Volume 13, No 1 | International Journal of Radiation Research, January 2015

Optimization study for BNCT facility based on a DT neutron generator

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► ***Original article***

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Revised: April 2014
Accepted: Sept. 2014

Int. J. Radiat. Res., January 2015; 13(1): 13-24

DOI: 10.7508/ijrr.2015.01.002

ABSTRACT

Background: A Boron Neutron Capture Therapy (BNCT) facility, based on a DT neutron generator, with the final goal to find out a potential, alternative, solution to existing BNCT treatment facilities which are based on nuclear reactors is examined. ***Materials and Methods:*** With the aim of the MCNP4B Monte Carlo code different beam-shaping assembly (BSA) configurations were considered. Lead was selected as reflector material while CF_2, D_2O, Fluental, PbF_4, PbF_2, BiF_3, BiF_5, MgF_2, Al_2O_3, AlF_3, TiF_3, BeD_2, CaF_2 and ^7LiF were examined as spectrum shifters. In order to improve the quality of the beam titanium, nickel-60, iron and titanium alloy ($Ti_6Al_{14}V$) were simulated as fast neutrons filters while lead and bismuth were considered as gamma filters. ***Results:*** An extensive set of calculations performed with MCNP4B Monte Carlo code have shown that the combination of ^7LiF which accommodates a conic part made of D_2O, then followed by a TiF_3 layer is the optimum moderator design. The use of three different materials for further reduction of fast neutrons, thermal neutrons and gamma rays is necessary. ^{60}Ni, Cd and Bi were chosen respectively for these purposes. The epithermal neutron flux obtained at the beam exit window turned out to be 3.94×10^9 n cm^{-2} s^{-1} while fulfilling all the recommended IAEA in-air Figure Of Merit (FOM) criteria. The assessment of the dose profiles in head phantom and the in-phantom FOM are also presented. ***Conclusion:*** The proposed assembly configuration may provide an attractive option for centers wishing to install a BNCT facility.

Keywords: *BNCT, DT neutron generator, epithermal neutron, MCNP.*

INTRODUCTION

Boron Neutron Capture Therapy (BNCT) is an effective and promising treatment of tumor types which are resistant to conventional therapies. BNCT is a binary treatment modality, first a ^{10}B compound is delivered to the patient and differently accumulates in cancer cells versus healthy tissue; then, when a high boron concentration ratio between tumor and healthy tissue is reached, the patient is irradiated with neutrons inducing the $^{10}B(n,\alpha)^7Li$ reaction. The alpha particle emitted and the ^7Li nuclei created have high Linear Energy Transfer (LET), and an associated high Relative Biological Effectiveness (RBE). The mean free path is about 7 μm and 4 μm for α particle and for ^7Li, respectively. Considering that the mean cellular diameter is almost in the same order of magnitude, the BNCT technique may therefore be effective in selective tumor cell destruction [1, 2].

Due to their poor tissue penetration, thermal neutrons are only applicable to the direct treatment of tumors which are located near the tissue surface. Epithermal neutrons with an energy range between 1 eV and 10 keV are more

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penetrating and able to reach deep-seated tumors. A typical example is glioblastoma multiform a quite aggressive type of brain cancer, by far the most common and malignant of the glial tumors. The application of the BNCT technique in clinical trials requires a neutron beam having a high enough flux level and, mainly, a proper spectrum shape. In order to reduce the irradiation time, the desirable minimum beam intensity should be 1×10^{9} $cm^{-2}s^{-1}$. In order to limit the treatment time to reasonable levels (i.e. 1 hour) the requested epithermal neutron flux level should be at least 10^{9} s^{-1}, and also well collimated to avoid excessive dose to adjacent healthy tissues [3-5].

A number of candidate neutron sources for BNCT technique can be considered. Neutrons may be generated by nuclear reactors, accelerator-driven systems or generators based on either spontaneous fission of transuranic heavy materials, or exploiting specific nuclear reactions induced by radioactive sources. Radioisotope sources, such as ^{252}Cf and $^{241}Am/Be$ are commonly used for detector calibrations because of low yield and energy up to 10 MeV. Nuclear reactors provide high-intensity neutron beams but are very expensive and considerably sizeable to be used in hospital settings. Additionally, safety and authorization concerns prevent their installation in urban hospitals. Accelerator-driven systems, based on linacs, cyclotrons, or tandem van de Graff may instead be properly used to yield and tailor an epithermal neutron beam for this purpose. Their cost is generally lower compared to even small research reactors, although they need a series of ancillary systems which may occupy large space [6-8].

DT neutron generators, based on the fusion reaction $^{3}H(d,n)^{4}He$, may be an attractive choice as they warrant high safety, smaller size and high social acceptability. Furthermore, these neutron sources require low energy deuteron beam (100–400 keV) which is available with smaller, simpler, electrostatic-type accelerators. Last but not least they offer an on/off switching of the emitted neutrons and are less costly. A number of studies on the use of DT neutron generators for BNCT were recently published [4, 5, 9-12].

The main goal of this study was to optimize a BNCT facility based on a DT neutron generator - which yields 10^{14} n s^{-1}- in terms of beam shaping assembly (BSA) design (moderator, gamma ray, fast and thermal neutron filters) and calculate the dose in a simulated head phantom. The facility was designed using the Monte Carlo MCNP version 4B, transport code which is suitable for gamma and neutron calculations [13].

MATERIALS AND METHODS

Neutron source

DT tubes are based upon deuteron beams bombarding a tritiated target with the resultant yield of fusion neutrons. The neutron spectrum from the DT neutron generator, which was derived by Fantidis *et al.* [14], has been used for the purposes of this paper. In order to minimize the treatment time in BNCT the epithermal neutron flux has to be sufficiently high ($\approx10^{9}$ n cm^{-2} s^{-1}). According to Rasouli *et al.* [11] a fission-converter -based sphere made by natural uranium surrounding the DT source target could be used as neutron multiplier and energy degrader device in order to increase the number of neutrons via fission reaction. Based on results from the MCNP4B calculations, the ratio of neutrons yielded (mainly by fission reactions) per source neutron (N/N0), available over the surface of such a sphere, is peaked for 14 cm radius (figure 1). These results are similar to the previous studies by Martin and Abrahantes[12] and Rasouli *et al.* [11].

The MCNP facility modeling

Different beam-shaping assembly (BSA) configurations were considered, in order to fulfill the parameters required (table 1) [15]. Based on the literature, lead (Pb) was selected as reflector material (8,9). Because of the high (14.1 MeV) mean energy neutrons yielded by DT reactions, a spectrum shifter system is needed in order to slow neutrons down to the required epithermal energy range (1 eV to 10 keV). In order to achieve such a goal, the "ideal" spectrum shifter should provide the following

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nuclear properties: a low down scattering cross section at the epithermal energy range, high removal cross section at higher energies and limited radiative (n, γ) captures. In addition, it should not produce large quantities of gamma-rays by inelastic scattering. In order to produce an epithermal beam, the most suitable materials to moderate neutrons with different combinations and thickness were therefore investigated by Monte Carlo simulations. Fourteen different materials namely, Teflon (CF_2), heavy water (D_2O), Fluental, PbF_4, PbF_2, BiF_3, BiF_5, MgF_2, Al_2O_3, AlF_3, TiF_3, BeD_2, CaF_2 and ^7LiF were considered.

Neutrons, once being moderated pass through filters, in order to improve the quality of neutron beam. An ideal neutron filter must absorb only the unwanted fast and thermal neutrons without producing gamma rays. Unfortunately such nuclear properties are not fulfilled by existing materials, either in elemental or compound forms. A balanced compromise has therefore to be taken. For such a reason, the selection has been limited to four different materials able to improve the spectrum shape of the neutron beam: Titanium (Ti), Nickel-60 (^{60}Ni), Iron (Fe) and titanium alloy ($Ti_6Al_{14}V$). They have proven to be effective as neutron filtering materials aiming to improve the

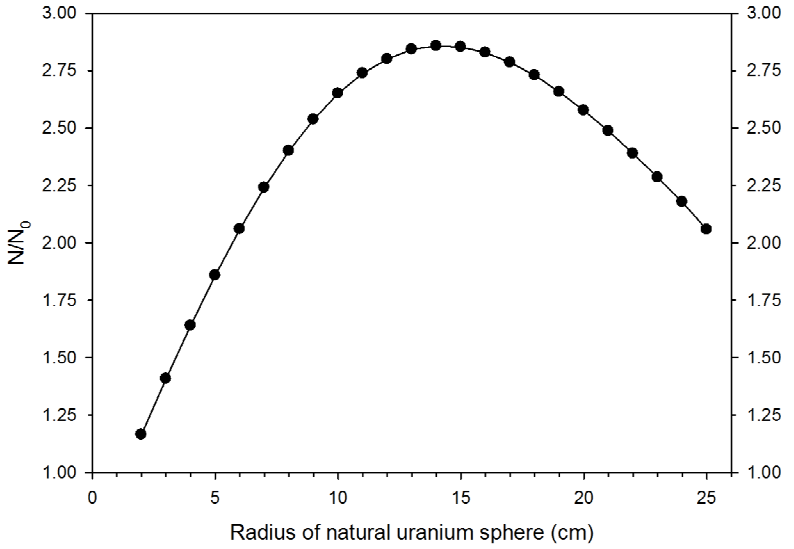

Figure 1. Number of neutrons per neutron source for different thicknesses of natural uranium as a neutron multiplier.

Table 1. Recommended values in the beam exit window.

BNCT beam port parameters	Recommended value
$\Phi_{epithermal}$ (n cm^{-2} s^{-1})	~10^9
$\Phi_{epithermal}/\Phi_{fast}$	>20
$\Phi_{epithermal}/\Phi_{thermal}$	>100
$\dot{D}_{fast}/\Phi_{epithermal}$ (Gy cm^2)	<2 × 10^{-13}
$\dot{D}_{\gamma}/\Phi_{epithermal}$ (Gy cm^2)	<2 × 10^{-13}
Fast energy group (Φ_{fast})	E>10 keV
Epithermal energy group ($\Phi_{epithermal}$)	1 eV ≤ E ≤ 10 keV
Thermal energy group ($\Phi_{thermal}$)	E<1 eV

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epithermal to fast neutron ratio in the BNCT neutron beam. High Z materials, such as lead (Pb) and Bismuth (Bi) are instead suitable in order to remove the gamma component. Moreover, in order to increase the epithermal to thermal ratio materials having a high absorption cross section in thermal range are needed. An absorber material, lithiated poliethylene (poly-Li), is at last included as delimited to get a collimated neutron beam. The final part of the BSA design includes a delimiter with the intention to minimize the dose rate outside of the tumor cells. It should be noted that the unit is designed in the form of coaxial cylinders and the neutron distribution is symmetrical due to the symmetrical geometry considered.

RESULTS

A wide set of computational studies was carried out using the MCNP4B Monte Carlo code. The neutron flux and the dose rate were calculated at the exit of the facility across the 12 cm diameter window using the F2, Fm2 tallies and the DE, DF cards. An accuracy of less than 1% was achieved in all cases. Fourteen different spectrum shifter materials to slow neutrons down to epithermal energy ranges, having different thickness, were therefore investigated. Figure 2 shows the $\Phi_{epithermal}$ for the studied materials as a function of the moderators' thickness. In figure 3 the $\Phi_{epithermal}/\Phi_{fast}$ ratio of spectrum shifter candidate materials versus their thickness, is plotted. According to the results the BeD_2 and the D_2O give the higher $\Phi_{epithermal}$ short moderators length, although the flux level quickly drops off with increasing thickness. Taking into account plots in figures 2 and 3, it may be concluded that 19 cm thickness of ^7LiF provides the optimal balance between $\Phi_{epithermal}$ and $\Phi_{epithermal}/\Phi_{fast}$ ratio correspondingly.

With the aim to find out the best solution a huge number of configurations have been considered and the simulations show that 19 cm of ^7LiF housing at the beam axis an additional, truncated cone volume filled with D_2O is the optimum choice. The truncated cone moderator has a length of 6 cm and radii 6 and 1 cm with the larger radius close to the source. The conic part increases the $\Phi_{epithermal}$ and the $\Phi_{thermal}$ and reduces the Φ_{fast}. Particularly the introduction of the D_2O increases the $\Phi_{epithermal}$ more than 7% (3.04×10^{10} n cm^{-2} s^{-1} vs. 2.84×10^{10} n cm^{-2} s^{-1}) and improves the $\Phi_{epithermal}/\Phi_{fast}$ and the $\Phi_{epithermal}/\Phi_{thermal}$ by 9.89% and 0.87% respectively. However, both the $\Phi_{epithermal}/\Phi_{fast}$ and the $\Phi_{epithermal}/\Phi_{thermal}$ ratios have values (2.89 and 10.49

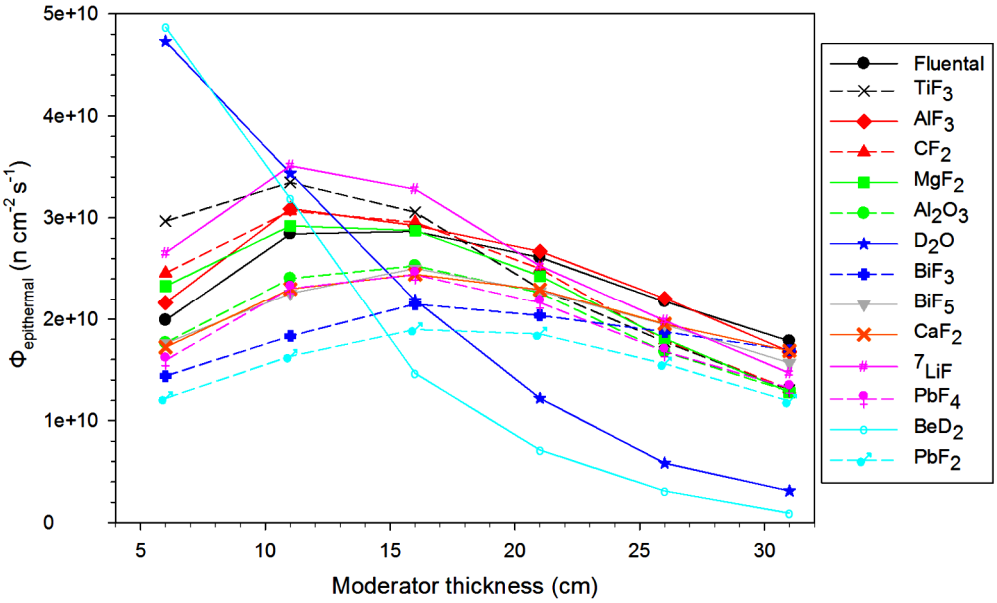

Figure 2. $\Phi_{epithermal}$ for different thicknesses of moderators.

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correspondingly) below from the recommended limits. For these reasons a second moderator should be used.

Figures 4, 5 and 6 show the $\Phi_{epithermal}$, $\Phi_{epithermal}/\Phi_{fast}$ and the $\Phi_{epithermal}/\Phi_{thermal}$ ratios for a number of materials which have been selected as second spectrum shifter versus their thicknesses, whilst 19 cm ^{7}LiF incorporating a D_2O conic part has previously been selected as the first part of the moderator. Even though Fluental is able to provide a larger $\Phi_{epithermal}$, the TiF_3 seem to be however a better choice because of superior values for $\Phi_{epithermal}/\Phi_{fast}$ and the $\Phi_{epithermal}/\Phi_{thermal}$ BSA modeling parameters. Indeed if TiF_3 is selected as spectrum shifter instead of Fluental the BSA shows to have comparable values for the $\Phi_{epithermal}$, a better performance for the $\Phi_{epithermal}/\Phi_{fast}$ ratio and by far higher values for the $\Phi_{epithermal}/\Phi_{thermal}$ ratio. Therefore results revealed that the optimum thickness for the TiF_3 spectrum shifter is 19 cm.

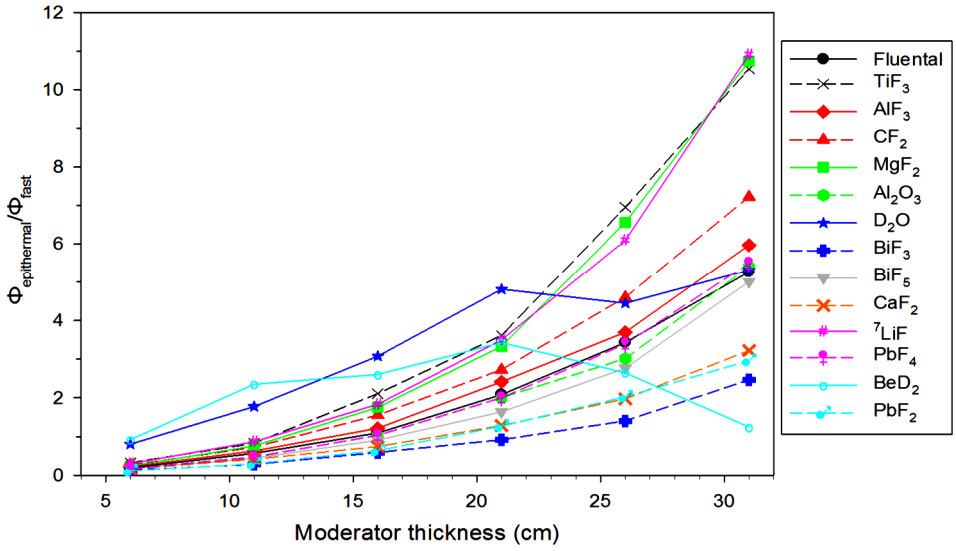

Figure 3. The $\Phi_{epithermal}/\Phi_{fast}$ ratio for different thicknesses of moderators.

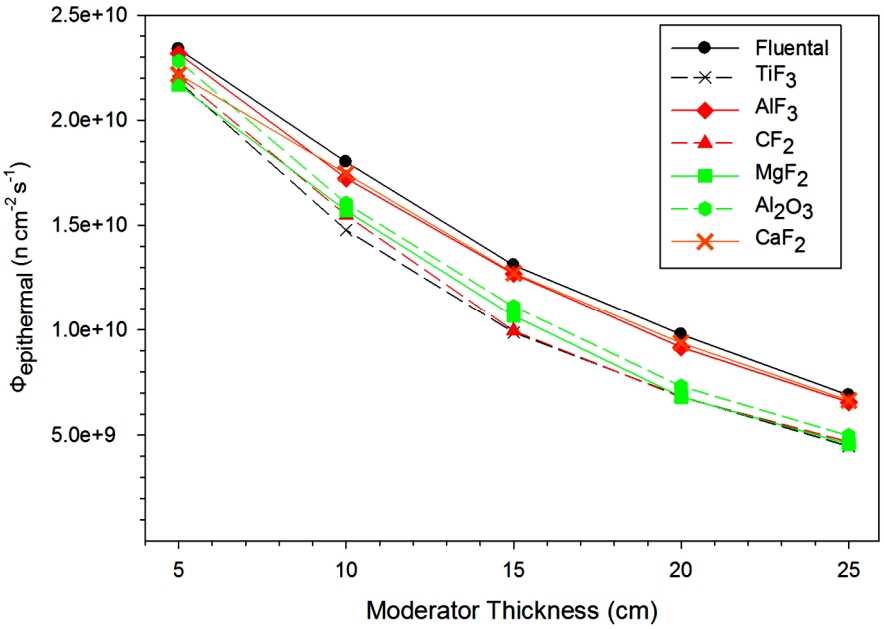

Figure 4. $\Phi_{epithermal}$ for different thicknesses of the second moderator where 19 cm ^{7}LiF which incorporates a cone made of D_2O are selected as the first part of the moderator.

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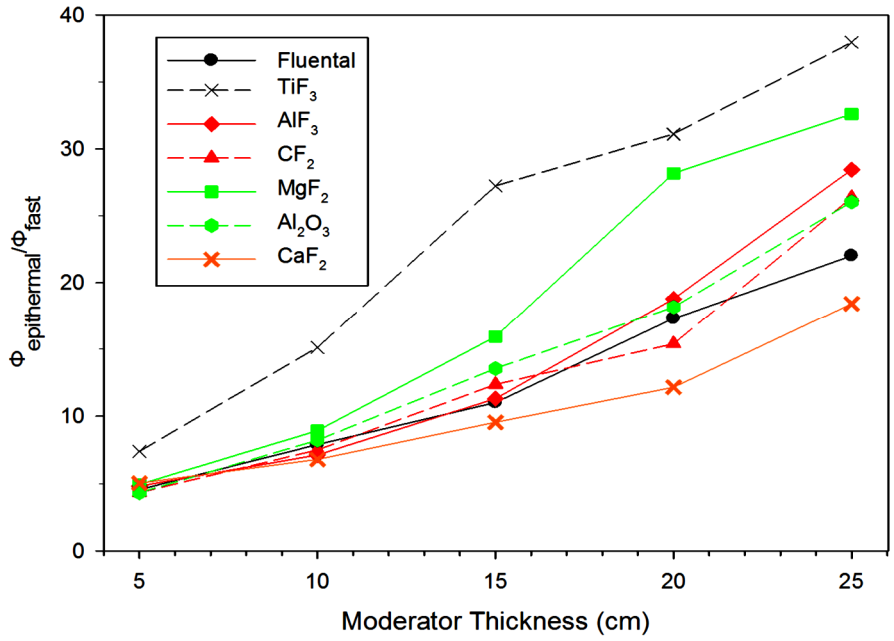

Figure 5. The $\Phi_{epithermal}/\Phi_{fast}$ ratio for different thicknesses of the second moderator where 19 cm ^{7}LiF which incorporates a cone made of D_2O are selected as the first part of the moderator.

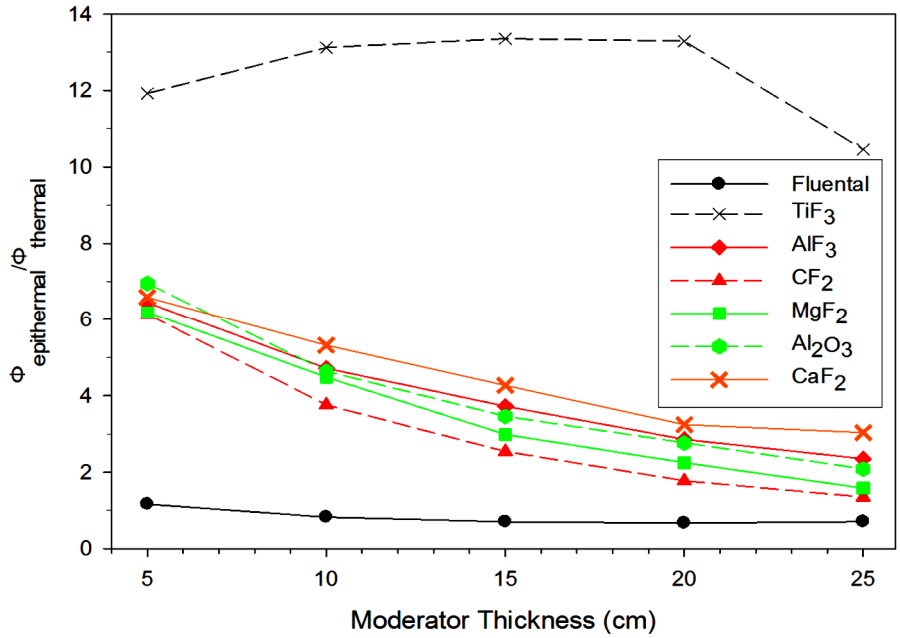

Figure 6. The $\Phi_{epithermal}/\Phi_{thermal}$ ratio for different thicknesses of the second moderator where 19 cm ^{7}LiF which incorporates a cone made of D_2O are selected as the first part of the moderator.

The BSA configuration thus selected allows for improving the quality of the in air FOM beam parameters, but the $\dot{D}_{fast}/\Phi_{epithermal}$ (4.57×10^{-13} Gy cm^2) and the $\dot{D}_{\gamma}/\Phi_{epithermal}$ (4.01×10^{-12} Gy cm^2) ratios turns out to be above the fixed levels. The value of the $\dot{D}_{fast}/\Phi_{epithermal}$ shows that the proper selections for a fast neutron filter is required in order to optimize the BSA design. Therefore 4 different materials (Fe, $Ti_6Al_{14}V$, Ti, ^{60}Ni) were examined as fast neutron filters. In figure 7 plots of the calculated $\dot{D}_{fast}/\Phi_{epithermal}$ ratio for different thickness of the investigated filters, shows that ^{60}Ni is a better choice. However the beam spectra owing to the fast neutron filters show (figure 8) that the presence of the Ti ensures higher $\Phi_{epithermal}$ with slightly lower values for the $\dot{D}_{fast}/\Phi_{epithermal}$ ratio. Motivated by these results all the BNCT in-air FOM parameters have been calculated and the results are summarized in table 2. From such results it may

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be noted that the Ti filter compared with the ^{60}Ni provides higher $\Phi_{epithermal}$ and has slightly higher value for the $\Phi_{epithermal}/\Phi_{thermal}$ ratio. However the final choice for the fast neutron filter is ^{60}Ni (with thickness 5 cm) because not only presents comparable values for the $\Phi_{epithermal}$, $\Phi_{epithermal}/\Phi_{thermal}$, $\Phi_{epithermal}/\Phi_{fast}$ and $\dot{D}_{fast}/\Phi_{epithermal}$ but also shows a basically lower level for the $\dot{D}_{\gamma}/\Phi_{epithermal}$ ratio. This fact is very important because require a less thick gamma filter with an improvement on the $\Phi_{epitermal}$ level as well, compared with Ti or ^{60}Ni.

Table 2. The relevant with BNCT parameters for 5cm thickness of the investigated fast neutrons filters.

Filter	**$\Phi_{epithermal}$ ($\times10^{9}$n cm^{-2}s^{-1})**	**$\Phi_{epithermal}/\Phi_{fast}$**	**$\Phi_{epithermal}/\Phi_{thermal}$**	**$\dot{D}_{fast}/\Phi_{epithermal}$ ($\times10^{-13}$ Gy cm^{2})**	**$\dot{D}_{\gamma}/\Phi_{epithermal}$ ($\times10^{-13}$ Gy cm^{2})**
Fe	4.31	33.07	96.30	2.60	2.11
$Ti_6Al_{14}V$	5.55	46.02	23.11	2.65	2.27
Ti	7.52	72.61	34.54	2.14	2.88
^{60}Ni	6.71	78.94	31.94	1.96	1.06
IAEA criteria	**>1**	**>20**	**>100**	**<2**	**<2**

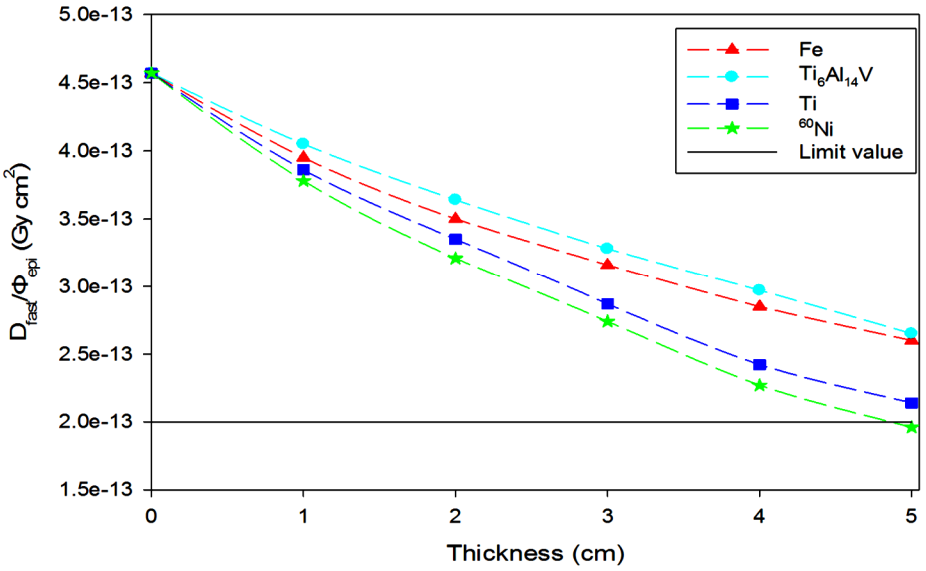

Figure 7. The $\dot{D}_{fast}/\Phi_{epi}$ ratio for different thicknesses of fast neutrons filters.

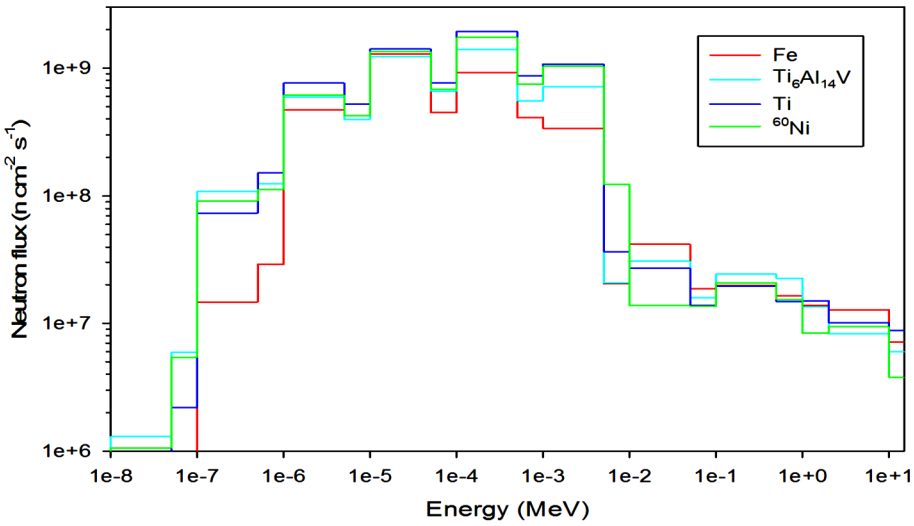

Figure 8. The neutron spectra for 5cm thickness of the investigated fast neutrons filters.

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The $\Phi_{epithermal}/\Phi_{thermal}$ ratio can be further raised up above the recommended level by using a thin layer of thermal neutron absorber. Just 0.15 cm of Cadmium (Cd) is indeed enough to absorb a large fraction of thermal neutrons with a negligible part of epithermal ones. On the contrary Cadmium has the drawback of a high energy gamma rays yield upon neutron capture but this problem may be overcome if the Cd thermal neutron filter placed before of a gamma shield [16]. Gamma rays can be attenuated by using appropriate high-Z materials such as the Bi or Pb. Bi is commonly used, since it provides photon attenuation comparable to that from Pb, while limiting the absorption for the neutron beam. Results of comparative calculations are summarized in table 3. Therefore 5.5 cm thickness Bi gamma shielding, completed by 2 cm thickness delimiter made of poly-Li is the last part of the BSA study which is shown in figure 9. Neutron spectra of the proposed facility, calculated in three configurations, without filters, with 5 cm ^{60}Ni fast neutron filter and for the final BSA configuration are shown in figure 10. The profile of the $\Phi_{epithermal}$ in front of the BSA is shown in figure 11.

In this study the Snyder's head phantom, which was derived by the MCNP sample files, is simulated using MCNP4B code. This phantom consists of three ellipsoids for scalp, skull bone and brain. The dimensions and the chemical composition for an adult proceed from ICRU46

Table 3. The BNCT parameters for different gamma ray filters.

Configuration	$\Phi_{epithermal}$ ($\times10^9$n cm^{-2}s^{-1})	$\Phi_{epithermal}/\Phi_{fast}$	$\Phi_{epithermal}/\Phi_{thermal}$	$\dot{D}_{fast}/\Phi_{epithermal}$ ($\times10^{-13}$ Gy cm^2)	$\dot{D}_{\gamma}/\Phi_{epithermal}$ ($\times10^{-13}$ Gy cm^2)
^{7}LiF, D_2O, TiF_3 moderators + ^{60}Ni fast neutron filter + Cd thermal neutron filter + 5.5cm Bi	3.94	52.29	107.95	0.179	1.27
^{7}LiF, D_2O, TiF_3 moderators + ^{60}Ni fast neutron filter + Cd thermal neutron filter + 4.5 cm Pb	3.53	56.70	139.18	0.241	1.90
IAEA criteria	**>1**	**>20**	**>100**	**<2**	**<2**

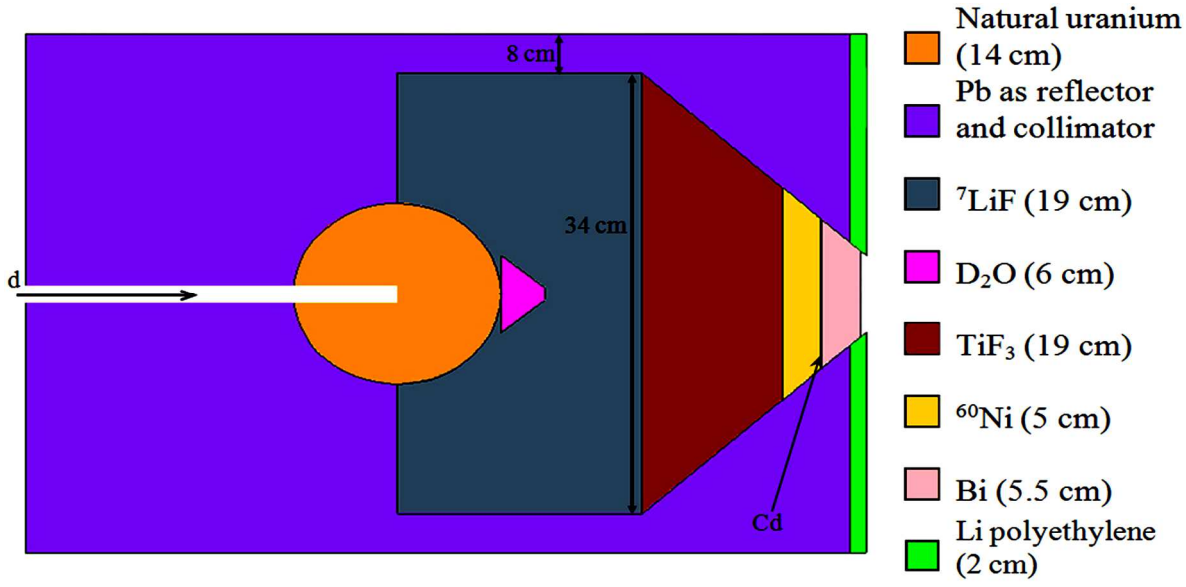

Figure 9. Geometric configuration of the BNCT system -not in scale.

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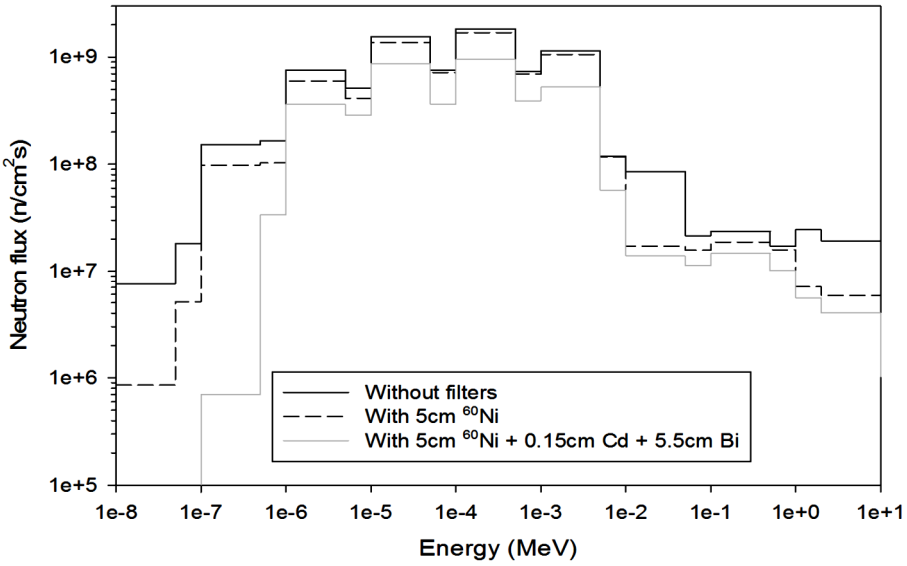

Figure 10. The neutron spectra at the exit of the facility with and without filters.

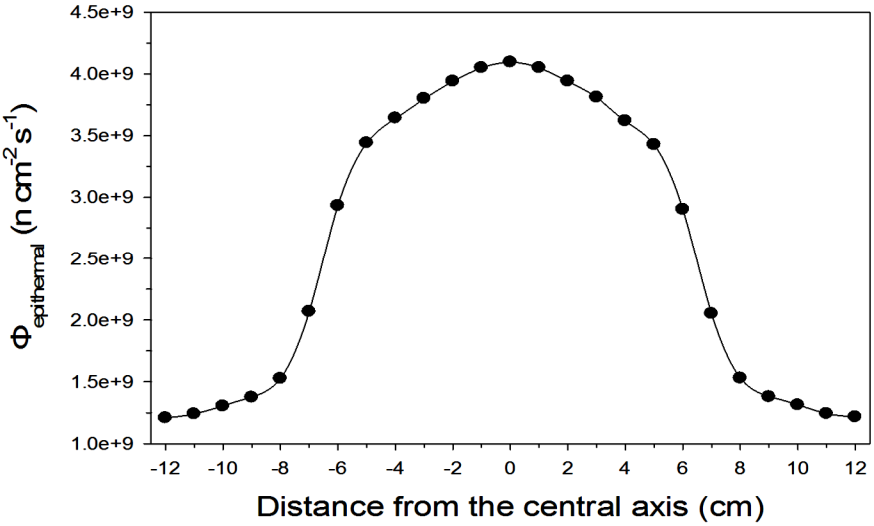

Figure 11. The profile of the $\Phi_{epithermal}$ in front of the suggested BSA modeling.

(17). The spatial distribution of the $\Phi_{thermal}$, $\Phi_{epithermal}$ and Φ_{fast} in the head phantom along the beam axis for Z direction are illustrated in figure 12. According to the results the $\Phi_{epithermal}$ and Φ_{fast} have the maximum values at the scalp and the flux level drops off with increasing thickness. The maximum $\Phi_{thermal}$ occurs at a depth of 1.5 – 2.6 cm.

The total absorbed tissue doses (D_T) are obtained by combining the four individual dose components, namely gamma ray dose (D_γ), fast neutron dose (D_{fast}), nitrogen dose (D_N), boron dose (D_B), weighted by their RBE (relative biological effectiveness) factors, using the equation:

$$D_T = w_\gamma \times D_\gamma + w_{fast} \times D_{fast} + w_N \times D_N + D_B \times w_B$$

where w_γ is 1, w_N and w_{fast} are taken as 3.2 while w_B is 1.3 for boron in tissue and 3.8 for boron in the tumor. In the tumor, a ^{10}B concentration of 40 ppm was assumed and a 4:1 ratio of ^{10}B in tumor to healthy brain was also assumed (9). Figure 13 shows the calculated dose rates in the tumor and healthy tissues at different depth in the head phantom.

DISCUSSION

In order to evaluate the proposed facility the results are compared with other published studies which are based on DT or DD neutron generator (table 4). These results (unacceptable values are in italic letters) indicate that only 2

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facilities satisfy all the recommended by IAEA criteria; the excellent extensive research from Rasouli *et al.* [11] and the study are presented which optimizes the previous BSA configurations. As shown in table 4 the proposed facility compared with the study from Rasouli *et al.* improves the $\Phi_{epithermal}/\Phi_{fast}$ ratio by a factor of ~2.2. At the same time reduces the $\dot{D}_{fast}/\Phi_{epithermal}$ and the $\dot{D}\gamma/\Phi_{epithermal}$ by 3.7 and 1.6 times respectively while decreasing the

Table 4. Comparison of the proposed facility with some published works (based on DT or DD neutron generator).

Facility	Neutron yield ($\times10^{14}$ n s^{-1})	$\Phi_{epithermal}$ ($\times10^{9}$n $cm^{-2}s^{-1}$)	$\Phi_{epithermal}/\Phi_{fast}$	$\Phi_{epithermal}/\Phi_{thermal}$	$\dot{D}_{fast}/\Phi_{epithermal}$ ($\times10^{-13}$ Gy cm^2)	$\dot{D}_{\gamma}/\Phi_{epithermal}$ ($\times10^{-13}$ Gy cm^2)
IAEA criteria		**$>10^9$**	**>20**	**>100**	**<2**	**<2**
Proposed facility	1	3.94	52.29	107.95	0.179	1.27
Rasouli and Masoudi (2012) [10]	0.05	1.04	20.21	-	0.67	5.79
Rasouli *et al*. (2012) [11]	1.45	4.43	23.75	121.2	0.59	1.98
Cerullo *et al.*, 2004 best configuration [4]	4	2.51	14.4	114.5	3.45	0.21
Cerullo *et al.*, 2002 final configuration [23]	1	0.66	23.2	133	3.19	1.1
Montagnini *et al*. (2002) [24]	0.187	0.29	19.8	16.6	6.3	7.3
Fantidis *et al*. (2013) [18]	0.001	0.00117	20.81	128.81	0.00011	0.00023

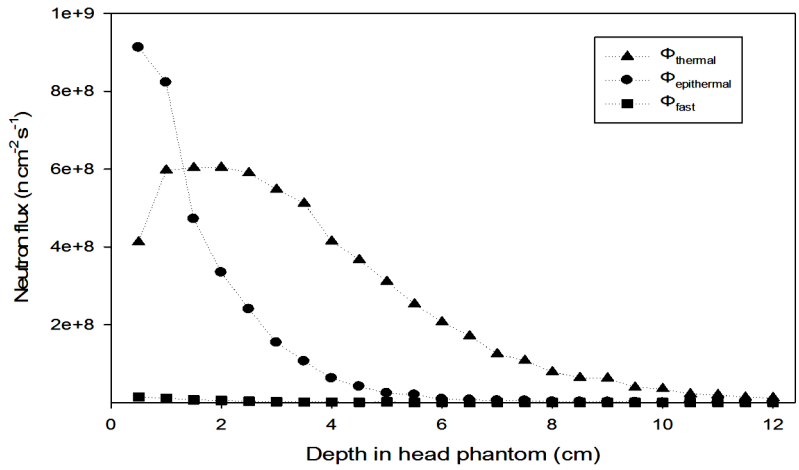

Figure 12. Distribution of $\Phi_{thermal}$, $\Phi_{epithermal}$ and Φ_{fast} in the human head phantom.

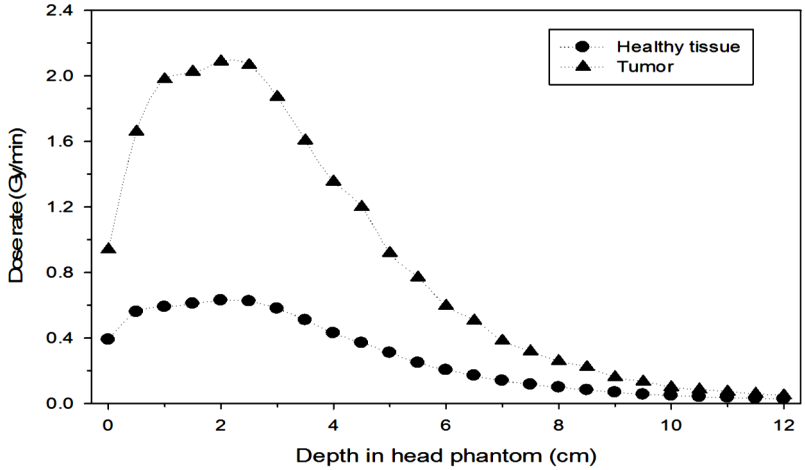

Figure 13. Comparison of depth dose profile between tumor and normal tissue.

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[DOI: 10.7508/ijrr.2015.01.002]

$\Phi_{epithermal}/\Phi_{thermal}$ ratio by only ~10.9%. The comparison between the proposed facility with a similar facility which proposed by Fantidis *et al.* [18] and based on DD neutron generator indicates that the use of DT neutron generator is by far the best solution owing to the fact that DT neutron source provides significant higher $\Phi_{epithermal}$ values. Considering that DT neutron generators having 10^{14} n s^{-1} neutron output may be feasible the proposed facility might be taken into account as an alternative for clinics which cannot afford to build and maintain a small nuclear reactor.

The therapeutic efficacy of neutron beam for the proposed BNCT facility were calculated through its FOM, i.e. Dose Rate (ADDR), Treatment Time (TT), Advantage Depth (AD), Advantage Ratio (AR) and Therapeutic Depth (TD). ADDR is defined as the maximum delivered dose rate to healthy tissue. Bearing in mind that the maximum allowable dose to the healthy tissue is 12.5 Gy [19], the TT can be estimated. AD indicates the depth in tissue at which the dose to the tumor equals the maximum dose to the healthy tissue. AR is the integral dose that would be delivered to tumor tissue, uniformly distributed within the brain, divided by the integral dose delivered to normal tissue, while TD defines the depth at which the tumor dose falls below twice the maximum dose to healthy brain [11, 20-22].

The in-phantom parameters of the proposed facility and from some previous published studies are listed in table 5 and show a neutron beam which can reach relevant deeply into the brain (AD has value about 6 cm). The TT parameter which indicates the treatment time has a very attractive value (less than 20 min indicating a reasonable treatment time) as a result of the relatively high $f_{epithermal}$ value.

CONCLUSION

BNCT is a potentially very useful cancer treatment modality; however only a few facilities are available for clinical trials, since all these facilities are currently based on a nuclear reactor source. In order to find an alternative source for BNCT applications a DT neutron generator has been considered, using the MCNP4B Monte Carlo code. The proposed facility is optimized in terms of the moderator and beam filtering. ^{7}LiF incorporating a truncated-cone-shaped made of D_2O and TiF_3 were chosen as the moderator materials. The use of ^{60}Ni as fast neutron filter, Cd as thermal neutron filter and Bi as gamma filter has led to improving the quality of the beam for BNCT. The resulting dose of the radiation emitted from the facility is evaluated defining the FOM in phantom. According to the results obtained, the proposed facility meets all the recommended by IAEA parameters and constitutes an attractive alternative to the nuclear reactors.

Conflict of interest: *Declared none*

Table 5. In-phantom parameters evaluated for the proposed designed BSA and some other facilities.

Facility	ADDR (cGy/min)	TT (min)	AD (cm)	TD (cm)	AR
Proposed facility	63.29	19.75	5.94	4.34	2.86
THOR [25]	50	25	8.9	5.6	-
FiR 1 [25]	45	30	9	5.8	-
R2-0 [25]	67	20	9.7	5.6	-
Kononov *et al.*, 2004 [26]	100	12.5	9.1	-	-
FCB MIT [27]	55	22.72	9.9	-	5.7
RA-6 [28]	16.25	76.92	6.8	-	2.8
Rasouli *et al.* [11]	41.3	30.2	9.4	7	-
Rasouli and Masoudi [10]	50.35	24.8	8	5.89	4.26

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[DOI: 10.7508/ijrr.2015.01.002]

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[DOI: 10.7508/ijrr.2015.01.002]