A Feasibility Study by Neutronics Analysis on the Usage of Hydrogen-rich Materials for Enhancing Blanket Shield Performance

Sunghwan Yun[a*], Seong Dae Park[a], Dong Won Lee[a], Cheol Woo Lee[a], Hyung Gon Jin[a], Chang Wook Shin[a], Suk-Kwon Kim[a], Jae Sung Yoon[a], Yi-Hyun Park[b], Mu-Young Ahn[b], and Seungyon Cho[b]

[a]Korea Atomic Energy Research Institute, Daejeon, Republic of Korea
[b]Korea Institute of Fusion Energy, Daejeon, Republic of Korea
*Corresponding author: syun@kaeri.re.kr

1. Introduction

The HCCR (Helium-Cooled Ceramic Reflector) blanket concept, in which a Li_2TiO_3 breeder, a beryllium multiplier, and a graphite reflector are used with helium coolant, has been developed [1, 2].

Previous our studies for a HCCR blanket has focused on enhancing nuclear performance of HCCR blanket with acceptable thermal-hydraulics condition. However, in addition to securing nuclear performance, it is also important to ensure sufficient shielding performance by introducing appropriate shielding.

Hence, this study analyzed the shielding performance of several candidate shielding materials and confirmed their feasibility. In detailed models such as the C-model used in the ITER neutonic analysis, neutron streaming from port-outside direction than that in the HCCR blanket direction may have a more significant impact on neutron shielding, so a simple LOCAL model is used in this study to easily examine the shielding performance of candidate materials.

2. Calculation Model and Codes

Based on the outboard blanket part of the HCCR model in reference [2], a simple local model as shown in Fig. 1 was developed and used for neutronics analysis with the MCNP6.1 code with FENDL ver.3.0 library [3]. Reflective boundary conditions were used for all other directions in the local model.

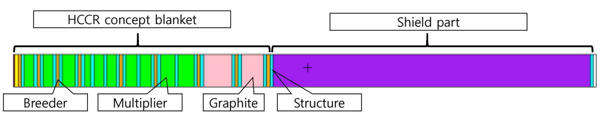

Fig. 1. Neuronics model of HCCR blanket concept with shield region

The main objective of shielding part is to reduce the fast neutron flux to lower the SDDR (ShutDown Dose Rate) of the structure that will be located after the shield as effectively as possible. Therefore, hydrogen-rich materials known to be effective in shielding fast neutron fluxes were considered as candidate shielding materials, as shown in Table I [4-6].

Table I: Specification of candidate shield Materials

Materials	Density, g/cc	Isotopes (weight fraction,%)
H_2O (ref.)	0.998	H(11.2), O(88.8)
TiH_2	3.770	H(4.0), Ti(96.0)
$Zr(BH_4)_4$	1.180	H(9.8), B(34.6), Zr(55.6)
$Mg(BH_4)_2$	1.480	H(14.9), B(40.1), Mg(45.0)

3. Numerical Results

Since our previous HCCR blanket design assumed water as a shield material, we consider water as the reference shield in this study.

Fig. 2 shows the fast and thermal neutron flux distributions in the blanket and shield regions when water is used as the shield. The fast neutron flux decreases rapidly at the beginning of the shield region due to the moderation effect of water, while the thermal neutron flux increases. It can be seen that the fast neutron flux continues to decrease and the thermal neutron flux also tends to decrease due to the neutron absorption.

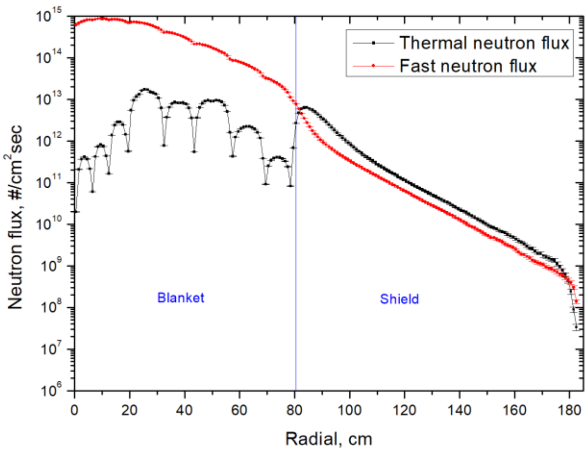

Fig. 2. Fast and thermal neutron flux distributions in a reference water shield case

Fig. 3 shows a comparison of the fast neutron flux distribution with various candidate shielding materials considered. $Zr(BH_4)_4$ exhibits fast neutron shielding performance similar to water, while TiH_2 and $Mg(BH_4)_2$ have about 100 times better fast neutron shielding performance than water because they contain more hydrogen.

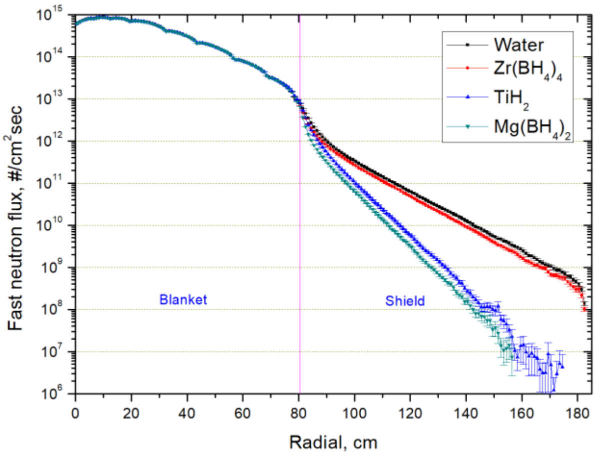

Fig. 3. Compared results of fast neutron flux distributions for considered candidate shielding materials

Fig. 4 shows a comparison of the thermal neutron flux distribution with the various candidate shielding materials considered. For thermal neutrons, $Mg(BH_4)_2$ shows the best shielding performance, with $Zr(BH_4)_4$ showing acceptable performance. However, fast neutron shielding is more important than thermal neutron shielding because thermal neutron can be easily with a very small amount of boron, which is known as a better neutron absorber, as reported in reference [7].

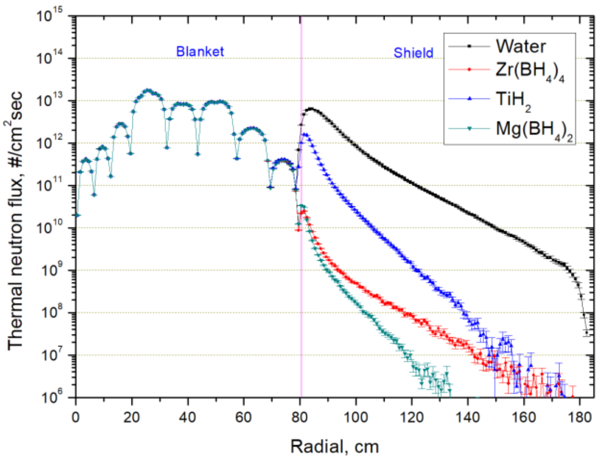

Fig. 4. Compared results of thermal neutron flux distributions for considered candidate shielding materials

3. Conclusions

In this study, neutronics analyses were performed on various candidate materials for the HCCR blanket shield to identify suitable materials for fast neutron shielding for SDDR reduction.

The analyzed results showed that materials containing more hydrogen than water have better neutron shielding performance, especially materials such as TiH_2 and $Mg(BH_4)_2$, which have about 100 times better shielding performance than water especially for fast neutron shielding.

Obviously, the good neutron shielding performance of these materials has only been analyzed form a neutronics point of view, and a more realistic design would have to take into account the cooling system to maintain the proper temperature of the shielding material, the system required to maintain the shielding material, and the purity control possibility of the shielding material.

ACKNOWLEDGMENTS

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REFERENCES

[1] S. Cho et al., Investigation of Technical Gaps between DEMO Blanket and HCCR TBM, Fusion Eng. Des. Vol. 136, p.190, 2018.
[2] S. Yun et al., Conceptual design and analysis of the HCCR breeder blanket for the K-DEMO, Fusion Eng. Des. Vol. 153, 111513, 2020.
[3] D. B. Pelowitz, et al., MCNP6^{TM} USER'S MANUAL, LA-CP-13-00634, LANL, 2013.
[4] R. Uhlar, M. Kadulova, P. Alexa, and J. Pistora, A new reflector structure for facility thermalizing D–T neutrons, J. Radioanal Nucl. Chem., Vol. 300, pp. 809-818, 2014.
[5] J. G. Fantidis, The comparison between simple and advanced shielding materials for the shield of portable neutron, International Journal of Radiation Research, Vol. 4 p. 13, 2015.
[6] S. Yun et al., An optimization study for shielding design of D-D and D-T neutron generators, Fusion Engineering and Design Vol. 146, pp. 531–534, 2019.
[7] S. Yun et al., A Neutronics Analysis for 6 MWth Small-Size Molten Chloride Salt Reactor Core, Transactions of the Korean Nuclear Society Autumn Meeting Changwon, Korea, October 20-21, 2022.