TOMSK POLYTECHNIC UNIVERSITY

29th International Seminar on Interaction of Neutrons with Nuclei:

«Fundamental Interactions & Neutrons, Nuclear Structure, Ultracold Neutrons, Related Topics»

Modified Collimator for Neutron Therapy Applications: Enhancing Narrow Beam Collimation of Fast Neutrons

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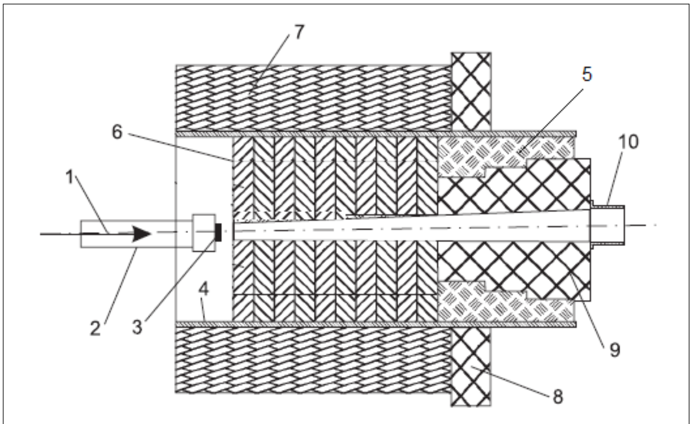
(The work was carried out at Tomsk Polytechnic University)

The main advantage of neutron therapy is that unlike gamma and electron therapy neutrons destroy damaged tissue irreversibly, i.e. there is no recurrence after neutron therapy. The negative aspects of neutron therapy are associated with affecting healthy tissues of the body.

The existing technology operates a wide horizontal beam, the direction of which we cannot control in fact. But by optimizing geometry and materials for collimator we will be able to focus the scattered neutrons to a narrow beam.

A narrow beam allows introducing a safer method of irradiating tumors from different sides. Here the objective is to maximize the use of neutrons going out of the source and to focus them in such a way as to ensure a maximum therapeutic effect.

The collimator used for fast neutron treatment at the cyclotron laboratory of Tomsk Polytechnic University had a length of 100 cm from the Be source to the irradiation aperture. To carry out experimental studies with collimators made of different materials and different geometries, it was necessary to create a smaller collimator.

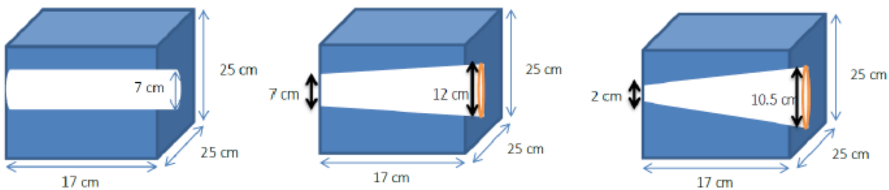


Neutron beam collimator in the treatment room; 1 – deuteron beam; 2 – ion beam channel; 3 - Be-target; 4 - iron pipe; 5 – polyethylene collimator; 6 - iron disks; 7 - concrete wall; 8 - radiation protection made of polyethylene; 9 - removable polyethylene collimator; 10 - cone.

Ten small collimators were tested using three different paraffin pieces 25 x 25 x 17 cm^3 with different internal designs.

Metal parts were used, including separate metal plates made of iron and lead of various sizes: 4 plates 25 × 25 cm^2, 4 plates 25 × 9 cm^2 and 4 plates 25 × 5 cm^2 2 cm thick for iron and 0.5 cm thick for lead plates.

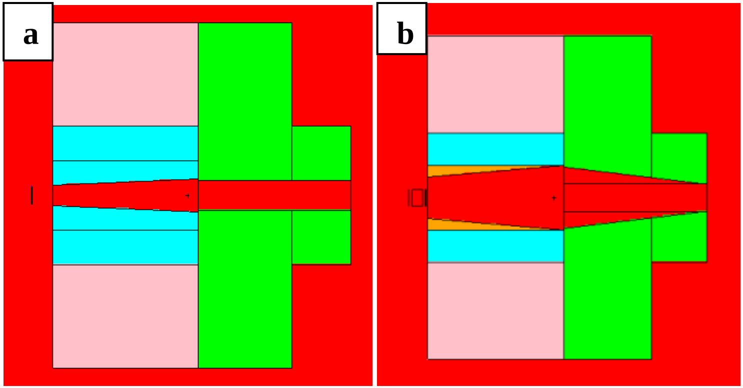
Thus, there are opportunities for the formation of various combinations of iron, lead and paraffin.



Three types of paraffin collimators 25×25×17 cm^3; Col.1, Col.2 and Col.3.

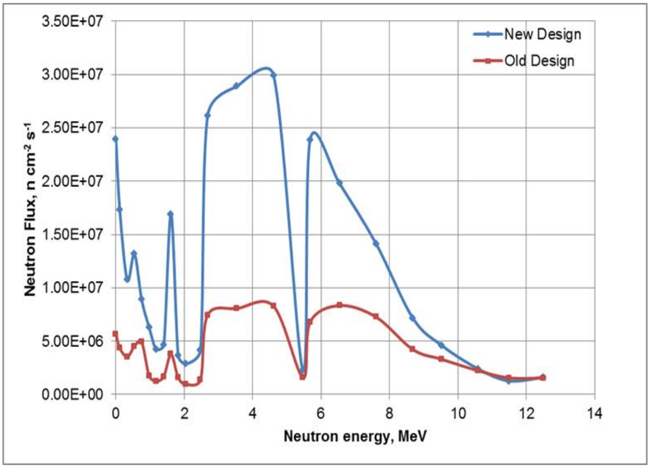
- This study was carried out by modeling neutron transport using the MCNP code.

- The optimal design of the collimator made it possible to triple the neutron flux compared to the collimator (A), which was located in the treatment room of the TPU cyclotron laboratory. The neutron flux increased mainly in the high-energy part of the spectrum.



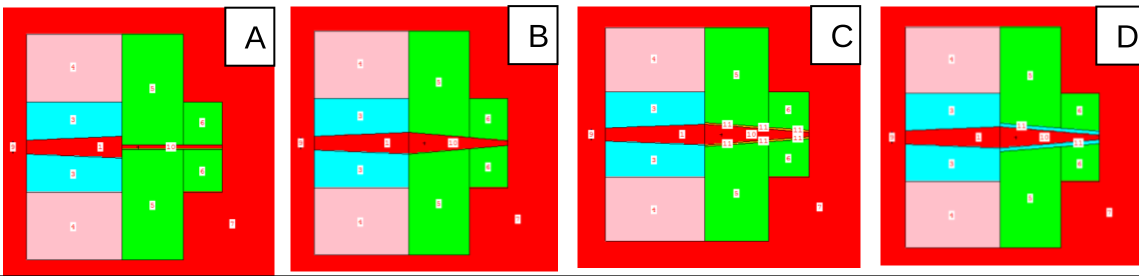
Collimator created with MCNP5 code; (A) the case of an existing collimator without any changes, (B) the case of a collimator with different internal geometry and materials.

The internal geometry and composition of collimator materials significantly affect the neutron spectrum.



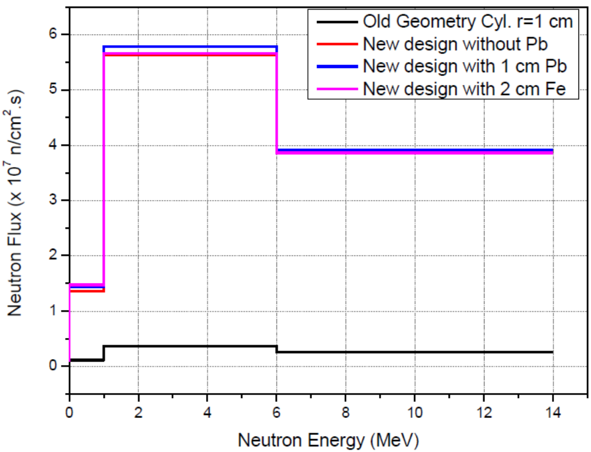
MCNP Neutron spectra for two collimators: the spectrum for the original design (A) (red curve) and the spectrum for the optimized design (B) with a change in geometry and material composition (blue curve).

A narrow beam of fast neutrons is important for more precise tumor irradiation and preservation of healthy tissues. The channel optimization was carried out using the MCNP code. Further, its internal geometry was changed to obtain a high-intensity and narrow neutron beam. In this case, the first part of the collimator, which is made of iron, has not changed geometrically. Changes were made to the second cylindrical polyethylene part.



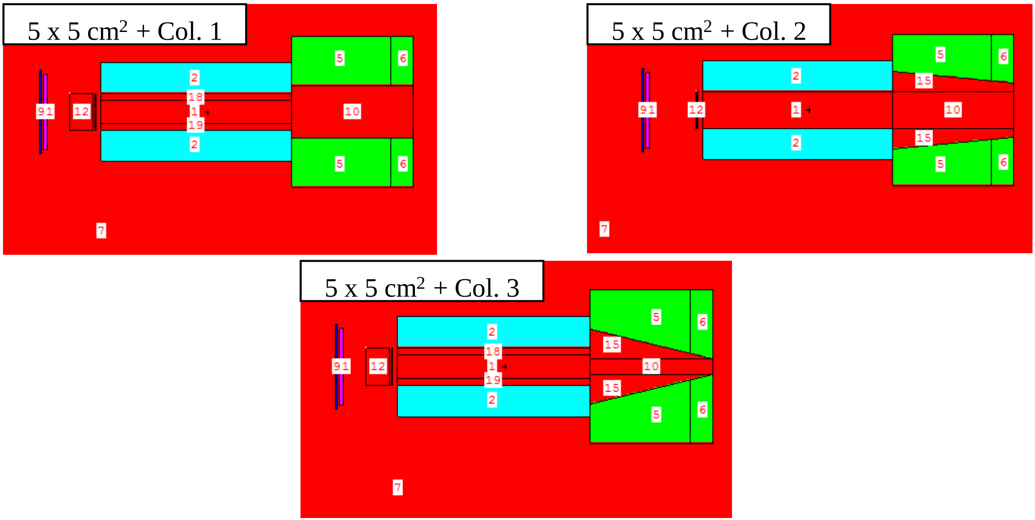
Collimators created using the MCNP5 code for various polyethylene part geometries; (A) original polyethylene collimator, (B) modified polyethylene collimator, (C) with additional Pb layer, (D) with additional Fe layer.

There is a significant increase in neutron flux density, about 15 times, when moving from collimator A (initial version) to B, C and D. This indicates that for use in small radiation fields, the design of the collimator can be changed in a certain way to achieve such the same neutron intensity and dose rate as for large irradiation fields.

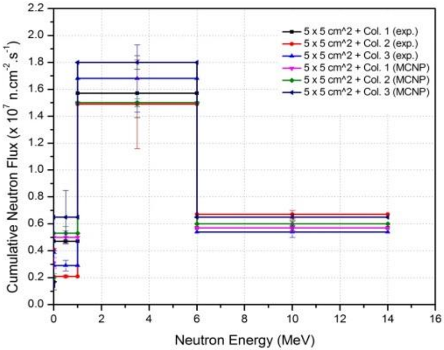


Results of modeling the intensity of the neutron flux using the MCNP code in three energy groups; 0-1 MeV, 1-6 MeV and 6-14 MeV for collimators A, B, C and D.

The experimental works:

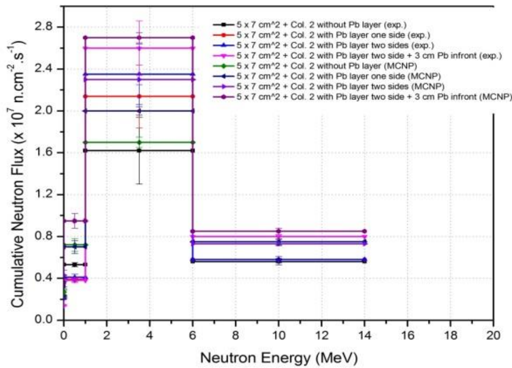


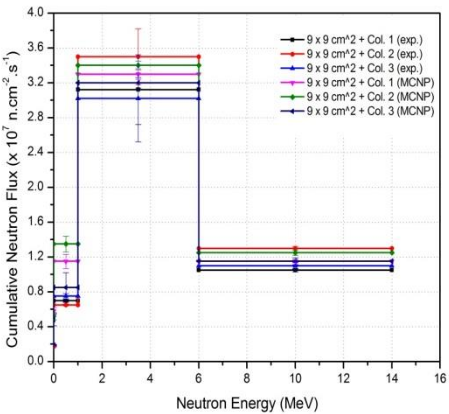
Schematic diagram of a 5 × 5 cm² iron collimator with three types of paraffin elements.



a

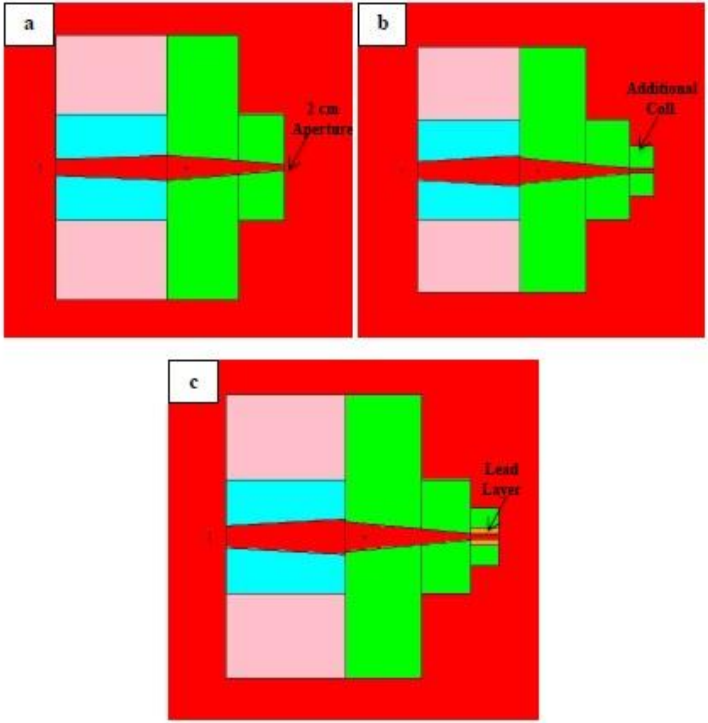
c



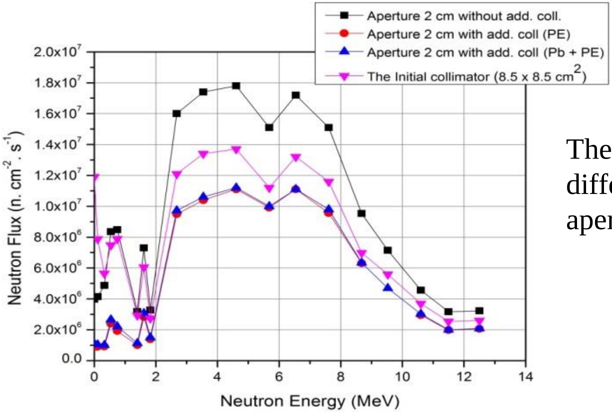


b

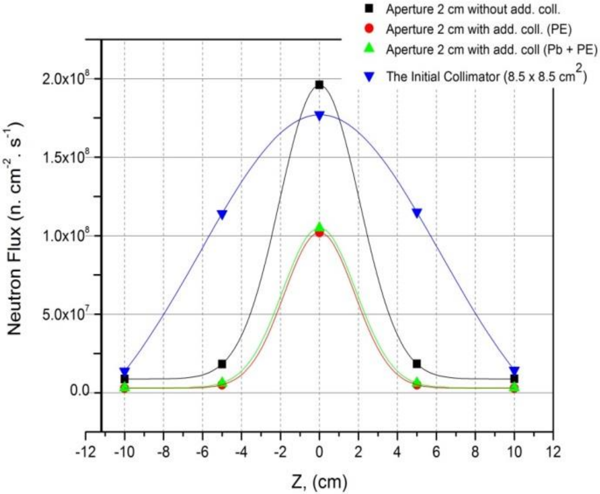
Calculated (MCNP code) and experimental results of modeling neutron spectra for an open hole of an iron collimator with dimensions of 5 x 5 , 9 x 9 and 7 x 5 cm^2.



MCNP5 schemes of the simulated collimators; a) the collimator with 2 cm diameter of aperture, b) the collimator with 2 cm aperture and additional collimator 10 cm in length and 20 cm thickness, c) the case (b) plus an addition inner layer of lead metal.



The simulated neutron spectra for the four different collimators, which have different apertures.



The simulated spatial distribution of fast neutron for the four different collimators at 10 cm from the aperture.

Conclusions

1. Simulation of fast neutron transport using the MCNP code and the results of experimental studies have shown that a significant increase in the density of their flux (about 3 times) is physically possible and practically achievable by optimizing the material and geometric parameters of the collimator.
2. The possibility of obtaining a narrow neutron beam (with a diameter of 2 cm or even less) has been proven. This makes it possible to significantly increase the fast neutron flux density compared to a cylindrical channel.
3. There is reason to hope that narrow beams will make neutron beam radiotherapy for the treatment of small and irregularly shaped tumors more accurate and safer for the patient.
4. The fraction of the flux density of fast neutrons with energies in the range 1 – 6 MeV is about 83% of the total flux. This makes it possible to minimize the number of neutrons with energies above 6 MeV and below 1 MeV, undesirable for clinical use, which do not contribute to the radiation therapy process. As a result, we minimize the dose absorbed by healthy tissues.

Thank you for your Attention