Semester report

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Ph.D. thesis title: The physics of hadron cancer therapy with neutron beams

Introduction

As a noninvasive method for treating tumors, neutron capture therapy has been under the attention of researchers for decades. In recent years, the compact accelerator-driven neutron source (CANS) has become the optimal choice for BNCT, because of its low cost and no radiation hazard compared to reactors. Another advantage of CANS is its compact volume so that it can be placed in a hospital, rather than suburb of the city where reactors are built, so that can benefit the patients.

Now, all the CANSs project for BNCT using epithermal neutrons are aiming at the criteria proposed by IAEA [1]. Neutron sources always generate mix radiation field, besides the desired epithermal neutrons, but also thermal neutrons, fast neutrons and gamma rays. These components can cause additional radiation hazard to the patient. In this proposal [1], the suggested beam characteristics are epithermal neutron flux larger than 1×10^9 n/cm^2/s, fast neutron dose lower than 2×10^{-13} Gy cm^2 per epithermal neutron, gamma neutron dose lower than 2×10^{-13} Gy cm^2 per epithermal neutron, ratio between thermal neutron flux and epithermal neutron flux lower than 0.05, and ratio between total epithermal neutron current and flux higher than 0.7.

Research work

This semester, I mainly systematically studied of various moderator materials and the Pb reflector through the frame of Geant4 [2][3]. The first step is to simulate the neutron transport in various moderator materials. The second step is to calculate radiation field of moderators with Pb reflector. The cross sections are got from Ref [4].

1) Moderator material simulation

The schematic diagram of moderator testing is shown in Figure 1. Neutrons are produced by 10 mA continuous proton beam hitting a Li target with a diameter of 10 cm and a thickness of 0.2 mm. A moderator with a length varies from 5 to 30 cm with a step of 5 cm and a diameter varies from 25 cm to 40 cm with a step of 5 cm is placed adjacent to the Li target. And the detector is placed 5 cm behind the moderator.

The epithermal neutron intensity produced by MgF_2 moderator and MgO moderator are similar, the epithermal intensity is peaked at the length of 15 cm, and neutron intensity increases as the diameter of moderator increases. The epithermal neutron intensity produced by AlF_3 and Al_2O_3 moderator ae also similar, but lower than that of MgF_2 and MgO moderator, and the peak of neutron intensity shifts from the length of 15 cm to 20 cm as diameter of moderator increases.

While the epithermal neutron intensity is peaked at the length of moderator 5 cm and 10 cm, and the epithermal neutron intensity is larger than 1×10^9 n/cm^2/s. Then the neutron intensity decreases rapidly as the increase of length of moderator.

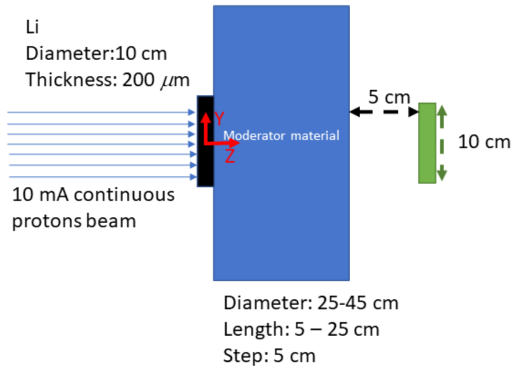


Figure 1. The schematic view of moderator material simulation. The diameter of moderator varies from 25 cm to 40 cm with a step of 5 cm and the length of moderator varies from 5 cm to 25 30 cm. The tested materials are MgF_2, AlF_3, MgO, Al_2O_3 and Be. The neutrons are detected by a detector with a diameter of 10 cm placed 5 cm behind the moderator.

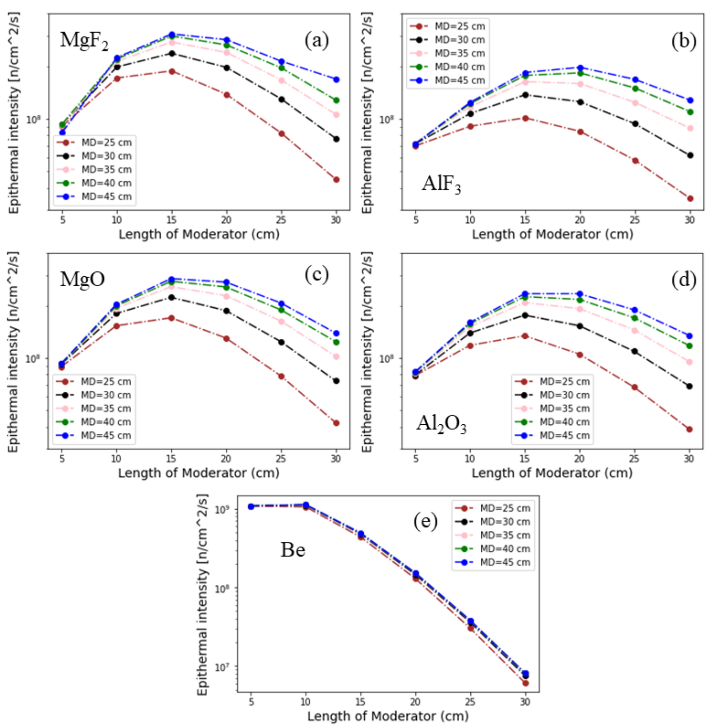


Figure 2. The epithermal neutron intensity detected by the detector for various moderator material testing. (Scaled to 10 mA continuous proton beam).

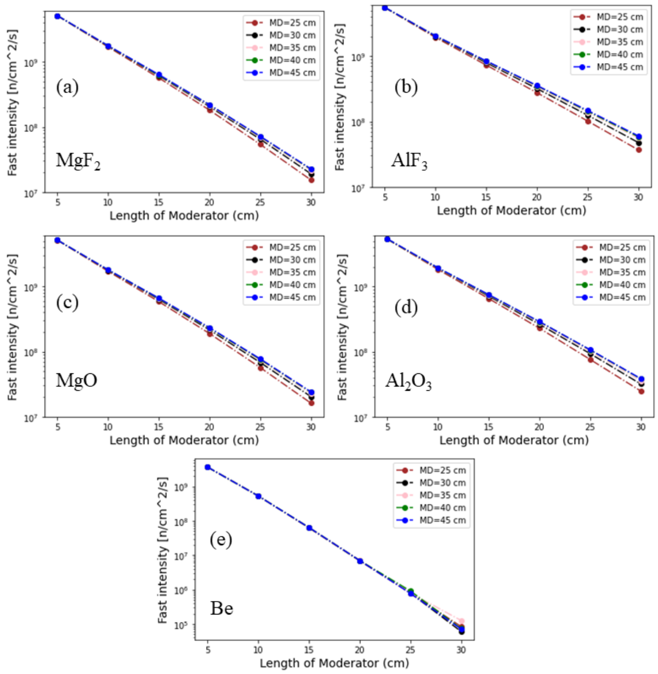


Figure 3. The fast neutron intensity detected by the detector for various moderator material testing. (Scaled to 10 mA continuous proton beam).

As it shown in Figure 3, the fast neutron intensities produced by MgF_2, AlF_3, MgO and Al_2O_3 are similar, but the fast neutron intensities produced by materials containing Al are higher than materials containing Mg. It is because the neutrons scattering cross section of Al is smaller than that of Mg. While the fast neutron intensity produced by Be moderator decreases faster than other 4 materials, because of its stronger slow-down power compared to other 4 materials. The ratio between thermal neutron fluxes produced by MgF_3, AlF_3, MgO and Al_2O_3 are generally smaller than the topmost limit proposed by IAEA. But there are strong thermal neutron intensities produced by Be. But it is an advantage other than a disadvantage, because filtering thermal neutrons out is much easier than absorbing fast neutrons. The accompanying gamma rays are generally not a big problem to BNCT, because most of the energies of generated gammas are smaller than 0.4 MeV, using Pb/Bi shielding can easily remove most of the accompanying gammas.

2) MgF2 moderator with Pb reflector

The second step is to place Pb reflector around the moderator to improve the epithermal neutron yield. The configuration is shown in Figure 4. Following the proton beam direction, the first part of Pb reflector is a cylinder with an inner diameter of 12 cm and length of 1 m in front of the moderator. The second part of Pb reflector is another cylinder surrounding the MgF2 moderator with an inner diameter the same as the outer diameter of moderator and the same length as moderator. The thickness of the second part of the Pb moderator are 20 cm or 30 cm. The first and second part of the Pb reflector has the same outer diameter. The diameter of MgF2 moderator changes from 25 cm to 45 cm with a step of 5 cm, and the length of MgF2 moderator increases from 5 cm to 30 cm with a step of 5 cm. The produced neutrons and gammas are still detected by a detector 5 cm behind the MgF2 moderator.

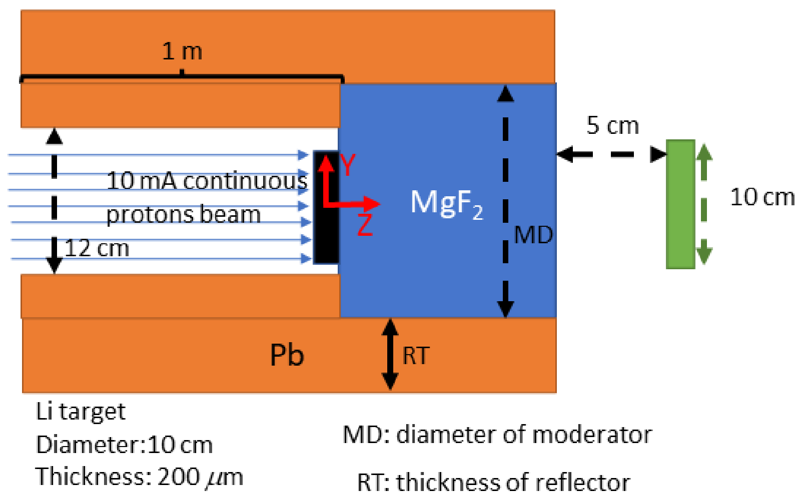


Figure 4. Schematic view of target, moderator and reflector.

The Pb reflector has significant effect on improving the epithermal intensity. As shown in figure 5, the epithermal neutron intensities got from most moderator with length between 10 cm and 20 cm are more than the recommendation of IAEA. But unfortunately, the fast neutron dose got from most TMR are higher than the topmost of the recommendation of IAEA. The fast neutron dose decreases as the length of moderator increases. But only when the length of moderator reaches 30 cm and the diameter of moderator is larger than 35 cm, the fast neutrons dose is lower than the topmost of the recommendation. This means a filter is needed to absorb the fast neutrons.

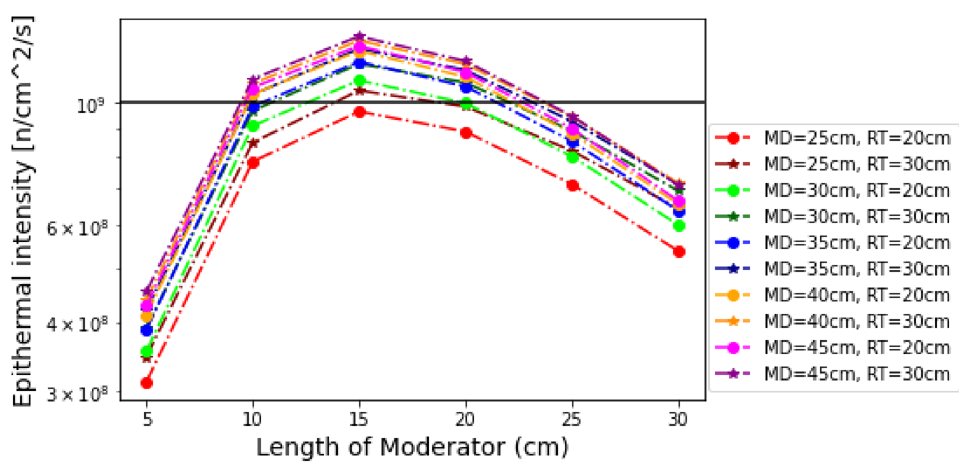


Figure 5. The epithermal neutron intensity produced from various configurations of MgF2 moderator and reflector. MD stands for the diameter of moderator and RT stands for the thickness of reflector.

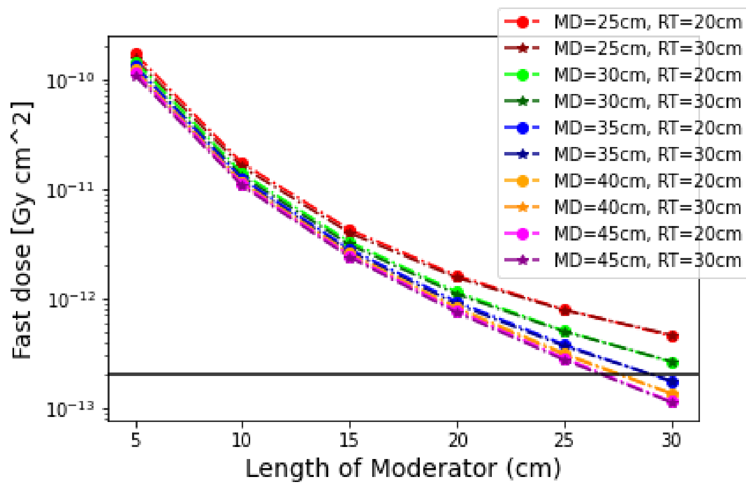
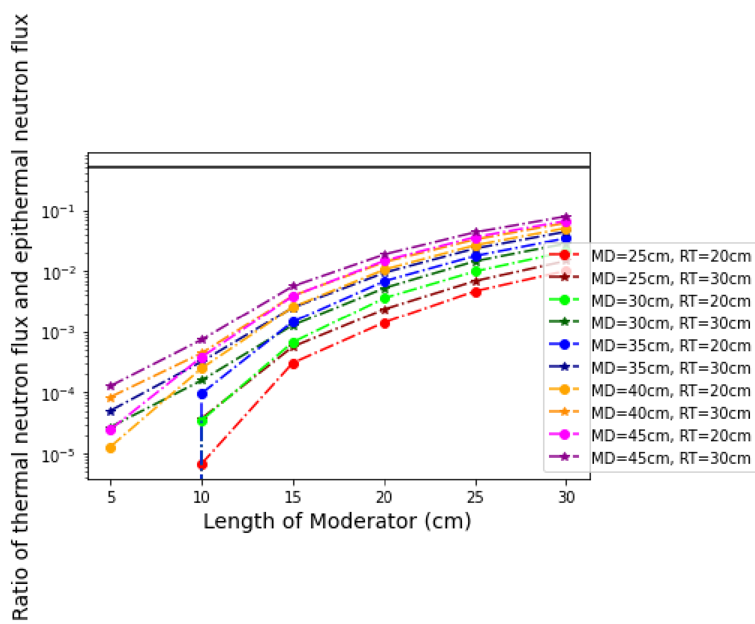


Figure 6. The fast neutron dose produced from various configurations of MgF2 moderator and reflector. MD stands for the diameter of moderator and RT stands for the thickness of reflector.

The ratio of thermal neutron flux and epithermal neutron flux is shown in Figure 7. It can be seen that this ratio got from all the TMR is much lower than the recommendation of IAEA.



Study activities

This semester, I enrolled in the course “Advanced Statistics and Modelling” and achieved the grade good. I also enrolled in course “Hungarian language - General Erasmus beginner double class”, which I achieved the grade excellent.

Reference

[1] International Atomic Energy Agency. IAEA in Austria.2001. Available from: http://www-pub.iaea.org/MTCD/publications/PDF/te_1223_prn.pdf

[2] S. Agostinelli, J. Allison, K. Amako, et al. Geant4—a simulation toolkit. Nuclear Instruments and Methods in Physics Research A 506 (2003) 250-303.

[3] J. Allison, K. Amako, J. Apostolakis, et al. Recent developments in Geant4. Nuclear Instruments and Methods in Physics Research A 835 (2016) 186-225.

[4] D. A. Brown, et al., ENDF/B-VIII0: The 8th Major Release of the Nuclear Reaction Data Library with CIELO-project Cross Section, New Standards and Thermal Scattering Data, Nuclear Data Sheets, 148 (2018) 1-142.