EVALUATING THE DEPENDENCY OF NEUTRON SPECTRA AND DOSE RATE ON THE IRRADIATION FIELD SIZE FOR FAST NEUTRON THERAPY PURPOSES

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ОЦЕНКА ЗАВИСИМОСТИ НЕЙТРОННЫХ СПЕКТРОВ И МОЩНОСТИ ДОЗЫ ОТ РАЗМЕРА ПОЛЯ ОБЛУЧЕНИЯ ДЛЯ ЦЕЛЕЙ БЫСТРОЙ НЕЙТРОННОЙ ТЕРАПИИ

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Аннотация. *Циклотрон Томского политехнического университета ТПУ типа Р7М в настоящее время используется для разработки радиофармацевтических препаратов и лечения онкологических заболеваний. Для дистанционной терапии необходимы достаточно большие потоки быстрых нейтронов, которые могут создавать достаточные уровни поглощённой дозы излучения в раковой ткани не менее 0,1 гр/ мин при расстоянии источник-пациент 1 м. Целесообразно использовать реакцию* $^{9}Be\,(d, n)\,^{10}B$ *с энергией дейтрона 13,6 МэВ. Средняя энергия испускаемых нейтронов рассчитывалась по коду PACE 4 (LISE++), который составлял около 5,2 МэВ, а наиболее вероятная энергия около 2,5 МэВ. Уточнены и оценены параметры полей нейтронного облучения, энергетических спектров и поглощённых доз излучения нейтронов источником* $^{9}Be(d, n)$ *на основе циклотрона методом нейтронной активации и гамма-спектрометром в диапазоне энергий нейтронов от 0 до 14 МэВ для более эффективного лечения онкологических заболеваний. В процессе этого исследования на окно коллиматора были вставлены экспериментальные работы с фольгами Al, Fe, Cu и Cd. Исследованы различные размеры полей нейтронного облучения, которые могут регулироваться съёмным полиэтиленовым коллиматором для исследования характеристик нейтронного пучка. Результаты имитационных работ с кодами MCNP-4C и PACE 4 (LISE++) хорошо согласуются с экспериментальными данными и литературой, учитывающей некоторые важные различия в зависимости от размера коллимационного поля.*

Introduction. The reason of supporting the utilization of neutrons for treatment is their relative natural adequacy (RBE). For the neutron energies provided by the cyclotron beam, 1/3 fewer doses are required to accomplish an indistinguishable clinical impact with neutrons from is required with customary photons. Certain tumors are named being radioresistant. They react ineffectively to ordinary photon treatment [1-3].

Research methods. Four different collimator-irradiation fields were studied with removable polyethylene collimators, which have different irradiation field sizes; 8.5 x 8.5 cm^2, 10.5 x 6 cm^2, 7 x 4.5 cm^2 and 4.5 x 4.5 cm^2. The geometry of collimator materials and shielding are shown in Figure 1. To have a comparison with the actual values of neutron flux, an experiment was conducted using Al, Fe, Cu, and Cd foils for neutron activation method.

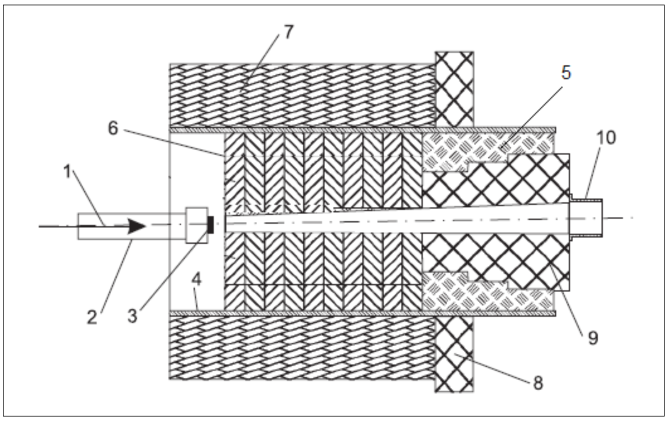

Fig.1. Neutron beam collimator. 1 – deuteron beam; 2 – ion beam channel; 3 – Be target; 4 – iron pipe; 5 – polyethylene collimator; 6 – iron disks; 7 – concrete wall; 8 – radiation protection of polyethylene; 9 – removable polyethylene collimator; 10 – cone

The beryllium target was irradiated by 13.6 MeV deuteron ions for a period of 30 minutes with deuteron beam of current ~ 45 µA and spot size ~ 15-20 mm. The neutron energy spectrum simulated and obtained by PACE 4 (LISE++) code [4].

The gamma-ray activities were measured by a high purity coaxial germanium HPGe (GC1020) detector for a period of 250 seconds for Al, Cu and Cd samples and 4000 seconds for Fe samples. The calculated values obtained using the equation:

$$\phi\ (\mathrm{n/cm^2.s}) = \frac{A}{<\sigma> N(1-e^{-\lambda t_{irr}})e^{-\lambda t_c}} \qquad (1)$$

Where A, λ, $<\sigma>$, N, t_{irr}, and t_c denote the activity (Bq), decay constant (s^{-1}), effective cross section (cm^2), number of target nuclei, time of irradiation and time of cooling respectively.

Results. The results were extracted from experiments and MCNP-4C simulations for neutron fluxes in different energy ranges of neutrons and the neutron absorbed dose rates were presented in Table 1. These results with results obtained by PACE 4 code were compared in Figure 2.

Table 1

The neutron dose rate for different collimation sizes

	Neutron absorbed dose rates in Gy/min at 1 m from the source for different irradiation fields			
	$8.5 \times 8.5\ cm^2$	$10.5 \times 6\ cm^2$	$7 \times 4.5\ cm^2$	$4.5 \times 4.5\ cm^2$
Exp. results	0.225	0.216	0.21	0.20
MCNP-4C_results	0.225	0.217	0.191	0.17

The absorbed dose rates were differed depending on the collimation field size. Experimental and simulated MCNP-4C values almost equal for big irradiation fields, and begin to differ for smaller ones. As a result, the dose rate decreases about 10 % between collimators with irradiation fields 8.5 x 8.5 cm^2 and 4.5 x 4.5 cm^2 as demonstrated by the experiments. While, these values are decreased approximately 25 % as calculated by MCNP-4C code.

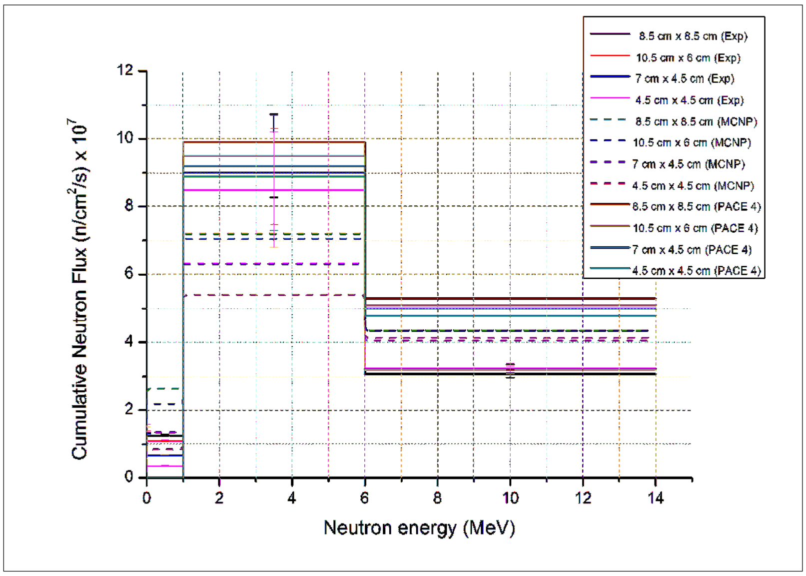

Fig.2. the cumulative neutron fluxes over energy regions of neutrons for different collimation irradiation fields. This scheme presented data obtained experimentally (with error bars) and simulation results by MCNP4C and PACE 4 codes

These results can be explained as appearing in Fig .2 that the neutron flux calculated by MCNP-4C is less than measured experimentally in the energy region between 1 MeV and 6 MeV (taken into account the big errors for some experimental results about 20 %).

Conclusions. As a result, the neutron fluxes from ^{9}Be(d, n) source and the dose rates conducted experimentally and simulated by the code MCNP-4C were in good agreement with literature. These values were differed according to the irradiation field size. The experimental and MCNP-4C values are very close to each other for big irradiation fields and begin to differ significantly for smaller ones. There is a drop of dose rate value by 10 % between collimators 8.5 x 8.5 cm^2 and 4.5 x 4.5 cm^2 as appeared from experiments and 25 % as calculated by MCNP-4C code. That because of the neutron fluxes calculated by MCNP-4C is less than measured values in the energy region between 1 MeV and 6 MeV. Consequently, that leads us to the most optimal option of collimation field size to be used to maximize the neutron flux and dose rate delivered to the treated tissues.

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