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Experimental Determination of Neutron Beam Spatial Distribution of Nuclear Research Reactor LVR-15 for BNCT Applications

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Abstract*: Boron neutron Capture Therapy (BNCT) is a method of treating incurable or recurrent malignant tumors. Its application is particularly in the field of brain tumors - especially very aggressive type of Glioblastoma Multiforme. BNCT reduce radiation dose to healthy tissue and allow considerable selectivity of the therapeutic dose to the tumor. The source of ionizing radiation is usually a nuclear reactor which provides an optimum neutron flow. To determine the appropriate therapeutic dose is necessary knowledge of characteristics of the neutron beam. In this study, experimental measurements and simulations have been carried out to determination of neutron beam spatial distribution of nuclear research reactor LVR-15, Czech Republic. To do this, a special positioning device with ^{6}Li + Si detector was used. It was also performed by neutron radiography method. The results obtained from the measurement of 3D neutron field were compared with Monte Carlo N-Particle eXtended Transport Code (MCNPX).*

Keywords*: Boron Neutron Capture Therapy, Glioblastoma Multiforme, LVR-15, epithermal neutron beam, measurement of distribution of neutron field, neutron radiography.*

I. INTRODUCTION

Glioblastoma multiforme is the most common malignant radioresistant and chemoresistant tumor of the central nervous system which has been incurable for decades and even today, unfortunately, prognosis is not favorable. This type of tumor is characterized by very fast growth and aggressive invasion of the surrounding normal brain tissue.It is very difficult to remove all of the affected tumor cells without serious damage to the brain.In this regard, Boron Neutron Capture Therapy is an unique selective radiotherapy based on detection of non-radioactive nuclide ^{10}B by cancer cells and then the subsequent capture of thermal neutrons is provided, resulting in the nuclear reaction ^{10}B (n, α) ^{7}Li. The products of this reaction have high linear energy transfer characteristic and very short reach range. For this reason the selective destruction of tumor cells which contain sufficient quantities of ^{10}B is reached.

Research reactor LVR-15 is only nuclear device which was used for BNCT clinical trial in Czech Republic(Burian J. M., 2001). A very important part of BNCT treatment planning is to determine the parameters and the correct setting of the neutron beam used to irradiate the patient. Therefore the proper knowledge of current characteristic (the neutron spectra, homogeneity, accurate beam collimation, etc.) is required. For this reason the measurements of 2D and 3D neutron spatial distribution of the beam were provided via ^{6}Li + Si detector and neutron radiography method. The measurement of 3D neutron field was compared with MCNPX simulation.

II. MEASUREMENT DEVICES AND METHODS

2.1 The BNCT horizontal channel of LVR-15 reactor

The LVR-15 reactor represent a light water research reactoroperated on 10 MW thermal power and situated in Research Centre Rez Ltd., near Prague, Czech Republic.The reactor is equipped with ten horizontal channels which the epithermal one is used for BNCT experiments (Fig. 1). The neutrons from the core pass through a set of filters (Al-AlF3) and collimator (Al with inner layer from Pb) to the outlet of the channel. The diameter of the outlet is 12 cm and the distance of the reactor core is about 4 m (Viererbl L., 2012). Measurements were performed with two kinds of method – special positioning device with ^{6}Li + Si detector and neutron radiography.

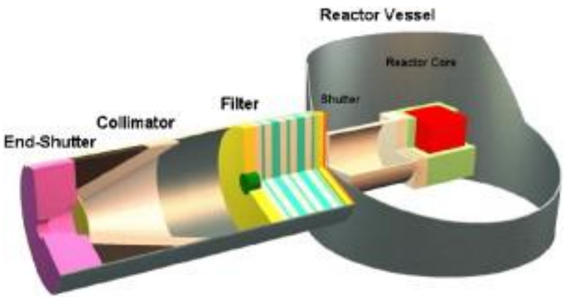

Fig. 1: The LVR-15 epithermal neutron beam used for BNCT experiments*(Burian J. K., 2009)*.

2.2 Special positioning device with ^{6}Li + Si detector

Special positioning device is consisted of supporting frame which serves as a holder for the detector (**Error! Reference source not found.**). Simultaneously via use a stepper motors allows its controlled movement along the axis x, y, z. The movement detector is controlled by a computer program via the control unit.

^{6}Li + Si detector is consisted of ^{6}Li converter and Si diode. ^{6}Li converter (isotopically enriched $^{6}LiF_6$) after insertion into the neutron flux provided reaction $^{6}Li(n, \alpha)^{3}H$. The tritium (with energy 2,73 MeV (Viererbl L., 2007)) is then detected in the Si detector. The active diameter of the converter is 3 mm due to small paper aperture (converter itself has a diameter of about 2.5 cm) and the Si detector 25 mm(Viererbl L.). The distance between the converter and the detector is approximately 8 mm.

Fig. 2: The special positioning device. Fig. 3: ^{6}Li + Si detector

The neutron beam parameters were monitored by measurements of neutron 2D and 3D profile.The positioning device moved with detector according beforehand prepared route (Fig. 4) in front of the output of neutron beam. The detector in x-axis during measurements had two positions: x = 0 cm and x = 5 cm from the output of neutron beam.

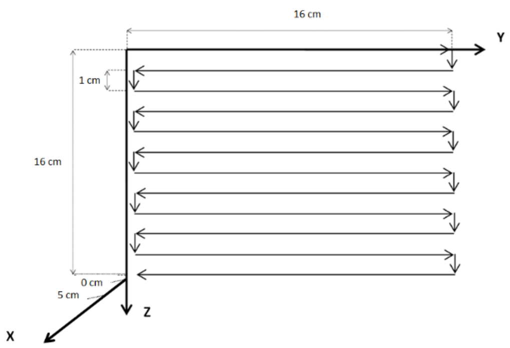

Fig. 4: The scheme of motion of positioning device with ^{6}Li + Si detector.

2.3 Neutron radiography method

Screening of neutron flux through an imaging plates is mainly used for neutron radiography method. It´s principle is based on passing a neutron beam trough an object and subsequent detection on the image plate. The result is a 2D image of the different intensities of the neutron flux which is determined by the absorption properties of the materials in the object. In the measurement in this work neutron radiography method was used as a projection of the neutron beam profile itself.

III. RESULTS

The experimental results of peak areas of detected ^{3}H in the distance x = 0 cm from the output of neutron beam are shown atFig. 5 and Fig. 6. The corrections for the unstable reactor power during the irradiation were calculated for all the measurements. The symmetry of the neutron beam is ascertained.

Z [-] \ Y [-]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	3503	3676	3800	3979	4466	4608	5128	5582	6051	6220	6395	6508	6701	7164	6891	6830
2	11660	12850	14350	16680	20230	24120	25700	26060	24480	21240	16540	12880	10250	8638	7933	6952
3	12270	14420	18620	26330	35430	42560	49190	49840	51010	50220	46920	40300	30980	23440	19370	17180
4	23140	29150	40100	51520	60440	65580	66020	66440	64360	63440	59420	52510	42380	30670	22390	18220
5	25160	33680	50200	62410	70680	71750	75420	75540	73630	75360	76350	72000	64990	49860	35490	27170
6	33600	47180	65370	73130	77700	79260	80150	82530	80780	79690	81340	75670	72890	58400	40710	29050
7	34480	49310	67820	75460	81920	84040	83900	85520	83820	84990	83590	82710	79270	65820	45650	32500
8	35570	49010	67560	78770	79650	83680	83840	83440	84580	84510	83730	80180	78430	65880	46720	32880
9	33480	47570	64960	74680	78680	80140	81610	83030	81210	80510	80600	79270	72520	61380	43750	31050
10	30880	41900	59280	71820	76670	78090	79410	82900	83140	80930	76980	78000	69010	56320	39580	29960
11	28490	36320	50410	64290	73360	78670	81870	79140	80400	78000	77900	71000	62980	46390	33800	27420
12	25910	31250	40630	51800	66520	71590	75560	77330	75500	75610	69380	63720	50750	38510	30160	25430
13	23710	27820	32420	40640	50380	61480	64390	67130	66990	64550	57390	47430	37690	31620	26850	22930

Fig. 5: The intensity distribution of the neutron flux (x = 0 cm).

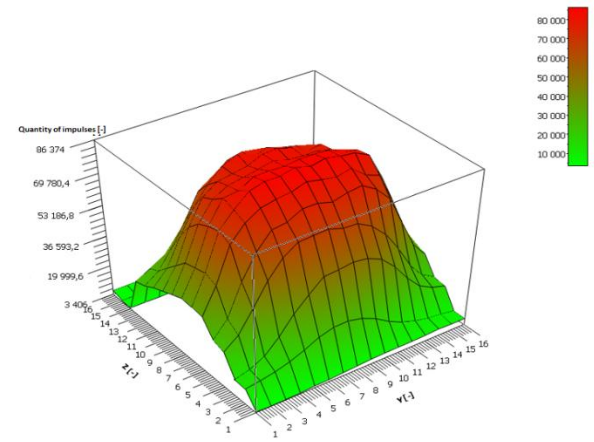

Fig. 6: 3D projection of 2D profile of the neutron beam (x = 0 cm).

The results of the distance x = 5 cm are at Fig. 7 and Fig. 8. It can be seen that the center of the beam is moved to the lower half of Fig. 7. However, this phenomenon is not related to deflection of the neutron beam, but with a change of the initial position of the detector when there is no precise alignment on the output of the beam.It is significant distraction of neutron beam in this distance (x = 5 cm) compared to the distance x = 0 cm.Symmetry remains in the y-axis, but it is less evident in the z-axis, which is caused by the move of the positioning device.

Z [-] \ Y [-]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1270	1327	1344	1445	1479	1499	1569	1557	1631	1667	1740	1598	1615	1648	1574	1640
2	2013	2088	2103	2057	2124	2137	2192	2138	2163	2073	2092	1895	1847	1787	1687	1658
3	1945	2096	2233	2379	2529	2731	2926	3050	3134	3158	3082	2820	2682	2762	2582	2521
4	3034	3249	3575	4015	4445	4674	5169	5418	5021	4692	4285	3684	3255	3101	2671	2492
5	3047	3380	4055	4693	5658	6248	6834	7333	7575	7241	6866	6268	5456	4680	4185	3767
6	4414	5199	6165	7362	7964	8841	8757	8579	8637	8582	7858	7265	6061	5098	4264	3805
7	4373	5192	6556	7438	8362	8938	9371	9694	9983	9795	9663	9042	8371	7159	6076	5057
8	5862	7124	8455	9503	10248	10577	9969	10550	10596	9849	9822	8996	8386	7142	5985	4959
9	5502	6872	8098	9091	9916	9808	10605	10466	10700	10701	10650	10516	9884	8733	7644	6445
10	7032	8222	9537	10563	10768	11384	11298	11001	11322	10659	10339	10045	9122	8263	6917	5920
11	6347	7359	8646	9409	10498	10424	11022	11019	11323	11067	11265	10757	10540	9509	7969	6964
12	6980	8206	9523	10659	11007	11015	11236	11111	11334	10764	10396	10058	9505	8433	7320	6372
13	6569	7227	8319	9212	10229	10446	10724	11123	11293	10837	11014	10440	9990	8764	7874	6871
14	6956	7537	8780	9556	10135	10544	10692	10951	10542	10696	10359	9280	8683	7825	7011	6268
15	6116	6873	7581	8197	9050	9760	10174	10359	10388	10340	10208	9540	8598	7843	7205	6455
16	6167	6850	7332	7979	8788	9111	9324	9581	9424	9456	8636	8196	7445	6937	6284	5746

Fig. 7: The intensity distribution of the neutron flux (x = 5 cm).

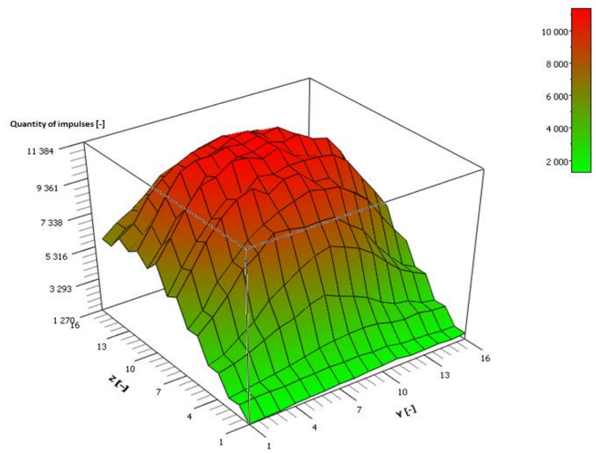

Fig. 8: 3D projection of 2D profile of the neutron beam (x = 5 cm).

The calculated neutron flux spatial distribution at the 3D graph in MCNPX is shown at Fig. 9 and Fig. 10. The simulations represent a model for the distances x = 0 cm and x = 5 cm. The results are the calculated values of reaction rates Li^6(n, t) (MT = 105) in measured points. The reaction rate corresponds with saturated activity of one ^{6}Li target nucleus and thus the response of the detector to neutron beam.The simulation shows that the real beam profile (according the measurements) is more balanced in all diameter (⌀ 12 cm) while the outside beam intensities decreases faster than in MNCPX. However, the higher uncertainties of MCNPX (about 10 %) compared to experimental (< 1 %) must be considered.

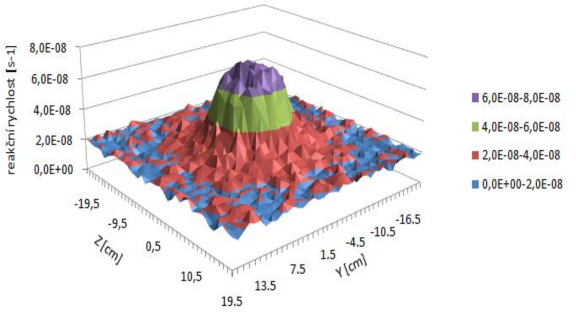

Fig. 9: MCNPX simulation for x = 0 cm.

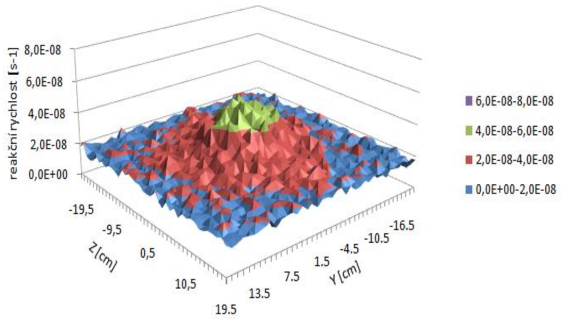

Fig. 10: MCNPX simulation for x = 5 cm.

The result of neutron radiography method is shown at Fig. 11. The dark blue color represents the lowest level of excitation (the largest decline), while the white color represents the high intensity. On the picture is evident symmetrical circular beam with the lowest attenuation values in the center. However, the upper half of the image shows a higher level of exposure than the lower half. Possible in this case, this could be the influence of gamma radiation to which the neutron plate can be also sensitive. This impact would be affected by the opening LVR-15 BNCT channel of neutron beam.

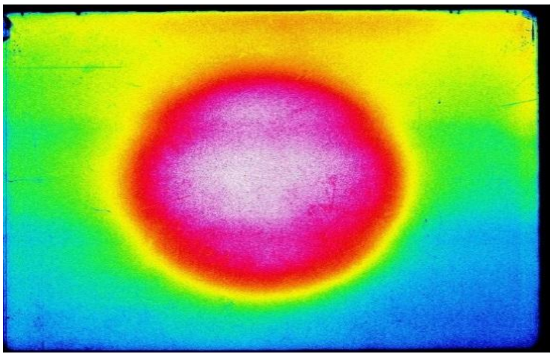

Fig. 11: The neutron beam (radiography method).

IV. CONCLUSION

The measurement results show that the profile of the neutron beam for BNCT applications of LVR-15 research reactor (Research Centre Rez Ltd., Czech Republic)is quite homogeneous in whole cross-section without any significant peaks. Also proper functionality of special positioning system which fixed the ^{6}Li + Si detector was confirmed. The measurement using neutron image plate proved that the neutron beam is symmetrical with the highest intensity in the center. Detected intensity changes in the upper/lower half of the image are caused by the influence of unwanted exposure during opening horizontal channel. The results of MCNPX simulation quite correspond with experiments but they should be examined by more accurate calculations and other measurements. In the future, more measurements with other types of detector´s converter are planned.

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