Investigations of using near-threshold ^{7}Li(p,n)^{7}Be reaction for NCT based on in-phantom dose distribution

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Summary

A neutron source at near-threshold energy of the ^{7}Li(p,n)^{7}Be reaction has been investigated. The study was performed for the purpose of upgrading an existing accelerator, KG-2,5 at IPPE, for clinical use.

Introduction

It is generally agreed that the ^{7}Li(p,n)^{7}Be reaction is most suitable neutron production reaction for accelerator-based NCT facility. Two different ways of using this reaction have been investigated. First idea is to use high energy protons (energy about 2.5 MeV) for neutron production [1-3]. This method is characterized by relatively high energy of primary neutrons (energy up to 0.7 MeV) and emission of neutrons to 360 degrees. It requires a special moderator assembly for slowing down and shaping neutron beam to satisfy treatment requirements. To have really good beam on output port of the moderator this method requires high intensity proton source.

Another one, proposed in IPPE in 1975, based on using protons with energy near threshold of the ^{7}Li(p,n)^{7}Be reaction (5-40 keV above threshold) [4-5]. This method is characterized by lower neutron energies (less then 0.12 MeV) and all neutrons due to kinematical collimation are emitted in forward hemisphere. This makes it possible not to use a big moderator assembly and work in an "open geometry" or with thin filter when necessary to reduce the effects of fast neutrons.

This work was directed to investigate possibilities of treating patients at an NCT facility to be created in IPPE based on existing high-current accelerator KG-2,5 by using near threshold ^{7}Li(p,n)^{7}Be reaction.

Materials and Methods

This work is the first stage of the activities directed to creation of therapeutic neutron beams on the upgraded IPPE high-current accelerator. The basic question is whether BNCT could be performed at such a facility. To get a solution a set of computational studies was performed. For modeling dose distribution in phantom, used were three Monte Carlo codes– C95, MMKFK and MCNP [6-8].

A simplified model of phantom was used in computation. The phantom had a cube form with dimensions 20x20x20 cm, and the front part had two layers, simulating skin and scalp, and the remaining volume represented brain. Material, density and composition were specified according to the recommendations of ICRU-46 [9]. Ring detectors are arranged in all phantom volume, in first 1.5 cm from front phantom surface in 1-mm steps and then in 1-cm steps to the rear surface. All rings had 1 cm width. Such an arrangement will make possible simpler future experimental testing of the computational results on accelerator with a real target.

Neutron source is thick metallic ^{7}Li target. Its description for Monte Carlo modeling was done by using special code. This code was created in IPPE based on two models of spatial and energy distributions of neutrons. The model of near threshold region (up to 1.92 MeV) was based on the approach used in Ref. 4 and 5 with new nuclear masses data. At higher proton energy (from 1.92 MeV), the code used models described in Ref. 10, but to have more precision description of spatial and energy distribution more detail cross-section and Legendre coefficients data bases were created. For calculation was used neutron spectral distributions made with steps of 1 degree.

For calculation accompanying gamma rays yield from lithium target were used evaluated cross-section data from Ref. 11.

Results of Monte Carlo simulation are neutron and photon flux density inside phantom. All neutrons and photons were divided into energy groups. In neutron energy region up to 10 keV were used BNAB groups and to 120 keV groups with width 10 keV. For calculation in phantom dose distribution were used neutron kerma factors calculated for this groups based on ENDF/B6 nuclear data library. This factors are in good agreement with data presented in Ref. 9, but distinct is that for neutrons with energy lower than 10 eV for hydrogen we used kerma factors only from recoil protons, because of gamma-ray dose from neutron capture by hydrogen are calculated in photon transport simulation. Neutron RBE was taken form Ref. 12.

Photon flux consist of accompanying target gamma rays and photons appear inside phantom during neutron transport inside phantom. Photons kerma factors was taken from ICRU 44 [9].

Results

Main goal of this investigations was to find optimal facility parameters to make possible patient treatment. Factors to be optimized are proton energy, distance between phantom and target, and the target size. In fig. 1 presented biologically-weighted dose rate from $^{10}B(n,\alpha)^{7}Li$ reaction in tumor (^{10}B concentration 30 ppm) and proton recoil in tissue-equivalent phantom for proton energy 1.885 MeV with different target radius (1 to 5 cm, distance target-phantom 2.5 cm).

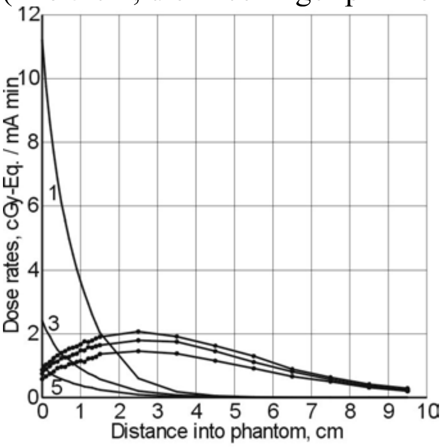

Fig. 1 Distributions of biologically weighted neutron (line) and boron (line with points) in-phantom dose rates for targets with radius 1, 3, and 5 cm, with proton energy 1.885 MeV.

So if we increased target radius, we could effectively decrease neutron dose on phantom surface with really small reduction in boron dose inside phantom. Studying the dependence of the target-phantom distance, we get that with increasing distance we decrease neutron dose; we also lose in boron dose significantly higher than in increasing target radius. In Fig. 2 presented are the same data for proton energy 1.89 MeV. With increasing proton energy boron dose also increased, and it is clear that to obtain treatment dose rate, the proton energy should be increased. In Fig. 3 is presented the dependence of boron and neutron dose for target with 5-cm radius for proton energy 1.915 MeV. Ratio between neutron and boron dose (curves a in Fig. 3) became not satisfactory. To improve it we placed water filter with thickness 2.5 cm between target and phantom. It helps dramatically change a situation. Also this picture shows that dose rate are acceptable for treatment on facility with proton current about 5 mA.

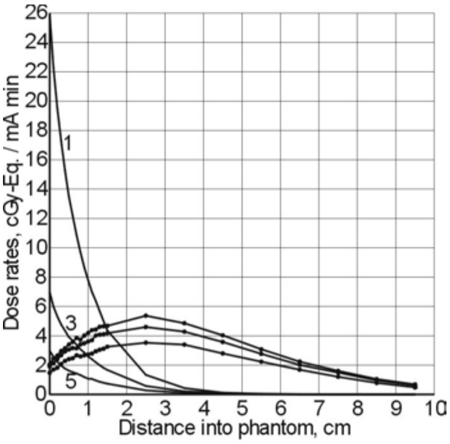

Fig. 2 Distributions of biologically weighted neutron (line) and boron (line with points) in-phantom dose rates for targets with radius 1, 3, and 5 cm, with proton energy 1.89 MeV.

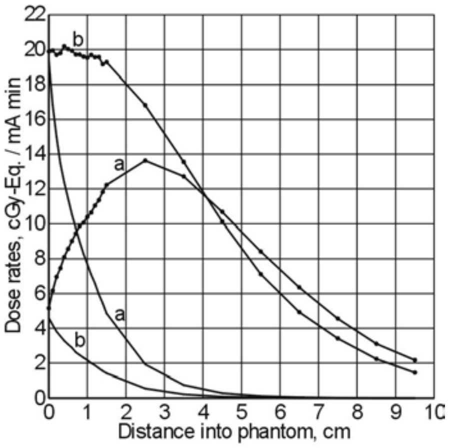

Fig. 3 Distributions of biologically weighted neutron (line) and boron (line with points) in-phantom dose rates for a 5-cm target, with proton energy 1.915 MeV.

This investigation shows that the configuration of the 5-cm target radius, the target-phantom distance of 2.5 cm filled by water filter and proton energy of 1.915 MeV is promising for near-threshold operation mode. The results of in-phantom dose-rate calculation of different components, including accompanying target gamma rays, for this configuration is presented in Fig. 4.

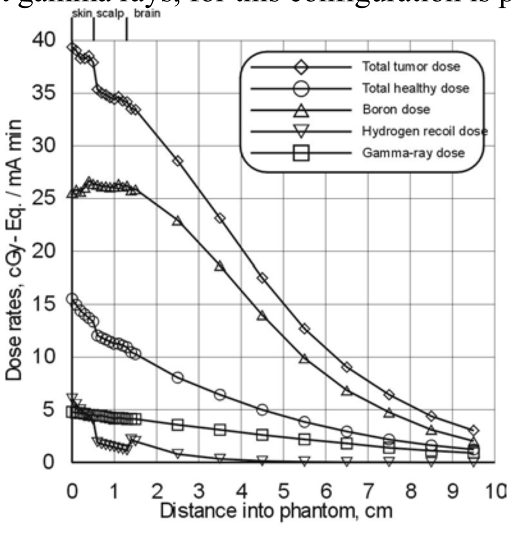

Fig. 4 Distributions of biologically weighted in-phantom dose rate components for water filter configuration, with proton energy 1.915 MeV.

Conclusion

Near-threshold ^{7}Li(p,n)^{7}Be neutron source was investigated through computation. Investigations shows that it is possible to perform patient treatment with such a source using a proton accelerator with current about 5 mA and at proton energy about 1.9 MeV.

Acknowledgment

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