INVESTIGATION OF HEAVY WATER LOADING IN NEUTRON BEAM CHANNEL OF TEHRAN RESEARCH REACTOR TO DECREASE FAST NEUTRON BACKGROUND AT DIFFRACTION TABLE

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ABSTRACT

To obtain very sharp neutron diffraction pattern using the diffractometer facilities in research reactors, high-efficiency detectors, low fast neutron backgrounds, and high intensity neutron beam in the range of analysis are important factors. To improve the old diffraction system of Tehran Research Reactor, some reformations were investigated to decrease the fast neutron backgrounds at the diffraction table. However, crystalline neutron filters could obtain this aim easily, the homemade high-purity heavy water accessibility in TRR caused the cheap procedure is investigated in the present study. Hence, heavy water usage inside the horizontal channel of TRR was investigated using MCNPX code simulation. The obtained results showed about 10 litres heavy water loading inside the channel would reduce the fast neutrons with E_n > 1 MeV about 124 times but the thermal neutron in the range of analysis (0.02 eV< E_n <0.33 eV) would be reduced about 7.5 times. The calculations showed a donate-shaped (hollow cylinder) heavy water cylinder would allow the thermal neutron reduction is not noticeable (about 21%) while the fast neutron reduction is 1.83 times.

Keywords: *Heavy water, Fast neutron shielding, Neutron diffraction, Tehran Research Reactor*

1 INTRODUCTION

Epithermal and fast neutrons are often a major source of background in detectors. Neutron filters scatter out fast neutrons utilizing solid-state effects, while thermal neutrons pass the filter material. Thus, the neutron spectrum is modified massively however, their cost and stress-resistance of them in high neutron flux should be discussed [1,2].

Wu et al. (2015) illustrated that In recent decades, beam tube research reactors have become the largest community of users worldwide, and the number of neutron beam users continues to increase. They investigated a novel compact core design for beam tube reactors, in which a heavy water reflector was used between the core and light water shielding to maximize thermal flux in the beam channel [3].

The fast section of neutron spectra not only disturbs the diffraction pattern but causes noticeably higher dose rates at the experiment table and thereby the device operator. Figure 1 could clear importance of shielding or filtering of such neutrons.

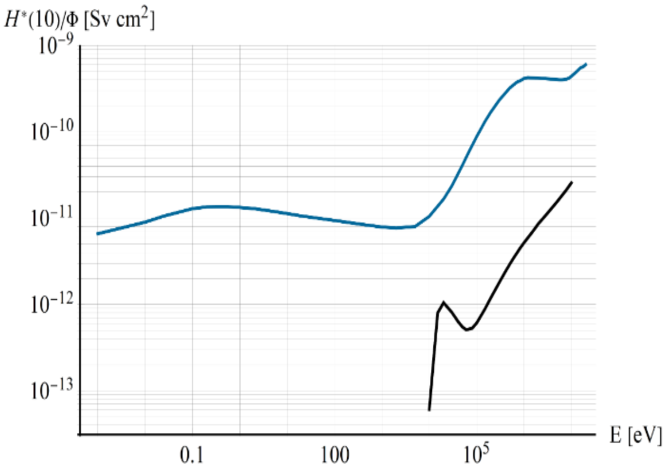

Figure 1: Plot of the energy dependency of the ambient dose equivalent H∗(10) from ICRP 74 [4].

From the above figure it is clear by shielding of neutron with E_n> 1 MeV, the neutron dose rate would be decreased drastically.

In the case of the Tehran Research Reactor (TRR), which is a pool-type reactor, the heavy water tank performance around the core is somehow difficult. Hence, in this work, loading of heavy water in the TRR horizontal channel has been investigated.

2 MATERIAL AND METHODS

TRR is an open pool, MTR- type, light water moderated reactor. The core consists of fuel elements, graphite boxes as reflectors and irradiation boxes. TRR is a 5 MW reactor with 20% enriched fuels and 500 m^3/h flow rate. There are two types of fuel elements, i.e. Standard Fuel Element (SFE) and Control Fuel Element (CFE). First of all the TRR core and beam channel of it was modelled using the MCNPX code (Fig.2). Effect of heavy water loading in the horizontal channel on thermal (E_n< 0.33 eV) and fast neutron (E_n> 1 MeV) spectra was investigated after the first soller-type collimator of the neutron channel. To reduce the calculation errors, the dxt capability of the computational code was used at the flux calculation position and F5 tally was used to determine the neutron flux at this position.

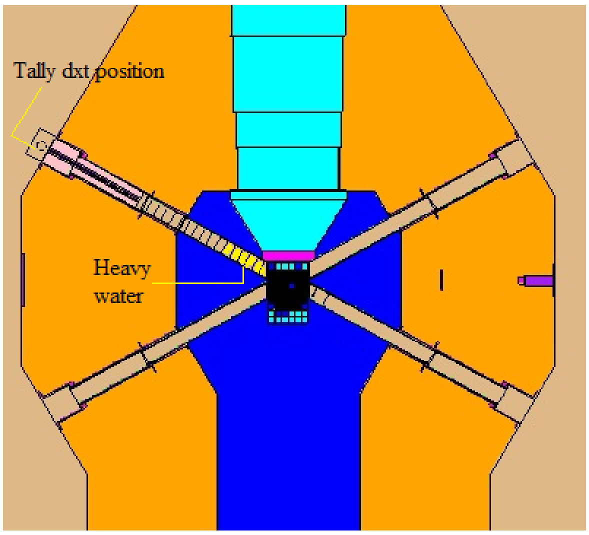

Figure 2: Schematic view of TRR core and its beam channel.

In this study MCNPX 2.6.0 have been used as a powerful particle transport code with the ability to calculate deposited power and dose calculation [5]. Application of a hollow cylinder, which allows the direct path of neutrons is open, was investigated at the second step of the present work. The deposited heat inside the heavy water was discussed in both configurations for loading of it in the horizontal channel. The heavy water temperature was determined at final step.

3 RESULTS AND DISCUSSION

For first step, heavy water thickness was optimized so that after that the fast shielding efficiency will not increase noticeably. For this purpose, inside the channel was divided to 11 cm sections as it is seen in figure 2. According to Fig.3, after 50 cm there is not noticeably reduction of fast neutrons at the flux monitoring position (after first collimator of the horizontal channel). The carried out calculations showed this thickness would result in the fast neutron reduction of 124 times than the empty channel. Nevertheless, this heavy water loading configuration decreases the thermal section of the neutron spectra about 7.5 times.

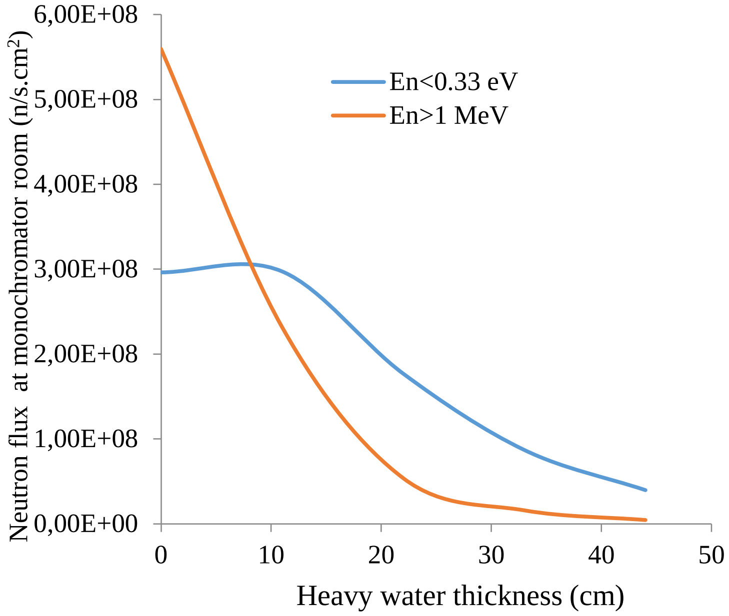

Figure 3: Thermal and fast neutron reduction as the heavy water thickness enhancement.

Next, the calculations were performed assuming that the path with the dimensions of the inlet of the first neutron collimator (radius of 7 cm) is open for neutrons and a hollow-shape heavy water cylinder according to Figure 4 is used to shield the fast neutrons. The results of these calculations showed that using a 50 cm hollow cylinder, the thermal neutron flux is reduced by 21% and the thermal neutron flux at the outlet of the first collimator will be 2.34×10^8 n/s.cm^2. In this case, the fast neutron flux decreases by 1.83 times and the fast neutron flux at the outlet of the first collimator will be 3.06×10^8 n/s.cm^2.

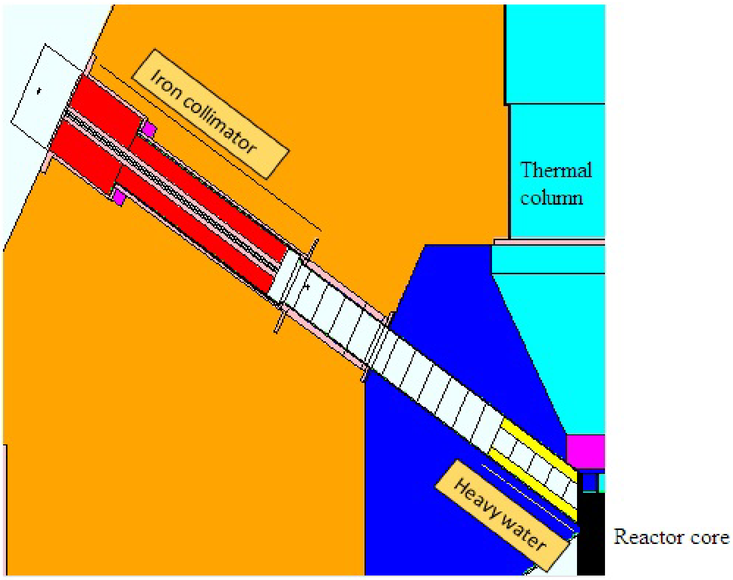

Figure 4: schematic view of TRR core and its beam tube with hallow-shape heavy water cylinder (yellow colour).

The above figure shows by using about 15 cm of solid cylindrical-shape heavy water inside the channel, fast section of the neutron spectra at the first collimator exit would decrease to half of its first value (the value without heavy water loading). In addition, the thermal section of the spectra remains approximately constant.

It should be noted that the use of heavy water in the channel should be checked for residual heat and heavy water temperature because its evaporation can cause problems due to the accumulation of steam in the monochromatic room. Therefore, in Table 1, the heat caused by neutrons and gamma in heavy water is presented in two states, solid and hollow cylinders. The table shows if 50 cm of heavy water solid cylinder is used, the total residual heat reaches to about 450 watts.

Table 1: Investigation of gamma and neutron heat deposition in heavy water

Heavy water thickness	Neutron deposited heat (W)	Gamma deposited heat (W)	Solid cylinder
0	0.107	0.182	
11	82.3	149	
22	117	277	
33	127	352	
44	129	393	
44	111	333	Hollow cylinder

At the next step, temperature of the hollow-shape cylindrical heavy water was calculated. The liquid heavy water could be loaded inside a hollow-shape aluminum box with thickness of 2 mm that avoids any evaporation formation inside the monochromatic room. The calculations showed the hollow cylinder temperature would reach to the order of 138 °C while the boiling point of heavy water is 104 °C.

However, heavy water decreases the fast neutron section of the neutron spectra inside the horizontal beam channels, but its application than neutron filter should be investigated in more details.

Stamatelatos et al. reported that sapphire of 15 cm thickness gives 62% transmission of neutrons with 0.11 nm wavelength (at the range of the interest wavelength in TRR) and 76% transmission for 0.25 nm (at the range of the interest wavelength in TRR) neutrons. The transmission of fast neutrons is 3% [7].

Also Adib et al investigated transition sapphire at different temperatures which their experimental measurements shows for 0.015–0.06 eV there are the highest transition of neutrons and the crystal temperature enhancement of 150 K to 300 K will result in about 6% reduction of the exited thermal neutrons from the crystal (Fig.5).

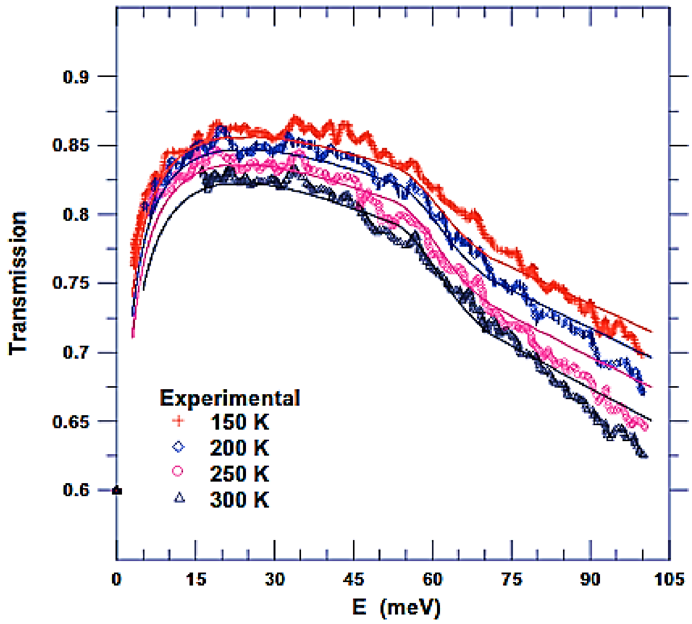

Figure 5: Neutron transmission of sapphire in the a-axis direction at various temperatures [8].

However, another experimental work published by Rantsiou et al. showed that transmission through sapphire crystals of various thicknesses for wavelengths between 0.7–10Å decreases by the crystal thickness enhancement: the minimum transmission for a 12 cm sapphire crystal is around ~30%. This goes up to ~50% when considering wavelengths between 1.5–6Å (at the range of the interest wavelength in TRR). Their report showed that by application of 12 cm of the sapphire filter the fast section of neutron beam decreases about 10 times; figure 6 [2].

In addition, we investigated our 111 homemade sapphire crystal in E radiography channel of TRR. The thermal and fast neutron flux was measured using gold foils and cadmium-covered gold foils respectively. The foils were placed on the front and back surfaces of the crystal. Fig. 7 shows the crystal and experiment setups. 5.5 cm 111 crystal decreases the thermal neutrons about 1.93 times. With cadmium ratio consideration, the fast neutron flux reduction is about 4 times using 5.5 cm 111 sapphire. The results showed good conformity with pervious reported experimental data by Rantsiou et al.

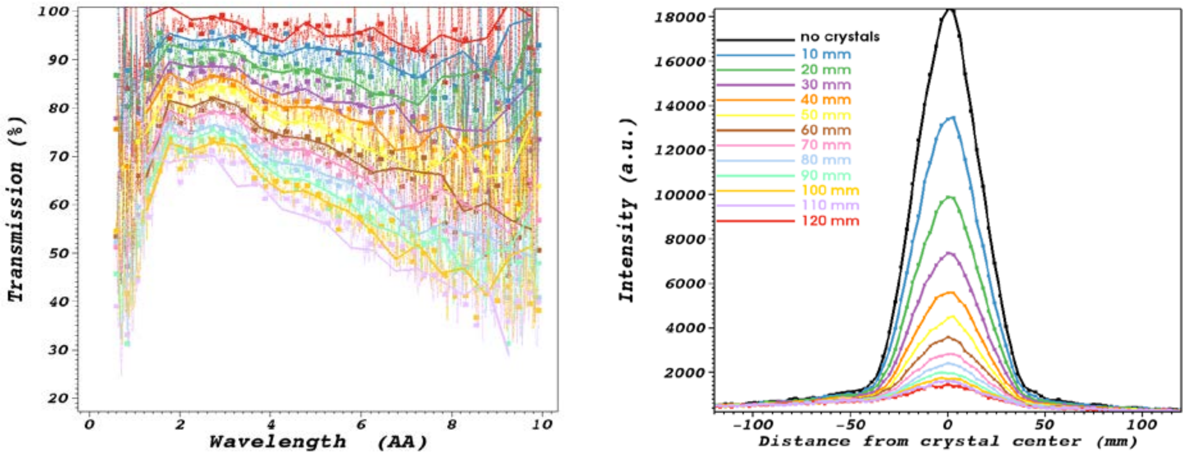

Figure 6: Neutron transmission of sapphire with different thicknesses, left) thermal, right) fast [2].

Figure 7: Neutron transmission measurement of sapphire with 5.5 cm thickness, right: experiment setup in front of radiography channel of TRR.

4 CONCLUSION

Fast neutron shielding at the analysis neutron devices position of research reactors is very important regard to both personnel received dose rates as well as achievement of sharper diffraction patterns with the least possible backgrounds. The present study investigated heavy water loading possibility inside the horizontal neutron channels of TRR in view of shielding power of fast neutrons. The obtained results showed however, the reflector would decrease the fast neutron section of the neutron spectra but in comparison with sapphire neutron filters, its application is less preferable for achieving a sharp diffraction pattern. However 15 cm heavy water solid cylindrical box (about 3.3 litter) decreases the fast neutrons about 50% and the thermal neutron intensity would be approximately constant but the deposited heat of about 230 W is a serious problem for avoiding vapour formation. 50 cm solid heavy water cylinder could compete with the sapphire crystal if the heat transmutation of the solid cylinder is solved. The sapphire crystals may decrease the fast neutron to one per tenth while the thermal neutron intensity may decrease about 50%.

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