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Neutron and Gamma dosimetry of the designed and installed shielding of TRR D channel

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Abstract

Neutron beam ports in research reactors are installed with utilization facilities including neutron scattering, neutron activation analysis (NAA) and neutron radiography. Moreover the main shield installed on the beam ports, the research reactor hall partitioning is mainly required to limit the occupation around the neutron analysis system because of the high neutron/gamma dose rates around the main shield; especially when the system is under operation. In the present work, neutron/gamma dose rate mapping around the main shield of D channel of Tehran Research Reactor (TRR) was calculated using MCNPX code. To benchmark study, some measurements were carried out. Comparison between the simulation and measurement data showed there is good conformity and acceptable relative discrepancy. Also the obtained neutron/gamma dose mapping data showed there is a necessity for partitioning around the main shield so that after the possible material for partitioning the dose rates could be reduced less than 7.5 μSv/h.

Keywords: TRR diffraction facility, Neutron/gamma dose rate, Computational dose mapping, Benchmark study

Introduction

Neutron analysis systems such as neutron radiography or neutron diffraction systems are installed around the horizontal channels of research reactors. In some reactors, walls have been used around each of these systems to divide the reactor hall space. These walls have been implemented mainly due to the reduction of gamma and neutron dose received by personnel as well as the controlled access of the operational system.

One of the most important research facilities in Hungary is the Budapest Research Reactor (BRR). The center responds to the needs of a wide and diverse scientific community by providing services and support for research and development opportunities, aiding innovation and providing a strong foundation for education. The 10-megawatt Budapest Research Reactor has provided analysis facilities of researchers with 15 neutron and analysis tools. The 13 instruments are mounted directly on the ports of the horizontal channels of the reactor, and the other 2 instruments are placed in the vertical radiation channels. A view of the reactor hall is shown in Fig. 1 [1-2].

For partitioning the hall of the reactor, a boric acid solution has been used in the steel tanks in the form of the walls around the neutron systems (orange walls in the Fig. 1).

Figure 1. View of the 10 MW reactor hall in Budapest [2-1].

HANARO Advanced High Flux Neutron Application Reactor is a 30 MW multifunction research reactor located in Dajon, Republic of Korea. The reactor was designed by the Korea Atomic Energy Research Institute as a facility for research and development in neutron science and its applications. Fig. 2 shows a view of the reactor hall and the partitioning around each of the neutron channels. The shielding walls around the neutron systems installed in this reactor are made of heavy concrete [3].

Figure 2. the partitioning around HANARO neutron diffraction systems [3].

Kyoto University Research Reactor (KUR) is a tank-type, light water reactor with a thermal capacity of 5 MW. Figure 3 shows a view of the partitioning around the reactor neutron analysis systems. In this partition, the walls are made of B_4C resin as well cadmium sheets are used for neutron dose reduction [4].

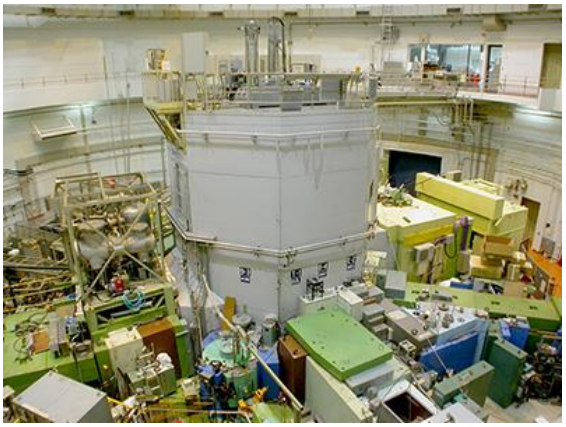

Figure 3. partitioning around the neutron diffraction systems of the Kyoto reactor in Japan [4].

The LVR-15 is a light water cooling tank research reactor housed in a stainless steel tank. The operating level of the reactor is 10 MW. The reactor usually shifts for 3 weeks, followed by a shutdown of 10-14 days for maintenance and refueling. In this reactor, Silicon neutron filter crystal is used in H1 channel and sapphire neutron filter crystal is used in H6 channel, which H6 channel crystal has much better performance. The following results were also obtained for the walls around the neutron systems:

Walls with a thickness of 10 cm to 20 cm are used around the reactor neutron systems, which are mainly portable polyethylene or lithium-containing polyethylene. Figures 4 shows a view of these walls.

Figure 4. the partitioning around the neutron diffraction systems of the Czech Republic LVR-15 reactor [5].

Due to the fact that around the material analysis by neutrons exited from research reactor channels, the neutron dose may be high and dangerous for reactor personnel and the neutron system user, as well as the scattered gammas and neutrons around the system also may cause noise and disturbance at the neutron analysis systems, many reactors use special shielding materials (so-called partitions) around their neutron system. In Tehran Research Reactor (TRR) an updated neutron diffraction system is being installed. The main shield of the system has been designed and installed. Before decision about the material is to be used as partition, calculation of neutron and gamma dose rates around the shield as well as the benchmark study of the calculations using experimental measurements was aimed in the present work. The evaluation would guide us about the proper selection of materials for the partitioning.

Experimental

Preparation of the materials

The 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. 5 shows the layout of this reactor's beam tube.

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. DE/DF card 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 [6].

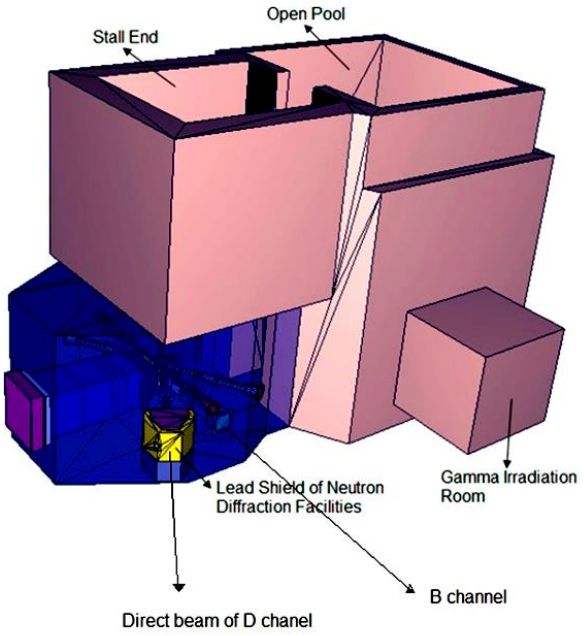

Figure 5. Schematic view of TRR and its D channel shield

Fig. 6 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 Figs.7-8.

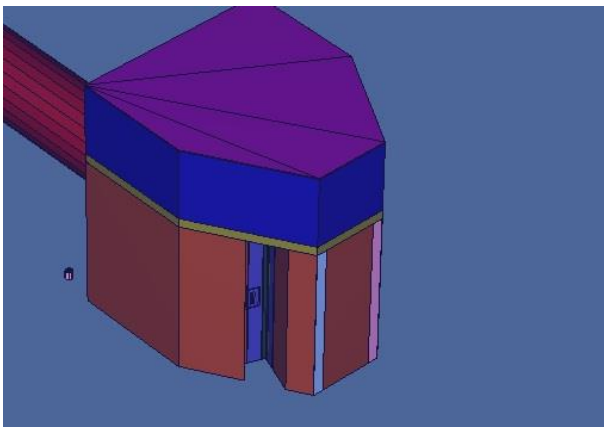

Figure 6. Simulation of main shield and D channel using MCNPX

Total graphical view of the main shield is observed in Fig. 7. As in the fiuger is seen, the shield is consisted of three layes; 55 cm paraffin, 5 cm boric acid, 15 cm lead which the final layer is lead. The simulation view of the main shield is observed in Fig.8. A monochromator room is seen in the figuer with dimension of 30 ×40 cm^2 which a soller collimator connected to its corner would guide the reflected monochromated neutrons at 20° angel toward outside the shield.

In the present work, we aimed to calculate gamma and neutron dose rates after the lead layer. Also mesh tally capability of MCNPX code was used to obtain gamma and neutron dose mapping up to 3 m far from the shield.

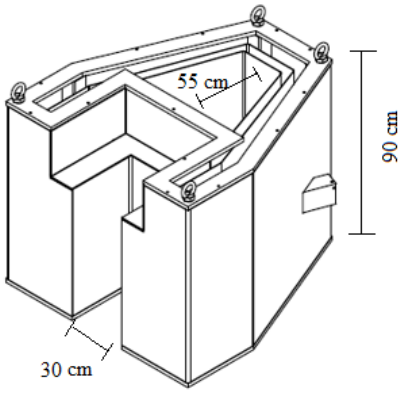

Figure 7. Graphical view of main shield

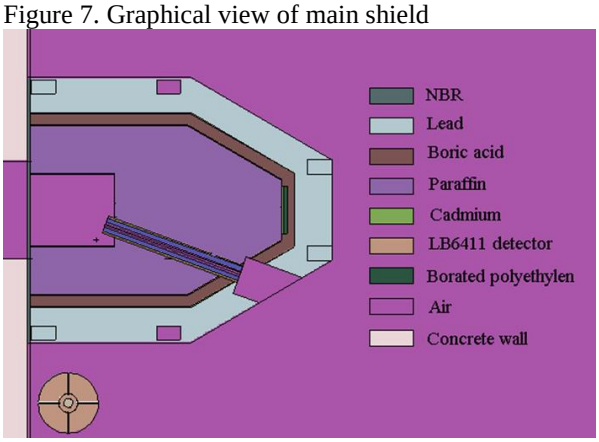

Figure 8. Details of main shield material simulated using MCNPX

For neutron and gamma dose measurements LB6411 and LB1234 detectors were used respectively. The dosimeter available for neutron dose measurements is the LB6411, which, according to ICRP 60, is designed by Berthold Technologies to measure the equivalent environmental dose. This neutron probe is very sensitive and its response function is extracted in a way that is equivalent to the flux-to-dose conversion coefficients. The probe is a spherical device 25 cm in diameter and can measure neutrons up to 20 MeV. It also includes a cylindrical tube of ^{3}He gas proportional meter with a diameter of 4 cm. The probe can be used both, as a portable measuring device and as a stationary monitor. The principal applications are reactors and the nuclear fuel cycle in the nuclear sector, accelerators in research and the use of neutron sources in the industrial sector. [7]. The dosimeter figure is shown at Fig.9. For gamma dosimetery only the sensitive volume of the detector was simulated in the MCNPX computational code. Because the thin layer of the detector wall has not much attenuation effect on the dose rate values.

The gamma dosimeter of 1236-H10 high-sensitivity dose rate which measures range of 50 nSv/h to 10 mSv/h at energy range of 30 keV to 1.3 MeV was used in the present work for measurements [7].

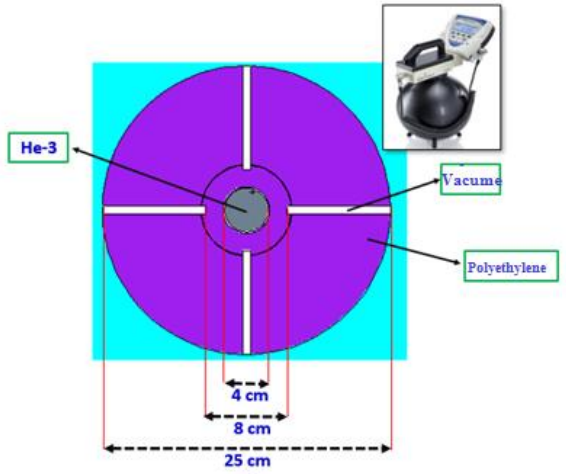

Figure 9. Dimension of the simulated neutron detector

Results and discussion

The carried out calculations showed clearly the most dose rates are experienced in front of the soller collimator because it is the only unshielded pathway for the neutrons. The mesh tally calculations showed that the second gamma dose rate around the shield changes from 1.37 to 0.125 mSv/h in front of the second collimator open pathway (Fig.10). In the case of primary gammas emerged from the operational nuclear core, the gamma dose rate around the shield changes from 1.64 to 0.263 mSv/h in front of the second collimator open pathway (Fig.11). Also the calculations showed the neutron dose rate changes from 2.16 to 0.421 mSv/h in front of the second collimator open pathway (Fig.12).

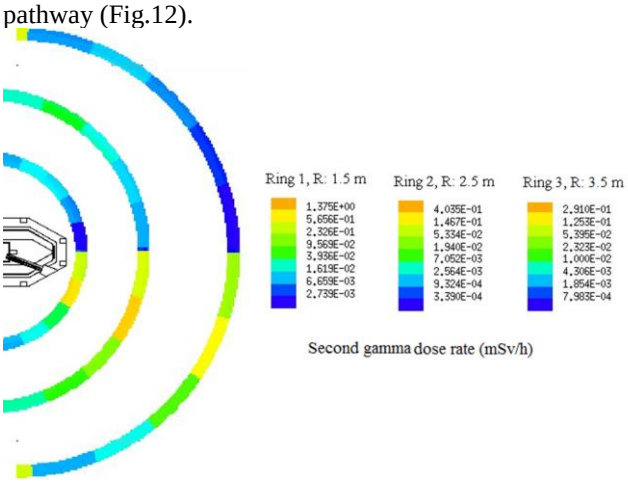

Figure 10. Two-dimensional distribution of secondary gamma dose around the shield when the reactor is on and the second shutter is open

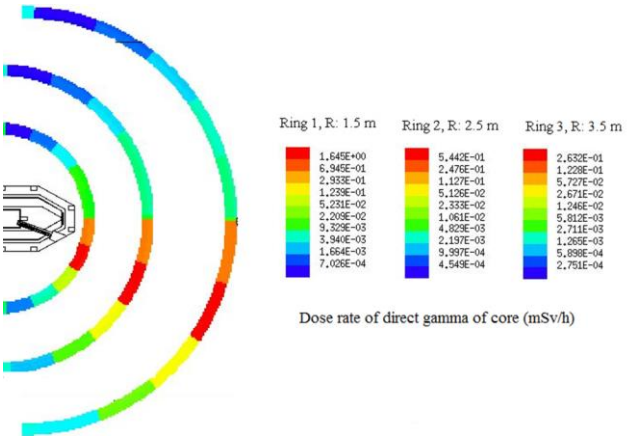

Figure 11. Two-dimensional distribution of primary gamma dose around the shield when the reactor is on and the second shutter is open

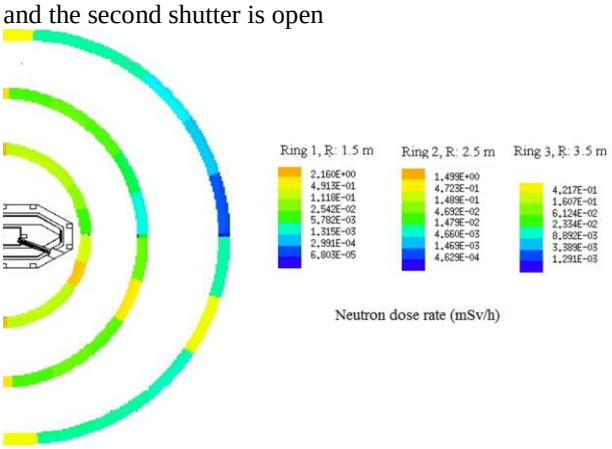

Figure 12. Two-dimensional distribution of neutron dose around the shield when the reactor is on and the second shutter is open

In overall primary gamma emerged from the operational nuclear core is more intense than the secondary gamma produced by the neutron intraction on the shield material. The obtained dose mapping would guide us to select the proper material for the required partioning.

The gamma and neutron dose rates were calculated in front of the shield exactly at a position that the material shields the direct beam from the nuclear core. The calculations showed primary and secondary gamma dose rates are 16±0.46 and 25±4 μSv/h respectively. So we expected a gamma dose rate of about 41±4.46 μSv/h would be experienced after the lead layer in front of the shield in the direction of the main beam (non-reflected one).

Also the calculated neutron dose rate using the MCNPX code showed in the same position 210±21 μSv/h is available when the reactor is operated at full power (5 MW).

The neutron and gamma dosimetry results in terms of reactor power are presented in Fig. 13 and Fig. 14. The measurements were carried out up 4.2 MW power. The diagram in Fig. 13 shows that if the reactor operates at 5 MW, the neutron dose rate at the measuring point would be about 20% higher than at 4.2 MW, so the neutron

dose rate estimated for full power (5 MW) is about 212 µSv/h which has less than 1% relative discripancy than the MCNPX simulation data.

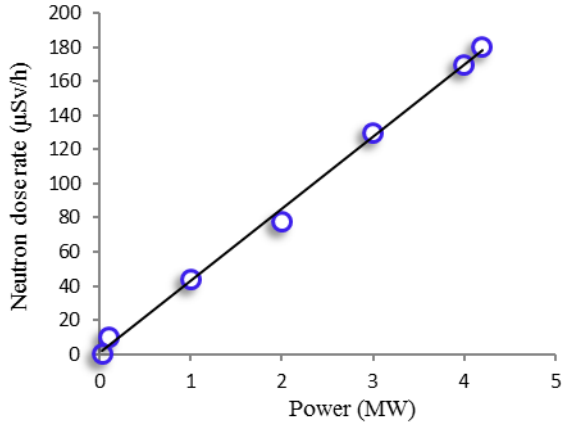

Figure 13. Neutron dose change in front of the main shield according to the reactor power

According to the diagram in Fig. 14, the gamma dose also increases by about 16% at 5 MW at the measurement point compared to 4.2 MW. Hence the estimated gamma dose rate at the position is about 63 µSv/h which has about 53% relative discripancy with the simulation data.

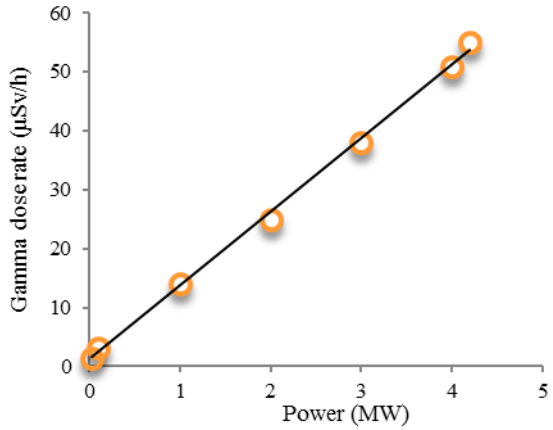

Figure 14. Gamma dose change in front of the main shield according to the reactor power.

In overall, the observed discrepancies between the calculations amd benchmark measurements (especially in the case of gamma) could be arisen of some facts such as buble formation in lead layer during the lead casting, incomplete delayed gamma libraries of the used code or even lack of calibration or no detector response factor application for the average gamma energy reached to the detector.

The high dose rates of neutron and gamma is not avoidable around such systems especially when they are in operation. So the carried out dose mapping help us to select suitable material for partioning of such facilities. For performance of partitioning around the system, suitable material should be selected so that the outer surface dose rate of the partition (includes gamma and neutron) is less than 7.5 µSv/h to avoid radiation damage and unnecessary occupational exposure [8].

Conclusions

Many neutron analysis systems are used around the research reactors to cover the science and industry requirements. In TRR, a diffraction system is being updated and equipped. The main shield of the system was constructed and installed. Evaluation of neutron and gamma dose rates in the present work reveals powerful neutron/gamma absorber material necessity in the direction of the reflected beam (direction of neutron collimator of system) for partitiong of the facility. Computational data achieved by MCNPX code would guide us, how could be performed a suitably partitioning around the system. The benchmark study shows there is good conformity between the simulation and measurement data.

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