Conceptual Design of Target Assembly System for Boron Neutron Capture Therapy

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1. Introduction

Accelerator based Boron Neutron Capture Therapy (BNCT) system is compact, safe, and useful comparing with nuclear power plant based boron neutron capture therapy. There are many type of accelerator based BNCT. Cyclotron based proton beam is high energy. But it has weakness about low current, severe target damage, and radioactivity problem. This research would be treat by LINAC based proton beam because LINAC based proton beam has high current and low energy. These point are possible to reduce treatment time. Therefore, patients don't have to irradiate at normal cell by neutron beam. Monte Carlo and thermal hydraulics simulation were conducted as neutron flux after moderator assembly, temperature distribution of beryllium target.

2. Simulation for Neutron Generation Target

2.1 Power Deposition on Beryllium Target by Proton

If 80 kW proton beam interact with beryllium target, the proton particles deposit its energy to target. And the proton would be disappeared on absorber. Proton energy is 10 MeV and current is 8 mA. Figure.1 shows the proton stopping point and deposit power to target assembly.

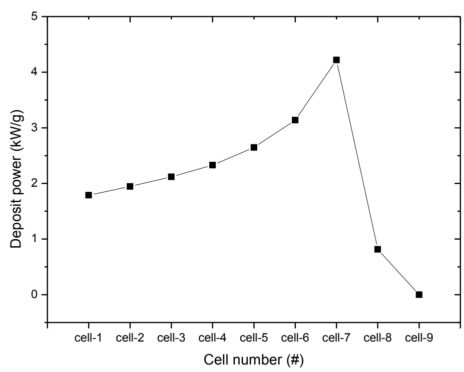
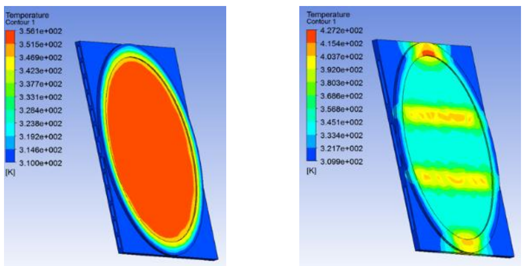


Figure. 1: Deposit power distribution in target assembly by proton

The total 79.693 kW power of proton beam deposited to target assembly by MCNP simulation. Whole proton have stopping range in target assembly thickness. The proton absorber added after beryllium target for protecting the swelling phenomena. The target assembly emit heat because of deposited proton beam power. And it is important to remove the heat by proton irradiation.

2.2 Thermal Analysis of Target Assembly

If 80 kW proton beam interact with beryllium target, the neutron and heat were generated in target. The beryllium target needs the cooling system for removing its heat generation. Conservatively, it assume that 80 kW beam power was generated to heat power. So, the cooling system has to reduce heat under the melting temperature of beryllium about 80 kW heat power. The target cooling system has simple structure. The target assembly is consist of beryllium, palladium, and copper. Each materials ideally bonded at each contact plan. So, the contact resistance is zero. And cooling line pass through the copper. Figure. 2 shows temperature distribution as cooling area and this simulation ignore the effect of coolant temperature drop while the water pass through the cooling line because mass flow rate is large than temperature drop of coolant.



(a) (b)

Figure. 2: Temperature distribution of target assembly as total cooling area (a) 0.04 m^2, (b) 0.0337 m^2

2.3 Fast Neutron Spectrum of Target Assembly

If high energy proton incident with beryllium, the neutron was generated by $^{9}\boldsymbol{Be}(\boldsymbol{p},\boldsymbol{n})\,^{9}\boldsymbol{B}$ reaction. Generated neutron has kinetic energy following incident proton energy. There are two type of BNCT proton source such as cyclotron and LINAC. Cyclotron has low beam current about 1 mA. But proton energy is large about 30 MeV. If proton energy over than ~15 MeV, lots of nuclear reaction was happened excluding proton-neutron reaction. Therefore, radioactive problem would be increased by this reaction. However, LINAC based proton beam has high current and beam energy lower than cyclotron. In this research, the simulation specifications are cyclotron of 30 MeV (1 mA) and LINAC of 10 MeV (8 mA). Figure. 3 shows comparison of proton source of above two types. And this convert simulation of proton to neutron was conducted by MCNP code and convert model was used Bertini model.

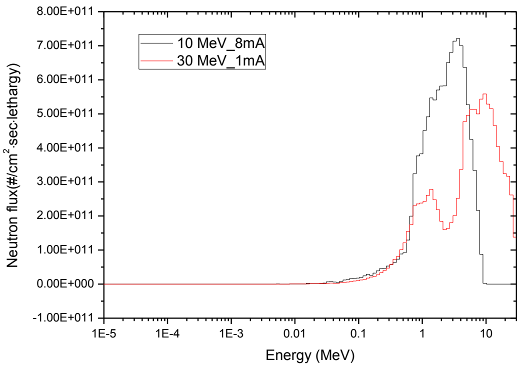


Figure. 3 : Comparison of cyclotron and LINAC based proton source

The generated neutron has different energy. The neutron has favorable energy for moderating to epithermal neutron energy range.

2.4 Neutron Spectrum after Moderator Assembly

Generated neutron from target assembly has high neutron energy. So, these neutrons need for moderation because fast neutron don't capture with boron in tumor cell. The fast neutron moderated to epithermal neutron passing through moderator assembly. This simulation was conducted by MCNP code and neutron library was used by ENDF-7. Figure. 4 shows the neutron spectrum at patient's irradiation site.

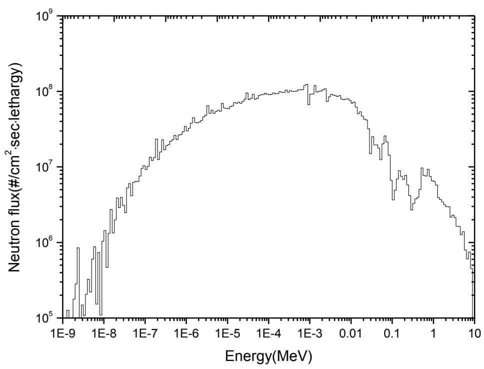


Figure. 4 : Neutron spectrum after moderator assembly

3. Results and Discussions

General consensus is that an epithermal neutron fluence of about $1 \times 10^{13}\ \#/cm^2$ is required for successful Neutron Capture Therapy (NCT). If epithermal neutron flux is $1 \times 10^{10}\ \#/cm^2 \cdot sec$, the neutron irradiation time would be necessary about 3 hours for therapy. And it is generally recommended to be desirable to have a fast neutron dose to epithermal fluence ratio of less than about $1 \times 10^{-10} Gy \cdot cm^2$ and a gamma ray dose to epithermal fluence ratio of less than about $2 \times 10^{-11} Gy \cdot cm^2$. And Epithermal neutron flux to thermal neutron flux larger than 20. The epithermal neutron flux is $6.61 \times 10^9\ \#/cm^2 \cdot sec$, fast neutron dose to epithermal neutron flux is $4.88 \times 10^{-14} Gy \cdot cm^2$, photon dose to epithermal neutron flux is $5.09 \times 10^{-14} Gy \cdot cm^2$, and epithermal neutron flux to thermal neutron flux is 20.2 in this simulation by MCNP code. This flux ($6.61 \times 10^9\ \#/cm^2 \cdot sec$) of simulation would be consumed 25 minutes for therapy.

Acknowledgment

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