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NEUTRON SPECTRUM MEASUREMENT ON EPITHERMAL BEAM OF LVR-15 RESEARCH REACTOR

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Abstract

Horizontal channel with epithermal neutron beam in LVR-15 reactor is used mainly for boron neutron capture therapy (BNCT). Neutron spectrum is basic characteristic of the beam. Number of methods has been used for the measurement of the beam neutron spectrum. This paper deals with two methods: activation detectors measurement and method based on depth profile measurement in water phantom using different types of detectors.

***Keywords**: neutron spectrum, research reactor, epithermal beam, BNCT*

1. INTRODUCTION

The LVR-15 reactor [1] is a light water research reactor, which is situated in Nuclear Research Institute, Rez near Prague. The reactor operates as a multipurpose facility with maximal thermal power of 10 MW.

The reactor contains 10 horizontal channels. One of them with epithermal neutron beam is used mainly for Boron Neutron Capture Therapy (BNCT) and for experiments with neutron fluence rate less than 10^9 $cm^{-2}s^{-1}$.

Neutron spectrum is basic characteristic of the beam. Knowledge of the spectrum is important for BNCT and other experiments. Number of methods was used for measurement of neutron spectrum in the beam. In this paper, activation method with resulted neutron spectrum is described.

Measured depth profiles in water phantom are presented in the next part of this paper. For the measurement, four types of detectors were used: Au, Au in a Cd cover and In activation detectors, and Si semiconductor detector with ^{6}LiF converter. From the depth profile data, neutron spectrum can be estimated. It needs more complex calculations and only basic idea is outlined in this paper.

2. EPITHERMAL BEAM

Epithermal neutron beam in LVR-15 was designed in 1992 for BNCT purpose [2]. Schema of the beam is in Fig. 1. Neutrons from reactor core go through special filter to collimator and outlet of the beam. The filter moderates neutron spectrum and is designed to meet BNCT requirements for neutron spectrum. The outlet of the beam is about 4 m from the reactor core and its diameter is 12 cm.

Total neutron fluence rate in the outlet depends on the core configuration and it is in the range 10^8 $cm^{-2}s^{-1}$ to 10^9 $cm^{-2}s^{-1}$. Also neutron spectrum slightly depends on the core configuration. All below given measurements were made with special BNCT core configuration.

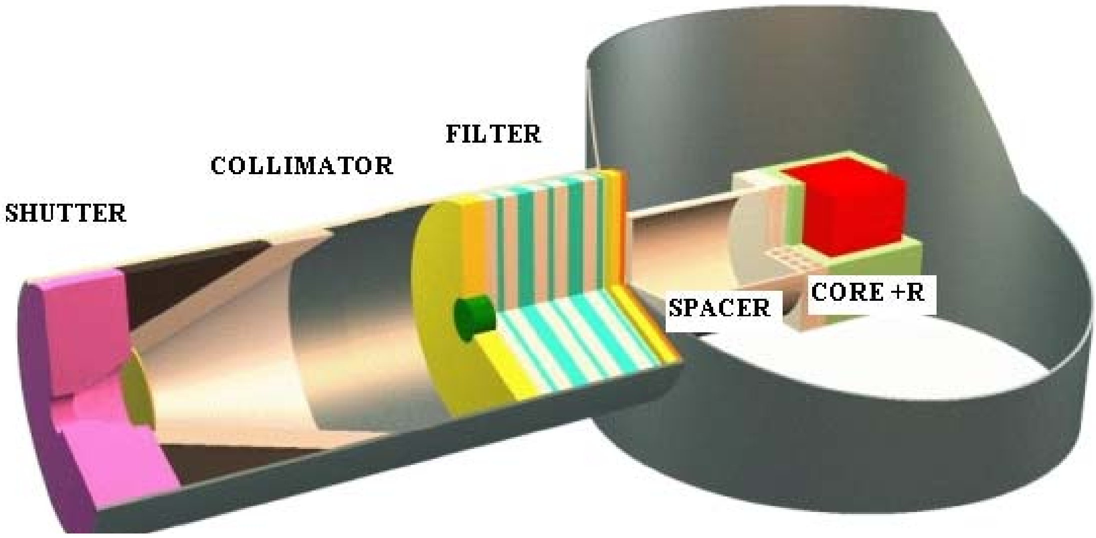

Fig. 1. Schema of epithermal neutron beam in LVR-15

3. ACTIVATION METHOD

Activation of foil detectors [3], [4] is basic method used for neutron spectrum determination in the LVR-15 epithermal beam. During the time standard set of detectors was chosen. The set includes 10 types of detectors according Table 1.

In Table 1 “Position number” represents location of detectors during irradiation, the first Au foil is the nearest one from the reactor core. The diameter of the detectors is 10 mm. Concentration of element less then 100 % means alloy of the element with Al. Detectors with position number 2 to 7 are in a Cd cover. Recommended sequence and measuring times of the activity measurement were chosen according to half-lives and typical activities of radionuclides.

The set of detectors is placed in free beam (in air without phantom) in the centre of the beam in the outlet plane. The typical time of irradiation is 12 hours.

Table 1. List of activation detectors used in free beam

Position number	Element	Concentration	Thicknes s	Cd cover	Reaction	Meas. sequence	Meas. time
		(%)	(mm)				(s)
1	Au	1	0.2	In front of Cd	$^{197}Au(n,\gamma)^{198}Au$	5	2000
2	In	1	0.2	inside Cd	$^{115}In(n,\gamma)^{116m}In$	1	2000
3	Sc	1	0.2	inside Cd	$^{45}Sc(n,\gamma)^{46}Sc$	10	80000
4	Au	1	0.2	inside Cd	$^{197}Au(n,\gamma)^{198}Au$	6	2000
5	W	0.1	0.2	inside Cd	$^{186}W(n,\gamma)^{187}W$	7	2000
6	La	0.5	0.2	inside Cd	$^{139}La(n,\gamma)^{140}La$	4	2000
7	Mn	4	0.2	inside Cd	$^{55}Mn(n,\gamma)^{56}Mn$	2	2000
8	Cu	100	0.2	inside Cd	$^{63}Cu(n,\gamma)^{64}Cu$	3	2000
9	In	100	1	behind Cd	$^{115}In(n,n')^{115m}In$	8	10000
10	Ni	100	1	behind Cd	$^{58}Ni(n,p)^{58}Co$	9	40000

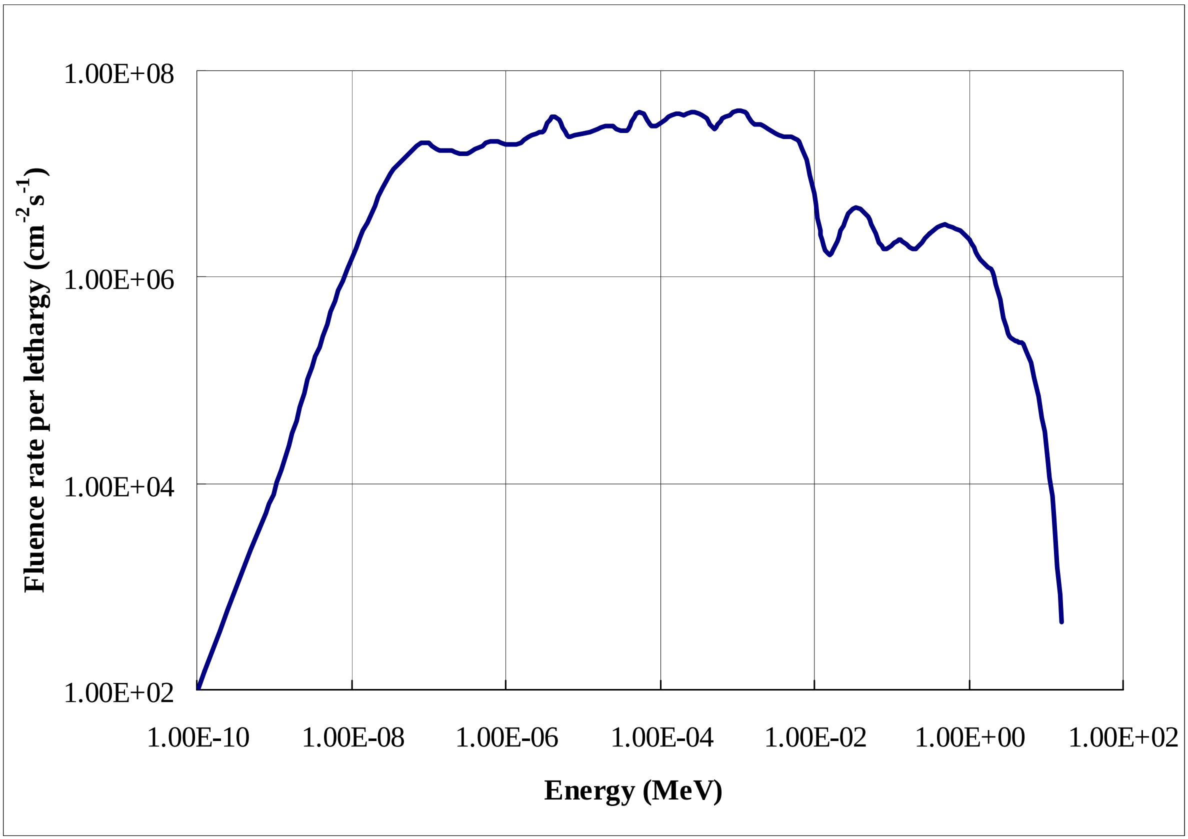

Fig. 2. Neutron spectrum of epithermal neutron beam in LVR-15 reactor

After irradiation gamma activities are measured with a coaxial HPGe detector with a relative efficiency of 18 % and FWHM resolution of 1.8 keV for 1332 keV photons of 60Co. The detector is placed in a shielding box with 5 cm thick lead walls. The calibration of the detector and the measurement method are in accordance with "ASTM E181-98(2003) Standard Test Methods for Detector Calibration and Analysis of Radionuclides". Genie 2000 software (Canberra) is used for the evaluation.

Reaction rates are calculated from the activities and the SAND II program with the IRDF90 dosimetry library is used for the evaluation of the neutron spectrum from these calculated reaction rates.

Neutron spectrum measured with activation foils in October 2004 is given in Fig. 2.

4. MEASUREMENT OF DEPTH PROFILES IN WATER PHANTOM

Set of 18 Au detectors in defined points along the beam axis was irradiated in water phantom and induced activities were measured. Similar measurements were made with In foils and Au foils in a Cd cover. In the same points measurement using Si semiconductor detector with ^{6}LiF converter (Si-^{6}Li detector) was made. From these data depth profile of relative fluence rate for thermal, epithermal and fast neutron was determined.

The water phantom is a tank (like "aquarium") with 5 mm perspex walls filled with demineralised water. Dimensions of the phantom (including walls) are 400 mm (width) × 400 mm (height) × 300 mm (depth).

Results for thermal neutrons made with two types of detectors are given in Fig. 3. For Au foils fluence rate is proportional to difference of "Au without Cd" and "Au with Cd" reaction rates (^{197}Au(n,γ)^{198}Au). For Si-^{6}Li detector (^{6}Li(n,t)^{4}He) fluence rate is directly proportional to count rate of the detector [5], [6]. Fluence rates are normalised to depth position of 20 mm. The dependence for both types of detectors is similar. The small difference can be cause by different spectral cross section characteristic of the detectors or by shift of zero position of measuring points.

Results for epithermal and fast neutrons are given in Fig. 4. In this case it is supposed that fluence rate for epithermal neutrons is proportional to reaction rate measured with Au foils in a Cd cover (^{197}Au(n,γ)^{198}Au) and for fast neutrons reaction rates measured with In foils (^{115}In(n,n')^{115m}In).

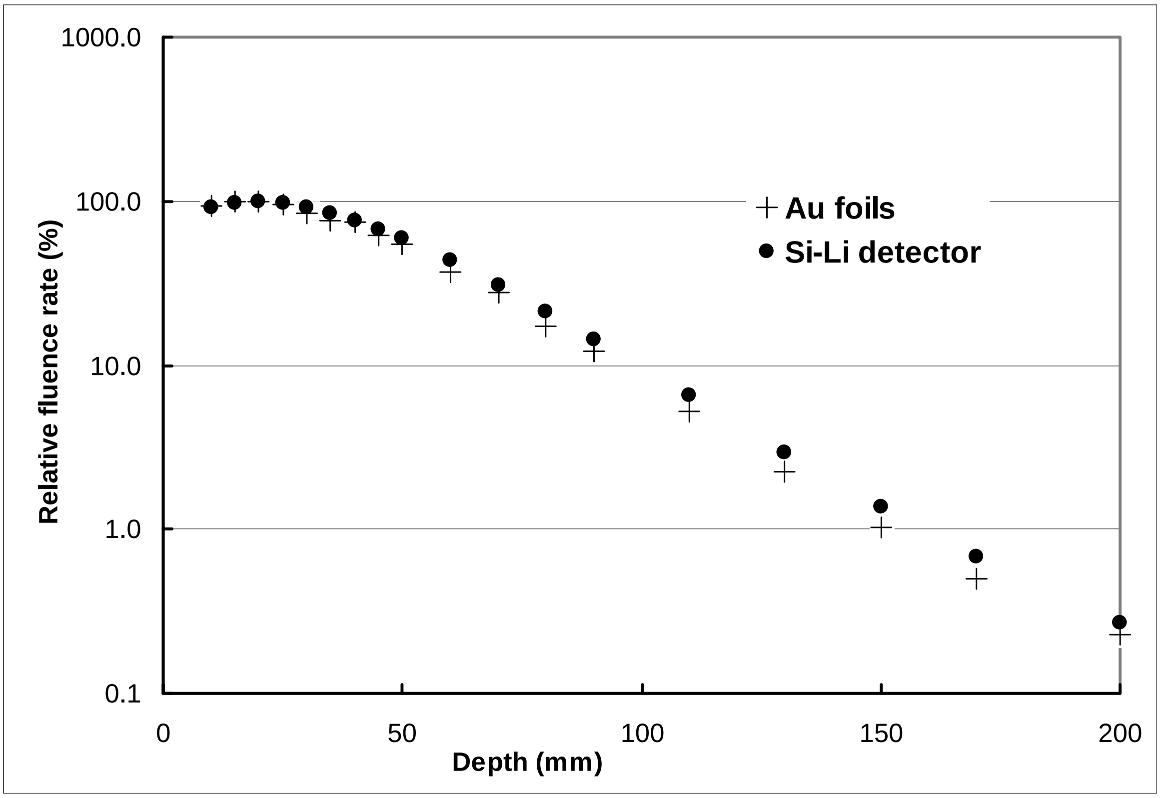

Fig. 3. Depth profile of thermal neutron fluence rate measured with Au foils and Si-Li detector (June 2006)

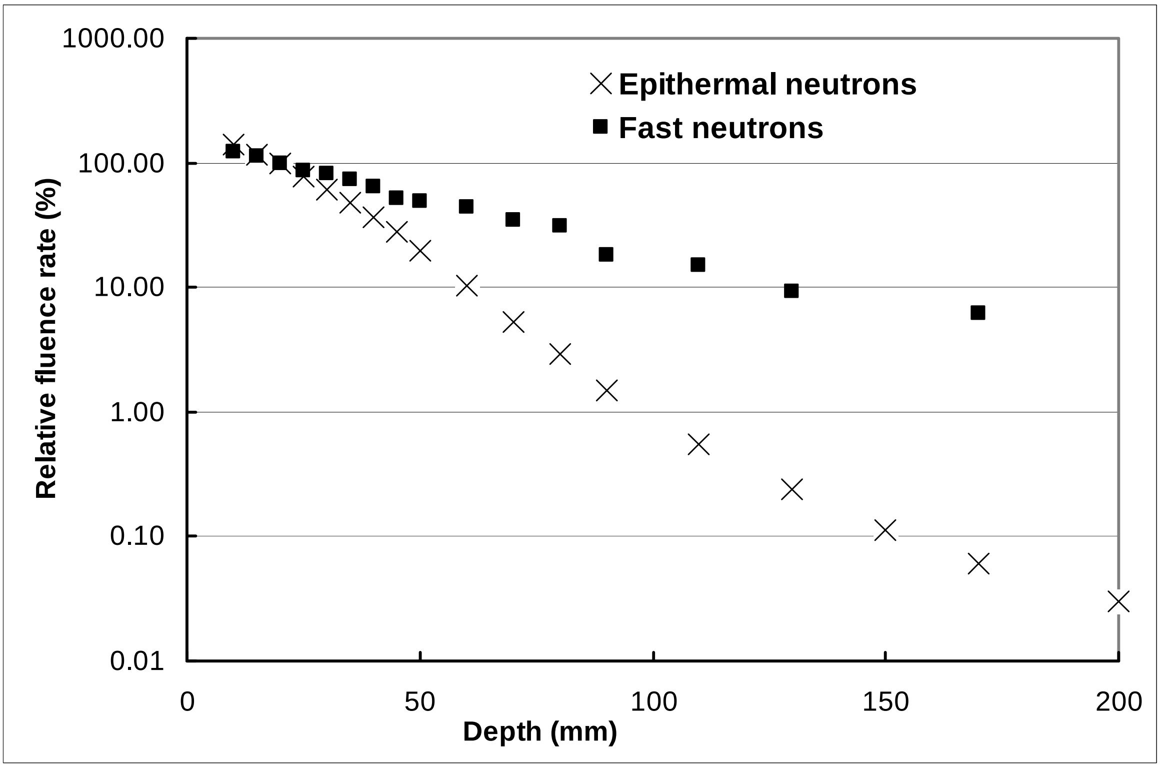

Fig. 4. Depth profile of epithermal and fast neutron fluence rate (June 2007)

Depth profile in water phantom for thermal neutrons and collimated beam gives similar information as measurement with Bonner spheres. Then, in principle, these data can be used for neutron spectrum determination or verification. To solve the task more complex calculations are necessary. In next text only basic comparison of the two methods are given:

1) Depth profile measurement can be done during one continuous irradiation (irradiation of one set of activation detectors or using automatic moving of a on-line detector). For every change of Bonner spheres neutron beam has to be closed.
2) For Bonner spheres usually only thermal neutron detector is used. Depth profile in water phantom can be easy measured also for epithermal and fast neutrons and data for neutron spectrum determination are therefore more complete.
3) For Bonner spheres measurement the detector is always in the same position relative to the beam, for depth profile measurement it is in different positions. Therefore in depth profile method it would be more important to take into account information about collimation (divergence) of the beam.

5. CONCLUSION

Neutron spectrum of epithermal beam was determined using set of activation foils. The spectrum meets requirements for boron neutron capture therapy. Depth profile measurement in water phantom for thermal, epithermal and fast neutrons was made with activation detectors and Si semiconductor detector with ^{6}LiF converter. These data can be used as next method of neutron spectrum determination.

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