A variable-geometry beam-shaping assembly for accelerator-based BNCT

Nima Ghal-Eh
Department of Physics
Faculty of Science, Ferdowsi University of Mashhad
Mashhad, Iran
ghal-eh@um.ac.ir

Faezeh Rahmani
Department of Physics
K. N. Toosi University of Technology
Tehran, Iran
frahmani@kntu.ac.ir

Sergey V. Bedenko
School of Nuclear Science and Engineering
Tomsk Polytechnic University
Tomsk, Russian Federation
bedenko@tpu.ru

***Abstract*— Although the beam shaping assemblies (BSAs) for reactor-based Boron Neutron Capture Therapy (BNCT) facilities are typically of a single design, the accelerator beams with the possibility to provide neutron spectrum to give characteristics which are optimum for different treatment sites and tumor depth generally may require a fine-tuning procedure which can be undertaken with variable-geometry BSA. In this study, a special geometry is proposed for use with a hybrid photoneutron source equipped with drill-chuck type head. Both the neutron spectrum and epithermal neutron flux can be treated by changing the BSA geometry.**

Keywords— Linear electron accelerator (LINAC), Variable-geometry beam shaping assembly, Boron Neutron Capture Therapy (BNCT).

I. Introduction

Boron Neutron Capture Therapy (BNCT) is a promising cancer treatment, which kills the cancer cells selectively by the use of a cancer-seeking boron compound and a neutron irradiation. BNCT is expected to be very effective for several types of cancer such as Glioblastoma Multiform (GBM) and Melanoma for which no successful treatment has been developed [1].

This method depends on (1) using an appropriate boron carrier drug with more ^{10}B deposition in cancer cells in comparison to normal tissue. (2) sufficient low-energy neutrons in tumor position for (n,α) capture in ^{10}B [2]. ^{7}Li nuclei and alpha particles as interaction products of neutron capture in ^{10}B have high linear energy transfer values, and hence will lead to high energy depositions within the cell dimension and may destroy the tumor.

Since thermal neutrons cannot penetrate into the position of the GBM deep in brain, a high energy neutron beam should be provided that thermalized after penetration in tumor position.

Higher flux of therapeutic epithermal neutron beam ensures that the treatment will be performed in a reasonable time.

Accelerator-based neutron sources are the most appropriate ones for the BNCT purposes which are safe and relatively compact which can be regarded as the feasible approaches that incorporate Linacs.

Linacs, as a neutron source for BNCT, have been investigated by different researchers worldwide through different simulations and modeling approaches [3-7].

In conventional designs, having determined the appropriate BSA for a given neutron source, the related component of BSA is normally fixed for treatment. In this research, based on electron Linac a variable-geometry BSA is mounted on the accelerator head which produces variable epithermal neutron flux and can be adjusted for various dose demands. This idea can be further developed for various requirements according to different needs in reactor-based BNCT. The Monte Carlo MCNPX code has been used for the simulations.

II. Materials and Methods

A. Photoneutron target design

In this research, we used a photoneutron target proposed by Torabi et al. for 25 MeV electron Linac [8]. Photon production (Bremsstrahlung) in tungsten target using 25 MeV electrons has been simulated using the MCNPX Monte Carlo Code [9]. The Bremsstrahlung spectra have been corresponded to the photon source, and moreover, the photoneutron production in uranium has been modelled. As shown in Fig. 1, the photoneutron source consists of the optimized sizes of tungsten and uranium hemispheres as the photon converter and photoneutron target, respectively.

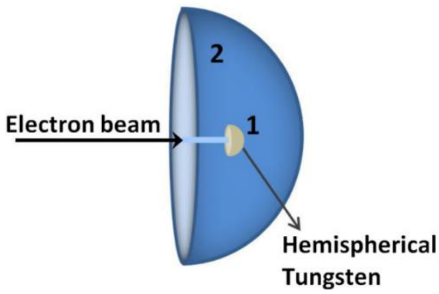

Fig. 1. A hybrid photoneutron source: (1) A 0.4-cm radius tungsten hemisphere as an electron/photon converter; (2) A uranium hemisphere with 6 cm in radius as photon/neutron converter.

Figs. 1 and 2 show the hybrid photoneutron source used in this study and also the neutron spectrum at the curved surface of the target, respectively.

978-1-7281-2896-2/19/$31.00©2019 IEEE

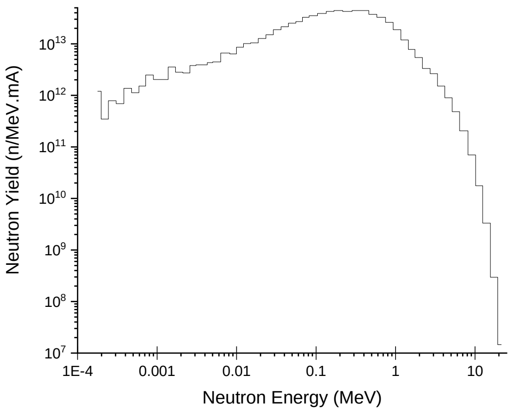

Fig. 2. Photoneutron spectrum at the end surface of the photoneutron target used in the present study (Fig. 1).

B. *Beam Shaping Assembly*

The neutron transport through moderator, reflector and collimator, as different components of the BSA, has been carried out by the Monte Carlo code, MCNPX, to obtain the therapeutic neutron beam so that the IAEA recommendations are fulfilled [2]. The materials with a maximum $\Sigma_{sf\rightarrow epi}/\Sigma\gamma$ can be selected as appropriate moderators, where $\Sigma_{sf\rightarrow epi}$ and $\Sigma\gamma$ are the macroscopic fast-to-epithermal scattering- and neutron-capture cross-sections, respectively [8].

The proposed BSA in cylindrical arrangement includes three layers of materials with an outer shell as shown in Fig. 3, such that the inner cylindrical parts are adjustable whilst the outer layer remains fixed. Having set the BSA diameter as 0.50 m, different compositions in various thicknesses have been examined in order to satisfy in-Air criteria determined by IAEA. Finally, as an optimum configuration, 15 cm of Fluental®, 30 cm of MgF_2 and 20 cm of TiF_3 have been selected as shown in Fig. 3. However, the drill-chuck parts can move in forward direction as shown in Fig. 4.

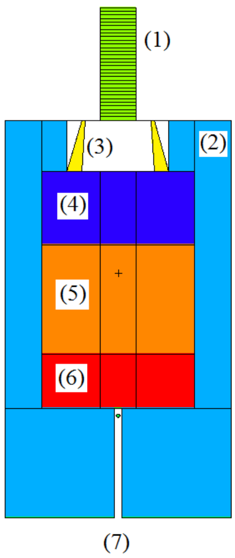

Fig. 3. The proposed drill-chuck shaped BSA assembly and water phantom: (1) Water phantom, (2) Lead, (3) Nickel, (4) Fluental®, (5) MgF2, (6) TiF3 and (7) Electron beam corridor.

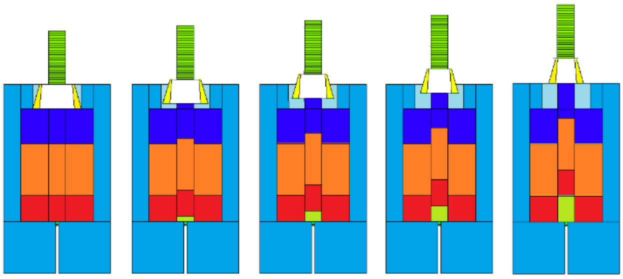

Fig. 4. Different drill-chuck head of the BSA head.

The proposed variable-geometry drill-chuck BSA together with a typical patient bed is illustrated in Fig. 5.

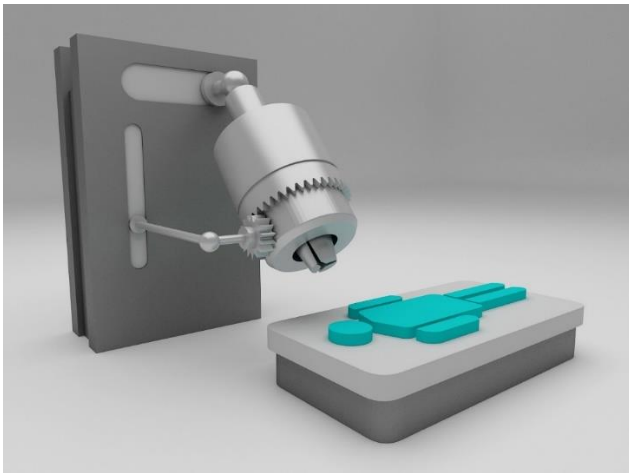

Fig. 5. Conceptual design of variable-geometry drill-chuck head BSA and a typical patient bed.

III. Results and Discussion

The most appropriate neutron spectrum with sufficient flux has been produced using the proposed hybrid photoneutron target design used in this study. Fig. 6 shows the MCNPX-simulated therapeutic neutron beam in the water phantom corresponding to five different positions of drill chuck part shown in Fig. 4.

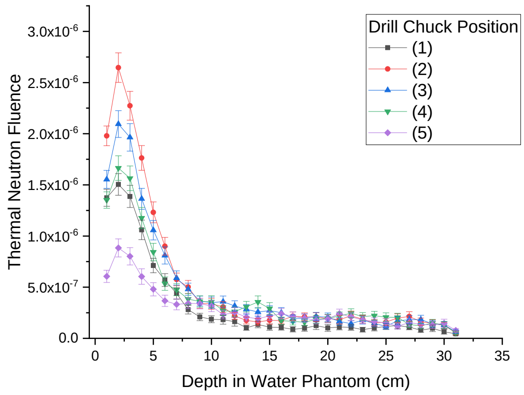

Fig. 6. Variation of thermal neutron fluence at different positions within the water phantom.

One may conclude that, using this variable-geometry BSA, several epithermal neutron flux can be available without the change in operational parameters of Linac.

IV. Conclusions

One of the requirements for the BNCT treatment is correct dose delivery to patient, which can be adjusted by Treatment Time (TT) or therapeutic neutron flux (which relates to dose rate). Technically, TT cannot be shorter than the determined duration, so the therapeutic neutron flux should be changed for low dose treatment. If the beam shaping assembly is variable in geometry, the BNCT can be performed without any limitation in treatment time. This design can also be used for reactor based BNCT to have thermal and epithermal neutrons for superficial and deep-seated tumor simultaneously.

Acknowledgment

The research is supported by Tomsk Polytechnic University within the frame work of Tomsk Polytechnic University Competitiveness Enhancement Program.

References

[1] M. Suzuki, Boron neutron capture therapy (BNCT): a unique role in radiotherapy with a view to entering the accelerator-based BNCT era, International Journal of Clinical Oncology (2019) 1-8.

[2] Current Status of Neutron Capture Therapy. IAEA-TECDOC-1223, 2001. International Atomic Energy Agency.

[3] K. Babaeian, F. Rahmani, Y. Kasesaz, Conceptual design of prompt gamma neutron activation analysis facility at Tehran Research Reactor for BNCT application, Nuclear Instruments and Methods in Physics Research, A935 (2019) 185-190.

[4] F. Rahmani, M. Shahriari, Hybrid Photoneutron Source optimization for Electron Accelerator-Based BNCT, Nuclear Instruments and Methods in Physics Research, A618 (2010) 48-53.

[5] F. Rahmani, M. Shahriari, Beam shaping assembly optimization of Linac based BNCT and in-phantom depth dose distribution analysis of brain tumors for verification of a beam model, Annals of Nuclear Energy, 38 (2011) 404-409.

[6] N. Ghal-Eh, H. Goudarzi, F. Rahmani, FLUKA simulation studies on in-phantom dosimetric parameters of a LINAC-based BNCT, Radiation Physica and Chemistry, 141 (2017) 36-40

[7] F. Rahmnai, S. Seifi, H. Anbaran, F. Ghasemi, Design of photon converter and photoneutron target for High power electron accelerator based BNCT, Applied Radiation and Isotopes, 106 (2015) 45-48

[8] F. Torabi, S. F. Masoudi, F. Rahmani, F. S. Rasouli, BSA optimization and dosimetric assessment for an electron linac based BNCT of deep‑seated brain tumors, Journal of Radioanalytical and Nuclear Chemistry, 300 (2014) 1167-1174.

[9] MCNP—A general Monte Carlo N-particle transport code, Los Alamos National Laboratory Monte Carlo Team, Version 2.6, LA-CP-07-1473, 2008.