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# Development and characterization of a neutron tomography system for a Research Reactor

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**Abstract**

Neutron tomography is a very powerful technique for the nondestructive evaluation of heavy industrial components as well as for soft hydrogenous materials enclosed in heavy metals, which are usually difficult to image using X-rays. It has found a variety of applications in medicine, agriculture and other heavy industries. In our effort to use this technique for non-destructive testing, a process has begun to upgrade the neutron radiography facility from static-based film (Nitrocellulose film and Agfa Structurix D7 photographic film) neutron radiography into a dynamic neutron radiography/tomography system by using scintillation screens (ZnS (Ag)-6LiF) and a CCD-camera.

Several experiments have been performed on this experimental station to study the feasibility of neutron tomography for various applications.



*Keywords:* ETRR-2; CCD-camera

## 1. Introduction

Neutron imaging techniques are important tools to investigate the internal structure of objects. The characteristics of neutron–matter interactions enable the visualization of hydrogen rich substances, even when these are surrounded by metallic layers that would render them invisible under X-ray imaging. Thus, neutron imaging techniques have found applications in technological fields, such as the automotive, nuclear and aerospace industries, as well as in medicine, archaeology, biology and geology [1–3] (Fig. 1).

A neutron image is obtained by irradiating the object in a uniform neutron beam and recording the intensity transmitted by the object. Several solutions have been used for image recording: X-ray films and track-etch foils associated with converter screens (gadolinium, dysprosium and boron), neutron scintillators coupled to charge coupled device (CCD) video cameras and neutron imaging plates.

Neutron computed tomography can be used to obtain important 3-D information about an object's internal

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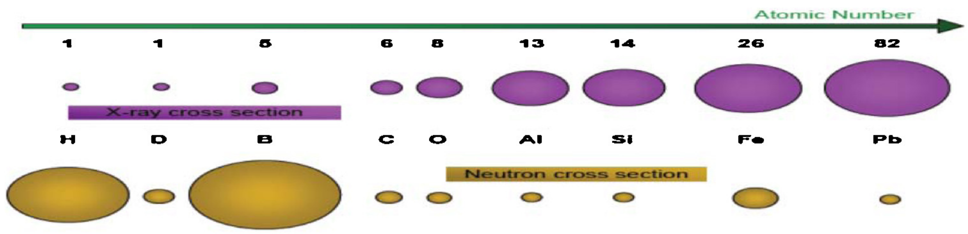


Fig. 1. Qualitative representation of X-ray and neutron cross-sections.

structure and material properties that other traditional methods cannot provide. Typically, a neutron computed tomography system consists of a neutron source with a collimator, a sample rotation device, a 2-D neutron imaging system and a motion control system (which synchronizes the sample rotation with the imaging system). A computer to capture, store and reconstruct the 3-D images is also required. The first step in the development of a neutron tomography system is to select and optimize the neutron imaging. The second step is the preparation of the image data and subsequent calculation of the 3-D voxel array using one of the many reconstruction techniques, such as filtered back-projection or an algebraic reconstruction algorithm [4]. Tomography image visualization software that recombines the 2-D vertical images into a 3-D image is commercially available and is useful to analyze the 2-D image projections [5] (Fig. 2).

ETRR-2 is an open pool type Material Testing Reactor (MTR) that produces 22 MW of thermal power. The reactor is cooled and moderated by light water. ETRR-2 reached first criticality in 1997. Irradiation facilities and beam tubes are installed at the reactor for research purposes, as shown in Fig. 3. The neutron radiography facility that utilizes one of these beam tubes was commissioned in 1999; the facility uses static based film neutron radiography [6].

The neutron radiography facility at ETRR-2 is being upgraded from static based film (Nitrocellulose film and Agfa Structurix D7 photographic film) neutron radiography system into a dynamic neutron radiography/tomography system based on scintillation screens (ZnS (Ag)-6LiF) and a CCD-camera; the instrument was commissioned in January 2013.

## 2. Description of the setup for neutron tomography

The tomography setup was installed at the horizontal access of the thermal column of the RPI, which is radial with respect to the reactor core. The thermal column is submerged into the water of the reactor tank. The column consists of a divergent aluminium tube lined by 2-mm of cadmium. The collimator is placed completely inside the reactor tank. The collimator inlet has a diameter of 30 mm. A gamma ray filter is placed at the inlet of the beam. The filter is separated from the beryllium reflector (which is placed in one row around the core) by a 2-mm water gap. The gamma filter is composed of lead and has a thickness of 145 mm Fig. 4 [7]. The main characteristics of the neutron beam at the irradiation position are presented in Table 1.

Fig. 5 shows a schematic diagram of the installed setup for a typical tomography system for which the image is obtained by using neutron scintillation screens (ZnS (Ag)-6LiF), a turntable object, a mirror, a cooled CCD camera and a computer running Labview. For every projection, the transmitted neutron intensity reaches the scintillator screen and the generated light is reflected by the mirror and recorded by the cooled CCD camera.

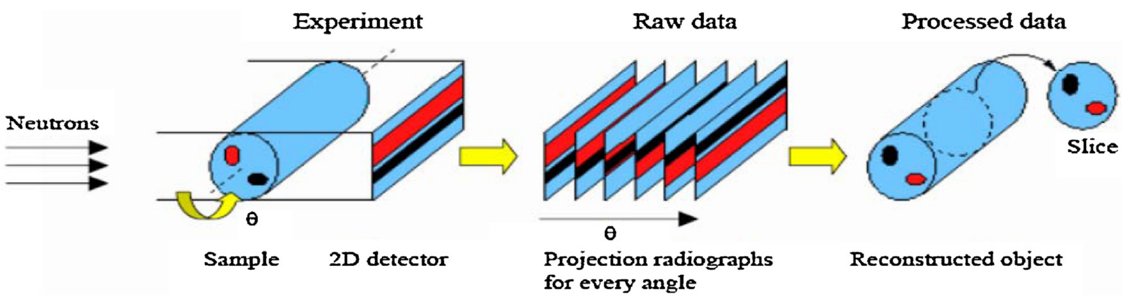


Fig. 2. Principle of computed tomography.