MEASUREMENT OF THERMAL NEUTRON BEAM PARAMETERS IN THE LVR-15 RESEARCH REACTOR

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ABSTRACT

The LVR-15 research reactor, situated at the site of the Research Centre Řež near Prague, is equipped with ten horizontal channels. In 2012, into one of them a special filter was mounted and a radiation shielding box was established around the channel in order to take preparations for a future neutron transmission radiography and tomography facility. Basic beam parameters comprise neutron fluence rate and spectrum, and spatial thermal neutron distribution (beam divergence). These parameters were measured with activation detectors and a silicon detector with a ^{6}Li converter. In addition, the gamma dose rate at the channel outlet was measured using TLD dosimeters. The measured thermal neutron fluence rate was determined at the value of about 2×10^{8} $cm^{-2}.s^{-1}$ and beam homogeneity was proclaimed acceptable at a diameter of 100 mm for the future neutron radiography facility. The results were discussed in relation to neutron radiography requirements, where the ideal case is a purely thermal homogenous parallel neutron beam.

1. Introduction

Neutron radiography is an imaging method often used at research reactor sites. One horizontal beam in the LVR-15 research reactor was adapted for neutron radiography and tomography in 2012. The LVR-15 reactor [1] is a light water moderated and cooled tank-type nuclear research reactor. It is situated in Research Centre Řež Ltd., in Řež near Prague. The nominal reactor thermal power is 10 MW and it is operated as a multipurpose facility. It offers services in many fields: material research, production of radioisotopes for medical and industrial purposes, irradiation of silicon single crystals, neutron activation analysis, boron neutron capture therapy, neutron diffraction etc.

The horizontal neutron channel HC1 has not been regularly used up to 2011, when a project has started to adapt the channel for neutron radiography. The final goal (2015) is to build a workplace for non destructive testing, diagnostics and 3D imaging with neutron radiography and tomography. Parameters of the free beam (without the filter installed inside the channel) and design of the outer shielding around the irradiation box was described in [2].

The ideal beam for neutron radiography and tomography is a collimated beam of thermal neutrons with a sufficient high fluence rate. The HC1 beam tube has a diameter of 100 mm and a length of 3 m. Evaluated values of fast neutron fluence rates and gamma dose rates for a free channel (without a filter) are significant high. To suppress fast neutrons and gamma radiation and to transmit enough thermal neutrons, a special filter was designed and inserted inside the beam tube. The filter is based on Si single crystals with total length of 1000 mm and diameter of 78 mm. The crystals are placed inside an aluminium tube with a diameter of 99 mm. The filter is positioned in the beam tube between the reactor core and the beam outlet, see Fig. 1. In this paper, a measurement of basic beam parameters is presented.

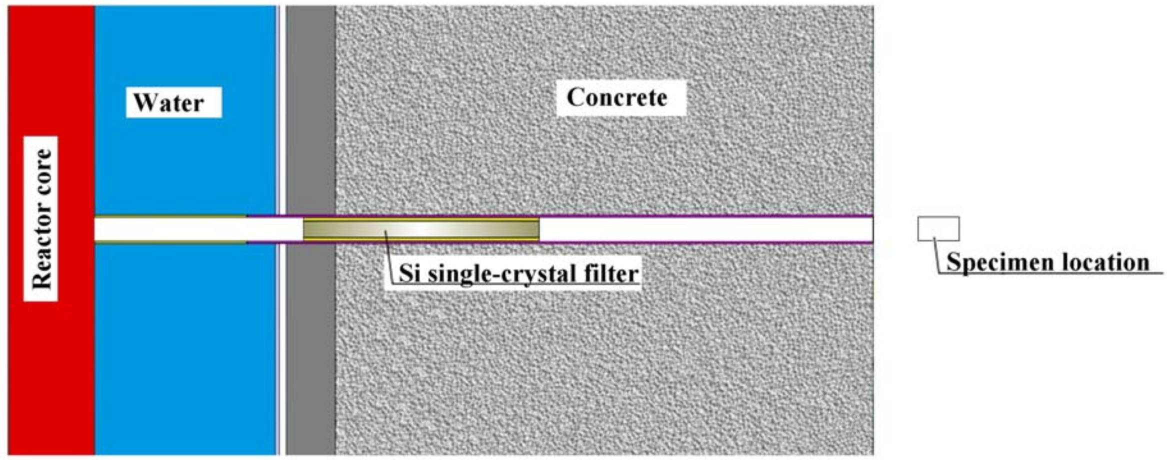

Fig. 1. Schematic arrangement of HC1 horizontal channel

2. Neutron fluence and gamma dose rate measurement

2.1 Experimental method

The neutron fluence and spectrum were measured with activation detectors – foils with Ø 10 mm x 0.1 mm. Seven types of activation detectors were used: Au, Cu, In and Ni without cadmium cover and Au, Cu and In with a 1 mm thick cadmium cover. The detectors were irradiated for 2 hours; afterwards, induced activities of the detectors were measured [3]. The neutron spectrum was evaluated with the SAND II unfolding code [4] using the IRDF90 dosimetry library. A neutron spectrum calculated by the MCNPX particle transportation Monte-Carlo code [2] was taken as an input spectrum for the unfolding.

The dose rate of gamma radiation was measured with TLD dosimeters. These dosimeters are made of aluminium-phosphate glass in form of a cylinder with 8 mm in diameter. These detectors can register gamma radiation in an energy range from 25 keV to 7.5 MeV while the total dose range is between 0.1 mGy to 10 Gy. The TLD dosimeters at the LVR-15 reactor are usually used for personal dosimetry. The measurement uncertainty varies from 15 % to 30 % depending on dose value and energy spectrum. In our case, also influence of neutron radiation is not negligible and may rise the uncertainty.

2.2 Results

Measured values of neutron fluence rates for the channel with the filter installed are divided into five energy groups and are listed in Tab. 1. The rates were measured at the outlet point of the channel. The uncertainty of the fluence rate determination was estimated at 20 %. The result of the gamma dose rate measurement was 0.4 Gy/h with an uncertainty of 30 %.

Neutron energy	Neutron fluence rate ($cm^{-2}.s^{-1}$)
< 0.501 eV	2.17×10^{8}
0.501 eV - 10 keV	1.60×10^{6}
10 keV – 0.1 MeV	8.41×10^{6}
0.1 MeV - 1 MeV	3.96×10^{7}
> 1 MeV	9.13×10^{4}
Total	2.66×10^{8}

Tab. 1. Neutron fluence rates for the HC1 horizontal channel at the outlet point

3. Spatial distribution

3.1 Experimental method

The spatial distribution of a thermal neutron beam gives information on the beam divergence, which is a basic parameter for evaluation of neutron radiography spatial resolution. The measurement was made with a detector based on a ^{6}Li converter and a heavy charged particle detector (Si diode). The distance between the lithium converter and the Si surface was approximately 8 mm [5]. The diameter of the converter was 3 mm and the diameter of the Si detector was 25 mm. The spatial resolution of the profile measurement is determined by the diameter of the converter. The detector signal was evaluated with a multichannel analyzer. The count rate from the triton peak was evaluated, whereas, it is proportional to the thermal neutron fluence rate.

The thermal neutron fluence rate profile was measured in three horizontal lines perpendicular to the beam axis. The distances of the lines from the beam outlet were 5 cm, 40 cm and 77 cm. The step of measurement points was 1 cm. The measurement time in one point was 100 s. The movement of the detector along the line was made with a remote control positioning device, see Fig. 2.

Fig. 2. Measurement of spatial distribution of the thermal neutron beam,
left – detector with the positioning device; right – beam outlet

3.2 Results

An example of the detector spectrum from the measurement of the thermal neutron spatial distribution in the HC1 horizontal beam is shown in Fig. 3. The peak with a maximum near 550 channels corresponds to the triton energy from the $^{6}Li(n,\alpha)^{3}H$ reaction (2.73 MeV). The counts below the pulse height of 350 channels correspond mainly to gamma radiation, counts below 200 channels were discriminated.

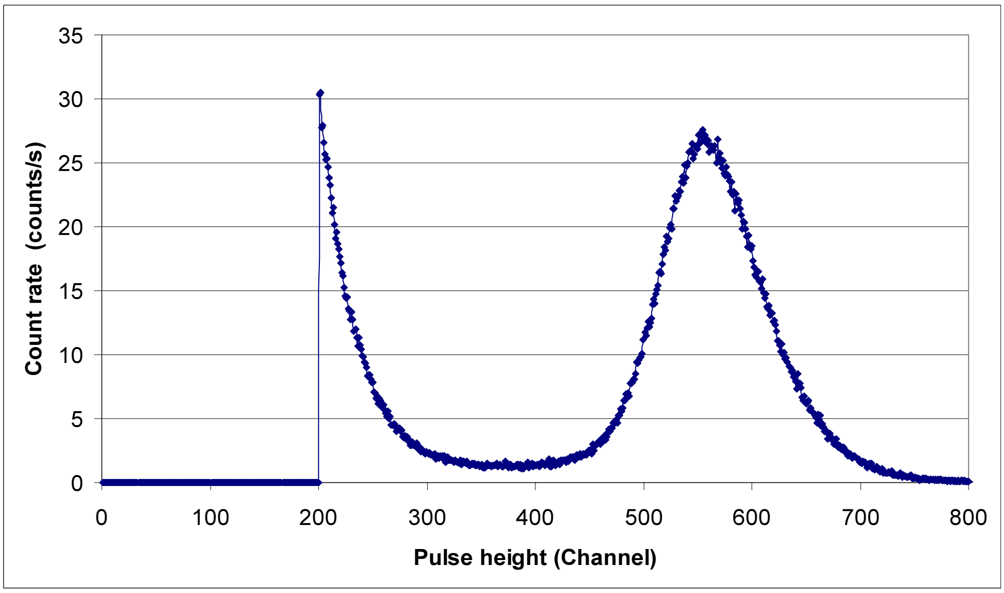

Fig. 3. A pulse height detector spectrum example measured with the Si heavy charged particle detector with the ^{6}Li converter in the HC1 thermal neutron beam.

Thermal neutron fluence rate radial profiles of the HC1 neutron horizontal beam are shown in Fig. 4. Relative fluence rates were derived from areas of the triton peaks in the pulse height detector spectrum. The count rate areas were evaluated by means of MCS (multi channel sweep) mode in Genie 2000, V3.1 software. The area of interest for the MCS mode was set to the triton peak position during a standard spectrum measurement. From the profiles, average beam divergence was estimated at about 1.5°.

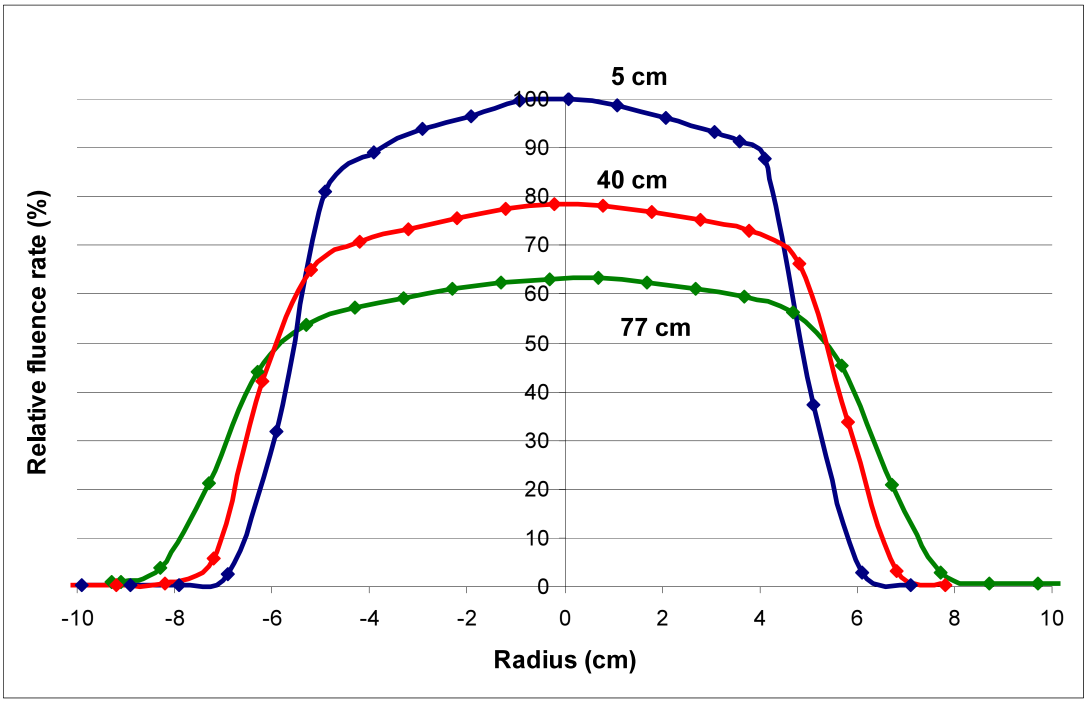

Fig. 4. Thermal neutron fluence rate profiles of the HC1 neutron horizontal beam, 5 cm, 40 cm and 77 cm from the outlet plane, normalized to maximum measured value.

4. Conclusion

The measured values confirmed that the horizontal neutron channel HC1 with the special filter has satisfactory parameters for neutron transmission radiography and tomography, i.e. thermal neutron fluence has an adequate value (about 2.10^{8} $cm^{-2}.s^{-1}$), and fast neutron fluence and the gamma dose rate are sufficiently low. A small value of thermal neutron beam divergence will allow a good spatial resolution of neutron radiography. The values of neutron fluence and gamma dose rate can vary for different reactor cycles due to changes of reactor core configuration. These value variations probably will not exceed 30 % from the measured values.

5. Acknowledgement

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6. References

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