effective for epithermal neutron generation below the 5 MeV energy. Below 5 MeV, the epithermal production is more than doubled compared to Be target. However, the advantage of high epithermal neutron yield in the case of the Li target was lost for proton energies above 6 MeV.

Based on this result, the advantages of each target could be maximized by selecting an appropriate proton energy.

REFERENCES

[1] Yoshiaki Kiyanagi et al., AIP Conference Proceedings 2160 (2019) 050012.

[2] Giani et al., GEANT4: An object-oriented toolkit for simulation in HEP, CERN/LHCC 98-44, 1998.

[3] IAEA-TECDOC-1223: Current Status of Neutron Capture Therapy. International Atomic Energy Agency, Vienna (2001)

[4] Jacob G. Fantidis, G. Nicolaou, Alex. Eng. J. 57 (2018) 2333.

[5] M.R. Hawkesworth, Neutron radiography: Equipment and Methods Atomic Energy Review, 15 (1977) 169.