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Neutron spatial distribution for BNCT applications of nuclear research reactor LVR-15

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ABSTRACT
Boron Neutron Capture Therapy (BNCT) is a therapeutic method of treatment for aggressive malignant tumors. Especially this method is used for brain tumor Glioblastoma Multiforme which is nowadays unfortunately still incurable. A key part of BNCT is proper determination of physical parameters of the neutron beam.This paper provides an overview of methods and results from measurement of neutron beam used for BNCT applications. An objective of this study was to determine spatial neutron distribution of epithermal neutron beam of nuclear research reactor LVR-15, Czech Republic. Experimental data for this study were collected using a special positioning device with ^{6}Li + Si detector. We also used a neutron radiography method. The resulting data from 3D neutron field measurement were compared with Monte Carlo N-Particle eXtended Transport Code (MCNPX).Together these results provide important insights into neutron spatial distribution of BNCT horizontal channel of LVR-15 which is quite homogenous in whole cross-section without any significant peaks. In summary, these results show that neutron beam (after repeating another important measurement) could be used for continuation of BNCT applications in Czech Republic.
Keywords: Boron Neutron Capture Therapy, Glioblastoma Multiforme, LVR-15, epithermal neutron beam, spatial distribution of neutron field, neutron radiography.

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I. INTRODUCTION

BNCT is based on chemical capture of compounds containing non-radioactive nuclide ^{10}B by cancer cells. The most frequently used compounds include BSH ($Na_2{}^{10}B_{12}H_{12}S$) and BPA ($C_9H_{12}{}^{10}BNO_4$). Tumor is subsequently irradiated by epithermal neutron beam. Epithermal neutronshave high cross section for ^{10}B contributing to high selectivity or irradiation (cancer cells enriched ^{10}B vs. health cells without ^{10}B). The products of ^{10}B (n, α) ^{7}Li reaction have very short reach range and high linear energy transfer characteristic leading to tumor cells destruction.

For the BNCT method it is essential to have a suitable neutron source capable of producing a neutron beam of characteristic and precisely required physical properties. At present, the nuclear reactor is still the only reliable source of such a neutron flux. LVR-15 research reactor situated in Research Centre Rez Ltd. is only nuclear device used for BNCT applications in Czech Republic(Burian J. M., 2001).The nuclear reactor is a research light-water reactor, water-cooled and moderated. At the present, the reactor is operated at a maximum power of 10 MW, but cooling is adjusted up to 15 MW (Ltd., 2017). The reactor is equipped with ten horizontal channels, named as HK1 - HK9 + NZT, of which the NZT is primarily designed for BNCT purposes (Fig. 1, Fig. 2).To determine the radiation dose that the patient should receive during irradiation, it is necessary to know the characteristics of the neutron field (for example homogeneity, neutron spectra, beam collimation, etc.). In order to determine some of these characteristics, measurements via ^{6}Li + Si detector for determination of 2D and neutron radiography method were provided.

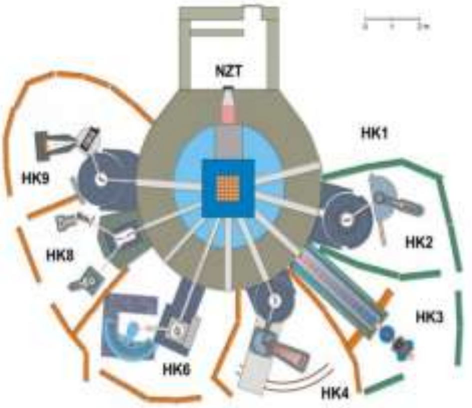

Fig. 1: Position of horizontal channels of LVR-15 research reactor (Šoltés, 2015).

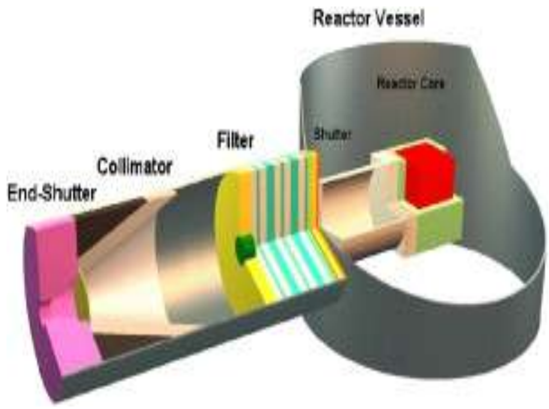

Fig. 2: The LVR-15 epithermal neutron beam used for BNCT experiments *(Burian J. K., 2009)*.

II. MEASUREMENTS AND METHODS

1.1 ^{6}Li + Si detector with special positioning device

The design of the measurement setup was based on ^{6}Li + Si detector and special automatic positioning holder of this detector. The detector was consist from Si diode and ^{6}Li converter – isotopically enriched $^{6}LiF_6$. This converter provide the ^{6}Li(n, α)^{3}H reaction while ^{3}H is detected by Si detector. ^{3}H has the energy of 2,73 MeV (Viererbl, 2007). The diameter of Si diode was 25 mm and 2,5 cm of converter, but small paper aperture to reduce the diameter of converter to 3 mm was used (Fig. 3). The distance from converter to Si detector was ~8 mm. Special positioning device was comprises support frame with holder of ^{6}Li + Si detector (Fig. 4, 5). Three stepper motors allows the movement of the detector in three axis (x, y, z). Motion of the detector in holder was provide by computer program by the control unit of the positioning device. Two scanning maps were prepared – one with position of detector in x = 0 cm from the end-shutter of neutron beam and the second with position x = 5 cm. Then the 2D and 3D neutron profiles were measured. The scheme of detector motion could be seen at Fig. 6.

Fig. 3: The ^{6}Li + Si detector.

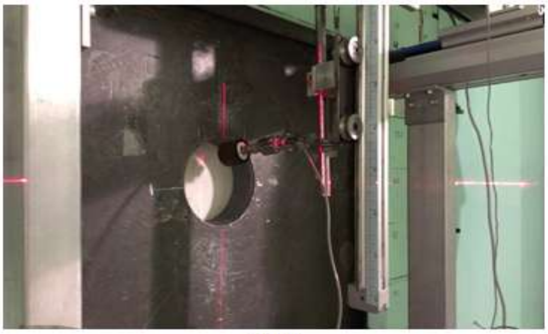

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Fig. 4: The ^{6}Li + Si detector in the holder.

Fig. 5: The positioning device.

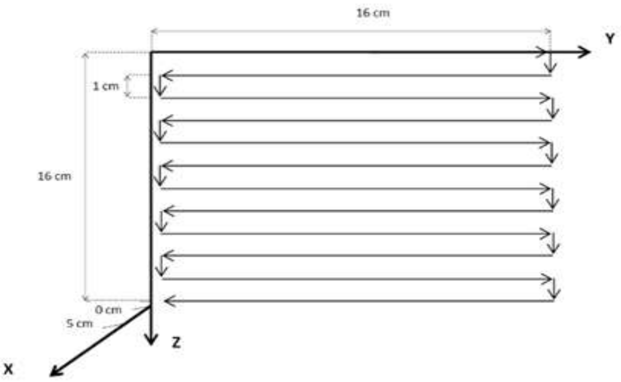

Fig. 6: The scheme of the motion of detector in positioning device.

1.2 Neutron radiography

To obtain 2D image of the different intensities of the neutron flux and gain the projection of neutron beam the neutron radiography method was used. Method is based on neutron irradiation of image plateand subsequent analysis by FUJIFILM BAS – 1800 device of the irradiated image.

III. RESULTS

1.3 Data from ^{6}Li + Si detector

Data obtained from ^{6}Li + Si detector represent the intensity distribution of the neutron flux in the concrete step position of the detector (represented by each on cell in the images). For all the experiments were calculated the unstable nuclear reactor power corrections. In the position of detector x = 0 cm distance was the symmetry of neutron beam confirmed (Fig. 7, 8). Data analysis from x = 5 cm evince the move of neutron beam to lower half of image (Fig. 9, 10). But this effect is caused by an inadvertent change of initial position of detector and no precise position of detector from the end-shutter of beam. It has no relation to deflection of neutron beam. The distraction of neutron beam with detector position x = 5 cm compare to x = 0 cm is considerable.

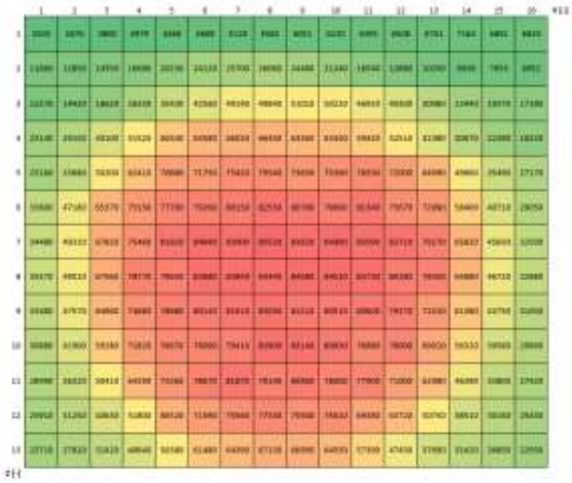

Fig. 7: The distribution of neutron flux intensity (x = 0 cm).

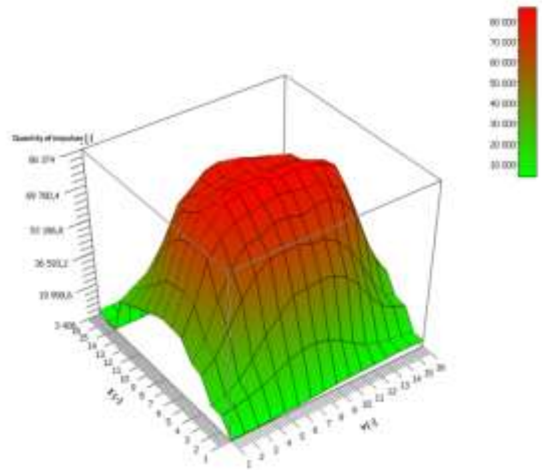

Fig. 8: The 3D projection of 2D profile of neutron flux intensity (x = 0 cm).

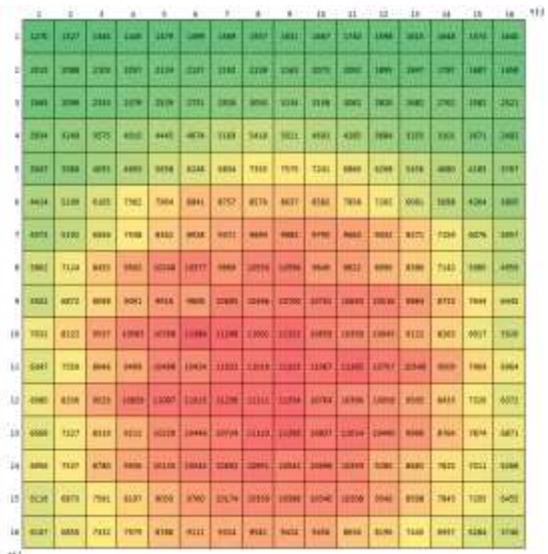

Fig. 9: The distribution of neutron flux intensity (x = 5 cm).

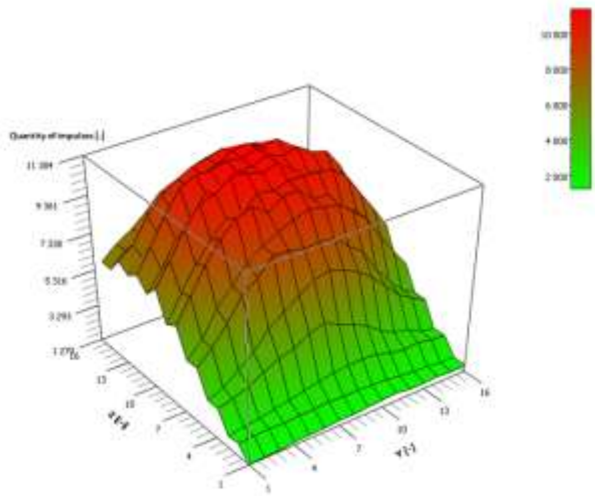

Fig. 10: The 3D projection of 2D profile of neutron flux intensity (x = 5 cm).

1.4 MCNPX comparison data

The experimental data from 3D neutron spatial distribution (distances of detector x = 0 cm, x = 5 cm) were compared with calculated by MCNPX (Fig. 11, 12). The data represent reaction rates – saturated activity of on ^{6}Li target nucleus and response of the detector to neutron beam - of Li^{6}(n, t) (MT = 105) reaction in every step position of detector. The comparison between MCNPX simulations and real data from ^{6}Li + Si detector shows that the beam profile of simulation is more balanced in all diameter and outside beam intensities decreases slower than according real data. Nevertheless, MCNPX simulations had a higher uncertainties (about 10 %) than the experimental ones (< 1 %).

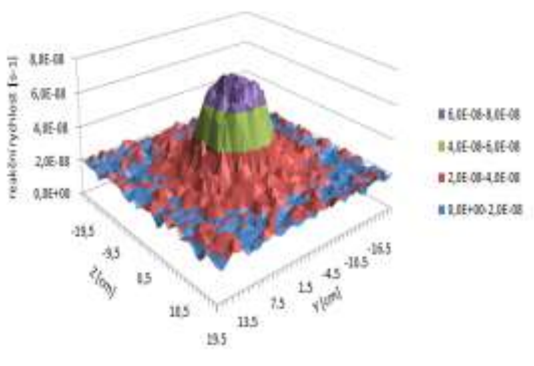

Fig.: 11: The MCNPX data simulation (x = 0 cm).

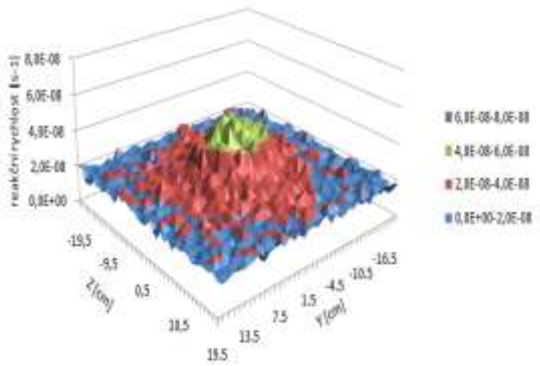

Fig. 12: The MCNPX data simulation (x = 5 cm).

1.5 Neutron radiography data

Experimental results from neutron radiography method were in the form of radiography image (Fig. 13). The white colour represents the high intensity of neutron beam while blue ones the spots with lower intensities. The neutron beam is symmetrical with lowest attenuation values in the center of the beam. Overall, the upper half of image is more expose than the lower half. We suppose that it is an influence of gamma radiation because the image plate is also sensitive at γ-rays. It is an impact caused by opening/closing effect of LVR-15 BNCT channel during the start and finish of experiment.

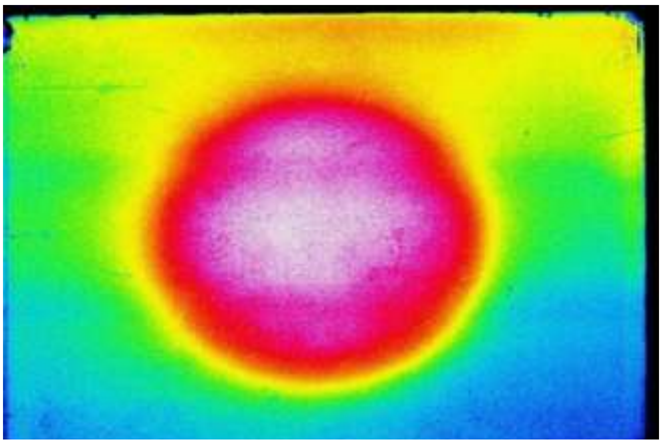

Fig. 13: The irradiated image plate after analysis.

IV. CONCLUSION

The study was undertaken to prove physical qualities of BNCT neutron beam of LVR-15 research reactor, Research Centre Rez Ltd., Czech Republic. This study has found that generally the neutron beam is quite homogeneous in whole cross-section and without any significant peaks of intensities which was proved by measurements with ^{6}Li + Si detector and radiography method. One of the other results was a proper functionality of the special positioning device with ^{6}Li + Si detector. More research is required to improvement MCNPX simulations, primarily to reduction of computation uncertainties. This research will serve as a base for future studies of BNCT neutron beam and experiments.

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