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Design of a model for BSA to meet free beam parameters for BNCT based on multiplier system for D–T neutron source

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ABSTRACT

Extensive research has recently been carried out for the development of high-energy D–T neutron generators as neutron sources for BNCT. The energy of these high-energy neutrons must be reduced by designing a Beam Shaping Assembly (BSA) to make them usable for BNCT. However, the neutron flux decreases drastically as neutrons pass through different materials of BSA. Therefore, it is very important to find ways to treat the neutrons economically. In this paper the possibility of using natural uranium as a neutron multiplier is investigated in order to increase the number of neutrons emitted from D–T neutron generator. According to the simulations and performed calculations, a sphere containing natural uranium as neutron multiplier was used to increase the number of neutrons generated by the D–T neutron generator. The energy of fast neutrons that are generated by D–T fusion reaction and amplified by neutron multiplier system is decreased using proper materials as moderators and fast neutron filters in BSA. The gamma rays which are generated as a result of neutron interaction with moderators are removed from neutron spectrum using bismuth as the gamma filter. Also, a thermal neutron absorber omits undesired low-energy neutrons which lead to a high radiation dose for the skin and soft tissues. The results show that passing neutrons through such a BSA causes the establishment of free beam parameters yet the reduction of the output beam intensity is unavoidable. The neutron spectrum related to our BSA has a proper epithermal flux and the fast and thermal neutron fluxes are compatible with the IAEA recommended values.

1. Introduction

As a prominent method for treating tumors, radiotherapy is classified into "direct" or "indirect" categories. In direct method, the tumor is influenced by proton or alpha radiation which directly leads to the destruction of cancer cells. However, the second method destroys cancer cells indirectly. As an example of indirect destruction of tumor cells, BNCT (Boron Neutron Capture Therapy) treats the tumors by particles which are generated in the process of a nuclear reaction such as the resultant particles of interaction between boron and low energy neutrons (Cerullo et al., 2004; Durisi et al., 2007).

In this method, ^{10}B compounds – which is a stable isotope of boron with large absorption cross section for thermal neutrons – are directed towards the cancer cells. The ^{10}B compounds accumulate in a different way in cancer cells and healthy tissue. Only when a high boron concentration ratio on tumor than healthy tissue is reached, the patient is irradiated with thermal or epithermal neutrons. The interaction between boron and neutron produces an alpha particle and a lithium ion (Cerullo et al., 2002; Sakamoto et al., 1999; Kotiluoto and Auterinen, 2004). These particles deposit their energy over the range of reaction origin and so destroy cancer cells without damaging the normal tissue (Yamamoto et al., 2008). In BNCT, epithermal neutrons are the best option to treat deep seated tumors such as Glioblastoma multiforme. These neutrons reach the thermal energy range after passing through brain tissues (Elshahat et al., 2007; Rahmani and Shahriari, 2010).

Neutron flux is one of the most important characteristics of the neutron source for BNCT. The flux must be large enough so that the therapy procedures can be established in a reasonable time. Initially, nuclear reactors have been the only neutron sources which are capable of providing the required neutron beam with high neutron flux (Auterinen et al., 2004; Tahara et al., 2006). However, recently the use of other potential neutron sources have been investigated for BNCT method (Durisi et al., 2007; Cerullo et al., 2002; Rahmani and Shahriari, 2010; Kononov et al., 2004; Ghassoun et al., 2009). Compact neutron generators based on D–T fusion reaction ($^{3}H(d,n)^{4}He$) seem to be much better for in-hospital treatments due to greater safety, lower energy for incident deuteron beam (100–400 keV) (Montagnini et al., 2002), lower cost, smaller size and high social acceptability.

High energy neutrons of 14.1 MeV are emitted from this fusion reaction. As these neutrons cannot be used directly in BNCT, it is

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