The neutron radiography and tomography method: practical applications

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1. Introduction

One of the non-destructive methods is X-ray tomography, which makes it possible to obtain 3D petrographic data with good accuracy and precision in qualitative and quantitative studies. However, X-ray tomography methods, including those using synchrotron radiation sources, have some restrictions related to the dimensions of objects under study and worsen the imaging data because of the X-ray attenuation by heavy elements, which causes beam hardening. The neutron radiography and tomography methods are the powerful tool of non-destructive analysis, which demonstrates importance in industrial and scientific research. The fundamental difference in nature of neutrons interaction with matter compared to X-rays provides additional benefits to neutron methods, including sensitivity to light elements, notable difference in contrast between neighboring elements or isotopes, high penetration effect through metals or heavy elements. All these features make neutron radiography and tomography highly demanded tools with growing range of applications in industry, geophysics, paleontology, archeology and other various fields, included culture heritage investigations. the newly developed neutron radiography and tomography facility at a high flux pulsed reactor IBR-2 is described. The obtained technical parameters are suitable for a wide range of applications, as demonstrated in the given review of the performed studies of industrial, paleontological and meteorite objects, like as shown in Figure 1. The non-destructive character of the neutron radiography and tomography method has prompted the rising interest in studying rare archaeological items and museum rarities, especially metallic artifacts, weapons and ancient jewelry.

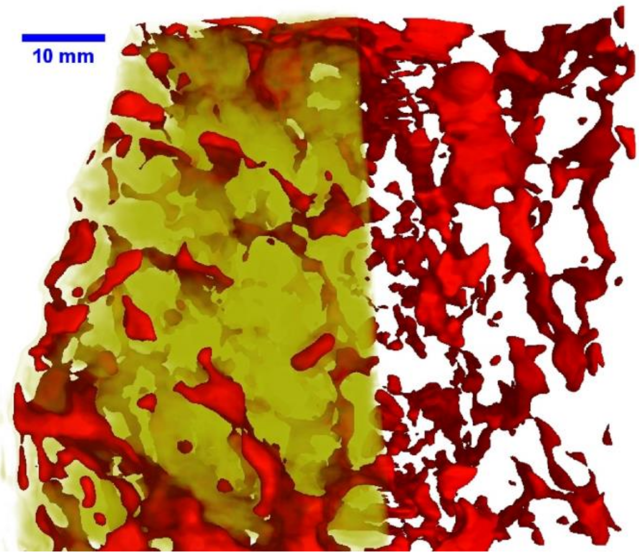

Figure 1. *The virtual 3D model of the fragment of the Seymchan meteorite after tomographic reconstruction. The metal regions are labeled in red color, the olivine component is yellow. The olivine fraction of the left part of the meteorite is made transparent for convenience.*

2. Description of the project

From the point of view of the increase of a piece of knowledge of students about the opportunities of neutron radiography and tomography method, we propose a course focused on a knowledge about radiography experiments, treatment of imaging data, obtaining the basis of tomography reconstruction procedure.

During the project, it is planned to perform neutron radiography experiments on experimental station for neutron radiography and tomography, treat the obtained imaging data using ImageJ software, and reconstruct the 3D model from tomography data.

3. Experimental

The neutron tomography experiments were performed at the neutron radiography and tomography facility located on beamline 14 of the IBR-2 reactor. The IBR-2 reactor is one of the most powerful pulsed neutron sources in the world, with the average power of 2 MW, a power per neutron pulse of 1850 MW, and a neutron flux in pulse of 5 10^{15} n/cm^2/s. The pulsed operation regime of the IBR-2 reactor is at a frequency of 5 Hz, and the long pulse duration for thermal neutrons of 350 μs makes it attractive not only for traditional neutron imaging applications, but also for the development of modern energy-selective techniques used in time-of-flight methods. The IBR-2 reactor provides a thermal neutron beam with wavelengths ranging from ~0.2 to 8 Å and a spectral distribution maximum of ~1.8 Å. The neutron flux at the sample position is $\Phi = 5.5(2) \times 10^6$ n/cm^2/s. A set of neutron radiography images was collected by a CCD-based detector system with a maximum field of view of 20 × 20 cm.

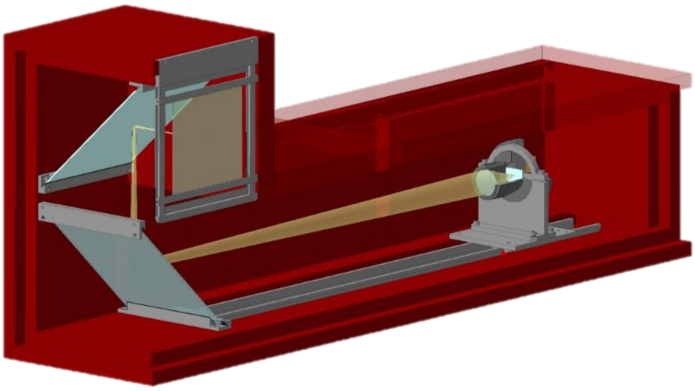

Figure 2. *Scheme of the detector system used on the neutron radiography and tomography facility on the IBR-2 reactor. Firstly, the neutron radiation is converted into light photons by a scintillator plate. The scintillator thickness is 100 μm. The light from the scintillator is reflected by the mirrors, and then directed to the optical system of the high resolution and high sensitive CCD-based video camera.*

4. Requirements for the level of student training

Students should know the basic principles of condensed matter physics, be guided in the principles of radiography methods, have basic skills of working with typical scientific software for imaging data treatment.

5. Recommended literature

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2. Domanus, J. C. (Ed.), 1992, Practical neutron radiography. Kluwer academic publishers, Netherlands, Dordrecht, pp. 269.

3. Kozlenko, D.P.; Kichanov, S.E.; Lukin, E.V.; Rutkauskas, A.V.; Bokuchava, G.D.; Savenko, B.N.; Pakhnevich, A.V.; Rozanov, A.Y. Neutron Radiography Facility at IBR-2 High Flux Pulsed Reactor: First Results. *Phys. Procedia* **2015**, *69*, 87–91.
4. Kozlenko, D.P.; Kichanov, S.E.; Lukin, E.V.; Rutkauskas, A.V.; Belushkin, A.V.; Bokuchava, G.D.; Savenko, B.N. Neutron radiography and tomography facility at IBR-2 reactor. *Phys. Part. Nucl. Lett.* **2016**, *13*, 346–351.
5. Lehmann, E.; Kaestner, A.; Gruenzweig, C.; Mannes, D.; Vontobel, P.; Peetermans, S. Materials research and non-destructive testing using neutron tomography methods. *Int. J. Mater. Res.* **2014**, 105, 664–670.

6. The number of participants of the project: up to 2 persons

7. The project leader from JINR:

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