3rd-Semester report

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

1. Introduction

IAEA proposed the recommendation for boron neutron capture therapy using epithermal neutrons with energies ranging 0.5 eV ~ 10 keV in 2001 [1]. However, two decades have passed, there is still some controversy regarding the useful epithermal neutron energy. The useful neutron energy for BNCT was evaluated by many researchers [2-3]. As currently the only clinical used accelerator-based epithermal neutron source, the C-BENS project adopted 0.5 eV – 40 keV as the epithermal neutron energy [2]. The accelerator-based epithermal neutron source in Helsinki stayed with the IAEA recommended epithermal neutron energy [3]. P. Torres-Sánchez, et al, studied the upper energy limit for of useful epithermal neutrons based on the spectra of C-BENS project, found that neutrons with energies higher than 40 keV dramatically decrease the ratio of tumor dose to maximum normal tissue dose and the upper limit of epithermal neutron dose should be relaxed to at least 20 keV [4]. Based on these disagreements, a neutron source with multiple exits and spectra shifters can help to meet different recommendations and achieve maximal therapeutic dose rate at various depths in human tissue.

2. Research work

This semester, I have achieved good progresses for designing a multi-exits epithermal neutron source. The simulation work is almost done, and the results is quite nice.
My findings are mainly 3 points:

1) Collimator: The ratio of neutron current density and neutron flux can be understood as the neutron beam divergence. In order to improve this value to 0.7, the collimator should be at least 12 cm long for a neutron exit with a diameter of 12 cm. And neutrons have the possibility to be scattered by the Lead reflector to the beam exit, a thin nozzle has to be set on top of the collimator. Collimator provides the function of collimate and scatter neutrons back to the axis of exit, nozzle helps with only collimating neutron beam.

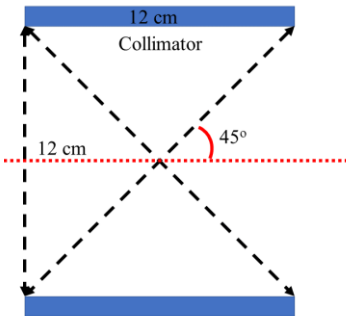

Figure 1. Schematic view of collimator

2) Titanium filter: natural titanium has a large neutron absorption cross-section peaked at 10 keV, and it can effectively absorb neutrons with energies of about tens of keV. The Ti filter's thickness is chosen to be 2 cm, because a thicker Ti filter increase the gamma dose. The combinations of collimator and nozzle are tested for this design as well. The combination of a 10 cm long collimator and a 4 cm long nozzle turns out to be the optimal solution.

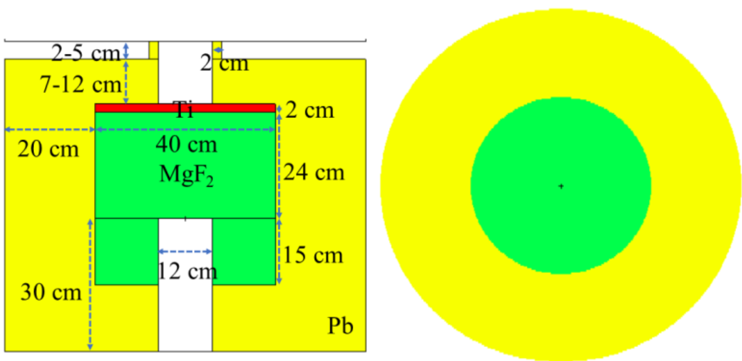

Figure 2. Simulated geometry for Ti filter testing. The left is the side cross section of the simulated geometry; the right is the top cross section of the simulated geometry.

3) Multi-exit neutron source is feasible: Through plotting the epithermal neutron trajectories, it is found that the epithermal neutrons almost isotropically maps in the moderator and reflector (Figure 3). Which means the neutron exit's angle doesn't affect the neutron characteristics significantly. This gives us the probability to design a neutron source with multiple exits. An innovative beam shaping assembly (BSA) is shown in Figure 4, the moderator consists of 2 parts, AlF_3 part and MgF_2 part. the tilt angle of the MgF_2 exit is 45° and the tilt angle of the AlF_3 exit is 60°. The neutron exit at the MgF_2 side provides epithermal neutron beam satisfying the IAEA recommendation, and the neutron exit at the AlF_3 side gives us epithermal neutron beam with the same characteristic as that of the CBNS project, Japan.

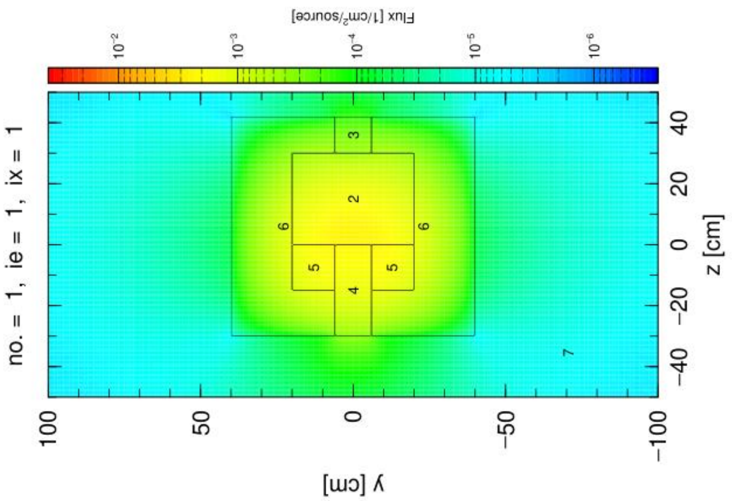

Figure 3. Epithermal neutron trajectories in the simulated geometry.

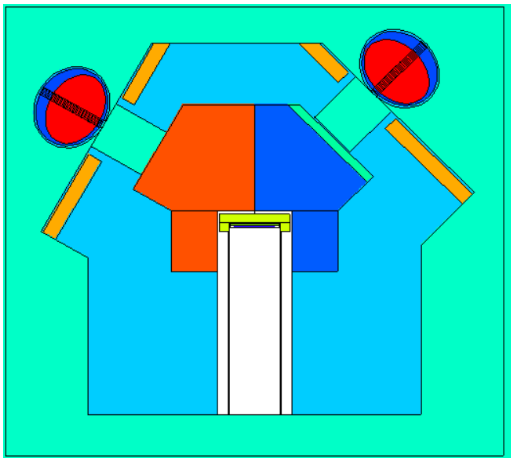

Figure 4. Side cross-section of the simulated geometry.

3. Study activities

This semester, I had 3 courses:
"X-ray and XUV physics and spectroscopy"

"Monte Carlo Particle Transport Methods"

"Introduction to quantum optics"

I also participate the "PHITS Advanced Training Course" in Paris and learned the necessary skills for using the software PHITS.

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] H. Tanaka, Y. Sakurai, M. Suzuki, et al. Experimental verification of beam characteristics for cyclotron-based epithermal neutron source (C-BENS). Applied Radiation and Isotopes

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[3] L. Porra, T. Seppälä, L. Wendlanda, et al. Accelerator-based boron neutron capture therapy facility at the HelsinkiUniversity Hospital. Acta Oncologica 61 (2022) 269-273.

[4] P. Torres-Sánchez, I. Porras, F. A. de Saavedra, et al. Study of the upper energy limit of useful epithermal neutrons for Boron Neutron Capture Therapy in different tissues. Radiation Physics and Chemistry 185 (2021) 109490.