Implementation of a new and high quality neutron radiography beamline at the Tehran Research Reactor

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Abstract

A new neutron collimator as an important part of a neutron imaging facility is designed, installed and experimentally characterized at the Tehran Research Reactor. The design calculations are performed using MCNP Monte Carlo code. Preliminary experimental characterization of the beam shows a thermal neutron flux of about 6.1×10^6 n cm^{-2} s^{-1} and a N/G ratio of about 4.82×10^5 n cm^{-2} mrem^{-1} at the 3-m image plane (L/D=150). Furthermore, the obtained neutron beam is characterized using the ASTM BPI and SI indicators and measurements indicate that the obtained radiographic image at this beam is of Category-I beam quality as defined in ASTM E545 standard.

Keywords: Neutron radiography; Collimator; MCNP; Tehran Research Reactor; ASTM standard

Introduction

TRR is a 5 MW pool type research reactor with seven beam tubes (Fig. 1). Six beam tubes are radial (beam tubes A, B, D, E, F, and G) that terminate close to the reactor core with only a small gap filled by water. An NR system was installed at the H beam tube of the TRR about three decades ago as the first and the only national NR system. This system has a neutron collimator that was installed at the H beam tube of TRR. The thermal neutron flux at the sample position (at the L/D=115) was measured 5×10^4 n cm^{-2} s^{-1}. The thermal neutron flux at the sample position in this system was lower than a typical reactor-based NR system. In addition, due to the replacement of the HEU fuel with the LEU fuel and the changes in the reactor core configuration, the shape of neutron spectrum throughout the core was changed, especially near the inlets of the beam tubes.

In this study, a neutron collimator as an important part of an NR facility has been designed, installed at the E beam tube and characterized to meet the appropriate neutron beam parameters according to the other word-wide NR facilities. Design calculations of the collimator components (position, dimensions and materials) and investigation of beam parameters have been carried out by MCNPX Monte Carlo transport code.

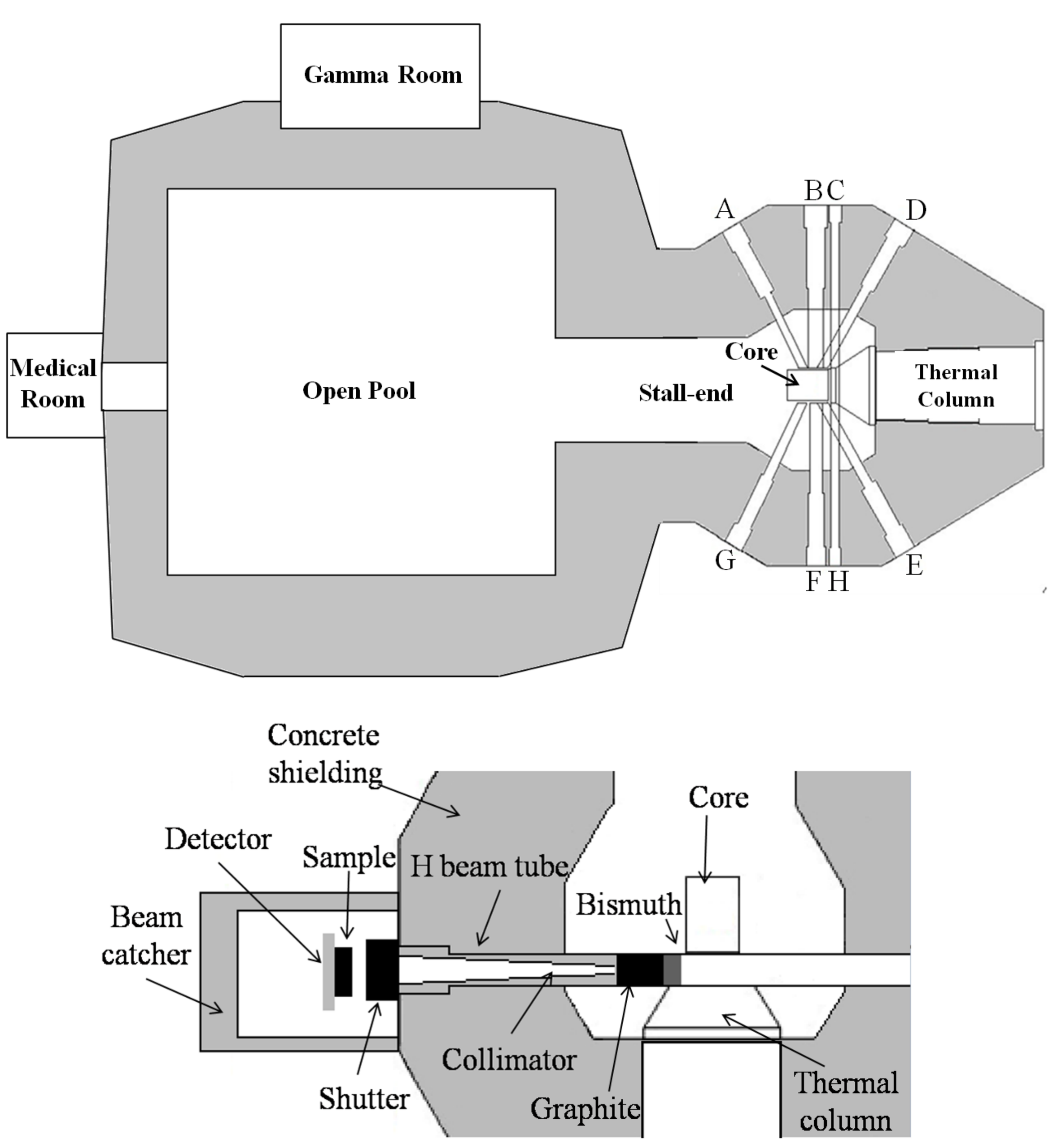

Fig. 1 : Various sections of TRR such as pools and beam tubes (up), Sketch of the previous (old) NR facility at TRR (down).

Materials and Methods

Among the all beam tubes, E beam tube was chosen to implement the new NR beamline due to the various practical considerations. E beam tube is comprised of an aluminum chamber and stainless steel housing with cylindrical structures. It is a radial beam tube with an overall length of 304.8 cm and has three sections. The dimensions and geometrical shape of the beam tube is one of the intrinsic constrains on collimator design.

The parameters of beamline design were considered to obtain a thermal neutron flux of $n_{th}>10^6$ n cm^{-2} s^{-1} at the image plane and L/D ratio of >130 and the neutron beam divergence of under 2˚. Moreover, the uniform neutron beam was designed with a neutron to gamma ratio of $>10^5$ n cm^{-2} mrem^{-1} at image plane of >20 cm in diameter.

The collimator design has been based on the divergent collimator because a divergent beam collimator produces the highest resolution.

In order to increase the thermal neutron content (TNC) of the beam and to provide a source of neutrons that is approximately uniform, a cylindrical slab of graphite illuminator was placed on the beam tube near the core. To reduce the gamma content of the beam a cylindrical slab of polycrystalline bismuth is used.

A boral disk as aperture and several cylindrical lead parts as the gamma shield with cadmium lining as collimator absorbing wall are used.

Simulations have been done in two stages. In the first stage, the TRR core and its surroundings have been simulated to obtain the neutron and gamma energy spectrum at the E beam tube entry. In the second stage, the performance of the designed collimator and the beam parameters has been investigated. The MCNP model of the TRR core and the neutron and gamma spectrum at the inlet of the E beam tube are shown in Fig. 2. The designed collimator is shown in Fig.3.

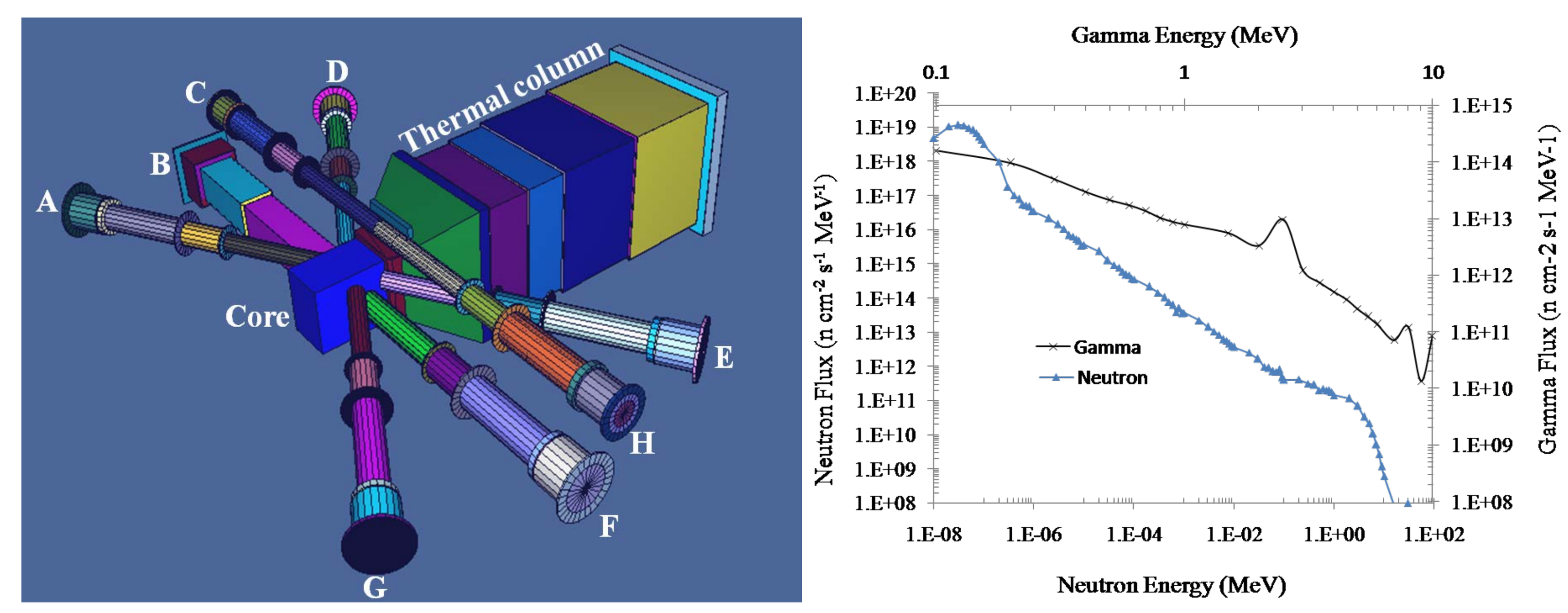

Fig. 2 : 3D MCNP model of the TRR (left), neutron and gamma spectrum at the E beam tube entrance (right).

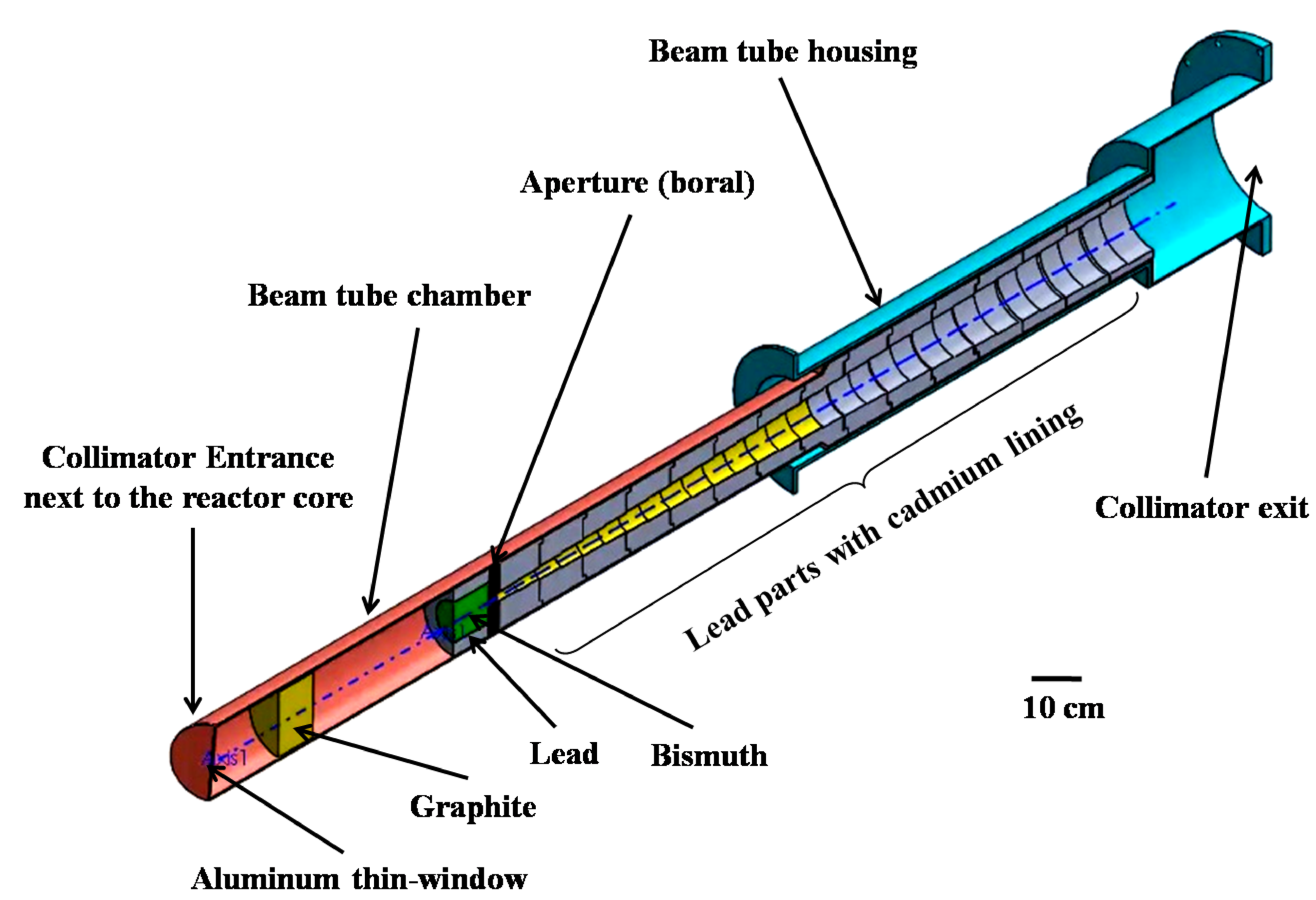

Fig. 3 : The designed collimator and its components.

Results and Conclusion

The total and thermal neutron fluxes at the entrance of the beam tube have been calculated 7.12×10^{12} n cm^{-2} s^{-1} and 4.52×10^{12} n cm^{-2} s^{-1} respectively. The TNC of the beam (n_{th}/n_{total}) is 63% which indicate that this beam tube has a good thermal neutron flux for NR purpose. The gamma dose rate at the entrance of the E beam tube has been calculated 88.54 Mrem/hr.

The graphite slab and polycrystalline bismuth increase the TNC of the beam at the aperture position from 52% to 79%. The thermal neutron flux at the 3-m image plane (L/D = 150) and 5-m image plane (L/D = 250) has been calculated 6.5×10^6 n cm^{-2} s^{-1} and 2.26×10^6 n cm^{-2} s^{-1}respectively. The existence of the bismuth as the gamma ray filter and lead parts of the collimator components reduced the gamma ray content at the exit from 9.08 rem s^{-1} to 13.4 mrem s^{-1} and improved the N/G ratio to 4.85×10^5 n cm^{-2} mrem^{-1} at the 3-m image plane (L/D = 150)

The mechanical design and construction of the collimator has been done in a modular fashion (as shown in Fig. 4).

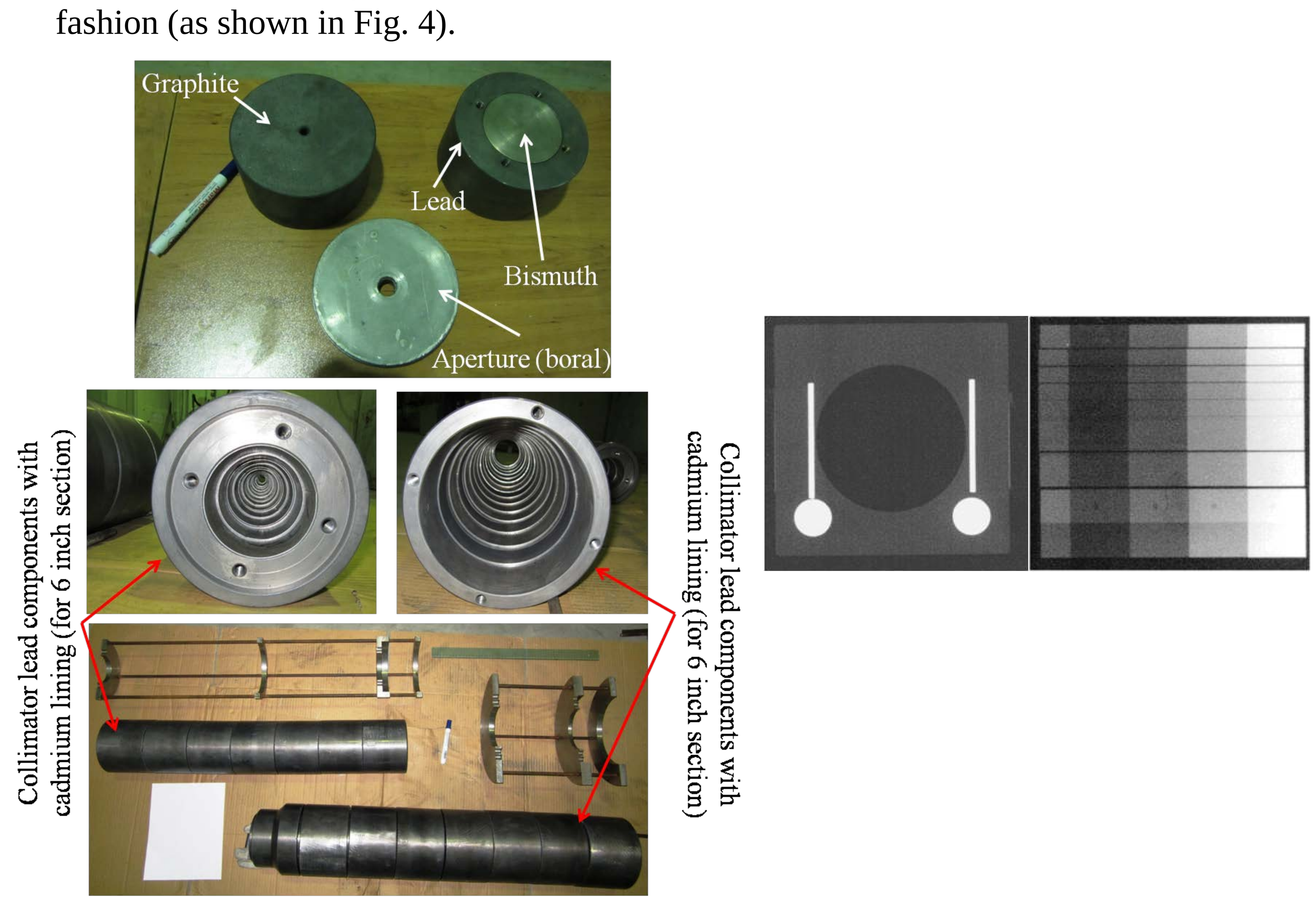

Fig. 4 : Components of the collimator (left), The radiographic image of the BPI and SI indicators (right)

Determination of the beam quality has been done with the beam quality indicators according to the ASTM standard E545. A 25 µm gadolinium foil mated with single-coated D3 film in a light tight cassette has been used to radiograph the BPI and SI. Fig. 4 the obtained radiograph of the BPI and SI.

Based on the analysis of the BPI and SI radiographs it is concluded that the NR beamline of the TRR is a category I radiographic facility.