Quality assessment of the radial and tangential NR beamlines of the Tehran Research Reactor

M. H. Choopan Dastjerdi*, A. Movafeghi, H. Khalafi, Y. Kasesaz

Nuclear Science and Technology Research Institute, Tehran, Iran

*Email: mdastjerdi@aeoi.org.ir

Abstract

Characterization of a neutron radiography beam, such as determination of the image quality and the neutron flux, is vital for producing quality radiographic images and also provides a means to compare the quality of different neutron radiography facilities. This work provides a characterization of the radial and tangential neutron radiography beamlines at the Tehran research reactor. This work includes determination of the facilities category according to the American Society for Testing and Materials (ASTM) standards, and also uses gold foils to determine the neutron beam flux. The radial neutron beam is a Category I neutron radiography facility, the highest possible quality level according to the ASTM. The tangential beam is a Category IV neutron radiography facility. Gold foil activation experiments show that the measured neutron flux for radial beamline with length-to-diameter ratio (L/D) =150 is 6.1×10^{6} n cm^{-2} s^{-1} and for tangential beamline with (L/D) =115 is 2.4×10^{4} n cm^{-2} s^{-1}.

Keywords: Neutron radiography; Neutron beam; Beam Characterization; ASTM standard.

Introduction

There are two NR beamlines at the Tehran Research Reactor (TRR), which are installed in different beam-tubes of TRR. An NR system was installed at the tangential beam tube of TRR about three decades ago as the first and the only the national NR system. The system efficiency has been reduced due to the replacement of the high enriched uranium (HEU) fuel with the low enriched uranium (LEU) fuel and the changes in the reactor core configuration. A new NR beamline has recently been built at a radial beam tube of TRR in order to expand the applications of neutron radiography .

This work describes the characterization of these NR beams (radial and tangential beamlines) and compares the quality of the radiographic images produced using these beams. Beam characterization experiments and determination of the image quality are done based on the well-known methods and the available standards. American Society for Testing and Materials (ASTM) standards are followed to determine the category of the radiography facility, which provides a means to compare the quality of different neutron radiography facilities. The indicators developed in this project will benefit future radiography work at the facility. The characterization experiments provide baseline measurements which can be used to track the changes in the facility.

Materials and Methods

An NR system was installed at the TRR about three decades ago as the first and the only national NR system. As seen in Fig. 1, this system has a neutron collimator that was installed at the H beam tube of TRR. H beam tube is the north part of the trough tube and is 15.24 cm in diameter. The main collimator constitutes of two parts, Fe and Pb, which were covered thoroughly with cadmium. Cylindrical slabs of bismuth and graphite were used behind the collimator in order to minimize the gamma intensity and to thermalize the fast neutrons respectively.

A new NR beam line has recently been built at TRR in order to expand the national applications of neutron radiography. For this purpose, a neutron collimator has been designed and installed at the E beam tube of TRR. E beam tube is a radial beam tube and is 15.24 cm in diameter. In order to thermalize the fast neutrons and also to provide a source of neutrons that is approximately uniform, a cylindrical slab of the graphite illuminator has been placed on the beam tube near the core. To reduce the gamma content of the beam a cylindrical slab of the polycrystalline bismuth has been used. A boral disk as aperture has been used. Several cylindrical lead parts as the gamma shield with cadmium lining as the collimator absorbing wall have been used. Figure 1 shows the collimator design model.

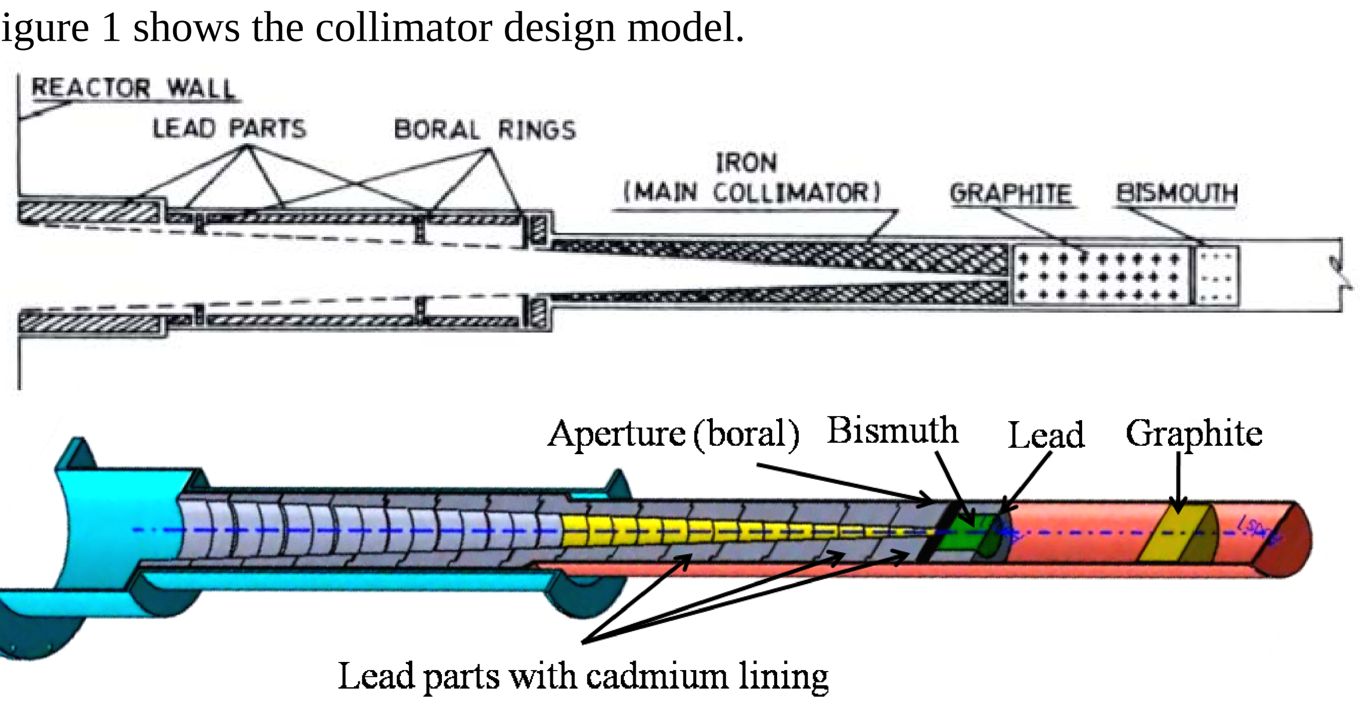

Fig. 1 : Sketches of the installed collimators at the tangential beam tube (up) and the radial beam tube (down).

The common quantities reported for NR facilities are the neutron flux and the effective collimation ratio (L/D), where L is the distance from the aperture to the image plane and D is the diameter of the aperture.

The thermal neutron flux and cadmium ratio are measured using the bare and the cadmium covered gold foils.

Beam quality indicators or in another words the Image Quality Indicators (IQI) are designed by ASTM to determination of the quality of the radiographic images produced by the direct, thermal neutron radiographic examination.

These beam quality indicators include the Beam Purity Indicator (BPI) and the Sensitivity Indicator (SI).

The BPI is constructed of a block of polytetrafluoroethylene (PTFE) with a hole cut out of its center, and contains two boron nitride discs, two lead discs, and two cadmium wires (Fig. 2).

Densitometric measurements of the image of the BPI in locations shown in Fig. 2 permit quantitative determination of the effective value for the thermal neutron content (NC), gamma content (γ), pair production content (P), and scattered neutron content (S). The equations relating the optical density measurements in each part of the image to NC, γ, P and S are given below:

$$NC = \frac{D_H - (\text{higher}D_B + \Delta D_L)}{D_H} \times 100$$

$$\gamma = \left(\frac{D_T - \text{lower}D_L}{D_H}\right) \times 100$$

$$P = \frac{\Delta D_L}{D_H} \times 100$$

$$S = \frac{\Delta D_B}{D_H} \times 100$$

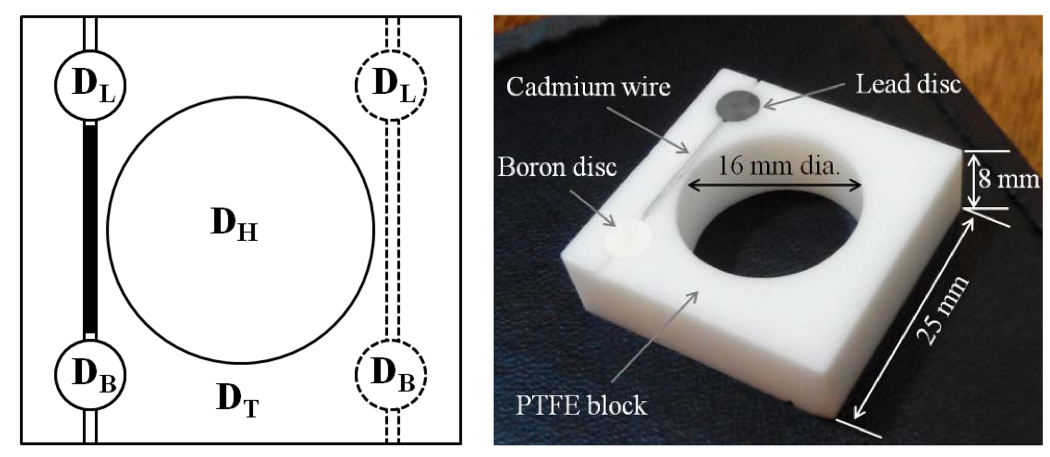

Fig. 2 : Top view and photograph image of the BPI and locations of densitometric values of the BPI.

The SI is an aluminum u-channel filled with the alternating strips of methyl metha crylate and aluminum (Fig. 3). The quantitative determination of the radiographic quality is determined by visually inspecting the SI for the number of visible simulated defects (e.g., holes and gaps).

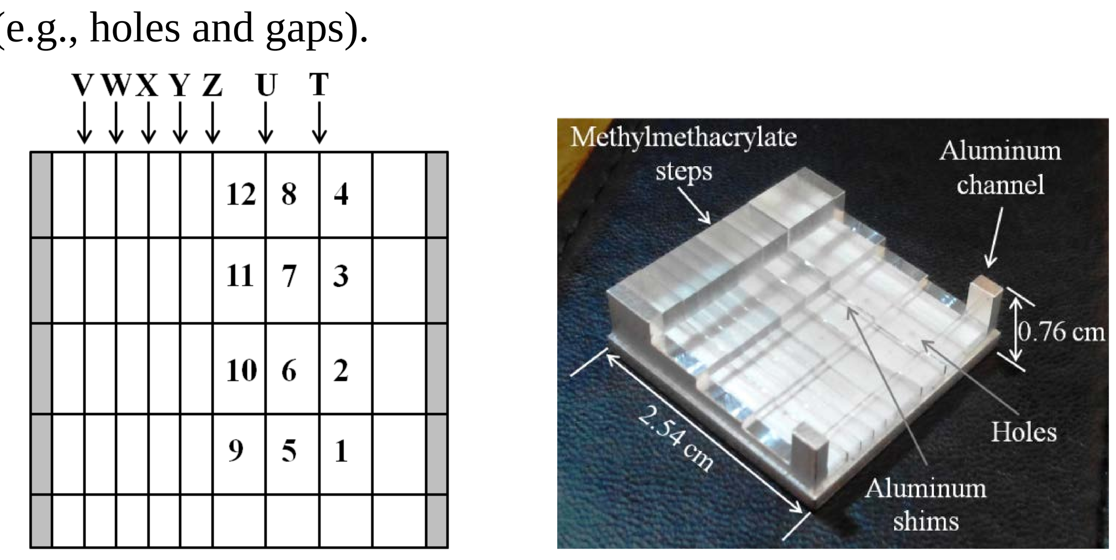

Fig. 3 : Down view and photograph image of the SI showing locations of shims and holes.

ASTM determines a category of the radiography facility based on the parameters taken from the visual analysis of a radiograph of the SI (G and H) and densitometric measurements taken from the radiograph of the BPI (NC, γ, P and S). Table 1 lists the beam parameters that determine the facility category, where a category I facility is the top rating.

A 25μm gadolinium foil mated with a single-coated D3 film in a light tight cassette is used to radiograph the BPI and SI and the exposure time was about 2.5 min for radial beam and about 3 hours for tangential beam.

Table 1: Values of beam quality parameters and neutron radiographic categories .

Radiographic category	NC	H	G	S	γ	P
I	65	6	6	5	3	3
II	60	6	6	6	4	4
III	55	5	5	7	5	5
IV	50	4	5	8	6	6
V	45	3	5	9	7	7

Results and Conclusion

In the tangential beamline, the used L/D for measuring the neutron flux is 115. The measured neutron flux and the R_{Cd} ratio in the tangential beamline are 6.1×10^{6} n cm^{-2} s^{-1}± 8% and 35, respectively. In the radial beamline, the used L/D for measuring the neutron flux is 150. The measured neutron flux and the R_{Cd} ratio in the radial beamline are 2.4×10^{6} n cm^{-2} s^{-1}± 7% and 70, respectively. The beam diameter at the sample position for both tangential and radial beamlines is about 25 cm.

The obtained neutron radiograph images of the BPI and SI shown in Fig. 4.

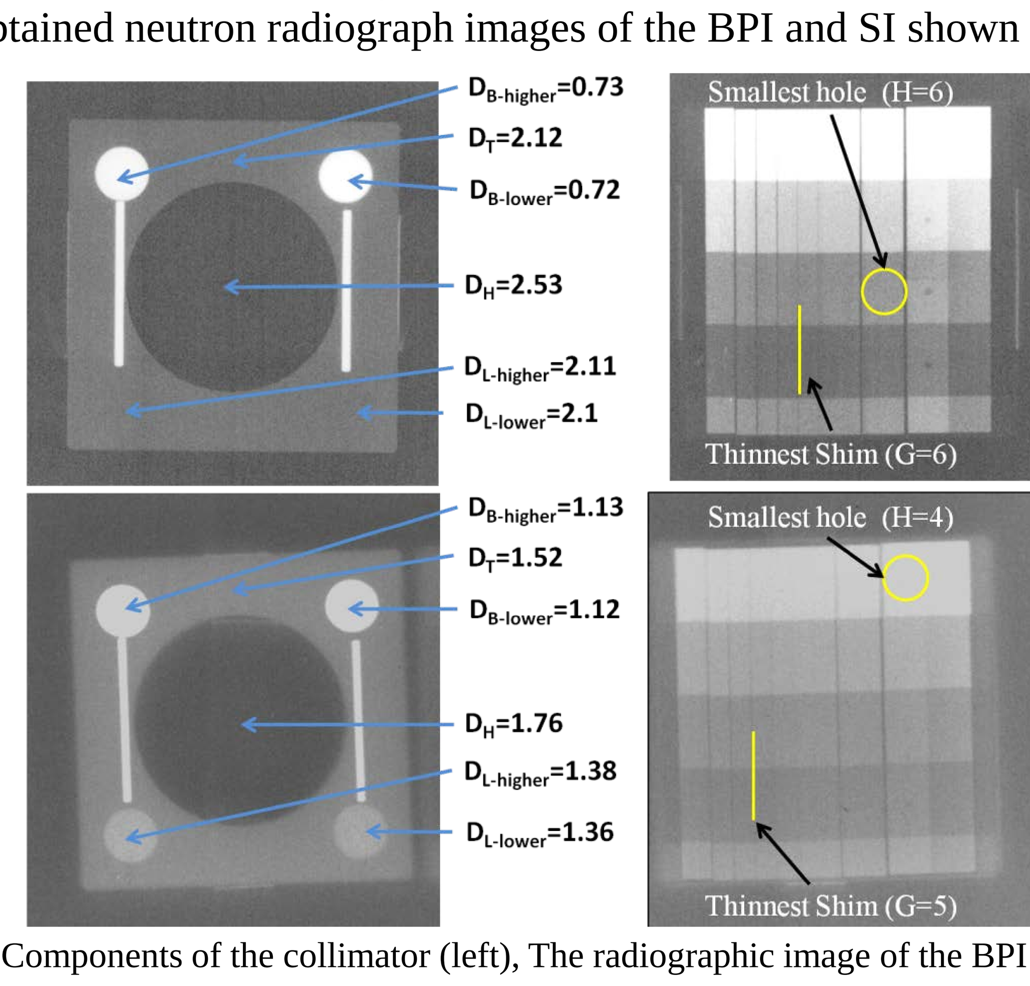

Fig. 4 : Components of the collimator (left), The radiographic image of the BPI and SI indicators (right)

Based on the analysis of the BPI and SI radiographs the radial and tangential beams are category I and IV radiographic facilities respectively, corresponding to the highest of the five possible radiographic categories in Table 1.