Feasibility analysis for the extraction of a thermal NR beam at the MNSR reactor

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Abstract

In order to expanding the utilization of MNSR reactor, the possibility of extracting an appropriate thermal neutron beam for neutron radiography (NR) application is investigated. According to the physical restrictions of the MNSR, neutron beams are designed based on the vertical-tangential and oblique-tangential directions. Also, a thermal column is considered to reduce energy of neutrons. All designs are done by considering the least possible changes in the current reactor status. Results show that it is possible to obtain an appropriate NR beam with thermal neutron flux of about 2.53×10^{6} n.cm^{-2}.s^{-1}. The diameter and the collimation ratio of the obtained neutron beam at the image plane are 24 cm and 96, respectively. In addition,the thermal neutron flux has a good uniformity at this plane (flux fluctuation is <5%).

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

Introduction

The Esfahan Miniature Neutron Source Reactor (MNSR) is a pool type research reactor with maximum nominated power of 30 kW, high-enriched (90.2%) UAl_4 fuel pins, and beryllium metal as reflector. This reactor is primarily designed for neutron activation analysis (NAA) and training. While many research reactors have beam port facilities, the original design of the MNSR did not include beam ports. The existence of neutron beams will expand the utilization of the reactor with a large number of researches and applications like NR.

Expanding the utilization of the MNSR, especially for NR application, can be made by installing an additional beam line. Such additional experimental facility has been performed at the Geological Survey TRIGA Reactor (GSTR) in United States, and at the Slowpoke-2 reactor in Royal Military College of Canada.

In this study, the MCNP Monte Carlo transport code is applied to study the possibility of extracting an appropriate NR beam for Isfahan MNSR. Several proposed designs of the beam line (with thermal column) are simulated and neutron beam characteristics are explored.

Materials and Methods

A complete MCNP model of MNSR that consists of geometries and configurations of the various zones, sections and materials such as the fuel assembly, control rods, reflectors, irradiation sites, reactor vessel, reactor pool, and other components are simulated (see Fig. 1).

In order to obtain an appropriate NR beam, a proper beam shaping assembly should be design according to the features of the neutron source. The beam shaping assembly consists of several elements like neutron and gamma filter, collimator, casing, and thermal column that some of them may not be used in all neutron source facilities. The neutron source in this study is MNSR core.

There are several physical restrictions in designing a neutron beam line (and a thermal column) for the MNSR. Due to the geometrical and physical shape of the structure of the vessel and the pool of the MNSR, the direction of the beam line would be limited to a vertically direction.

An important consideration in this study is that the all designs are done with the least possible changes in the current reactor status.

According to the above considerations, two main designs are supposed. First designs are based on a vertical-tangential direction beam line and second designs are based on an oblique-tangential direction beam line (see Fig. 1).

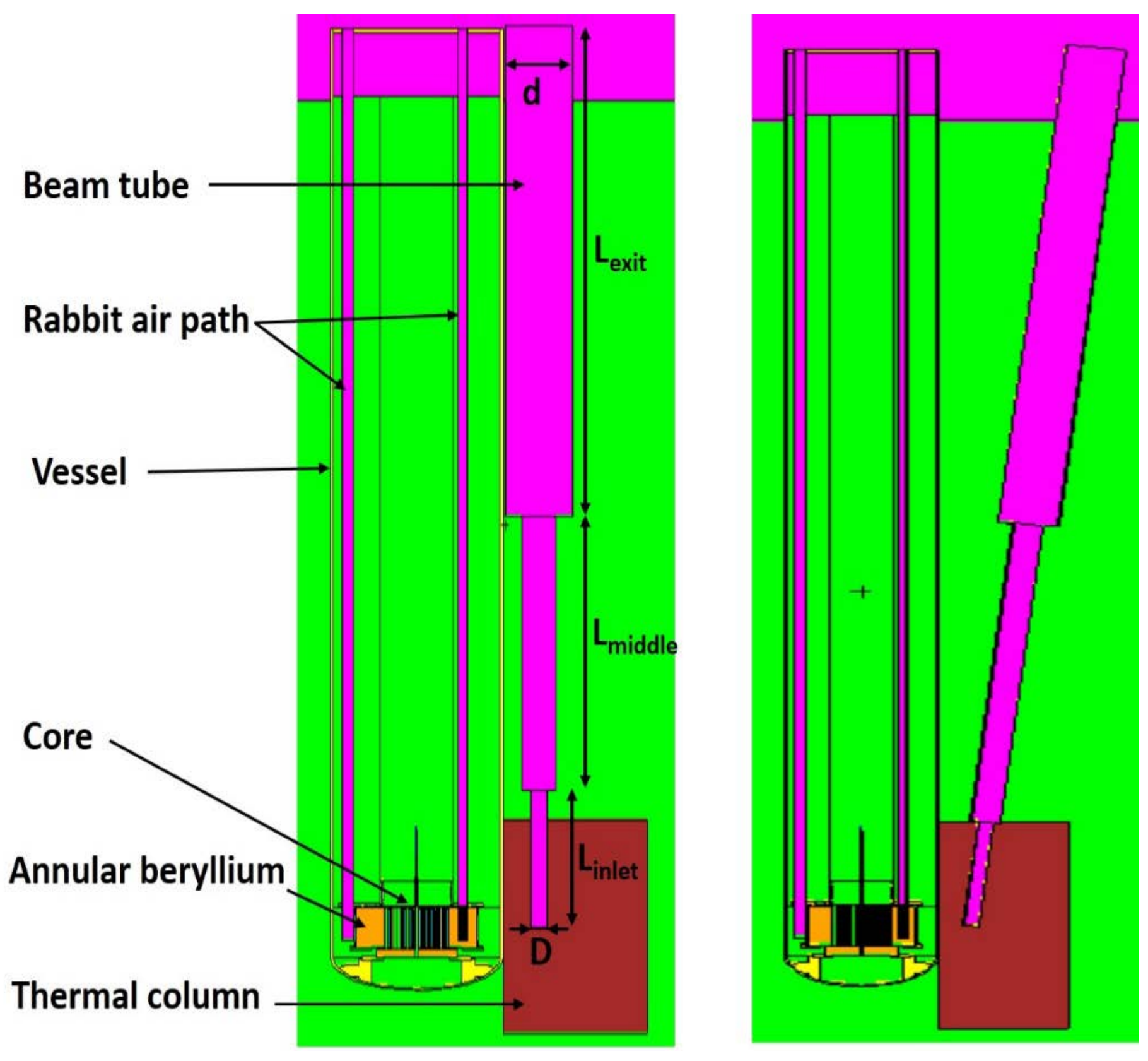

Fig. 1 : Vertical cross-section of the designed neutron beams in the plane X–Z (Y=0) using MCNP code: Vertical-tangential neutron beam (left), Oblique-tangential neutron beam (right).

The inlet aperture of the beam line is placed near the bottom of vessel (in the supposed thermal column) and the outlet aperture of the beam line reaches at the top concrete edge of the reactor pool. The oblique-tangential direction beam line provides a better accessibility from the top edge of the reactor pool, which provides a sufficient space for installing the other NR facility equipment (beam catcher and imaging system), and has a longer length (L) rather than the vertical-tangential direction.

A heavy water-filled tank as a thermal column is supposedas close as possible to the bottom of the reactor vessel in order to improving the thermal neutron content (TNC) of the neutron beam and to increasing the thermal neutron flux (φ_{th}) at the inlet aperture of the beam line.

Results and Conclusion

Thermal and total neutron fluxes, and also gamma dose are calculated in the level of the reactor core center in the horizontal direction (Z=0). As shown in Fig. 2, maximum thermal neutron flux in the thermal column is available near the vessel. The values of thermal neutron flux to gamma dose rate ratio and TNC increased with increasing distance of aperture from core center, whereas thermal neutron flux decreased along the thermal column.

It seems that these parameters have good values in points from X=41 to X=46 and this region is suitable place for locating the center of inlet aperture in the thermal column.

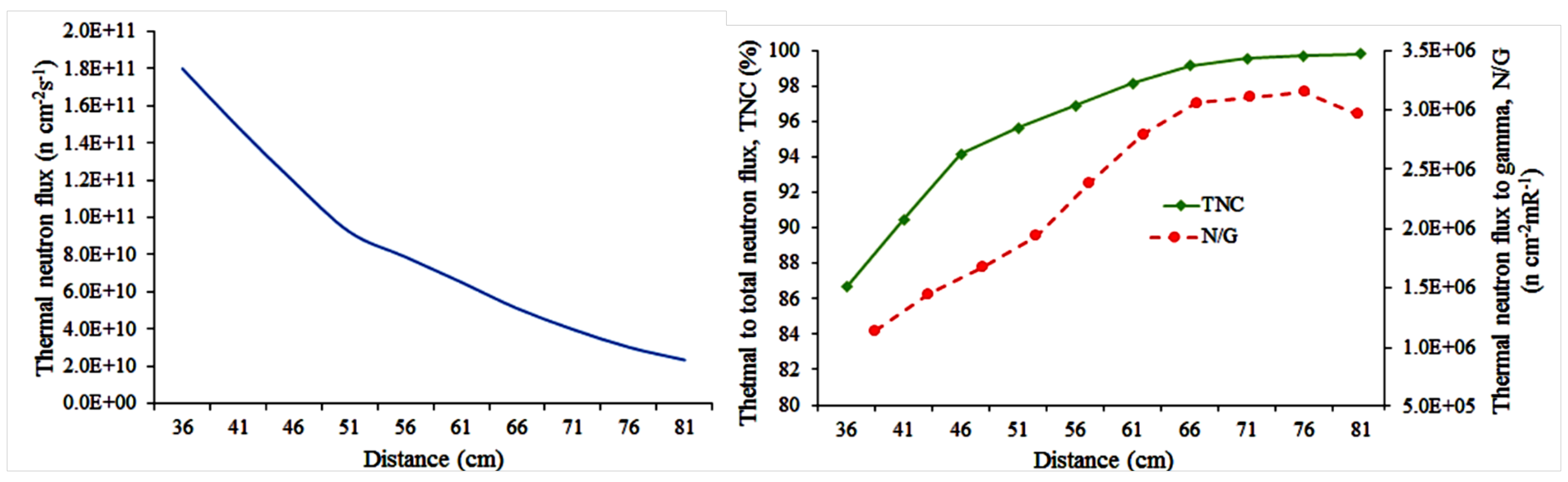

Fig. 2 : Calculated φ_{th}, TNC, and $\varphi_{th}/\dot{D}_{\gamma}$ in the thermal column adjacent to the reactor vessel (Z=0): Radial thermal neutron flux (left), TNC and thermal neutron flux to gamma ratio (right).

Four designs are proposed in the first case. The geometrical characteristics of the vertical-tangential beam line designs are presented in Table 1. The calculated neutron beam parameters of these four designs are presented in Table 2.

Table 1: Geometrical of the proposed vertical-tangential neutron beam (dimensions of L and D are in cm).

Type	L_{inlet}	L_{middle}	L_{exit}	L	D_{inlet} (D)	D_{middle}	D_{exit} (d)	L/D	2θ
First design	80	160	285	525	5	15	25	105	2.073
Second design	80	160	285	525	5.7	12	24	92.11	1.997
Third design	62	178	285	525	5.8	12	24	90.51	1.986
Fourth design	62	-	463	525	5.8	-	24	90.51	1.986

Table 2: Calculated neutron beam parameters of four designed vertical-tangential neutron beams

Type	φ_{th} (n.cm^{-2}.s^{-1})	TNC (%)	$\varphi_{th}/\dot{D}_{\gamma}$(n.cm^{-2}.mR^{-1})
First design	6.01×10^{5}	92.21	7.31×10^{5}
Second design	8.49×10^{5}	92.67	1.11×10^{6}
Third design	1.2×10^{6}	93.80	1.27×10^{6}
Fourth design	2.15×10^{6}	95.47	6.21×10^{5}

with the availability of a digital imaging system like CCD camera with scintillation screen, all of the four designs are suitable. But from the thermal neutron flux point of view, that is important in traditional image recording system (film/converter), the third and fourth designs are better than other two designs in this case, because they have more thermal neutron flux and lower $\varphi_{th}/\dot{D}_{\gamma}$, respectively.

The main reason of proposing the second case designs, which are based on oblique-tangential direction, is the better accessibility to the outlet aperture of the beam tube from the top edge of the reactor pool that provides a sufficient space for installing the other NR facility equipment and shields.

Two designs are proposed in the second case. The geometrical characteristics of the oblique-tangential beam line designs are presented in Table 3.

Table 3: Geometrical of the proposed oblique-tangential neutron beam (dimensions of L and D are in cm)

Type	L_{inlet}	L_{middle}	L_{exit}	L	D_{inlet} (D)	D_{middle}	D_{exit} (d)	L/D	2θ
First design	62	178	305	545	5.8	12	24	94	1.986
Second design	62	-	495	557	5.8	12	24	96	1.986

Table 4: Calculated neutron beam parameters of two designed oblique-tangential neutron beams.

Type	Filling gas	φ_{th} (n.cm^{-2}.s^{-1})	TNC (%)	$\varphi_{th}/\dot{D}_{\gamma}$ (n.cm^{-2}.mR^{-1})
First design	Air	1.15×10^{6}	91.63	1.34×10^{6}
	He	1.44×10^{6}	94.36	1.70×10^{6}
Second design	Air	2.05×10^{6}	96.22	6.84×10^{5}
	He	2.53×10^{6}	96.13	7.68×10^{5}

The calculated neutron beam parameters of these two designs are presented in Table 4. The latter design has better neutron beam parameters, better accessibility to the outlet aperture of the beam tube from the top edge of the reactor pool. Therefore, through the consideration of the all conditions, it could be concluded that the second design of the second case is the “best” design.

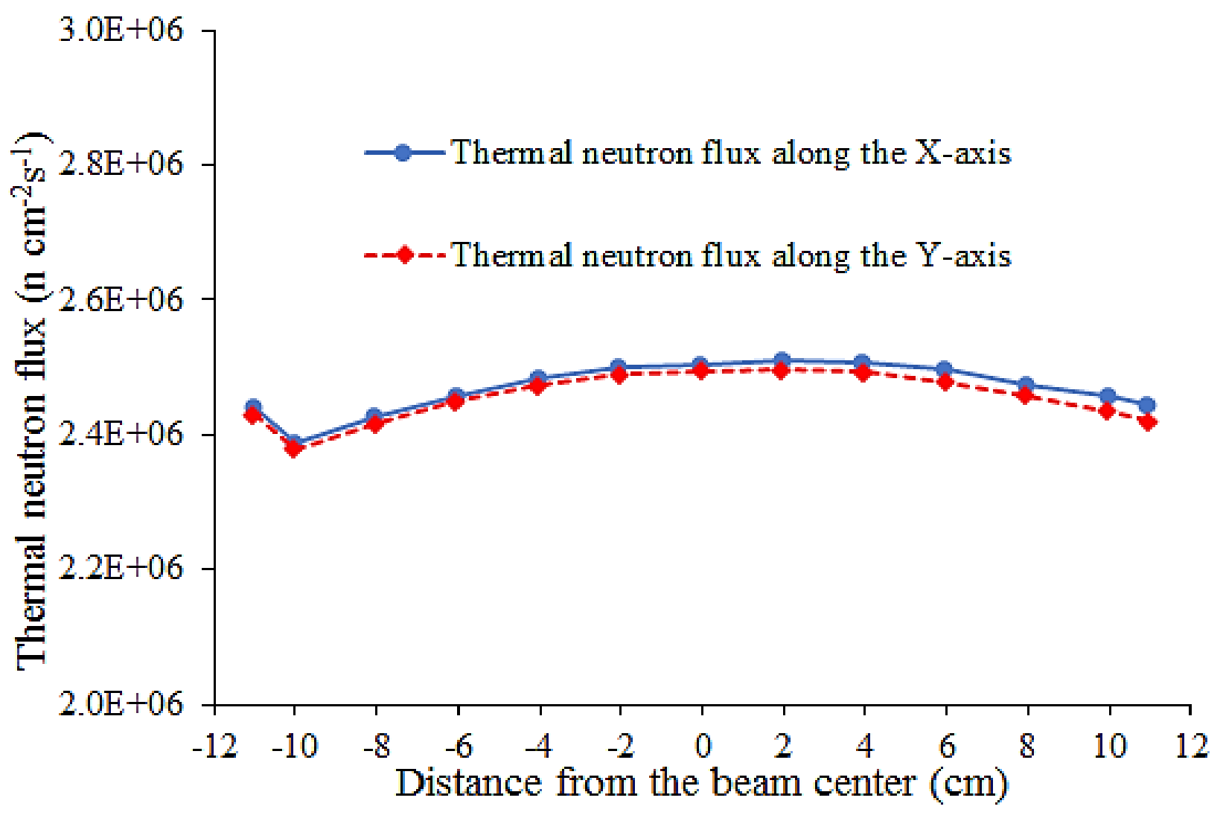

Fig. 3 : Distribution of the thermal neutron flux along the X- and Y-axis at the image plane (L/D=96).

The uniformity of the obtained neutron beam from the latter design, is investigated by calculating the thermal neutron flux distribution in X and Y directions on the image plane at L/D=96 (Fig 3). These fluctuations are under 5%, therefore the obtained neutron beam has a good uniformity at the L/D=96.