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Dose calculation of accelerator-based boron neutron capture therapy with Monte Carlo simulations

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1. Introduction

Boron neutron capture therapy (BNCT) is binary radiation treatment modality. It treats tumor cell using ^{10}B compound and neutron beam. The ^{10}B nuclei which have high neutron capture cross-section, release α particle and ^{7}Li ion in $^{10}B(n, \alpha)^{7}Li$ reaction. These products have high linear energy transfer characteristics and their ranges are around single cell diameter (~10 μm). Therefore, BNCT can selectively treat the tumor cell by the targeted boron drug delivery [1]. In the South Korea, accelerator-based BNCT (A-BNCT) facility is under construction aiming to make epithermal neutron source. A-BNCT has advantages over reactor based BNCT, i.e. comfortable accessibility, cheap maintenance costs, simple operation and neutron beam characteristics [2].

The primary object of this study was to calculate the dose of accelerator-based boron neutron capture therapy. We used Monte Carlo simulations with DICOM CT images.

2. Methods and Results

2.1 Target and moderator design

The target and moderator assembly (Figure 1) were fully designed and revised from the previous study by Pohang Accelerator Laboratory, PAL. The target is 3 mm thick and composed of beryllium and supporting materials such as palladium and copper. The palladium acts as a hydrogen mitigating material to prevent blistering problems in beryllium. The blistering can destroy beryllium target by the expansion of hydrogen in the target which is made from combination of stopped protons and electrons. The copper is used for the heat exchanger due to its thermal conductivity. The various materials of moderator, beam shaper, collimator and shielding are also marked on the Figure 1.

2.2 Monte Carlo Simulations

Monte Carlo simulations were done using Geant4 version 10.3 [3]. The entire assembly geometry was imported to Geant4 geometry. We used physics list named “QGSP_BIC_AllHP” which uses evaluated nuclear data sets from TENDL-2014 and ENDF/B-VII.1 for the precise simulations of neutron and proton.

The incident proton beam to the beryllium target was assumed as uniform field (13 x 13 cm^2) and mono-energy (10 MeV). Before the dose calculation, all neutrons and gamma were collected to make a phase-space file, which consists of position, direction, energy and particle name of each radiation that passed through the moderator and filter. Then, this phase-space file was used to irradiate DICOM CT images.

2.3 Dose components of A-BNCT dosimetry

The dose was separated into four components, (a) boron dose – from α, ^{7}Li particle, (b) nitrogen dose, (c) fast neutron dose, (d) gamma dose to correct the different biological effectiveness of each dose components in the tissue [4]. The boron dose is produced by $^{10}B(n, \alpha)^{7}Li$ reaction, nitrogen dose is produced by $^{14}N(n, p)^{14}C$ reaction, fast neutron dose is from $^{1}H(n, n')^{1}H$ reaction and gamma dose is from photons created inside the patient body and incident photons. These four dose components are classified and collected in the Monte Carlo simulations. The weight factors, CBE (Compound Biological Effectiveness) for the boron dose and RBE (Relative Biological Effectiveness) for the others were used from the previous study [5].

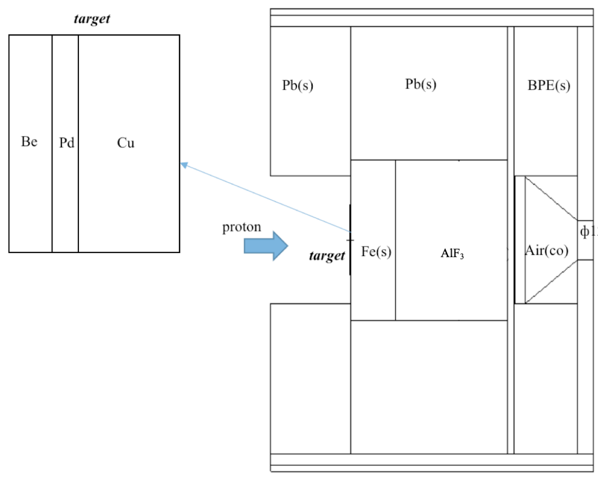

Fig. 1. The target and moderator assembly (designed by PAL).

3. Results

3.1 Neutron beam characteristics

Figure 2 shows the neutron and gamma beam spectrum at the beam exit. The neutron beams are moderated passing through the moderator. Over 85% of neutrons are in the epithermal range at the beam exit. Figure 3 shows the radial flux at the aperture whose final radius is 6 cm. The flux also steeply decreased after 6 cm apart.

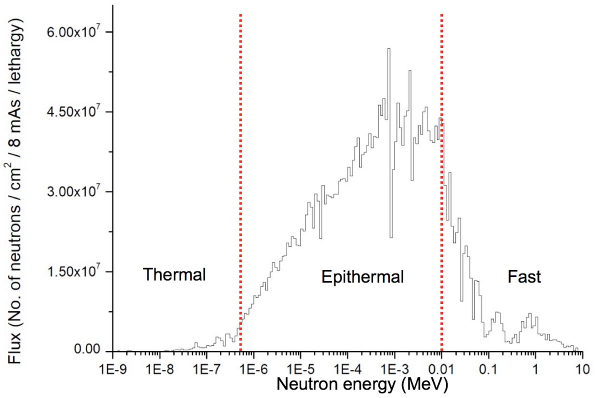

Fig. 2. The neutron energy spectrum.

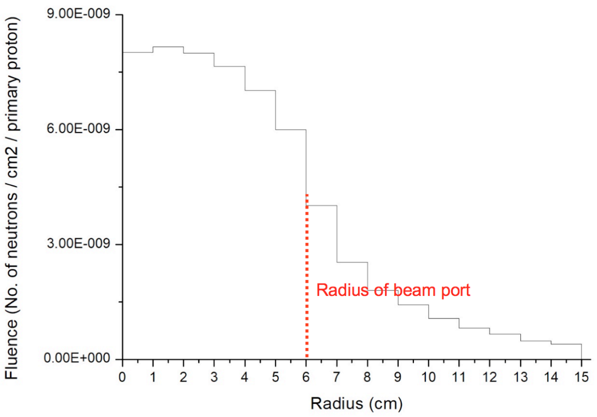

Fig. 3. The radial flux of neutron beam.

3.2 Dose along the beam axis

Figure 4 shows the depth dose (weighted) along the beam axis. At the depth of tumor, the boron dose steeply increased and kept plateau until tumor ends showing the therapeutic effect to the tumor region. At the shallow depth, however, the fast neutron dose dominates the total depth dose. This could be reduced by optimizing the moderator and collimator design.

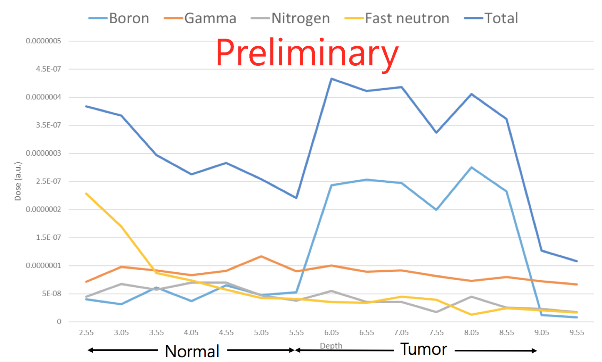

Fig. 4. The weighted depth dose along the beam axis.

4. Conclusions

The calculated dose components of A-BNCT from this study is the first step of getting better therapeutic effects. These data could be used for not only in the treatment planning system but also in the clinical research area in the near future.

5. Acknowledgements

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