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Optimization of shielding material thickness, composition for 14.1 MeV D-T fusion neutron shielding facility

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1. Introduction

Historically, neutron sources from reactors, accelerators, and spontaneous fission materials have been widely used for industrial and research purposes. For D-T neutron generator, 14.1 MeV fast neutrons are produced from D-T fusion reaction. For utilizing 14.1 MeV neutron source, appropriate radiation shielding facility is needed to reach the thermal neutron flux level for legal dose criteria.

In this paper, designing and optimization of D-T neutron facility for 14.1 MeV fusion neutron were held. Three strategies were mainly implemented for optimization: geometry of the shielding facility, shielding material arrangement, and shielding material thickness. Monte Carlo simulation results obtained by MCNP6.2 [1] were utilized for calculation. Under these optimization strategies, the dose rates were calculated to be under legal dose rate criteria.

2. Methods and Results

2.1. Shielding capability of D-D neutron shielding facility for 1.41 MeV D-T fusion neutron

In this section, comparison in dose rates subjected to D-T and D-D fusion neutron was simulated for same shielding condition such as thickness, composition. Comparison of calculated dose rates was held through MCNP6.2 simulations, with reference geometry of radiation shielding facility present at Seoul National University utilized for simulation.

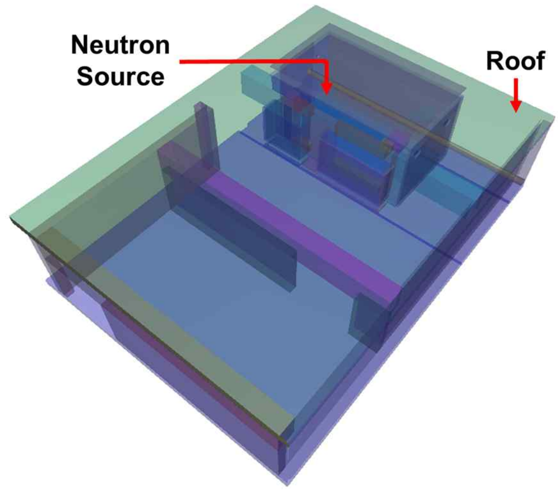
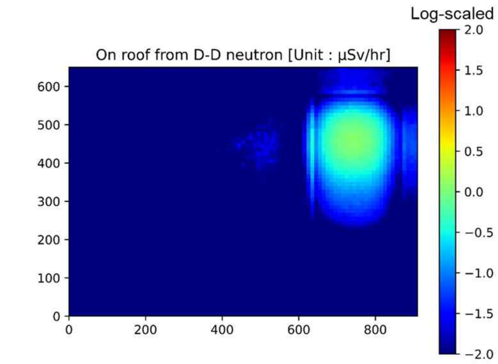


Fig. 3-dimensional design for D-D neutron shielding facility utilized for Monte Carlo simulation

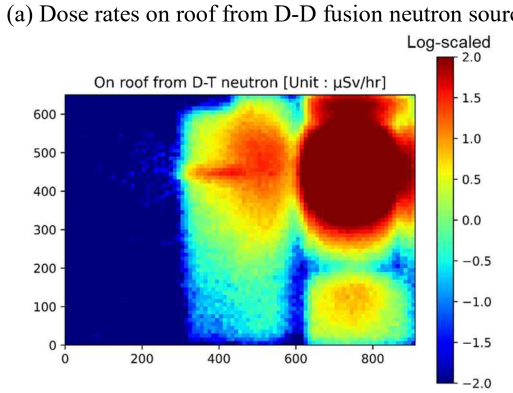
Fig. 1 illustrates the 3-dimensional design for the shielding facility via MCNPX visual editor. Two arrows in Fig. 1 indicate the region of interest for dose rate calculation: roof. Along the direction from neutron source to the roof, 36.5 cm of HDPE (high-density polyethylene), 5.4 cm of BPE (borated polyethylene), 20.0 cm of concrete (ceiling), and 1.5 cm of lead respectively are placed for shielding. HDPE and concrete are used for thermalization of fast neutron, while BPE is used for capturing thermalized neutrons which produces gamma. Lead is used for shielding gamma produced from BPE. In addition, as shown in Fig. 1, neutron generator is set in an inner-shielding room made up of HDPE and BPE.

For Monte Carlo simulation with MCNP6.2, D-T fusion neutron was approximated as isotropic 14.1 MeV mono-energetic sources. Neutron output for D-D and D-T neutron generator were both set as 5×10^8 n/s. Neutron/gamma dose rates were calculated with flux-to-dose conversion factors from ICRP report 74 [2] and neutron/gamma flux from MCNP simulation. Acquired Neutron/gamma dose rates were summed for total dose rate. 20 μSv/hr, the criteria from Korea Institute of Nuclear Safety, was used for legal dose criteria [3].

Fig. 2 illustrates the log-scaled calculated dose rate on the roof.



(a) Dose rates on roof from D-D fusion neutron source



(b) Dose rates on roof from D-T fusion neutron source

Fig. 2 Calculated log-scaled dose rates (a) from D-D fusion neutron source on roof (b) from D-T fusion neutron source on roof

Results in Fig. 2 shows that shielding facility optimized for D-D fusion neutron is deficient for shielding D-T fusion neutron. The maximum dose rates for unit area turned out to be 1.09 μSv/hr for D-D fusion neutron and 79.01 μSv/hr for D-T fusion neutron. This implies that more extreme shielding D-T fusion neutron is needed. However, due to the spatial and financial limitations, consideration of optimizing the shielding facility is essential for compact economical, and effective shielding.

2.2. Optimization of shielding facility design for 14.1 MeV D-T fusion neutron

In this section, shielding facility design was contrived for 14.1 MeV D-T fusion neutron source with different optimization strategies for additional shielding.
Fig. 3 illustrates newly designed shielding facility which is sufficient enough to shield radiations from 14.1 MeV D-T neutron source.

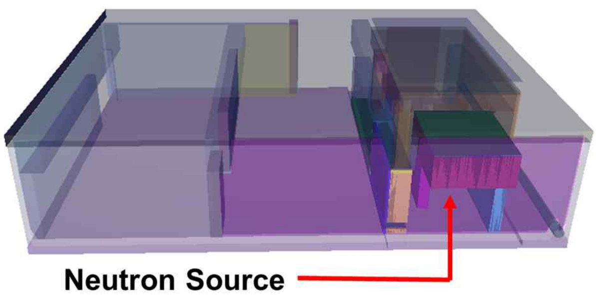
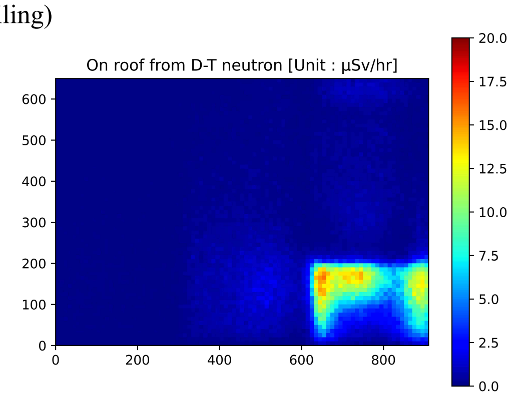


Fig. 3 Design for optimized D-T neutron shielding facility

Three strategies were mainly implemented for optimization. Firstly, geometry of the shielding facility was modified for D-T fusion neutron shielding. It is noticeable that neutron generator is placed outside the previous inner-shielded room, with new walls added for shielding. Along the direction from neutron source to the wall toward door, sliding door made up of HDPE and BPE with same thickness of doors of inner-shielding room is added so as to make a way for approaching the neutron generator.

Secondly, optimization in shielding material arrangement was made. Here dose rate calculations with different shielding material arrangement were tried. It was found that arranging in HPDE-BPE-lead order showed the most outstanding performance for shielding 14.1 MeV fusion neutron.

Lastly, optimization in shielding material thickness was made. Increase in shielding thickness led to enhanced performance in shielding, but also led to increase in total cost of the shielding materials. For this reason, weighing between the shielding capability and the cost was made for the calculation of the optimal shielding facility. For HDPE, dose rates for different HDPE thickness were calculated to obtain optimal thickness. Likewise, dose rates were calculated depending on the presence of lead. For BPE, it was found that shielding capability of gamma was saturated. Optimized arrangement and thickness along the direction from neutron source to the roof are as: 60.0 cm of HDPE, 2.0 cm of BPE, 1.0 cm of lead, 20.0 cm of concrete (ceiling)



(a) Dose rates on roof from D-T fusion neutron source

Fig. 4 Calculated dose rates (a) from D-T fusion neutron source on roof.

Fig. 4 illustrates the calculated dose rates on the roof for D-T fusion neutron. Calculated dose rates on both cases seemed to be under 20 μSv/hr, meeting the legal dose rate criteria.

3. Conclusions

D-D fusion neutron shielding facility was found to be deficient for shielding D-T fusion neutron. To manage this problem, new 14.1 MeV fusion neutron shielding facility was designed. Various optimizations strategies for shielding facility design helped reducing the dose rates to under 20 μSv/hr. Factors such as facility geometry, shielding material thickness and arrangement were differently simulated for shielding facility design optimization.

Acknowledgments

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