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DOSE ASSESSMENT WITH MCNP5/X CODE FOR BORON NEUTRON CAPTURE THERAPY OF PANCREAS CANCER

by

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Boron neutron capture therapy is based on neutron capture by ^{10}B and creation of high energy alpha particle and recoiled ^{7}Li ion which have ranges comparable to cell dimensions. The MCNP5/X code is applied for calculation of the absorbed doses as well as dose distribution by depth in pancreas cancer and the organs of the analytical and voxelized Oak Ridge National Laboratory phantom, which represents the human body. The depth dose distributions for thermal, epithermal neutrons, and neutron spectrum, show that the absorbed doses are the largest exactly in the cancer, in all cases. It is found by this simulation that the epithermal neutrons are the optimal choice for BNC therapy. They deliver a similar dose to cancer as the thermal neutrons but, spare the healthy tissue more than the thermal ones.

Key words: Boron neutron capture therapy, MCNP5/X code, absorbed dose, pancreas, cancer

INTRODUCTION

The Boron neutron capture therapy (BNCT) is a type of radiotherapy, based on nuclear reaction ^{10}B $(n, \alpha)^{7}Li$. The products of this reaction (alpha particle and recoiled lithium ion) have the range which is comparable to the size of the cell. Carcinogens have a higher binding affinity for ^{10}B than a healthy cell. After infusion of agents with boron for clinical treatments, an irradiation is followed by a collimated beam of neutrons [1-7]. Neutron beam parameters were defined by International Atomic Energy Agency [8]. The advantage of using epithermal neutrons above the thermal is especially effective in the case when the cancers are located deep in the body. Neutron capture on ^{10}B, enables delivering the therapeutic dose to the cancer cells, while healthy tissue can be speared. This type of therapy gives an advantage over conventional radiotherapy, especially in the presence of metastases of whole organs, such as the brain, liver, lung, pancreas, spleen, prostate and bones [9-12]. Experiments on the mice and rats also confirmed the success of this therapy [13,16].

In this work, BNCT for possible treatment of pancreas cancer using neutron beams, is investigated. The MCNP5/X software [17] for neutron transport simulation was used and doses in organs of interest in ORNL phantom [18-20] were calculated. Organs of the ORNL phantom were filled with voxels by dimensions of 1 cm cm 1 cm in order to obtain depth-dose distributions in them. It is assumed that the cancer with dimensions of 2 cm cm 2 cm is located in the pancreas.

Absorbed doses for different concentrations of boron in pancreas cancer, using thermal, epithermal neutrons and real neutron spectrum for BNCT, were calculated.

MATERIALS AND METHOD

The purpose of this paper is to investigate the benefits of the application of BNCT to cancers that are found in the pancreas. The BNCT is said to be very well used in treatments of cancers in certain organs such as lungs, liver and the brain itself. The MCNP5/X code and ORNL phantom were used to simulate the neutron transport from the source to the cancer and the target organs [21-23].

Pancreas and the surrounding organs were represented as a set of voxels in order to obtain dose distribution in the direction of the collimated beam, and to minimize dose in healthy tissue. To ensure isotropic neutron field in cancer, irradiation was simulated in anterior-posterior (AP) and posterior-anterior (PA)

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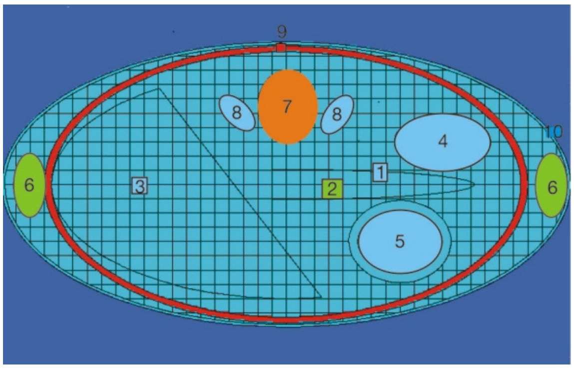

Figure 1. The horizontal cross section of ORNL voxelised phantom with a plane *pz* = 38 cm

geometry. Two opposite neutron beams were considered in this simulations, in order to obtain uniform neutron flux distribution inside the pancreas. The cancer size was similar, but still different compared to previous work [11]. In this study cancer was represented with four voxels, each 1 cm 1 cm 1 cm, fig. 1. The coordinate origin is at the center of the lower base of the trunk of ORNL phantom, *z*-axis is vertical, *x*-axis is directed to the right, and *y*-axis to the back of phantom. Coordinates of cancer in this co-ordinate system are *x*: from 3 to 5 cm; y: from –1 to 0 cm, and *z*: from 37 to 39 cm, *i. e.*, cancer size is 2 cm 1 cm 2 cm. Position of the organs of interest are marked with numbers in fig. 1: 1 – pancreas, 2 – cancer, 3 – liver, 4 – stomach, 5 – bladder, 6 – arm bones, 7 – spine, 8 – kidneys, 9 – rib cage and 10 – skin of trunk. The cross-section (shape) of the neutron beam was chosen to be the same shape as the pancreas and collimated with direction towards the cancer. Energy of the neutrons used in the calculation was taken as 0.025 eV to represent the thermal neutrons, 1 keV for epithermal neutrons and neutron spectrum obtained from the reactor, as it was described in ref. [11].

In this study, three cases were considered: cancer tissue was injected with 25, 50, and 75 ppm of boron. It is assumed that the concentration of boron in healthy tissue is about 10 % of the administered concentration.

For each neutron source, separate input file for the MCNP program was written. In addition, total dose was taken into account, in accordance with the limited capabilities of this version of the MCNP code. The simulation comprised 10^7 independent histories to achieve statistical uncertainty (1σ) lower than 3 %. Output of MCNP calculation was defined as F6 tally which gives an absorbed dose in units MeVg^{-1} per particle which are later converted in Gy per one particle.

Calculations were performed on AEGIS04-KG cluster, which is an integral part of the European Grid Initiative (EGI) and Serbian National Grid Initiative.

RESULTS AND DISCUSSION

The cancer in pancreas, presented on fig. 1, was irradiated with two separate neutron beams in AP and PA geometry, under the assumption of uniform irradiation. The results of doses for AP and PA irradiation were summed to give dose per particle from both geometries. The depth distributions of absorbed dose (dose in voxel) are presented on figs. 2(a), 2(b), and fig. 3, for thermal, neutron spectrum and epithermal neutrons, respectively. It can be seen that absorbed doses have the highest values exactly in the cancer, in all cases.

The dose depth distributions for 25, 50, and 75 ppm (1 ppm = 10^{-6}) of boron concentration in cancer are shown in figs. 2 and 3. It is evident that the ab-

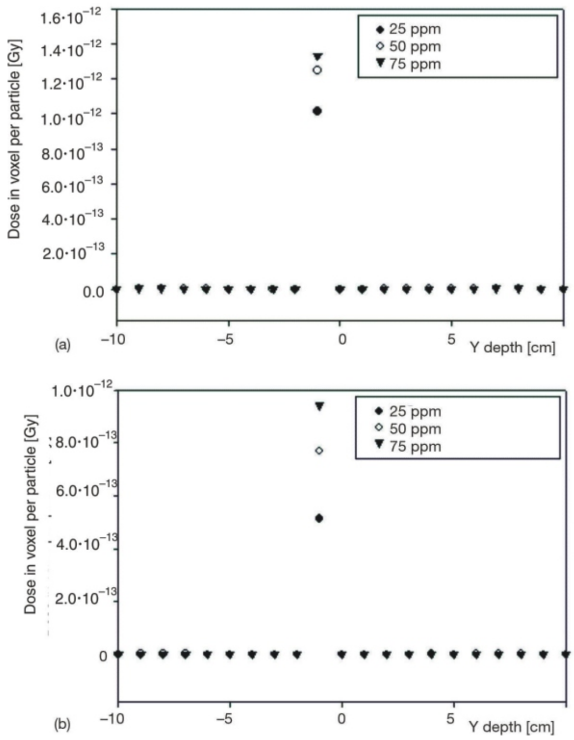

Figure 2. The dose depth distribution for thermal neutrons (a) and neutron spectrum (b)

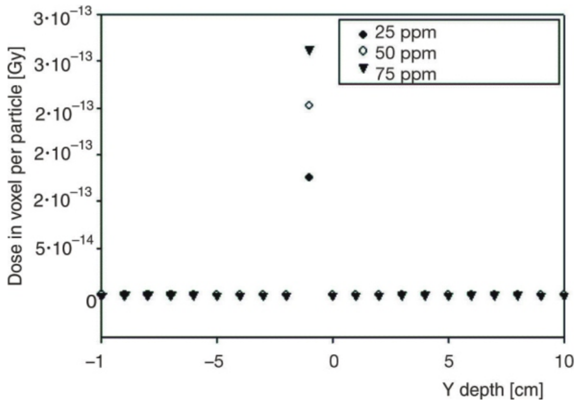

Figure 3. The dose depth distribution for epithermal neutrons

sorbed dose increases with the increasing of the concentration of boron in the cancer.

From figs. 2(a) and 2(b), it can be estimated that the cancer dose from neutron spectrum is about an order of magnitude lower than for thermal neutrons.

By inspection of fig. 3, obtained for epithermal neutrons, it can be seen that doses in the healthy tissue are lower than doses obtained by thermal neutrons and neutron spectrum, fig. 2. These results are significant, because it is important to protect healthy tissue and to achieve the desired effect to kill cancer cells. Theoretically it has been proven that epithermal neutrons are a convenient choice for BNCT.

Table 1 shows the results of the absorbed dose in aGy per neutron for several organs, and the cancer, for the considered spectra of neutron and various concentrations of ^{10}B in the cancer. The obtained results confirm that the dose in the cancer is much higher than in healthy organs for all three neutron spectra. The dose ratio in cancer and healthy organs is the lowest for the lungs and the highest for the pelvis and bladder.

In clinical studies [24-26], considering relative biological effectiveness (RBE), the authors reported that the optimal BNCT parameters and characteristics of the patient's cancer, which is the *C*/*H* ratio (*C* is a cancer dose, *H* is healthy organ or tissue dose) 3, depending on the type of cancers.

The largest cancer doses were obtained in the case of thermal neutrons for all three concentrations of boron. The situation is somewhat more unfavorable for cancer doses in the case of epithermal neutrons. In the case of a real neutrons spectrum obtained from nuclear reactor, the doses received by the cancer are between the values for the previous two spectra.

It can be seen that in the cancer, the dose from thermal neutrons is an order of magnitude larger than that for epithermal neutrons and is nearly three times greater than for the real spectrum of the neutron.

Comparison of doses in other organs shows that, in the case of thermal neutrons, majority of other organs receive larger doses than in the case of epithermal neutrons, except for the bladder.

The goal of radiotherapy is to deliver the planned and optimum dose to the cancer [11, 24], but also to protect the other organs as is reasonably achievable for a particular case. Theoretically, it is more appropriate to use epithermal neutrons for BNCT of pancreatic cancers for the reason that other healthy organs are spared.

CONCLUSIONS

The BNCT is a newer treatment method for both localized cancers and metastases. The goal is to deliver as much as possible larger doses to the cancer tissue, and to protect healthy tissue and other organs. The BNCT showed incredible signs in treatments of cancers in lungs and liver, as well as brain metastases. In addition, we can conclude that this method is very useful as a pretreatment approach and gives us an opportunity to get a better view on further treatment. The use of BNCT is also possible with pancreatic cancers, and this is especially effective with the collimated beam of epithermal neutrons. The healthy organs and tissue, that are on the way of the beam, receive far lower doses than the tissue of cancer. The BNCT is, therefore, one of the most promising methods of new generation therapy, especially in the treatment of cancers, which are not operable.

The results of this work suggest that BNCT with epithermal neutron beam could be applied for the treatment of pancreas cancer.

Table 1. Doses in organs (in aGy per neutron) for different concentrations of ^{10}B in pancreatic cancer

Organs	Epithermal neutrons			Thermal neutrons			Real neutron spectrum		
	25 ppm	50 ppm	75 ppm	25 ppm	50 ppm	75 ppm	25 ppm	50 ppm	75 ppm
Liver	60.40	59.06	58.15	295.29	289.71	286.32	102.23	100.48	99.26
Stomach	191.94	190.26	189.14	1835.97	1823.38	1816.30	607.56	604.32	602.36
Bladder	10.03	10.02	9.97	7.81	7.71	7.64	6.81	6.79	6.74
Esophagus	90.65	117.54	143.42	545.89	727.14	907.49	138.49	176.82	213.96
Colon	38.06	37.87	37.71	81.25	80.35	79.83	39.10	38.75	38.51
Pelvis	15.96	15.89	15.83	21.65	21.41	21.23	12.19	12.10	12.02
Rib cage	37.73	43.97	57.32	501.63	643.94	935.01	69.67	81.91	107.89
Spine	69.49	84.61	115.89	500.74	641.40	928.18	68.09	82.28	112.41
Kidneys	90.12	89.29	88.76	675.85	670.9	667.73	95.95	94.35	93.38
Pancreas	224.24	220.79	218.61	1469.81	1437.83	1422.67	589.59	581.77	577.18
Spleen	260.92	356.62	418.69	3036.41	4725.13	5835.56	412.28	558.38	652.72
Adrenals	159.00	156.63	155.01	1493.07	1478.35	1468.27	179.79	175.47	172.68
Gallblader	89.49	88.55	87.95	336.05	331.71	329.53	127.42	125.97	125.12
Heart	71.52	88.08	97.82	288.33	362.83	406.09	105.25	129.36	143.67
Lung	$6.11 \cdot 10^3$	$10.25 \cdot 10^3$	$13.45 \cdot 10^3$	$25.62 \cdot 10^3$	$39.10 \cdot 10^3$	$47.50 \cdot 10^3$	$7.17 \cdot 10^3$	$11.59 \cdot 10^3$	$14.77 \cdot 10^3$
Cancer	$25.54 \cdot 10^4$	$40.67 \cdot 10^4$	$52.56 \cdot 10^4$	$196.5 \cdot 10^4$	$240.16 \cdot 10^4$	$256.41 \cdot 10^4$	$54.18 \cdot 10^4$	$81.51 \cdot 10^4$	$100.14 \cdot 10^4$

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AUTHOR'S CONTRIBUTIONS

Conceived and designed the computations: D. R. Nikezić and D. Ž. Krstić; performed the computations: D. Ž. Krstić; analyzed the data: D. Ž. Krstić, D. R. Nikezić, M. P. Živković, and M. Ž. Jeremić; wrote the paper: D. Ž. Krstić, D. R.Nikezić, M. P. Živković, and M. Ž. Jeremić.

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ПРОЦЕНА ДОЗЕ У ПАНКРЕАСУ ПОМОЋУ MCNP5/X СОФТВЕРА ЗА ТЕРАПИЈУ ЗАХВАТА НЕУТРОНА БОРОМ

Терапија захвата неутрона бором је тип радио терапије, која је заснована на неутронском захвату ^{10}B, да би се добила алфа честица високе енергије и узмакнуто језгро литијума, чији је домет реда величине ћелије. Софтвер MCNP5/X је коришћен за прорачун апсорбованих доза, као и расподеле дозе по дубини у тумору и органима аналитичког и вокселизованог ORNL фантома, који представља људско тело. Израчунате апсорбоване дозе за термалне, епитермалне неутроне и неутронски спектар, показују да су највеће вредности управо у тумору, у свим случајевима. Добијени теоријски резултати показују да се терапија захвата неутрона бором може користити за лечење карцинома панкреаса. Овом симулацијом је утврђено да су епитермални неутрони погодан избор за терапију, јер је испоручена доза тумору приближна као код термалних неутрона, али бивају поштеђени остали органи.

Кључне речи: терапија захвата неутрона бором, MCNP5/X софтвер, апсорбована доза, панкреас, канцер