Applied Radiation and Isotopes 88 (2014) 233–237

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

Beam shaping assembly optimization for $^{7}Li(p,n)^{7}Be$ accelerator based BNCT

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HIGHLIGHTS

- A Beam Shaping Assembly for accelerator based BNCT has been designed.
- A conical port for easy patient positioning and the cooling system are included.
- Several configurations can deliver tumor doses greater than 55 RBEGy.
- Good tumor doses can be obtained in less than 60 min of irradiation time.

ARTICLE INFO

Available online 4 December 2013

Keywords:
Accelerator-based BNCT
Neutron sources
$^{7}Li(p,n)$ reaction

ABSTRACT

Within the framework of accelerator-based BNCT, a project to develop a folded Tandem-ElectroStatic-Quadrupole accelerator is under way at the Atomic Energy Commission of Argentina. The proposed accelerator is conceived to deliver a proton beam of 30 mA at about 2.5 MeV. In this work we explore a Beam Shaping Assembly (BSA) design based on the $^{7}Li(p,n)^{7}Be$ neutron production reaction to obtain neutron beams to treat deep seated tumors.

1. Introduction

In the framework of Accelerator-Based Boron Neutron Capture Therapy (AB-BNCT) a ~2.5 MeV, 30 mA proton beam accelerator is being developed in our group (Kreiner et al., 2011 and references therein). The final objective is to install a BNCT facility at the Roffo Cancer Institute in Buenos Aires. The project includes the development and construction of the accelerator and all its anxiliary systems, the beam shaping assembly (BSA) and the patient irradiation room. This article is devoted to the BSA.

One of the possible reactions to produce neutrons is the $^{7}Li(p,n)^{7}Be$. Although this reaction has important difficulties regarding the target construction, its relative high neutron yield and the fact that it is an endothermic reaction makes protons on lithium the optimal choice from a neutronic point of view. The near threshold option – i.e. proton energies of about 1.9 MeV – has the advantage of not requiring a BSA due to the fact that the neutrons have energies not far from those required for the treatment; but it has the disadvantage of a low yield. Some authors have worked with good results in this regime (Tanaka et al., 2004). On the other hand, working at energies near the resonance (~2.5 MeV) the neutron spectra are a bit harder and need to be moderated but the higher yields compensate the losses in the beam shaping process. In this manuscript the last option has been explored as a neutron source for BNCT.

In previous work (Minsky et al., 2011) we have designed a BSA based on the $^{7}Li(p,n)$ reaction which could provide high doses to tumor without exceeding healthy tissues tolerance doses. In that design the port was sited on a plane of a prism shaped BSA; in the new design shown in this manuscript a cone shaped port has been used to help in the patient positioning and avoiding unnecessary doses to regions away from the target. The new design also takes into account the cooling system of the target. This article is devoted to the optimization of the BSA.

2. Materials and methods

2.1. Reaction yield calculation

The generation of the neutrons is based on the reaction of protons on a metallic lithium target. A code developed for the previous design with a lithium fluoride target was extended to calculate the yields for metallic lithium which offers a factor of 3 greater neutron yield than lithium fluoride. The double differential neutron yield per solid angle and energy has been calculated following Lee and Zhou (1999), but more recent cross section data

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http://dx.doi.org/10.1016/j.apradiso.2013.11.088

has been used and since higher proton energies have been studied the $^{7}Li(p,n)^{7}Be^{*}$ channel which is open at proton energies above 2.37 MeV has also been included. For further details on the cross section data refer to Minsky et al. (2011). A matrix consisting in the double differential neutron yield every 1 degree and 1 keV is generated with this code.

MCNP cards for this source are generated by a Perl script. Instead of using the usual source definition by defining histograms of the energy and angle distributions, the distributions are constructed by linear interpolations between some defined points in the distribution. The number of points and their values are defined in order that the error in any distribution does not exceed 1%. The definition of the angular distribution has been made every 10 degrees.

2.2. Beam shaping assembly

A Beam Shaping Assembly with cylindrical symmetry has been designed (Fig. 1). The BSA consists in a moderating volume of a stack of layers of aluminum, Teflon® and natural lithium carbonate. A cooling system that has been developed and tested in our group (not shown) has been considered since the important amount of water has important implications on the neutron transport and moderation. The moderator is surrounded by a neutron lead reflector that also serves as shielding. An external layer of polylithium (7% in weight natural lithium) further shields from thermal neutrons. The 12 cm diameter port has a 95% ^{6}Li enriched lithium carbonate layer to avoid undesirable thermal neutrons in the beam. The proton beam current was adopted to be 30 mA as the specification of the accelerator being developed at CNEA (Kreiner et al., 2011).

The proton energy (E_p), the target to front distance (TFD), the target to back distance (TBD) and the moderator radius (MR) has been varied in discrete steps (Table 1). Each set of these parameters constitutes a different setup configuration that has been simulated by means of MCNP5 (Brown et al., 2002) Monte Carlo simulations. A total of 2376 configurations have been analyzed.

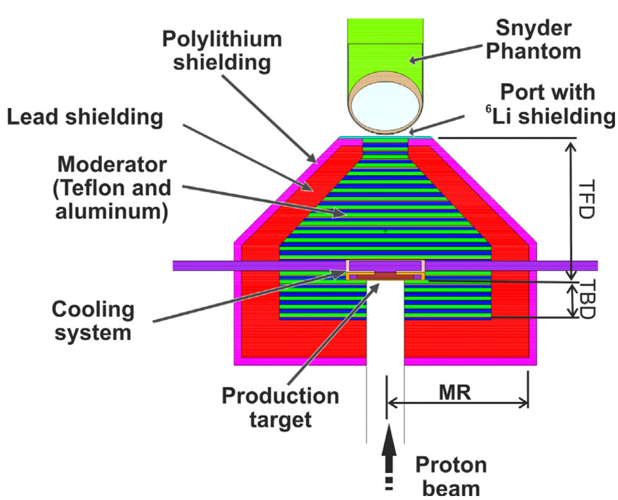

Fig. 1. Beam shaping assembly design.

Table 1
Parameters that have been varied and their values.

Parameter	Analyzed values
Proton Energy	2.2, 2.3, 2.4 … 3 MeV
Target to front distance (TFD)	22, 26, 30 … 54 cm
Target to back distance (TBD)	2, 6 and 10 cm
Moderator radius (MR)	10, 12, 14, 16, 18, 20, 24, 28 cm

2.3. Dosimetry

A Snyder head phantom (Goorley, 2002) was sagitally positioned in the setup and depth dose profiles have been computed. ICRU 46 (1992)

Table 2
Weight factors assumed for dose calculations.

Tissue	γ RBE	Neutron RBE	^{10}B CBE	^{10}B concentration [ppm]
Healthy brain	1	3.2	1.3	15
Skin	1	3.2	2.5	22.5
Tumor	1	3.2	3.8	52.5

Table 3
Prescriptions for the treatment session.

Maximum healthy brain punctual dose	11 RBEGy
Maximum skin dose	16.7 RBEGy
Maximum healthy brain mean dose	7 RBEGy
Maximum irradiation time	60 min

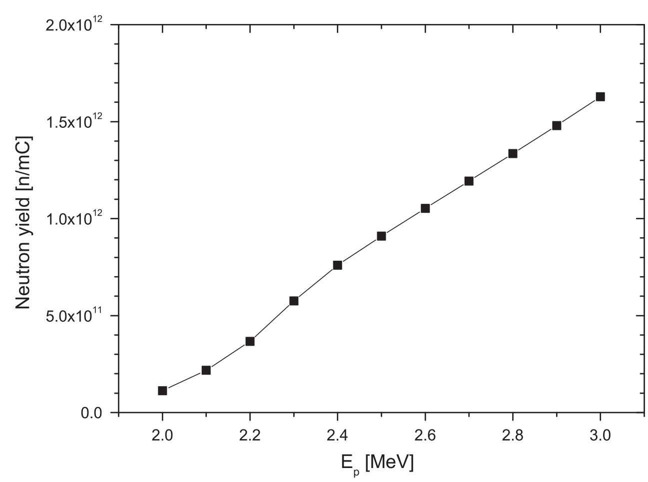

Fig. 2. Neutron yield for $^{7}Li(p,n)$ vs. proton energy.

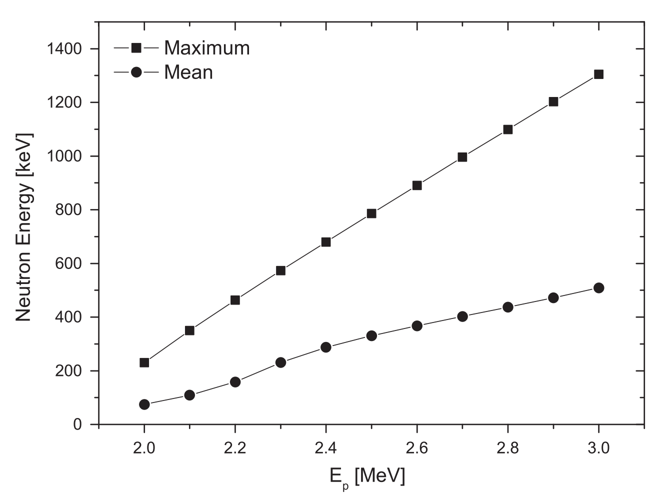

Fig. 3. Maximum and mean energy of the resulting neutrons for $^{7}Li(p,n)$ vs. proton energy.