Semester report

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

Introduction

Neutron capture therapy (NCT) is a noninvasive method for the treatment of malignant tumors. Isotopes with high neutron capture cross section distribute to tumor cells and keep their concentration in health tissue and blood much lower than in tumors. Therefore, neutrons are mainly captured in tumor cells and produce high linear energy transfer charged particles through strong nuclear reactions. For this reason, theoretically, normal tissues won't absorb too much radiation dose comparing to tumors. So far, the most promising NCT method is Boron neutron capture therapy (BNCT), which was first proposed by G. Locher in 1936 [1]. ^{10}B has a large neutron capture cross section (3850 barns), it can capture neutrons and produces a ^{7}Li and a ^{4}He particle. The ranges of produced ^{7}Li and ^{4}He are about 9 and 5 μm, respectively. The range of Combined ^{7}Li and ^{4}He is similar to the size of cells, so that the released 2-3 MeV can deposit in the cellular scale.

In the several decades, BNCT clinical trials were performed in reactors. But recently. reactors have faced shutdown or have been shut down for a number of reasons. Compact accelerator-driven neutron source (CANS) has become the most promising method for performing BNCT in the future, especially the CANS based on ^{7}Li (p, n) ^{7}Be reaction. Because of the low neutron yield of low energy ions with target, the beam shaping assembly of CANS needs to be carefully designed to maximize epithermal neutrons flux and minimize the accompanying radiation field. The commonly accepted neutron characteristics and treatment protocol for BNCT were recommended by International Atomic Energy Agency (IAEA) [2].

Research work

I have been applying for MCNP license for more than 3 months, but I still haven't got it. So that I practiced some analytic calculations and simulation work with Geant4.

Analytic calculation:

To estimate the radiation hazards, it is necessary to evaluate the radiation dose from the RFQ Linac and target because of neutron activation. According ENDF database [3], the yield of neutron for 1 mA 2.5 MeV proton beam hitting a Li target with a thickness thicker than 100 mm is about 1×10^{12} /s. Suppose the neutrons emitted isotopically by a point source and the spectrum of neutrons follows Maxwellian distribution with maximum probability at 25 keV. The neutron angular distribution was found in Ref [3]. Based on the neutron capture cross sections [4,5] for Cu and Al, the activities of linac bunker and target were calculated. Then, assuming the linac and target were point sources, through the fluence to dose table, the radiation doses received by objects 1 m and 10 m from the linac and target were estimated.

Geant4 simulation:

Geant4 has a data driven particle high precision physics models QGSP_BIC_AllHP for proton, neutron, deuteron, triton, ^{3}He and alpha with energies lower than 200 MeV [6]. This physics model is suitable for simulating neutron yield of 2.5 MeV protons interacting with Li target and the propaganda of neutrons produced by this reaction.

1) Prompt gamma simulation.

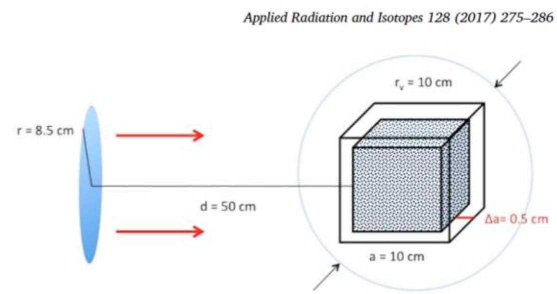
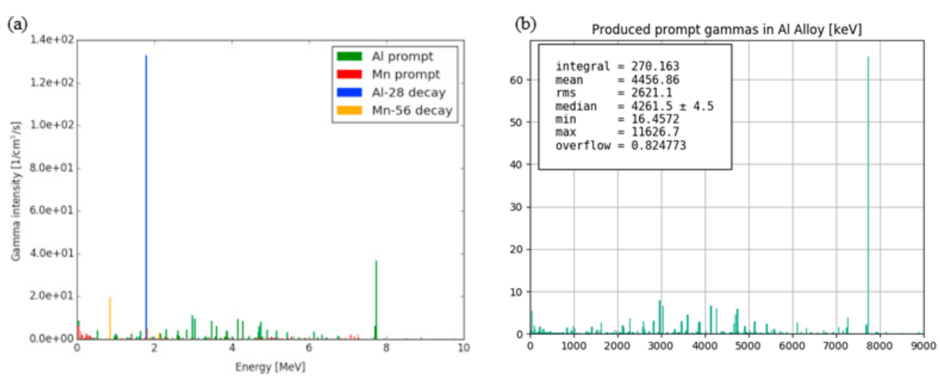
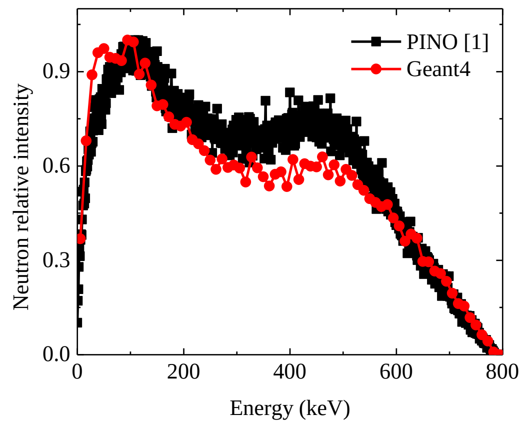


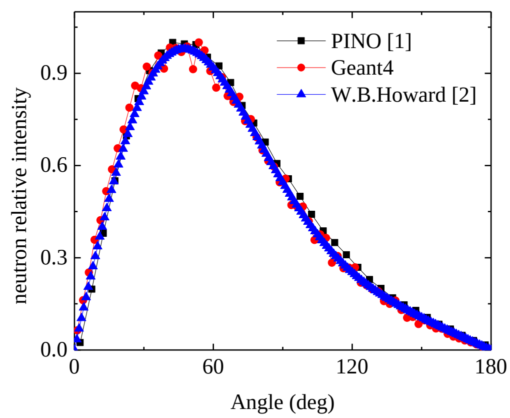
Fig. 1. Neutron irradiation geometry used in MCNP6 simulation.

E. Dian et al simulated the prompt gamma produced by 1.8 Å neutrons with flux of 10^4 n/cm^2/s colliding with Al5754 aluminum frame using MCNP [7]. The geometry is shown as above. I simulated the this work again by geant4.10.5, the result was similar to her work. (a) is the result from E. Dian's work, (b) is from my geant4 simulation.



2) Target and Beam Shaping Assembly (BSA) simulation.
   1. I simulated the spectra and angular distribution of neutrons produced by 2.5 MeV protons. The result was similar to the PINO online tool [8].





2. I simulated a BSA following a paper published by SARAF [9]. Its structure is shown as below. The simulated results (right) show slowdown of neutrons, and half more than half of the detected neutrons were epithermal neutron. The neutron spectrum was similar to the result from SARF (left). But scale simulated proton intensity to 1 mA, the flux of epithermal neutrons was about 2×10^{9} n/cm^{2}/s, which was almost twice as the result from SARAF.

Table 5. Calculated neutron beam quality parameters for 20 mA, 2.5 MeV proton beam in a BSA configuration as shown in Figure 11

Model	Φ_{epi} [10^9 n/cm^2/sec]	D_{fn}/Φ_{epi} [10^{-13} Gy cm^2]	$\Phi_{epi}/\Phi_{thermal}$	J/Φ
SimLiT-Geant4	1.02	14.3	666.4	0.6

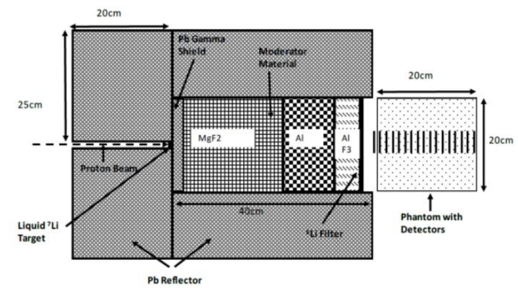
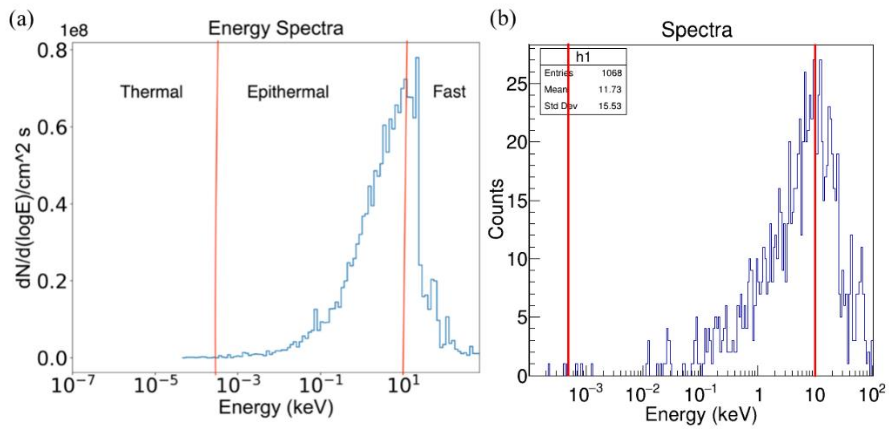


Fig. 10. BSA design for the SimLit-Geant4 calculation



Study activities

This semester, I enrolled in the course "Imaging techniques in modern biology" taught by Dr. Szabó Bálint, the grade will be given after 28th January. I also enrolled in course "Advanced neutron techniques of material characterization", which I achieved excellent grade.

"Advanced neutron techniques of material characterization" is a training school held by Budapest Neutron Centre. They also held a poster session during the training, where I presented my first poster "*Preliminary study of primary neutron spectra for "LvB" Compact Neutron Source*".

Reference

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