4th-Semester report

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

Introduction

Boron neutron capture is a 2-step radiation method treating tumor/cancerous cells. This method was proposed by GL. Locher[1], soon after neutron was found by Chadwick [2]. ^{10}B needs to be delivered to cancerous cells first, then the leisure tissue is exposed to thermal/epithermal neutron beam. ^{10}B captures a thermal neutron, then releases an α particle and a ^{7}Li ion. The ranges of the released particles in tissue are around 4-10 μm, which is comparable to cell size. So that the cancerous cells can be selectively killed. IAEA proposed criteria for the epithermal neutron source used for BNCT. However, there are some arguments regarding the useful neutron energy range. IAEA recommended the useful neutron energy range as 0.5 eV -10 keV [3], while C-BENS project adopted 0.5 eV – 40 keV as the useful neutron range [4]. P. Torres-Sánchez, et al pointed out that the useful neutron range may be affected by bone thickness [5]. In this case, a neutron source which can provide flexible neutron spectra is a favorable choice.
Except for the argument regarding the useful neutron range, the main obstacle is coming from biopharmaceuticals. The blood brain barrier which provides a relative isolating environment causes the difficulties of delivering ^{10}B into the brain tissue. BSH and BPA are the main agents used in BNCT, but clinically, the ^{10}B concentration in tumor is still less than 3 times that of normal brain tissue [6-8]. The new generations of ^{10}B delivery agents were studied in in cells and tumor models and showed great potential to achieve high T/N ratio in the near future [9].

Research work

1 Summary of the first 3 semesters' research work

In the first 3 semesters, we systematically studied MgF_2 and AlF_3 as moderator materials, the suitable dimensions of MgF_2 and AlF_3 moderators and Pb reflector. We found titanium is a good fast neutron filter material for absorbing fast neutrons, because of its relatively large neutron absorption cross-section at energy range of 10 keV – 100 keV. We also found that epithermal neutrons trajectories almost isotropically distribute in the moderator, which could help to build a multiple ports epithermal neutron source.

2) Research work of the 4th semester

This semester, we a) finalized the concept design of the dual moderator system, b) further studied the dose distribution in the Snyder head model, c) designed the 2.5 MeV proton beamline and d) started the work of designing a Lithium target with watering cooling channels.

a) Dual moderator system

The dual moderator system, which is made of half AlF_3 and half MgF_2, provides 2 beam ports with different spectra. As discovered in the 3rd semester, the epithermal neutron trajectories map almost isotropically in the moderator, this provides us the probability to design an epithermal neutron source with multiple neutron beam ports. Utilizing the difference between neutron scattering cross-sections of Al and Mg, i.e. Al is almost transparent for neutrons with energies less than 30 keV, while the neutron scattering cross-section of Mg is much larger than that of Al.
We successfully designed a 2-port epithermal neutron source with different spectra, as shown in Figure 1 and Figure 2.

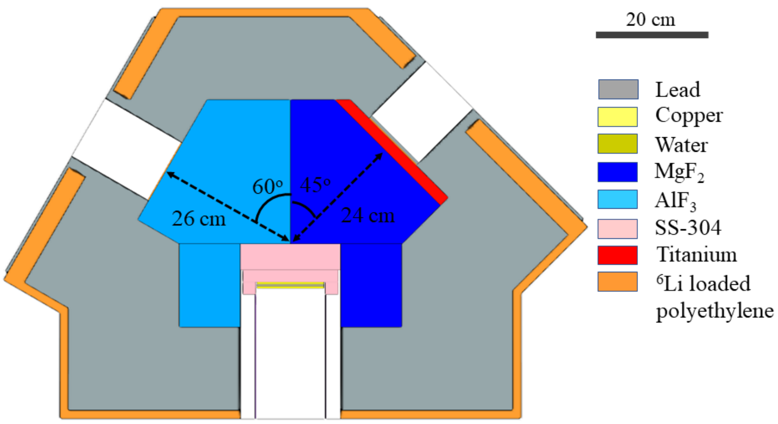

Figure 1. Geometry of the designed epithermal neutron source

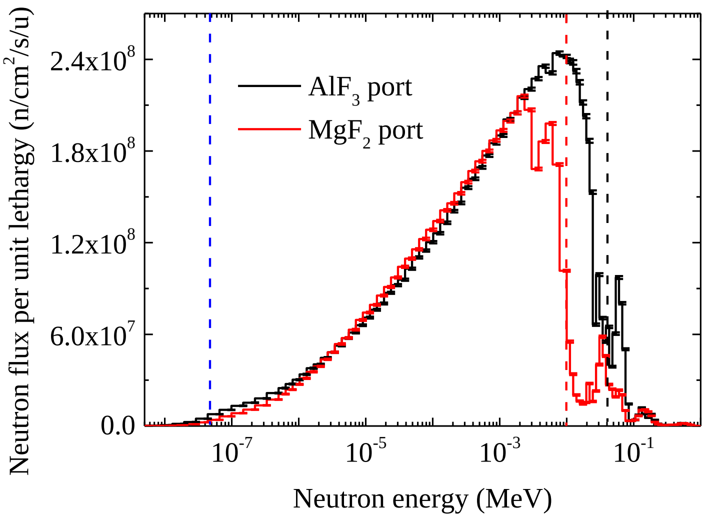

Figure 2. Neutron spectra at AlF3 port and MgF2 port, respectively.

b) In phantom dose calculation

The in-phantom dose distribution was investigated by the Snyder head model (Figure 3), which is widely used in BNCT. The detectors are cylinders with 1 cm radius aligned along the axes of the Snyder head. The dose rate distributions shown in Figure 4 are evaluated with the help of kerma factor [10]. It is found that the epithermal neutron beam at the AlF_3 side performs better for tumor in a slightly deeper depth.

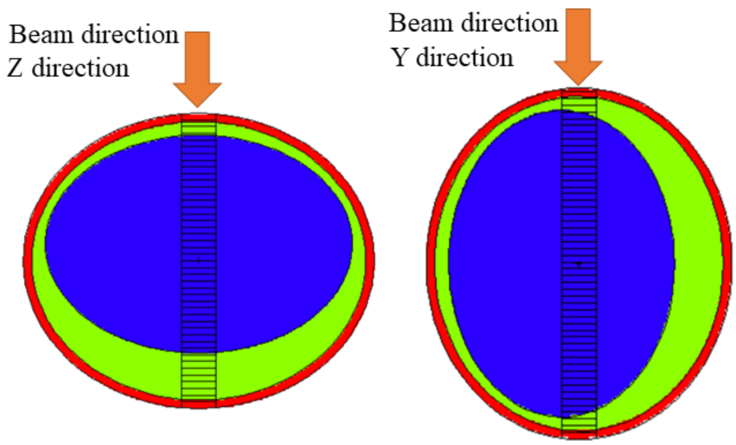

Figure 3. The modified Snyder head phantom and the incident beam direction

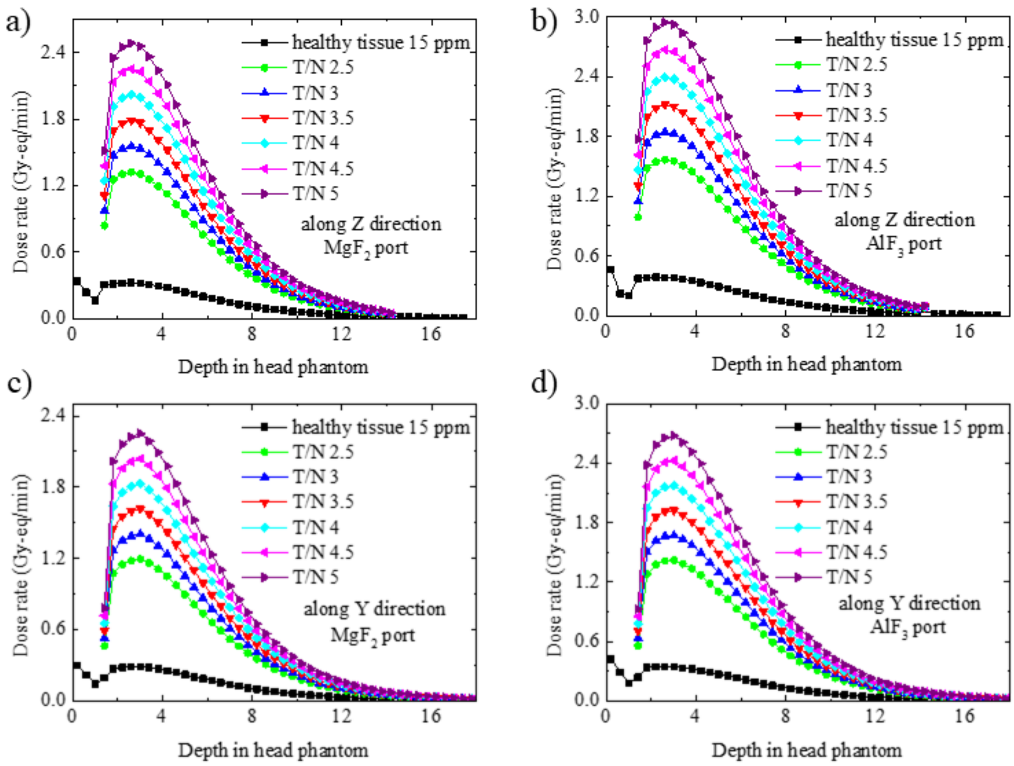

Figure 4. The total tumor dose rate distribution for various ratio of ^{10}B in tumor and normal tissue (T/N) along Z and Y direction inside the Snyder head phantom at MgF2 port and AlF3 port, respectively

c) 2.5 MeV proton beamline design

RFQ accelerator has the ability to accelerate and focus the ion beam. However, the focal length is very short, so the ion beam diverges fast after the foci. In our project, the proton beam needs to be bent by 90° and the proton beam needs to travel 5 m from the axial axis of the RFQ linac. Usually, this proton beamline consists at least 3 quadrupoles and a dipole. Through systematic study, we found that the proton beamline can be achieved by a quadrupole and a 90° dipole. The edge angles of the dipole behave like quadrupoles, if the edge angles are designed properly, in our case, only one extra quadrupole is enough.
Our final beamline design is a 90° dipole with 45° edge angles on both sides and a 15 cm long quadrupole with a magnetic field gradient of 3 T/m. With this design, we can transmit more than 99% protons to the target and save 2 quadrupoles.

d) Lithium target design

In epithermal neutron source simulations, we assumed the proton beam is 10 mA continuous beam at 2.5 MeV with a beam diameter of 10 cm. we designed the proton beamline, which shows that the proton beam hits on the target with a diameter of 7 cm (3σ), so that the beam power is highly focused within a 2.5 cm diameter circle. In this case, to let the Li target withstand the beam power, the proton beam has to be rotated and the target cooling system has to be carefully designed. In addition to the heat transfer problem, copper, as a good heat conducting material, cannot hold hydrogen diffusion, which causes blistering problem in copper surface. We designed a Lithium target containing 3 layers: a Li layer 10 cm of diameter and 100 μm thick, a Ta layer 11cm of diameter and 15 μm thick, and a copper holder of 12.5 cm diameter with V-cooling channels If the holder is made of pure copper, and the 25 kW, about 2.5 cm diameter continuous beam scans the Li target surface with 20 Hz repetition rate, then the peak temperature of the target can be kept lower than 150°C (Figure 5), which is lower than the melting point of lithium.

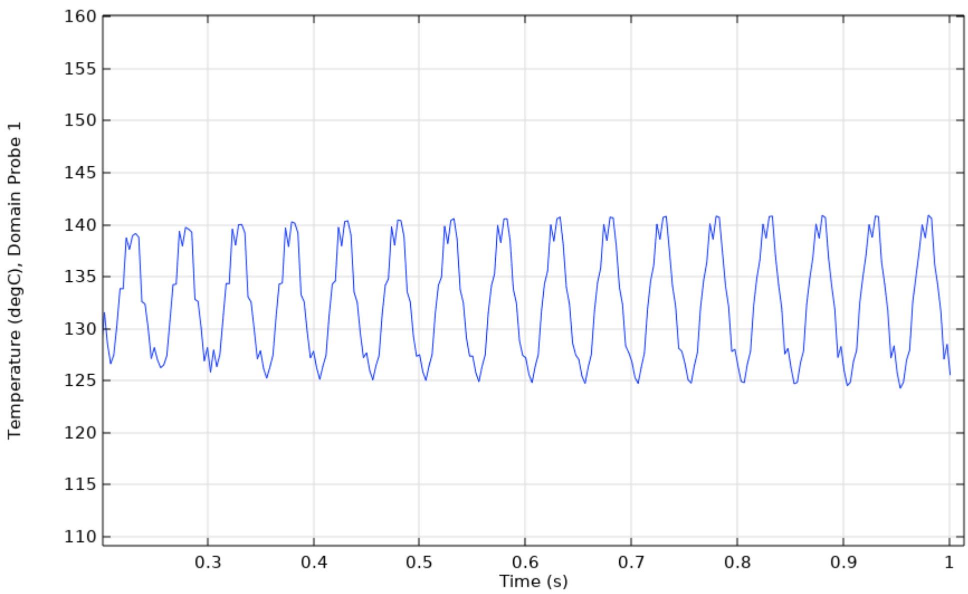

Figure 5 Time evolution of temperature on the Li target

Study activities

This semester, I had 3 courses:

“Nuclear Environmental Protection”

“Foundations of Quantum Mechanics”

“Radiation Protection and Shielding Calculations in Nuclear Environment”

The grades of these 3 courses haven’t been given yet.

Publication

We submitted a manuscript named “An innovative multi-ports accelerator-based epithermal neutron source design for Boron neutron capture therapy” to the journal Applied Radiation and Isotopes.

Action	Manuscript Number	Title	Initial Date Submitted	Status Date	Current Status
View Submission Send E-mail	ARI-D-23-00513	An innovative multi-ports accelerator-based epithermal neutron source design for Boron neutron capture therapy	May 26, 2023	May 30, 2023	With Editor

Conference participations during the doctoral studies

1. "Central European Training School on Neutron Techniques", I had my first poster "Preliminary study of primary neutron spectra for "LvB" Compact Neutron Source"

2. "10th International Meeting of the Union of Compact Accelerator-driven Neutron Sources". This conference will be held in October 2023, I am planning to submit an abstract to this conference.

3. "20th International Congress on Neutron Capture Therapy". This conference will be held in September 2023, I am planning to submit an abstract to this conference.

Reference

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