

The New Facilities for Neutron Radiography at the LVR-15 Reactor

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Abstract. Neutron radiography is an imaging method often used at research reactor sites. Back in 2011 a project was started with the goal to build a neutron radiography facility at the site of the LVR-15 research reactor in Rez, Czech Republic. In the scope of the project two horizontal channels were adapted for the needs of neutron radiography. This comprises the HC1 channel which offers an intense thermal neutron beam with a diameter of 10 cm, which can be used for imaging of larger samples, and the HC3 channel which beam is restricted just to 4x80 mm², but is highly thermalized, collimated and reduced from gamma background, thus capable of providing better radiograph resolution. Both facilities are equipped with newest Timepix based detectors, with thin ⁶LiF converters for neutron detection capable of delivering high resolution. Both facilities offer a unique opportunity for non-destructive testing in the Czech region. In 2015 both facilities were put into test operation and several radiographs were acquired, which are presented in the following text.

1. Introduction

The LVR-15 is a multipurpose tank-type light water moderated research reactor operated by the Research Centre Rez near Prague, Czech Republic. The reactor is operated at a maximum thermal power level of 10 MW. The utilization of the reactor is wide, covering material research, industrial and medical radioisotope production, neutron transmutation doping of silicon, neutron activation analysis, experimental boron neutron capture therapy, neutron diffraction experiments, prompt gamma activation analysis, etc. The reactor is equipped with nine horizontal channels and one thermal column providing ten neutron beams for further use (Figure 1). In 2011 in scope of a research project, two of the horizontal channels were chosen to be adapted for neutron radiography facilities. One radiography facility for larger samples was established at the beam exit of the formerly unused horizontal channel HC1. Additionally a second facility for microradiography (radiography with high resolution) of small samples was built on the HC3 channel.



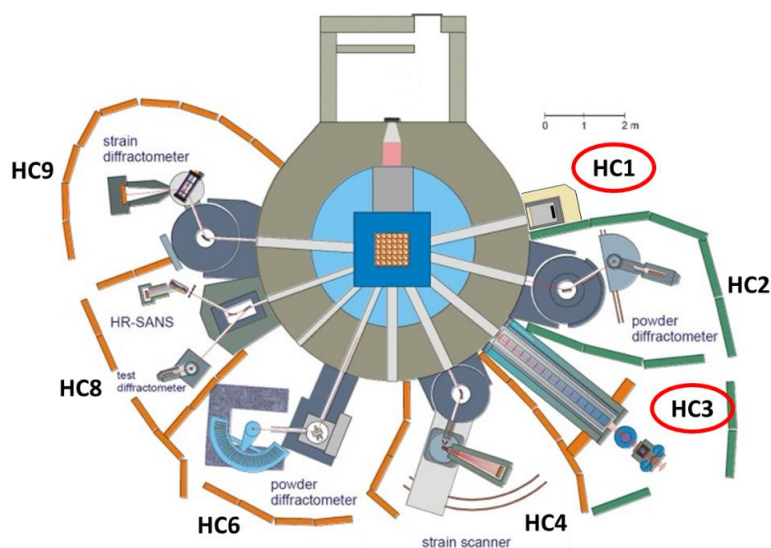


Figure 1. Horizontal channel layout at the LVR-15 research reactor. [1]

2. Neutron radiography on the HC1 channel

Before 2011 the HC1 horizontal channel was unused for many years. For the purposes of the neutron radiography facility several changes had to be done to the channel [2]. One of the key conditions for operating an effective radiography facility is the delivery of a high intensity, parallel, homogeneous and collimated thermal neutron beam at the sample location. Additionally the intensity of fast neutrons has to be kept as low as possible as the fast neutrons may damage the detectors used for neutron imaging. As the spectrum in the empty horizontal channel roughly copies the spectrum in the reactor core, which has a high ratio of fast neutrons, neutron filter components have to be installed inside the channel in order to achieve desired beam parameters. The radial channel HC1 was, therefore, equipped with a silicon single crystal filter-collimator. After the filter instalment it offers a neutron beam with a diameter of 10 cm with an intensity of thermal neutrons of $2 \times 10^8 \text{ cm}^{-2} \cdot \text{s}^{-1}$ [3]. This channel is designed for the radiography of larger samples (of several cm in size) at the costs of a lower resolution of $100 \mu\text{m}$. A shielded irradiation box was installed at the beam exit to house the samples while irradiation. The box is equipped with a positioning device enabling the movement and rotation of the sample (Figure 2).

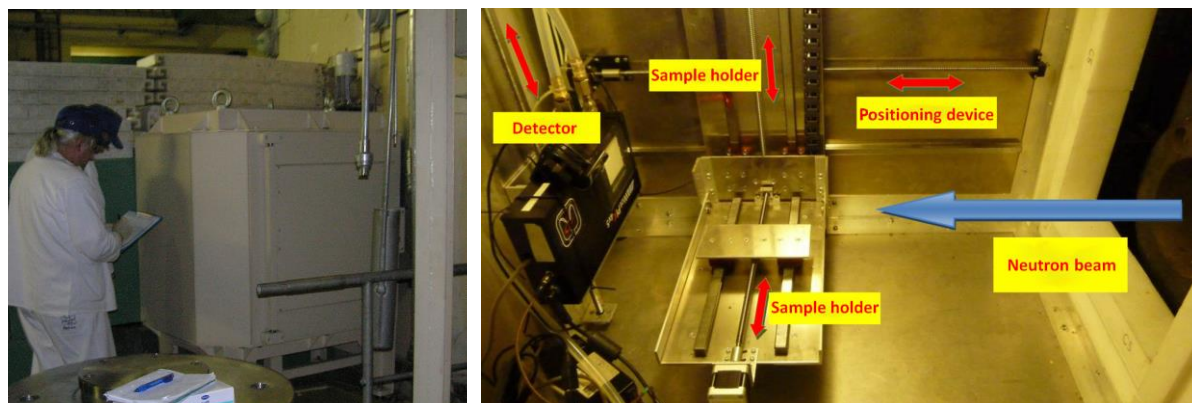


Figure 2. The irradiation chamber of the HC1 channel (left) and its equipment (neutron detector and sample holder) used for neutron radiography.

Several test samples have been recently measured. A first series of radiography measurements was realized before the Timepix detector instalment using a FUJIFILM neutron imaging plate [4]. Radiographs of steel bearings, a 5 cm thick concrete sample and steel samples with cracks are shown in Figure 3. After the first successful series of measurements a Timepix based detector was used for later tests. Several radiographs were gathered using the detector. Two of them showing an amulet and a rose are shown in Figure 4.

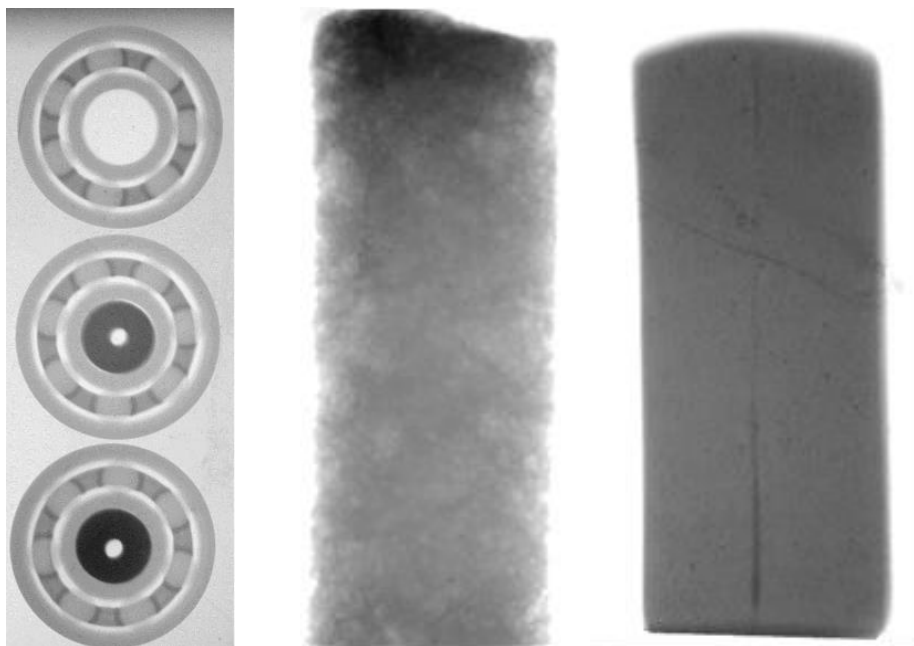


Figure 3. Radiographs from the HC1 facility (ball bearings, concrete sample, stainless steel sample with crack). A neutron imaging plate [4] was used as a detector.

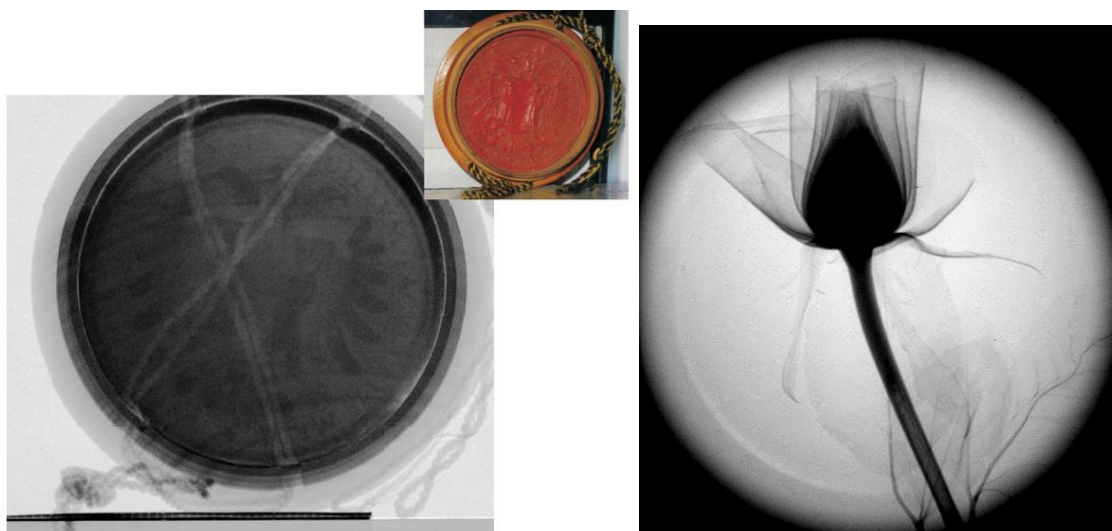


Figure 4. Radiographs of an ancient amulet and a rose acquired from the HC1 radiography facility with a Timepix based neutron detector.

3. Neutron microradiography on the HC3 channel

A second specific neutron radiography facility was built on the channel HC3. In contrast to the HC1 facility its resolution can be up to 10 times higher, however, at the cost of small neutron beam dimensions. The facility uses an old mirror-type neutron guide originally designed for other experimental methods and devices such as prompt gamma activation analysis or neutron depth profiling. The guide itself is composed of 15 coplanar Ni mirror section with the dimensions of 90 x 4 x 380 mm. The total length of the guide is 570 cm. At the exit a beam reduction shielding system containing ^6LiF was installed which enables the beam reduction from 4 x 80 mm to any lower value (Figure 5). This way unnecessary sample and construction parts irradiation can be lowered which leads to lowering the gamma background. The guide provides a pure collimated thermal neutron beam with an intensity of $110^7 \text{ cm}^{-2} \cdot \text{s}^{-1}$, a high Cd ratio $\sim 10^5$ and a very low gamma background. These beam parameters enable a great radiograph resolution of theoretically 10 μm in a contact geometry of the examined sample. The irradiation chamber installed at the beam-exit can be equipped with a rotational sample holder which enable tomographic reconstruction of the examined samples. The results of the first neutron tomography tests carried out at the channel are shown in Figure 5.

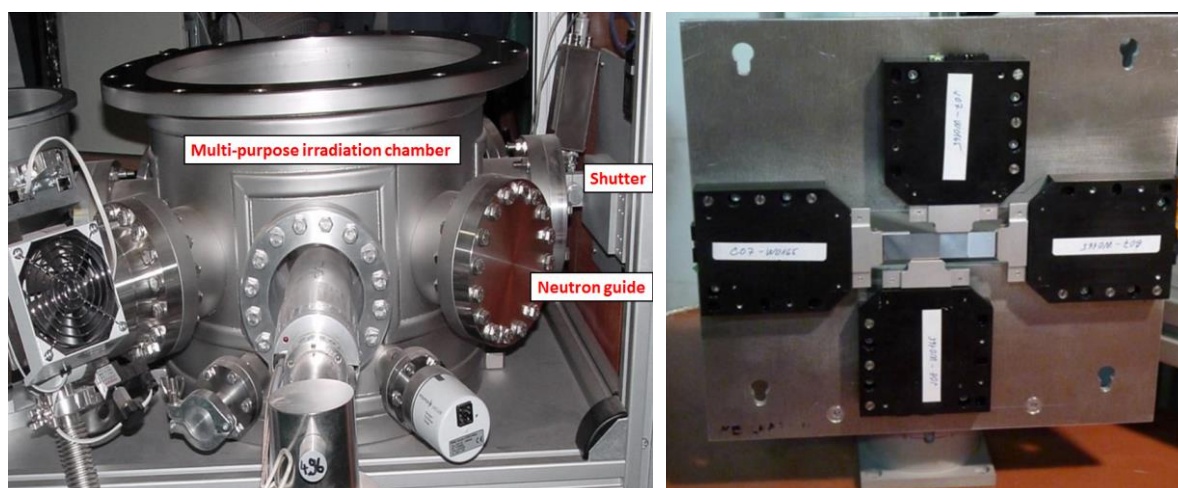


Figure 5. The multi-purpose irradiation chambers of the HC3 channel (left) and which can be equipped with a Timepix based neutron detector (right) for neutron radiography of small samples with better resolution.

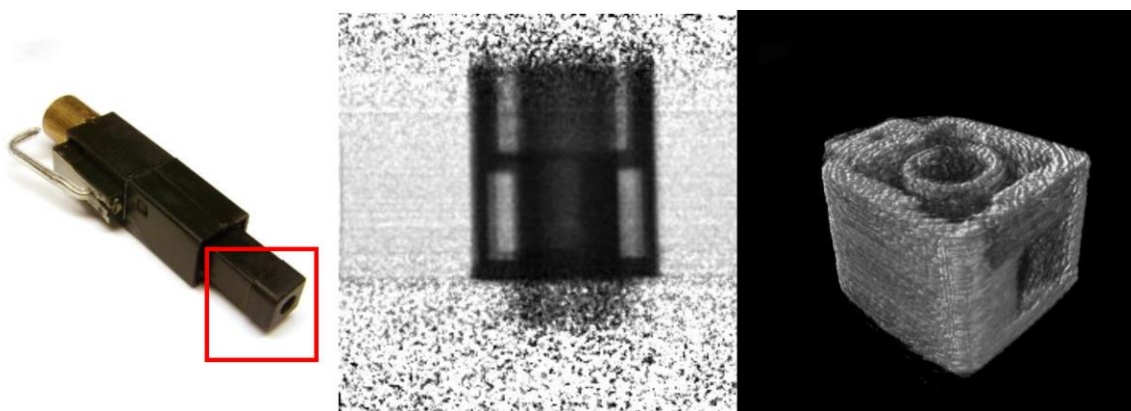


Figure 6. Neutron radiography and tomography reconstruction of a part of a piezoelectric spark generator. The tomograph was created out of 180 projections.

4. Detectors

Both facilities are equipped with Timepix tile-based detectors adapted for neutron imaging by applying a ^6LiF conversion layer on the Timepix tile surface.

The facility of the HC1 channel is equipped by large area WIDEPIX_{4x5} [6] detector consisting of 20 Timepix tiles. Its total detection area is $71 \times 57 \text{ mm}^2$ which equals 1.3 mega pixels. The detector detection efficiency for thermal neutrons is about 3 - 4 %. The device is connected to a DAQ computer via a USB 2.0 interface allowing a speed of 2 fps for frames of 1280×1024 pixels. The detector is attached to a positioning device which enables the sample motion and rotation. Both the detector and the device are shown in Figure 7.

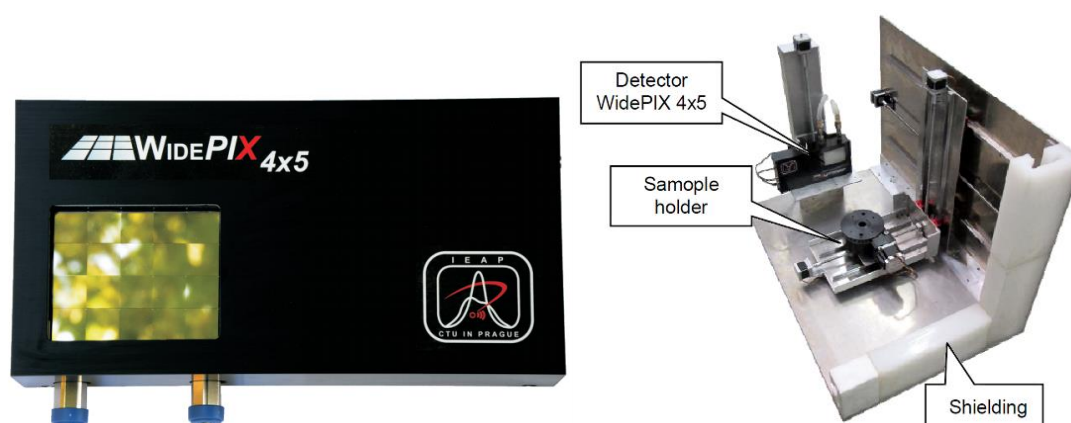


Figure 7. The WIDEPIX4x5 neutron camera (left) and its instalment on the rotational positioning device.

The micro-radiography facility at the HC3 channel is equipped by a modular detector MODUPIX [7] consisting of 4 edgeless Timepix tiles. The modular system allows the assembling of various 2D and 3D detector configurations (Figure 8) while each tile is read-out separately in a parallel mode. The USB 2.0 based FITpix 3.0 interface offers high read-out speed up to 850 frames per second. The detector thermal neutron detection efficiency can reach up to 10 % in the 3D stack mode.

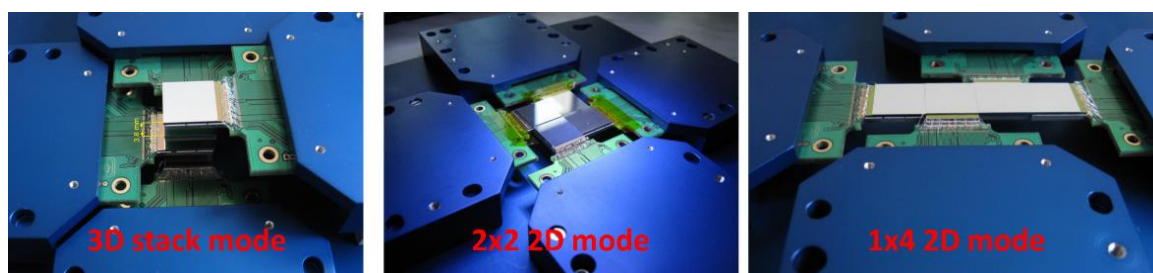


Figure 8. The MODUPIX detector in various detection configurations.

5. Conclusion

Since 2011 two neutron radiography facilities have been built at the site of the LVR-15 reactor in Rez. The first test have shown promising results. Both facilities offer a unique opportunity for non-destructive sample testing in the Czech region. By the beginning of 2015 the facilities has been put to test operation. Through the year more test measurement will be carried out on both facilities leading to their potential minor upgrades. Full operation of both facilities is expected from the beginning of 2016. However, further improvements leading to the improvement of beam parameters (instalment of

new neutron guides and collimators) can be expected in near future. As both facilities are equipped with rotational positioning devices neutron tomography is also expected to be introduced.

Acknowledgments

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