BEAM SHAPING ASSEMBLY OPTIMIZATION FOR BORON NEUTRON CAPTURE THERAPY*

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Abstract

Epithermal neutron source based on vacuum insulation tandem accelerator and lithium target has been developed and is now in use in the Budker Institute of Nuclear Physics. Neutrons are generated by ^{7}Li(p,n)^{7}Be reaction with proton beam energies from 2 to 2.5 MeV. A beam shaping assembly (BSA) for therapeutic neutron beam forming is used. It includes moderator, reflector, and absorber. In this work the simulation results of the depth dose rate distribution in modified Snyder head phantom for a range of neutron energies are presented and discussed. Variants of BSA optimization depending on tumor depth are proposed. The calculations were carried out by Monte-Carlo neutron and photon transport code NMC that was developed in NSI RAS. Our research reveal that high quality neutron beam generation may be obtained with proton energy of 2.3 MeV. Discovered optimal schemes of BSA including sizes and materials are presented and discussed.

INTRODUCTION

The main requirements to neutron source for BNCT is to generate epithermal neutron beam with neutron flux density more than 10^9n/cm^{2}s for treatment time less than 1 hour. Neutrons with energies from 0.5 eV to 10 keV are considered to be epithermal. The results of recent research clarified the requirements to the neutron spectrum and the range of neutron energies of 1 to 30 keV was established as the most suitable for BNCT [1].

For the therapy and determination of optimal treatment conditions such parameters as dose rate in healthy tissue and tumor, advantage ratio (AR, the ratio of maximum dose in tumor and healthy tissue), advantage depth (AD, the distance from the surface of the tissue in which the dose in tumor equals the dose in healthy tissue) are principal.

Minimum required values of these parameters are the following [1]:

- tumor dose rate 1 Gy/min;
- AD is 8 cm;
- AR is 4.

DETERMINATION OF THE OPTIMAL RANGE OF NEUTRON ENERGIES

To determine the range of neutron energies that are optimal for BNCT we performed the simulations of the depth dose rate distribution in the healthy tissue and in the tumor in modified Snyder head phantom for monodirectional, monoenergetic from 0.025 eV to 100 keV neutron beams with the diameter of 10 cm.

All calculations were carried out by Monte-Carlo neutron and photon transport code NMC that was developed in NSI RAS using cross sections from the ENDF-VII.0 nuclear database [2].

Code validation was performed using benchmarks of the thermal, intermediate and fast spectral regions as well as shielding experiments from the International Criticality Safety Benchmark Evaluation Project (ICSBEP) [3].

The simulation results of the dose rates in tumor and healthy tissue and therapeutic ratio are shown in Fig. 1 and 2. The results are given for neutron and photon flux 10^{10}particles/cm^{2}s. In the calculations ^{10}B concentrations in tumor and in healthy tissue were set to 52.5 ppm and 15 ppm, respectively. It can be seen that the values of dose rate, depth and therapeutic ratio most suitable for therapy are achieved with neutron energies from 1 eV to 10 keV.

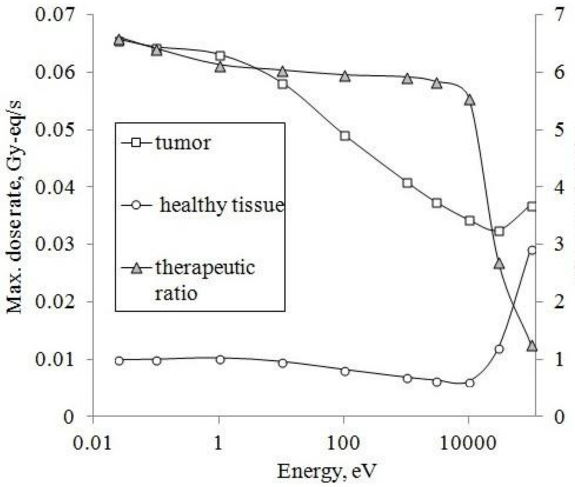

Figure 1: The dose rates in tumor and healthy tissue and therapeutic ratio for neutron beams with different energies.

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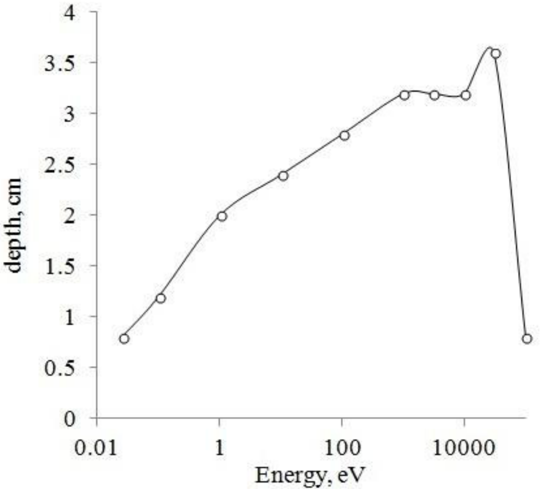

Figure 2: The dependence of the depth of the maximum dose in tumor on the neutron beam energy.

SELECTION OF OPTIMAL PROTON ENERGY

In the BINP neutron source the neutrons are generated with ^{7}Li(p,n)^{7}Be reaction under proton beam energies from 2 to 2.5 MeV. A beam shaping assembly (BSA) for therapeutic neutron beam forming is used. It includes moderator, reflector, and absorber.

To determine the optimal range of proton energies for neutron generation we performed simulations of dose rates and therapeutic ratio for proton energies from 1.9 to 2.5 MeV, moderator radius of 15 cm and heights from 15 to 30 cm.

The results of calculations are given in Fig. 3, 4, 5.

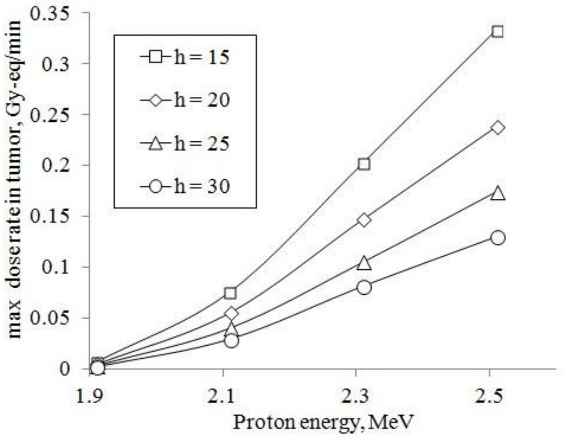

Figure 3: The dependence of the dose rate in tumor, on proton energy at different moderator heights (h) in cm.

It can be seen, that with increase of proton energy dose rate in tumor also increases, but therapeutic ratio decreases. This is due to the growth of fast neutron component with higher proton energy. Figures show, that the best values of dose rate, depth and therapeutic ratio are achieved at proton energy of 2.3-2.5 MeV and moderator height of 25-30 cm. The maximum value of the depth for the maximum dose rate in tumor is 3.6 cm.

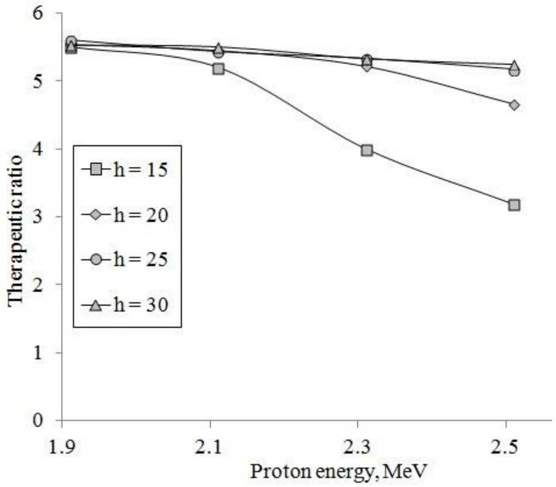

Figure 4: The dependence of the therapeutic ratio on proton energy at different moderator heights (h) in cm.

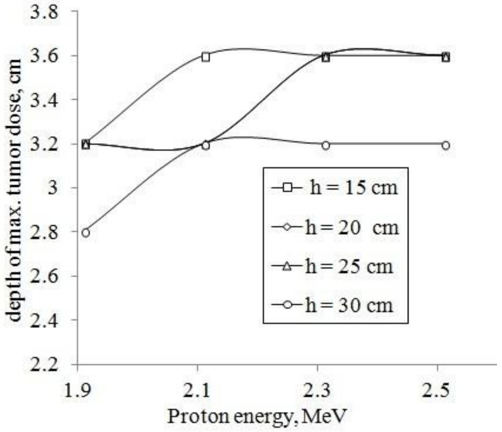

Figure 5: The dependence of the depth of the maximum dose in tumor on the proton beam energy.

OPTIMAL BSA

With the results of our simulations we designed model of the optimal BSA as shown in Fig.6 [1]. Distinctions of this model are composite moderator with MgF_2 near the target and AlF_2 near the beam outlet and composite reflector from graphite in the front hemisphere and lead in the back hemisphere. Besides, we propose to use proton energy of 2.3 MeV to generate optimal therapeutic beam, instead of commonly used range of 2.5-2.8 MeV. The reason is demonstrated in Fig.7. As it can be seen the attempt to reduce fast neutron component by increasing moderator height gives us the same neutron spectrum as with smaller moderator height and proton energy of 2.3 MeV. Moreover, at 2.5 MeV proton energy there is a significant neutron flux with neutron energies more than 500 keV.

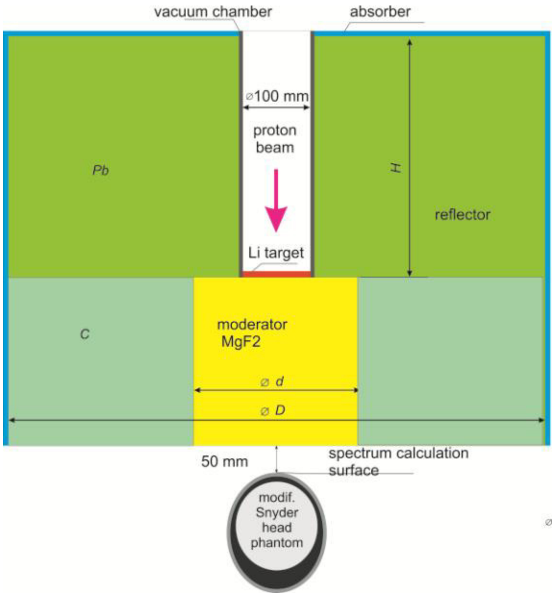

Figure 6: Optimal BSA.

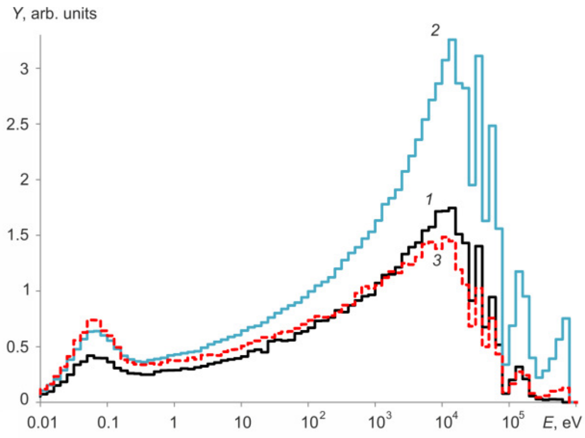

Figure 7: Neutron spectrum for BSA: 1 - proton energy is 2.3 MeV, moderator height is 21 cm, 2 - proton energy is 2.5 MeV, moderator height 21 is cm, 3 - proton energy is 2.5 MeV, moderator height is 26 cm.

The BSA has been manufactured, it is shown in Fig.8.

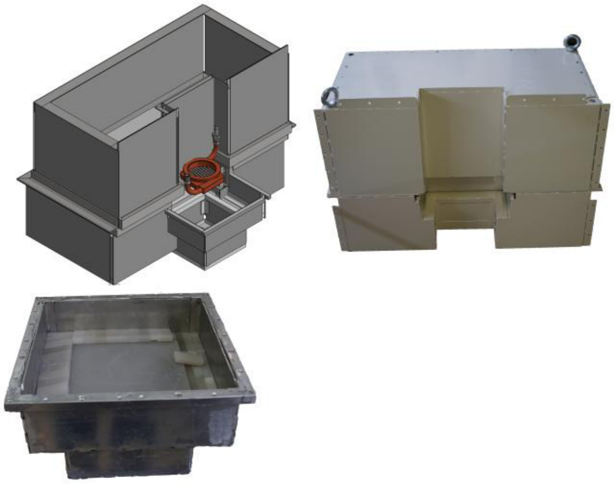

Figure 8: The appearance of manufactured BSA.

CONCLUSION

We demonstrated that neutrons with energies from 1 eV to 10 keV are the most suitable for BNCT. The BSA has been designed and manufactured, it was shown, that the best beam parameters are achieved with proton energies 2.3-2.5 MeV with moderator height of 25-30 cm. Our research revealed that high quality beam generation may be obtained with proton energy of 2.3 MeV.

REFERENCES

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