# Parametric Study for Gap Thickness of Compact Fusion Neutron Source Shield Design

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## 1. Introduction

The Compact-Fusion Neutron Source (C-FNS) is increasingly used in industrial and research area such as neutron activation analysis, neutron radiography, neutron capture therapy, and so on [1-3]. Also, for easier and wider applications of C-FNS, a need for more compact and even portable design is important. Recently, a $10^{10}$ n/s portable D-D neutron source has been developed at Korea Atomic Energy Research Institute [4]. In the previous study, the conceptual shielding design, in which 50-cm-thickness HDPE (High Density Poly Ethylene) were employed, was suggested with acceptable margin [4]. However, due to the limitation in fabrication technology, an undesirable gap will be placed between HDPE shield and which may induce considerable increase in dose rate at outside of the shield.

Hence, in this paper, the limitation of the gap thickness was evaluated using the MCNP6 code based on the 5 μSv/hr worker dose limit according to the recommendation of ICRP-60 with a margin factor of ten [5].

## 2. Description of Model

The layout of shielding design for the $10^{10}$ n/s portable D-D neutron source was shown in Figures 1 and 2. The HDPE shield is composed of two partial shields, namely, shield 1 and shield 2. The shield 2 is designed as "L" shape to move front and back easily. The movement of the shield 2 is an essential option to perform a foil irradiation test and management of D-D neutron source after or before operation. Hence it is expected that there will be a "gap" between the shield 1 and the shield 2.

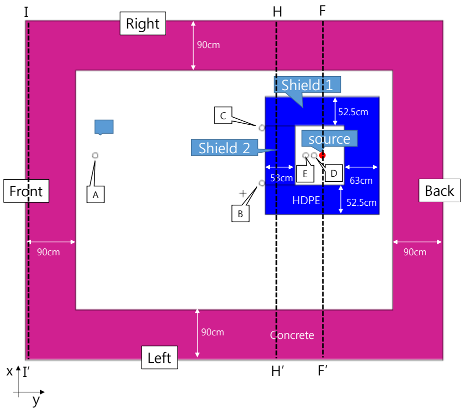
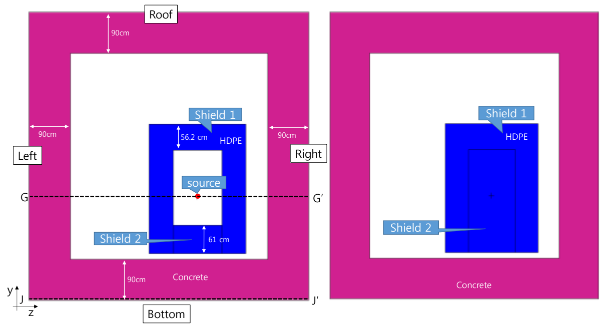



Fig. 1. Layout of shielding design at G-G' plane




(a) At F-F' plane (b) At H-H' plane

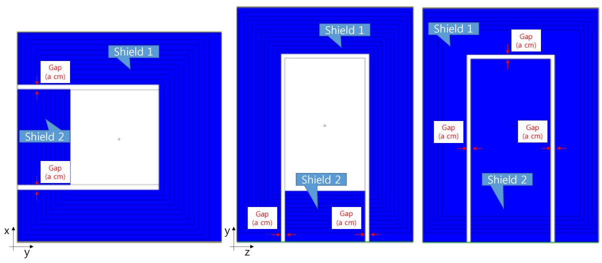
Fig. 2. Layout of shielding design at F-F' and H-H' planes

The HDPE shields are surrounded by 5-mm-thickness lead at front, right, left, and roof directions. At the bottom of the HDPE shields, 1-cm-thickness steel is modeled. Although realistic bottom steel is several cm-thickness, only 1-cm-thickness model was used in this study at conservative manner.

A through E positions, described in figure 1 are for neutron spectrum tally.

## 3. Numerical Results

The "gap-free" model described in figures 1 and 2 was selected as a reference model. Various gap size was considered, i.e., from 0.5-cm-thickness to 3.0-cm-thickness. The positions of gap with thickness "a" between shield 1 and shield 2 are shown in figure 3.



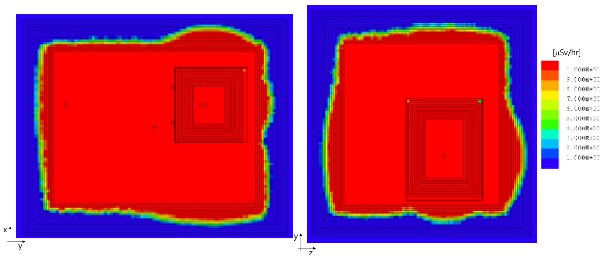

(a) At G-G' plane (b) At F-F' plane (c) H-H' plane

Fig. 3. Description of gap positions at HDPE shields

To provide a margin factor of ten, the MCNP6 calculations were performed with 2.45 MeV $10^{11}$ n/s source strength.

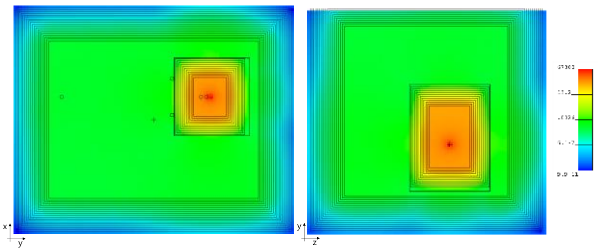
### *2.1 Results of Reference Model*

Numerical results of the reference model were shown in figures 4 and 5. As reported in the reference [4], the reference model showed well-shielded results in both of neutron flux distribution and total dose rate distribution.




(a) At G-G' plane (b) At F-F' plane

Fig. 4. Total dose rate distribution in the reference model



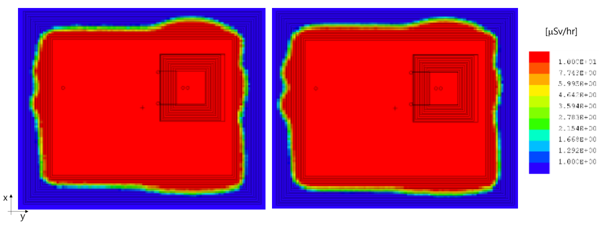
(a) At G-G' plane (b) At F-F' plane

Fig. 5. Normalized neutron flux distribution in the reference model

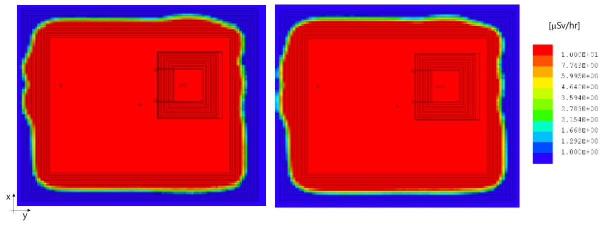
### *2.2 Results of Gap Model*

Numerical results of various gap size models were shown in figures 6 through 7. As shown in figures, incensement of gap thickness caused significant total dose rate increase at "front" and "bottom" direction. For more detailed information in dose rate, figures 8 and 9 show total dose rate distribution in outer surface of concrete at "front" direction, i.e., I-I' plane, and outer surface of concrete at "bottom" direction.

As shown in figures 8 and 9, 1.0-cm-thickness of gap showed acceptable in total dose rate results with 4.9 μSv/hr in maximum dose rate at "bottom" concrete surface. Total dose rate at both of "front" and "bottom" concrete surface exceeded the work dose limit, 5 μSv/hr, when more than 2.0-cm-thickness of gap were considered. This is mainly due to the leakage of neutrons through the considered gap as shown in figure 10.

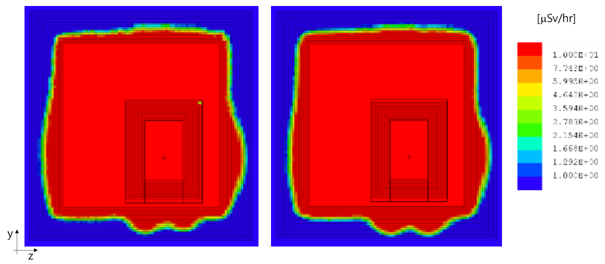



(a) 0.5 cm gap case (b) 1.0 cm gap case

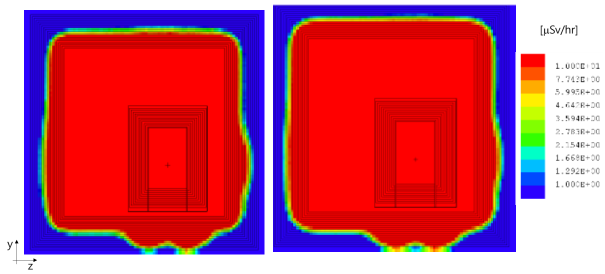



(c) 2.0 cm gap case (d) 3.0 cm gap case

Fig. 6. Total dose rate distribution in various gap size models at G-G' plane

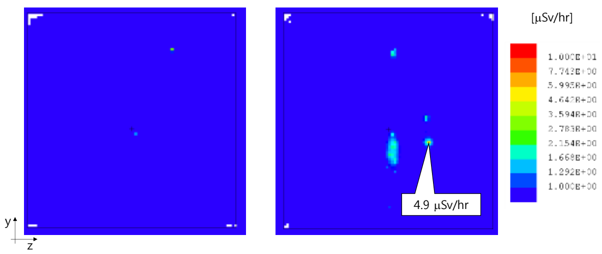



(a) 0.5 cm gap case (b) 1.0 cm gap case

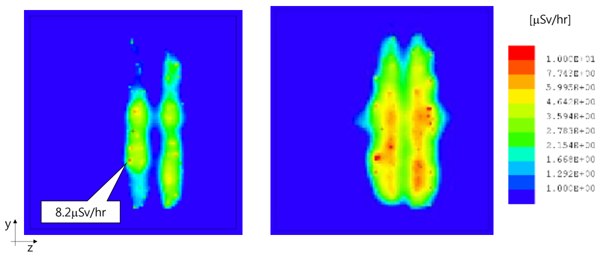



(c) 2.0 cm gap case (d) 3.0 cm gap case

Fig. 7. Total dose rate distribution in various gap size models at F-F' plane



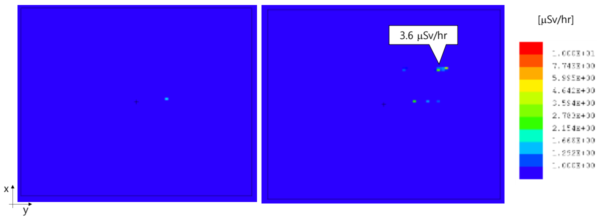

(a) 0.5 cm gap case (b) 1.0 cm gap case



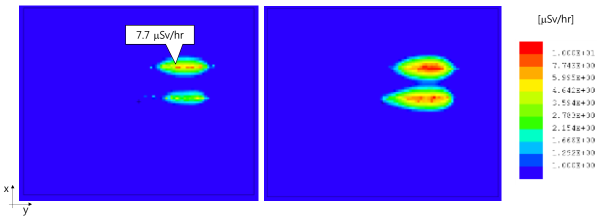

(c) 2.0 cm gap case (d) 3.0 cm gap case

Fig. 8. Total dose rate distribution in various gap size models

at I-I' plane (front surface of concrete)

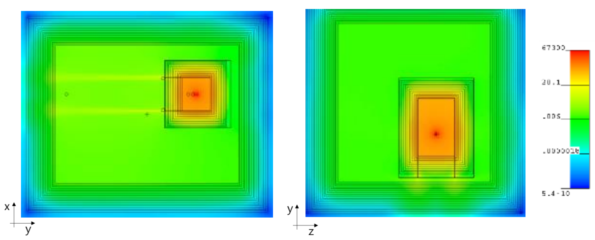



(a) 0.5 cm gap case (b) 1.0 cm gap case




(c) 2.0 cm gap case (d) 3.0 cm gap case

Fig. 9. Total dose rate distribution in various gap size models at J-J' plane (bottom surface of concrete)



(a) At G-G' plane (b) At F-F' plane

Fig. 10. Normalized neutron flux distribution in the 2.0-cm-thickness gap model

*2.3 Results of Neutron Spectrum*

Normalized neutron spectra at position A through E were shown in figures 11 and 12 for both of the reference and 3-cm-thickness gap models. In the reference model, thermalized neutron spectra were estimated at positions A, B, and C due to moderating effect of the HDPE shield. In 3-cm-thickness gap model, more softened neutron spectra were observed. This results were originated from relatively lower thermal capture due to the gap in 3-cm-thickness gap model comparing to the reference model. At position D, which is 10 cm far from the source position, most of neutrons were originated from the 2.45 MeV source neutrons rather than moderated neutrons by scattering events. At position E, which is 20 cm far from the source positions, the portion of 2.45 MeV source neutrons were reduced while portion of thermal neutrons by scattering events were increased.

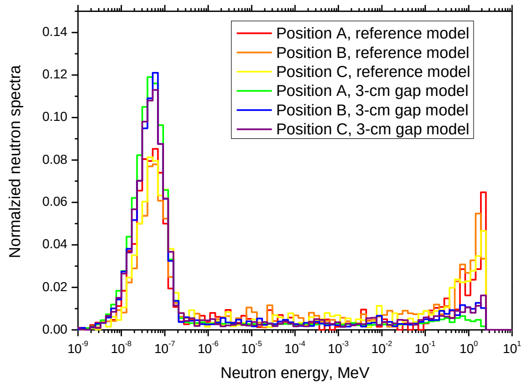



Fig. 11. Comparison of neutron energy spectrum at positions A, B, and C

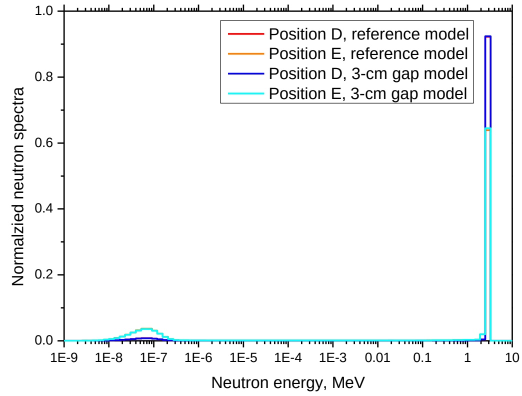



Fig. 12. Comparison of neutron energy spectrum at positions D and E

## 3. Conclusions

In this paper, shielding design for the $10^{10}$ n/s portable D-D neutron source were performed based on the parametric study of the gap thickness between two shields.

The limitation of the gap thickness between two shields were assessed as 1.0 cm based on the 5 μSv/hr worker dose limit with a margin factor of ten. In addition, gap thickness between two shields also induced softened neutron spectrum at outside of HDPE shield.

## REFERENCES

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