New exposure room shielding incorporated with ferro boron concrete for neutron radiography imaging (NURI) facility at TRIGA PUSPATI Research Reactor

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Abstract. Simulation of the new exposure room shielding for Neutron Radiography Imaging (NURI) at 1 MW PUSPATI TRIGA MARK II (RTP) nuclear research reactor in Malaysian Nuclear Agency, Malaysia has been presented in this article. Previous exposure room shielding has to be disassembled due to various reasons such as radiation streaming problem and outdated since the exposure room was constructed in 1985. The NURI facility had been undergoing major upgrading for all their instrument including beam collimator, imaging system, sample positioning, instrumentation shielding, and exposure room shielding. This paper aims to simulate the radiation dose rate mapping for the new exposure room shielding for the NURI facility using the Monte Carlo simulation code of MCNPX. The exposure room shielding design consists of several modular blocks built from ordinary concrete and Ferro boron concrete. Ferro boron concrete is used to enhance the shielding performance of the facility. Results showed that exposure room shielding containing Ferro boron concrete manage to reduce the radiation by 1150 % at the critical area compared to ordinary concrete. The average radiation dose rate around the facility during operation at 1 MW reactor power ranging from 1 μSv/hr – 10 μSv/hr.

1. Introduction

Neutron was discovered in 1932 by an English physicist, Sir James Chadwick [1]. Neutron is a particle that binds together with protons in the atomic nucleus. Neutron is neutrally charged and has a mass of about 1 amu, which is nearly the same as a proton. The special characteristic of the neutron is that they interact with the nucleus of the atom rather than its electron cloud, unlike X-ray and gamma-ray [2]. Hence, the interaction force between neutrons and nuclei is not correlated with the atomic number of the element but instead depends on the isotope of the element [3]. The first photograph capture by neutron source was obtained 3 years after the discovery of neutron itself by Kallman and Kuhn in Germany [4]. Since then, the development of neutron imaging is ongoing showing that neutron is capable of many imaging applications such as in the study of bulk materials including fuel cell, cultural heritage, concrete analysis, biological samples, etc. [5-8]. With the advancement of digital technology in the last decades, neutron radiography has been shifted from a film-based inspection method for NDT towards a powerful research tool with digital imaging detection capability [9]. To this date, there are about 50 neutron radiography facilities around the world [10].

In Malaysia, the one and only nuclear research reactor is located at the Malaysian Nuclear Agency (MNA) known as the PUSPATI TRIGA MARK II (RTP). It is a pool-type reactor capable of producing 1MW power throughout the steady-state. This research reactor has been utilized for neutron irradiations for many applications and neutron radiography [11]. The main applications are neutron activation analysis (NAA), radioisotope production, small-angle neutron scattering, and neutron radiography [12]. The layout of the beam port for the RTP reactor is shown in Figure 1.

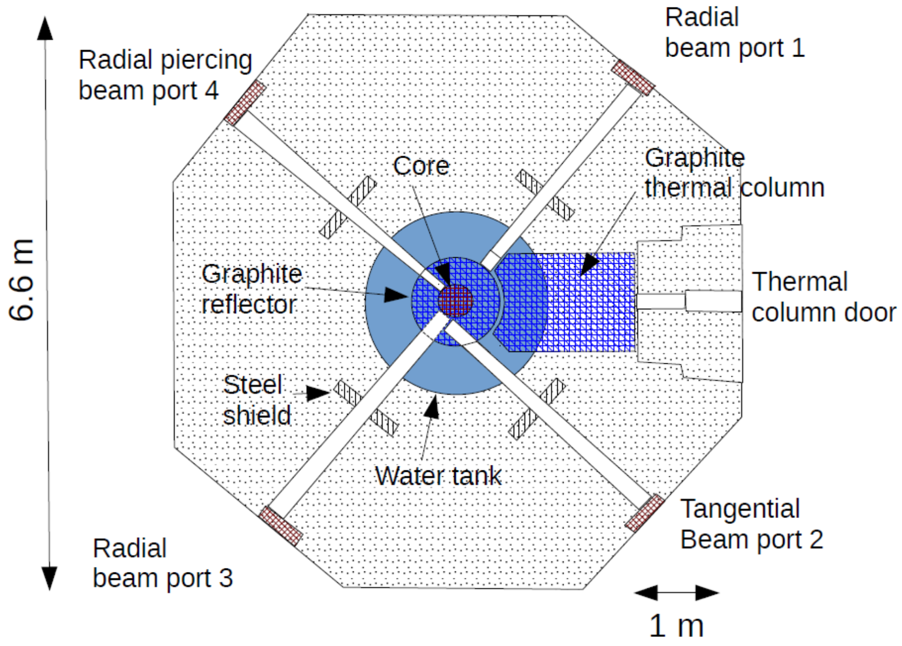


Figure 1. Top View of PUSPATI TRIGA MARK II Nuclear Research Reactor located in Malaysian Nuclear Agency [13].

The development phase of the neutron radiography facility in Malaysia has undergone three stages [11]. The first plan to construct the neutron radiography facility at RTP started soon after the research reactor was commissioned in June 1982. The first station is known as Nur-I was built from small modular concrete blocks and had been installed at radial beam port #1 [14]. The data collected from this test facility enabled the design and construction of the permanent neutron radiography facility, NUR-2. The second stage of facility development involves the relocation of instrumentations to beam port #3 and the construction of permanent exposure room shielding in 1985 as shown in Figure 2. NUR-2 had been utilized by many academia and research institutions since its operation. However, there are several limitations for NUR-2 such as low-quality neutron beam, high gamma radiation, and low collimation ratio [11, 15]. In addition, NUR-2 is only limited to the conventional film-based method due to high gamma radiation at the sample position area. Hence, due to this drawback old collimator in NUR-2 had been removed in 2014 for a new and improved collimator [15].

In the third development stage, the neutron radiography facility at RTP is moving toward digitalization same as other facilities in the world. In order to achieve this goal, a major instrumentation upgrade needs to be done. Series of studies have been done by several researchers to collect important data for designing new instrumentation such as collimator, imaging system, exposure room shielding, instruments shielding, etc. [11, 15-19]. Apart from the imaging system, exposure room shielding is one of the important components for a neutron radiography facility to ensure the safety of workers and the surrounding environment from harmful radiation exposure. In this study, a new design of exposure room shielding for the Neutron Radiography Imaging (NURI) facility at RTP is presented. This new shielding contains Ferro boron as coarse aggregates to enhance its shielding capability [20]. Initial study of using concrete containing Ferro boron had been done before, which lead to determine the ideal thickness and Ferro boron contents for the concrete [16]. The overall performance of the exposure room shielding was analyzed by using the Monte Carlo simulation codes of MCNPX.

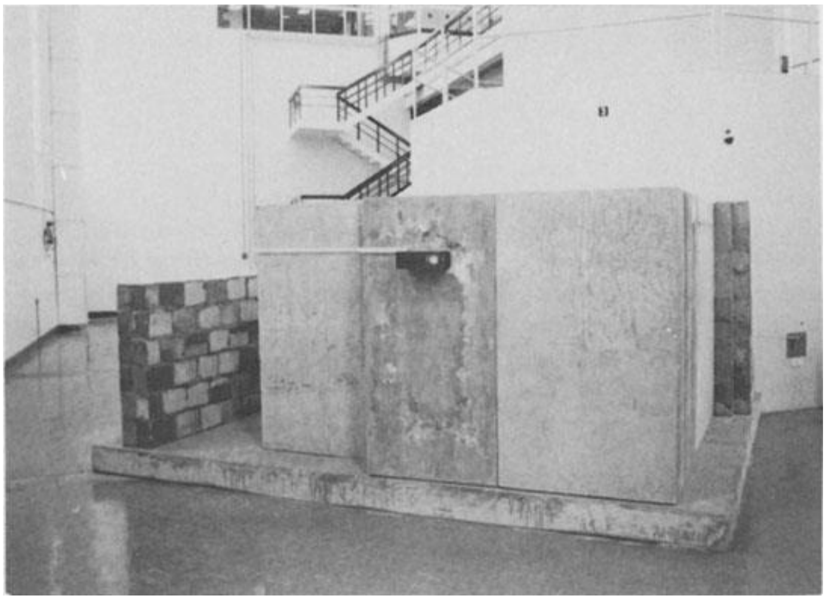


Figure 2. Permanent Neutron Radiography Facility, NUR-2 in 1985 [14].

2. Methodology

In this work, the Monte Carlo simulation code of MCNPX version 2.6 was used to simulate the radiation dose around the new exposure room shielding for NURI. Both neutron and gamma radiation were considered in this simulation. The performance of the new exposure room shielding was tested based on the worst-case scenario in which the reactor operating at the maximum power of 1 MW. However, in an actual situation, the reactor can only be operated at 750 kW reactor power. Therefore, some fractions of the radiation might be lower than actual values. The results are shown for the total dose rate of neutron and gamma. There were 4 cases simulated in this study which are listed as follows, (Case 1) without any shielding, (Case 2) exposure room shielding with ordinary concrete only, (Case 4) exposure room shielding with ordinary and Ferro boron concrete, and (Case 5) exposure room shielding with ordinary and Ferro boron concrete including beam shutter. The beam shutter in this simulation consists of 30% borated polyethylene with a thickness of 10 cm, lead with a thickness of 15 cm, and barite colemanite concrete with a thickness of 25 cm.

The beam source spectrum and fluence at 1 MW power level were set up based on the previous study and technical report [12]. The doses were calculated using MCNPX mesh tally, with flux-to-dose conversion factors, with data sets ICRP 21-1971. This simulation is important to forecast the radiation doses around the new exposure room shielding for NURI. The input files used in this simulation were prepared as close as possible to the actual radiation source, geometry, and materials which are shown in Figure 3.

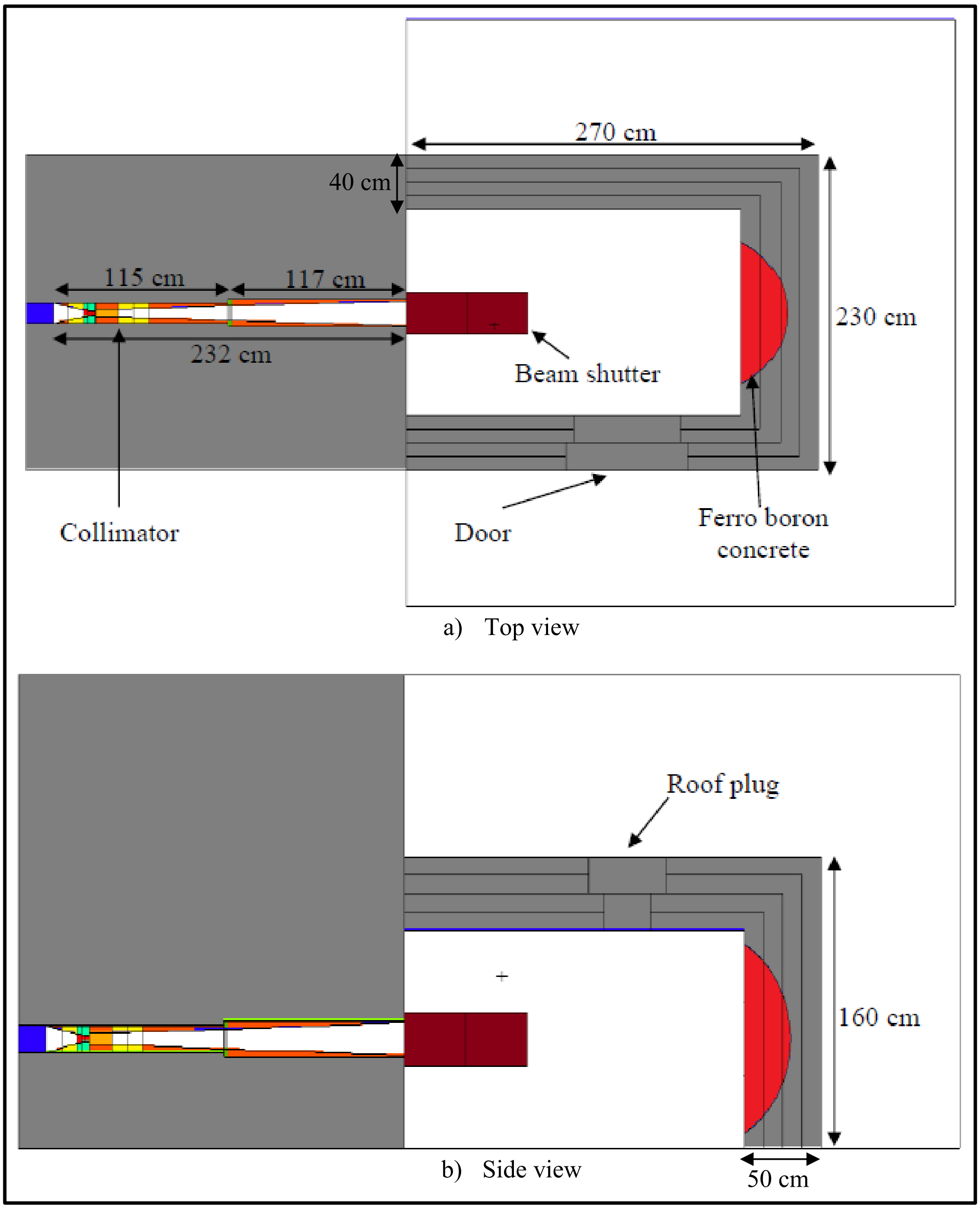
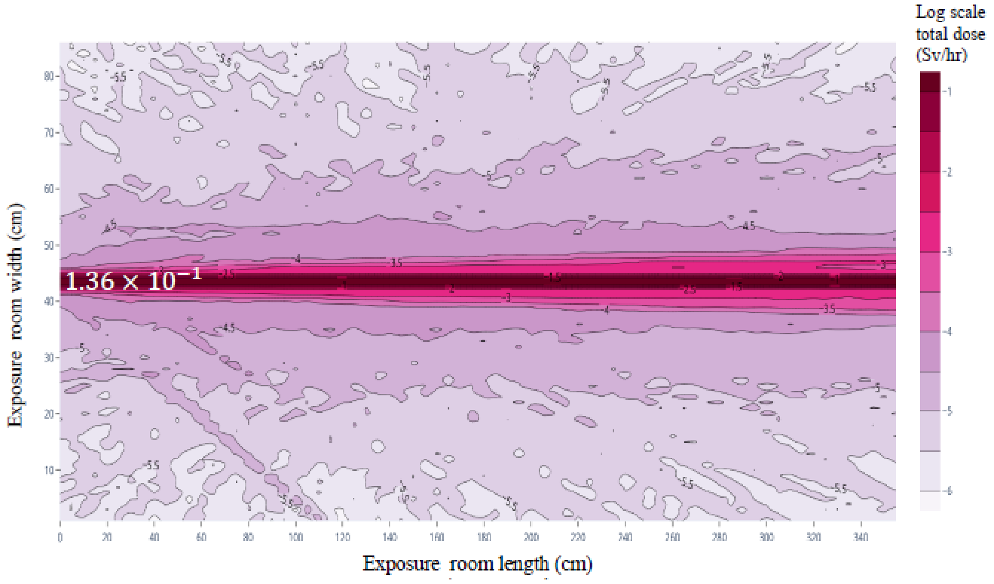


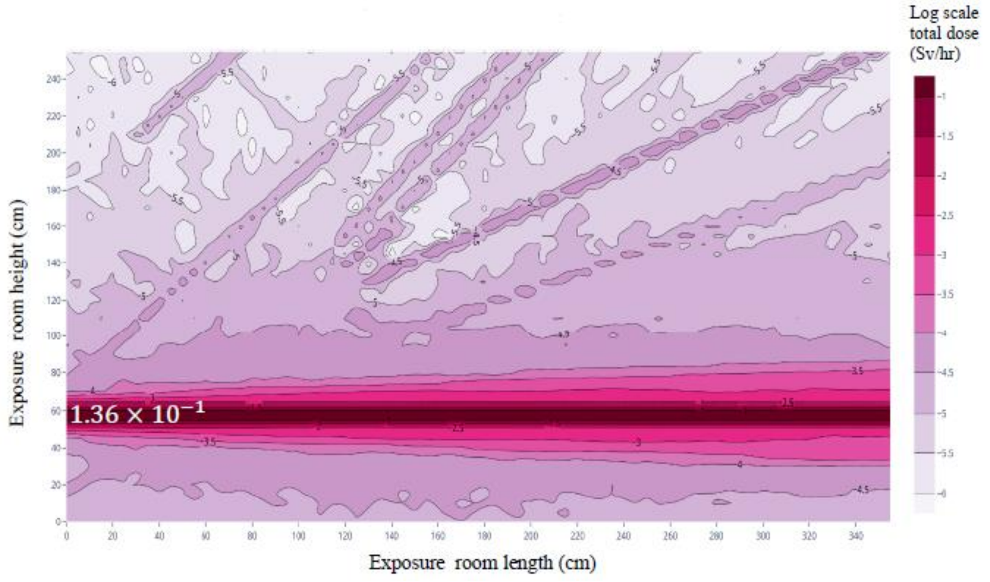
Figure 3. Side view of simulated geometry for new exposure room shielding for NURI.

3. Results and discussion

The radiation doses around the new exposure room shielding for NURI were investigated using MCNPX. The simulated results from these simulations give an estimation of the total dose rate at the NURI facility based on several cases. The simulated result for case 1 is shown in Figure 4, where a direct radiation beam was coming out from the beam port opening without any exposure room shielding. The highest dose rate measured was at the center of the beamline, with a value of approximately 0.136 Sv/hr. This showed that the most critical part that need to be addressed was the direct beam out from the beam port opening.



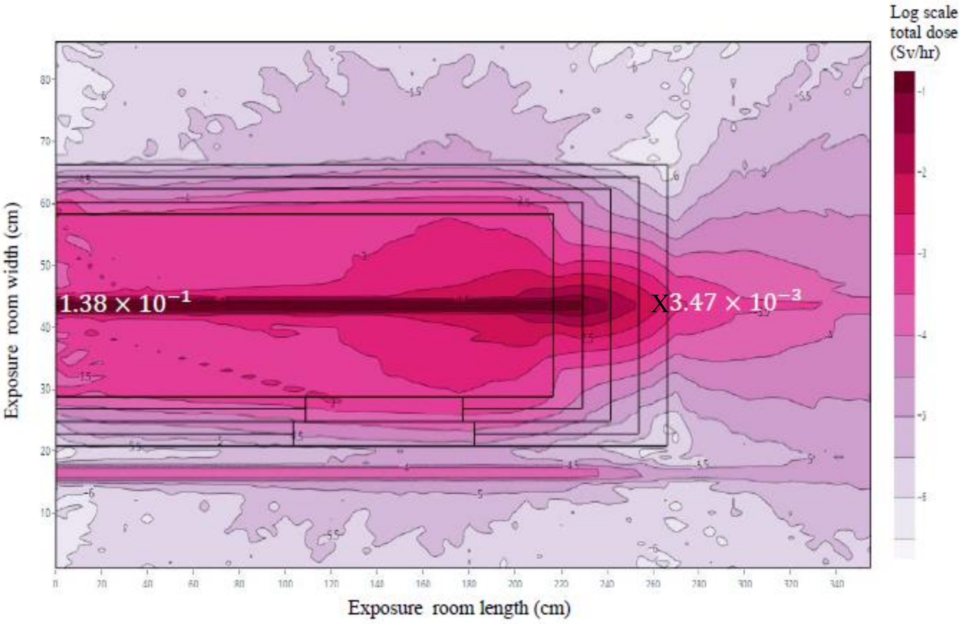
a) Top view



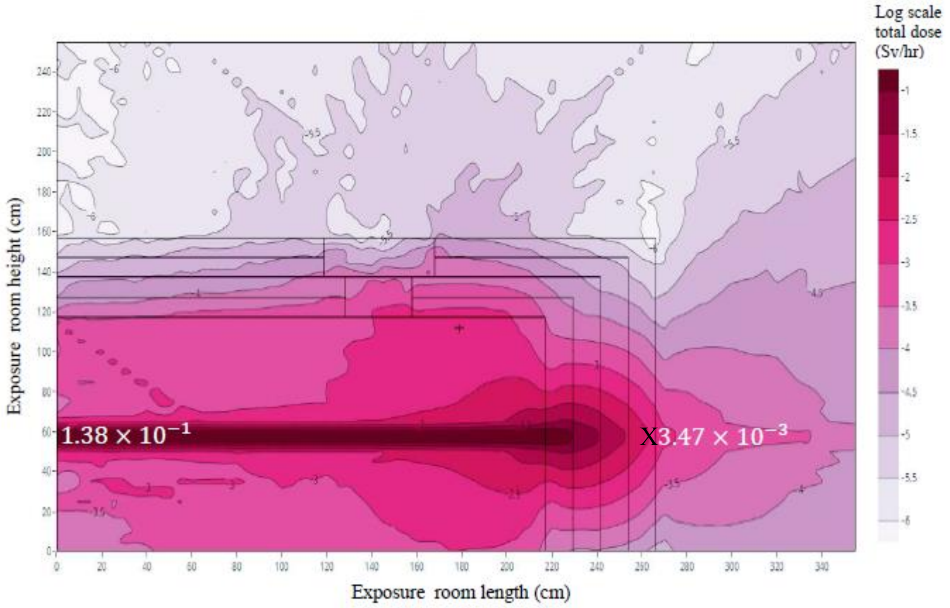
b) Side view

Figure 4. (Case 1) Contour plot of total dose rate at the NURI facility without shielding.

Next, case 2 was simulated with ordinary concrete only for the exposure room shielding as shown in Figure 5. The simulated results showed that the exposure room shielding managed to contain the radiation inside the exposure room. The highest rate of the total radiation dose at the outer part of the exposure room shielding was measured at the back of the shielding block surface (mark X) with a value of 3470 µSv/hr. As the value is significantly high, Ferro boron concrete was introduced in the design of the new exposure room shielding for NURI in order to reduce the radiation dose rate at that area. The other outer parts of the exposure room shielding have values ranging from 1 µSv/hr – 10 µSv/hr.

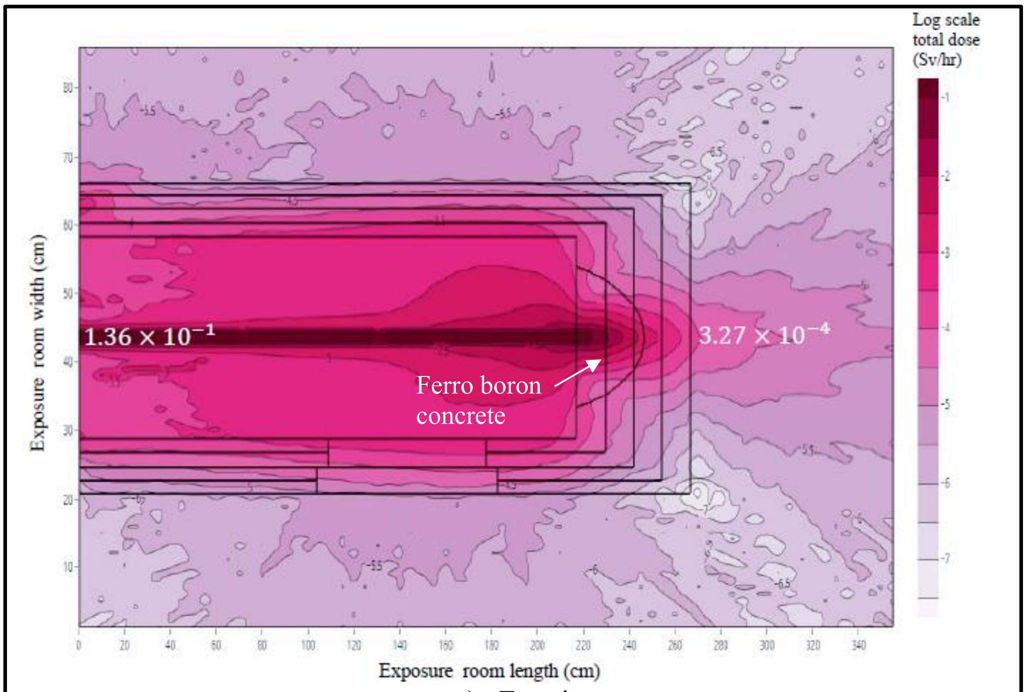


a) Top view

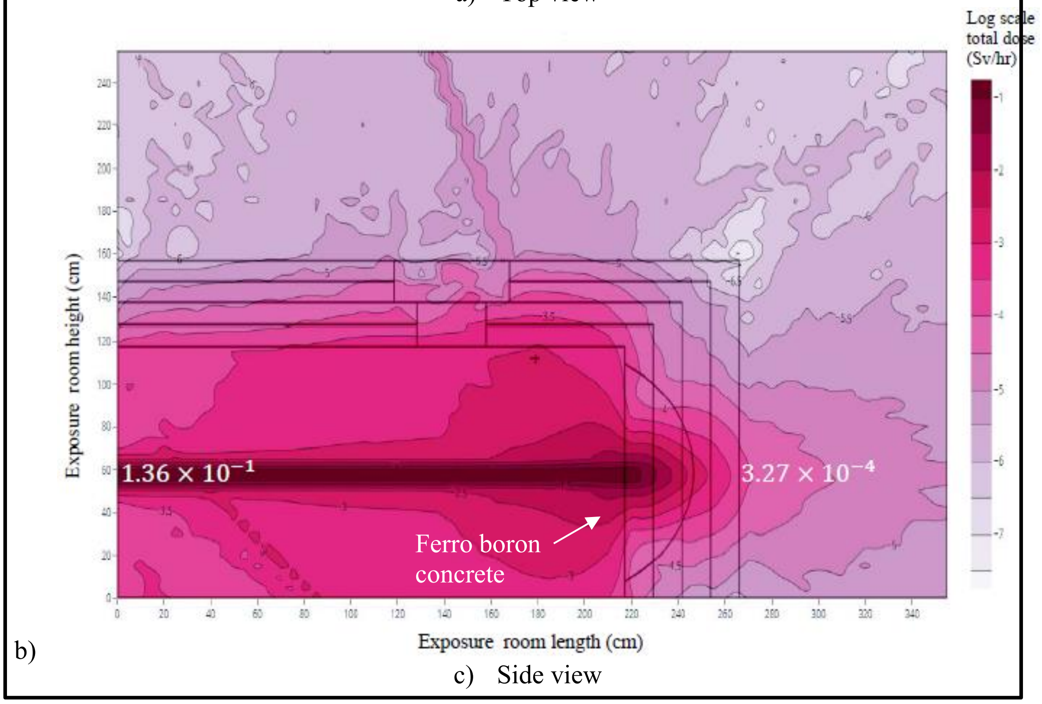


b) Side view

Figure 5. (Case 2) Contour plot of the total dose rate at NURI facility with ordinary concrete only.

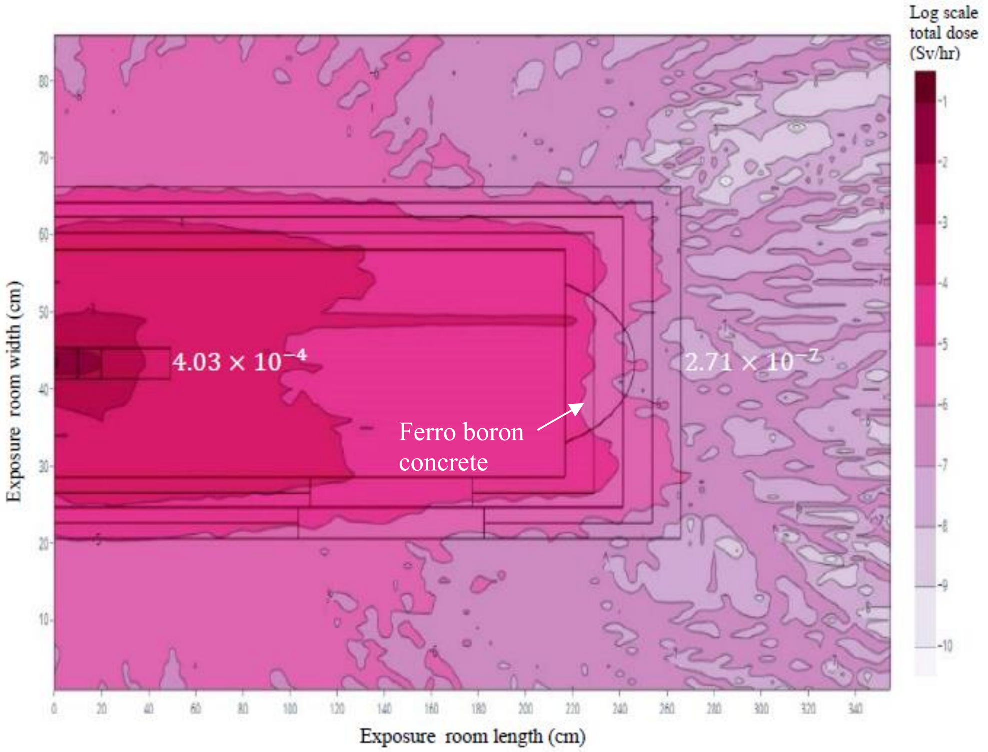


a) Top view

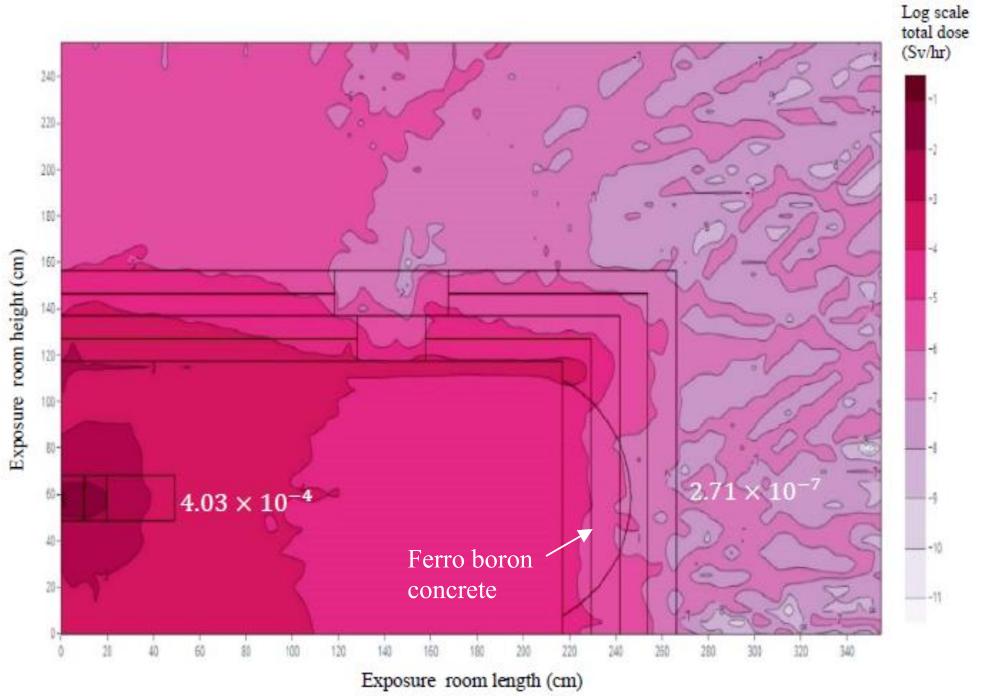


c) Side view

Figure 6. (Case 3) Contour plot of the total dose rate at NURI facility with ordinary concrete and ferro boron concrete



a) Top view



b) Side view

Figure 7. (Case 4) Contour plot of total dose rate at NURI facility with ordinary and Ferro boron concrete while beam shutter closed.

For case 3, the exposure room shielding was added with Ferro boron concrete at the direct beamline area. The contour plot of the total dose rate for the new exposure room shielding design at NURI is shown in Figure 6. Due to limited Ferro boron aggregates, smart approached need to be implemented in order to ensure effective shielding performance. That is why Ferro boron concrete was only be placed at a specific area not for the whole shielding blocks. From this simulated result, the dose rate at the critical area (mark x) which had been mentioned in the previous case was able to be reduced by a significant amount of about 1150%. The radiation dose rate managed to be reduced significantly due to Ferro boron concrete that has a high specific density of about 4 g/cm^3 and contains boron compounds. High-density materials are good to attenuate gamma radiation and thermalized fast neutrons. Thermalized neutron then will be captured by boron compounds in the concrete which ordinary concrete does not have. The dose rate at the back of the shielding wall surface was measured at 327 μSv/hr and the other outer parts of the exposure room shielding have values ranging from 1 μSv/hr – 10 μSv/hr. Hence, it clearly showed that Ferro boron is a good material for enhancing radiation shielding performance, especially for neutron radiation.

Case 4 was designed to simulate the total dose rate at the new NURI facility with the beam shutter closed as shown in Figure 7. Based on the simulated results, the total dose rate at the back of the beam shutter surface was 403 μSv/hr. The dose rate was reduced by a factor of 1 at 120 cm from the reactor wall. During the operation, the operator needs to consider lowering the reactor power or limiting the time when entering the exposure room even if the beam shutter is closed. The total dose rate at the outer parts of the NURI facility when the shutter closed was less than 1 μSv/hr.

Based on all the simulated cases, it shows that the new exposure room shielding at the NURI facility managed to improve its shielding capability by adding Ferro boron concrete at the wall facing directly the beamline. However, during the operation of the facility, safety measures and precaution must be taken at all time because certain areas, especially inside the exposure room has high dose rate measurement even when the beam shutter is closed. Proper procedure as stated by Atomic Energy Licencing Board (AELB) must be followed at all times during the operation [21].

4. Conclusion

The total radiation dose rate mapping for the new exposure room shielding for the NURI facility at RTP has been simulated in this study using the Monte Carlo simulation code of MCNPX. 4 cases have been simulated which the first case is without any exposure room shielding and it is to show the neutron beam at 1 MW reactor power. The second case is exposure room shielding with ordinary concrete only which is used as the control to observe the effect of the Ferro concrete. The third case is set to be as close as possible to the actual design of the exposure room shielding at NURI. The design consists of ordinary and Ferro boron concrete. The Ferro boron concrete was designed to be moulded in a semi-spherical shape in order to maximize the usage of the limited raw material of Ferro boron. Based on the simulated results, it shows that the exposure room shielding containing Ferro boron concrete manage to reduce the radiation dose rate by 1150%. It is known that Ferro boron is a great material for radiation shielding especially for neutron radiation due to boron contents [16, 20]. With the new exposure room shielding, the NURI facility at RTP can ensure the safety of all the users and the surrounding environment at all times.

5. References

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