Investigation shielding properties of NBR sheet used as sealant layer for TRR diffractometer main shield

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Abstract

New nitrile butadiene rubber (NBR) materials are being considered to use for neutron shielding. Such light and siutable material could be used for sealing of the gaps or even for shielding of low radiation environments. In the present work, theoretically and experimental investigation of NBR shielding effects of neutrons was proposed. MCNPX code was used to simulate the main shield of Tehran research reactor (TRR) while NBR layer was used as sealing for the gaps between the reactor wall and the main shield. The NBR damage also was investigated using the material irradiation inside the TRR core for 24 h. The obtained results showed desirable stability of NBR in high neutron fluences. Simulation data showed by 2 cm NBR layer between the main shield of the TRR diffraction facility and the reactor concrete wall, the neutron dose rate would be decreased up about 20%. Also the measured data showed NBR layer could decrease the neutron dose rate about 31%.

Keywords: NBR, Neutron dose rate, Shielding

Introduction

Nitrile rubber, also known as nitrile butadiene rubber, NBR, is a synthetic rubber derived from acrylonitrile (ACN) and butadiene. NBR is the polymerization of Acrylonitrile (CH2=CHCN) and Butadiene (CH2CH-CH=CH2) into one large multiple-unit chains. NBR is used in the automotive and aeronautical industry to make fuel and oil handling hoses, seals, grommets, and self-sealing fuel tanks. It is used in the nuclear industry to make protective gloves. NBR's stability at high temperatures from −40 to 108 °C makes it an ideal material for aeronautical applications. Nitrile butadiene is also used to produce moulded goods, footwear, adhesives, sealants, sponges, expanded foams, and floor mats [1-2].

Julyani et al. (2020) reported that a rubber neutron shielding, could be made flexible, in accordance with the shape of the space that must be protected from neutron radiation. They explained although Polyethylene resin is effective and is the most popular for neutron shielding, but has poor heat resistant while concrete is more effective for neutron rays and gamma rays and can withstand high temperatures, but is not suitable for additional protection in tight and confined spaces. They investigated attenuation factor of Nitrile Butadiene Rubber (NBR), without and with fillers, Gd (Gadolinium), and B_4C (Boron Carbida) each composition has 5% by weight. They calculated attenuation coefficient (μ) using a comparison of the flux before and after the neutron beam through the sample using gold plates. Their results showed the neutron flux decreases 2,032, 3,772, 4,359 times for NBR, NBR-Gd, and NBR-B_4C respectively. Their work also shows after 1.4 cm thickness of NBR, the neutron intensity reduction is not noticeable [3].

Hegazi (2018) investigated Nitrile Butadiene Rubber (NBR) nanosilica-added as shielding materials for gamma radiations. In this work, Rubber silica nanocomposites were prepared by mixing nitrile rubber with surface modified and unmodified nanosilica. The Linear attenuation coefficient was measured experimentally and calculated for NBR rubber with different concentration of nano silica. This report shows that the addition of nanosilica particles improves the mechanical and nuclear properties of NBR rubber. The increase of modified nanosilica particles increases the total γ-ray attenuation coefficient μ for all energies. This study shows that NBR composite with surface modified with nanosilica particles, has higher tensile strength and elongation at break [4].

Jumpee et al. (2015) reported that the most effective neutron shielding material can be obtained by appropriately mixing high hydrogen-content materials, heavy elements and thermal neutron absorbers. High hydrogen-content materials can undergo elastic scattering with fast and intermediate-energy neutrons. Hence, they computationally designed an optimized flexible and lightweight neutron shielding material. Their results from the MCNP transport code showed that the 10-mm thick sample #2 (NR +SBR +B_2O_3) and 100-mm thick sample #10 (4 alternating layers of

$NR+Fe_2O_3/NR+SBR+B_2O_3$) exhibited excellent neutron and secondary gamma ray shielding [5].

Hence, in the present work, we aimed to use a 2 cm NBR layer between the main shield of D channel of Tehran Research Reactor (TRR) and the reactor wall to seal the possible free spaces.

Experimental

Preparation of the materials

Tehran research reactor is an open pool type reactor with a light-water moderator and coolant, with 5 MW thermal power, which is used for research, educational, and radioisotope production purposes. Fig. 1 shows the layout of this reactor's beam tube.

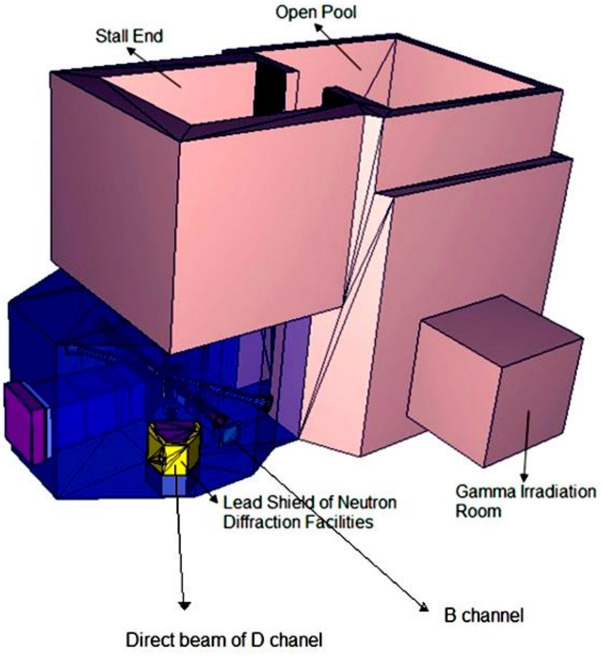

Figure 1. Schematic view of TRR

Fig. 2 displays the system main shield of neutron diffraction facility in TRR. The monochromatic neutrons exit from the second Soller collimator. The main shield details are shown in Fig.3.

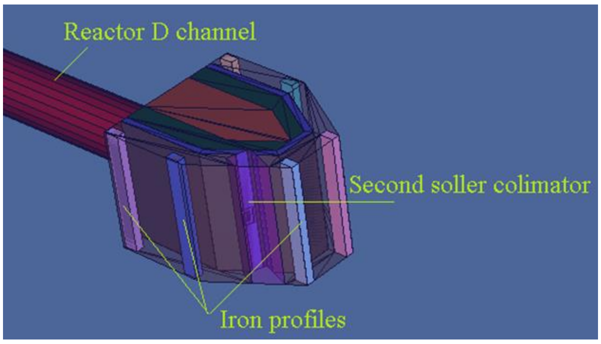

Figure 2. Simulation of main shield and D channel using MCNPX

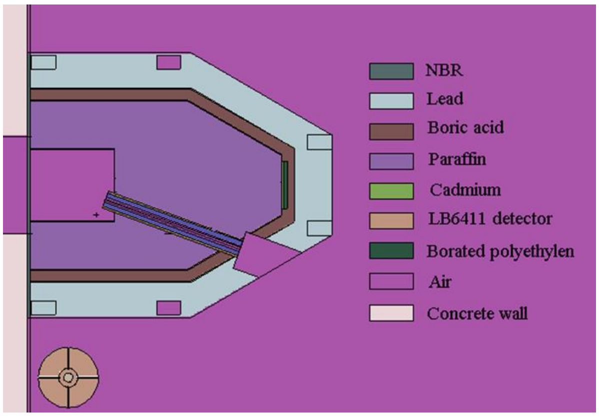

Figure 3. Detail of main shield simulated using MCNPX

MCNPX code was used to simulate the main shield. The code is a general radiation transport code with the Monte Carlo method to trace different types of particles within a vast spectrum of energies. First, the geometry of the system is simulated using this code. The output production process is done with the help of tallies. Using tallies and useful lateral cards, some quantities such as flux, flow, dose, current, the angular distribution of particles, the spatial distribution of particles, energy spectrum, etc. can be calculated [6].

Because the main shield would not stand completely fit with the concrete wall of the research reactor, we theoretically and experimentally investigated the NBR application between the wall and main shield and its effect on the reduction of neutron and gamma dose rates. The neutron dose rate near the wall (gap between the main shield and the reactor wall) was measured using a LB6411 detector with and without 2 cm NBR layer. Clearly the difference between the two measured values could reveal the NBR effectiveness for sealant the gap. Also, for another experimental investigation of NBR, a 2 cm layer of the material was placed in front of an Am-Be neutron source and neutron intensity was measured behind it using a ^3He counter. Comparison of the neutron intensity with and without NBR would indicate the shielding power of the NBR layer for the neutrons emerged from Am-Be source. In addition, the NBR material stability was examined by its irradiation inside the TRR core for 24 h in the neutron flux in order of 10^{13} $n/s.cm^2$. Neutron and gamma sources of TRR were written in MCNPX input and the gamma and neutron dose rates in front of the modeled shield and beside the wall near to NBR layer were calculated regarding with and without NBR layer; this comparison would make clear the NBR power on the sealing of the gaps between the reactor wall and the main shield. DE/DF tally cards and ANSI/ANS-6.1.1-1977 flux to dose conversion factors were used to calculate the gamma dose rates. Flux to dose conversion factor of NCRP-38, ANSI/ANS-6.1.1-1977 was used to calculate the neutron dose rates. For investigataion of NBR shielding effects, both main sheild and Am-Be source were simulated and the neutron dose rate was calculated with and without NBR layer (Fig.4).

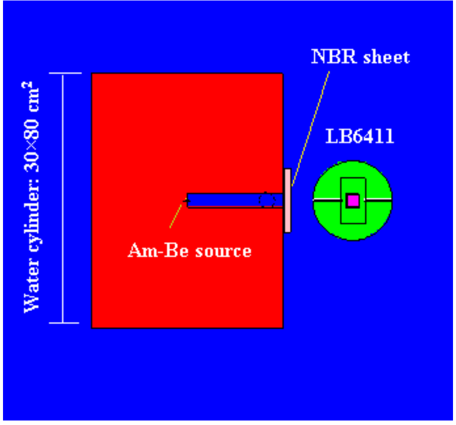

Figure 4. Simulation of NBR in front of the Am-Be neutron source

Also, neutron spectra in front of any source (D channel and Am-Be) was calculated using F4 tally of the computer code. The obtained spectra implies the NBR would act more powerfully for which energy range.

Results and discussion

Irradiation of the NBR sample inside the reactor core in a neutron flux in order of 10^{13} n/s.cm^2 showed after 24 h irradiation, the sample has good stability. At the place that the NBR layer is to be used, the available neutron flux is in the order of 10^8 n/s.cm^2; the received flounce of NBR at this place is equivalent with 273.97 years continuous work of TRR at 5 MW power. The irradiated sample has flexibility steel and dose not easily break or spread as powder according to Fig.5, which ensures the NBR stability at the sealing position without diffusion in the environment during the TRR lifetime (maximum 60 years).

Figure 5. NBR damage after 1 day irradiation in neutron flux of 10^{13} n/s.cm^2

Also, the NBR shielding effect was investigated by an experimentally test of it in front of Am-Be neutron source (Fig.6). A ^{3}He neutron counter was used to measure the neutron intensity. The experiment showed the neutron intensity decreases to its half value by using 2 cm NBR layer in front of the neutron source.

Figure 6. Test of NBR in front of the Am-Be neutron source

Finally the shielding effect of NBR was investigated theoretically using MCNPX code. Calculation of gamma and neutron dose rates beside the TRR wall (near to NBR layer) and in front of the main shield were carried out. Table 1 shows the gamma dose rates will not change because NBR is not a powerful shield of gamma rays while neutron dose rate of near the TRR wall decreases about 20%. The neutron dose rate of the main shield tip decreases about 12% according to the calculations.

Table 1. Investigation of NBR effectiveness as neutron shield

Situation	NBR presence	Without NBR
Neutron dose rate in front of the shield (mSv/h)	0.021	0.024
Neutron dose rate beside the shield near the wall (mSv/h)	4.07	5.1
Secondary gamma dose rate in front of the shield (mSv/h)	0.02	0.02
Secondary dose rate beside the shield near the wall (mSv/h)	0.33	0.33
Primary gamma dose rate in front of the shield (mSv/h)	0.01	0.01
Primary dose rate beside the shield near the wall (mSv/h)	0.09	0.09

After installation of the main shield of D channel of TRR, NBR effect in reduction of neutron dose rate was experimentally investigated. Although NBR had been used between the main shield and the TRR concrete wall during main shield installation, but understand of its behavior was very important. The measurements showed that before NBR presence, the neutron dose rate near the wall was 700 µSv/h while by using 2 cm NBR sheet the dose rated reduced to about 480 µSv/h. This proves the NBR sheet reduced the neutron dose rate about 31%.

Also the obtained neutron flux for the D channel gap between the TRR wall mand main shield as well as the end position of the guide channel of the Am-Be source (the source has been encapsulated in cylindrical water shield) showed that the neutron spectra shape is approximately identical in both cases. The thermal neutron (E_n<1 eV) fraction of the D channel gap is 64.6%, the epithermal fraction (1 eV<E_n< 1 keV) is 6.62% and the fast fraction (En> 1 keV) is 28.8%. The Am-Be source values are 57.9%, 5.6% and 36.5% respectively (Fig.7).

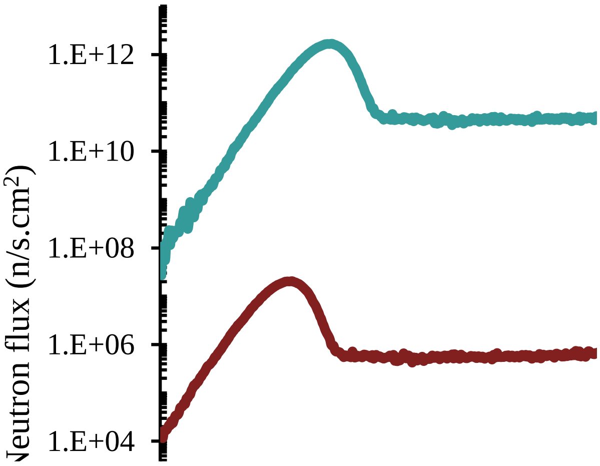

Figure 7. Comparison of neutron spectra in front of a Am-Be neutron source guide channel and the side gap of the TRR wall and main shield (the place near to LB6411 detector in Fig.3)

MCNPX code was used to model the NBR layer in front of the guide channel of the Am-Be source (Fig.4). Neutron dose rate with and without the 2 cm NBR layer was calculated. The calculations showed the neutron dose rates drops from 2.89 mSv/h to 2.21 mSv/h using the sheet which corresponds to about 23% reduction.
All the simulations had statical errors of less than 1%.

Conclusions

For sealing the gaps between the main shields and the neutron sources, flexible materials are suggested. Many of these materials with different combinations which ensures more neutron shielding are being investigated and tested. The present work proved the NBR layer used as a sealant between the main shield of the TRR diffraction system and the TRR concrete wall.

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