Reflector Material Effect in the Shielding Analysis for Small-Size SFR

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1. Introduction

The Sodium-cooled Fast Reactor (SFR) draws strong interest as candidates for a Gen-IV reactor concept in terms of uranium resources utilization and radioactive waste reduction.

In our previous study [1], the effect of reflector material was investigated to enhance the core performance for the 100 MWe SFR and the usage of MgO reflector showed significant improved results.

In this paper, the effects of reflector materials (D9, MgO, SiC and C) on both of the core and shielding characteristics for a new 150 MWe SFR are studied.

2. Description of the 150 MWe SFR

The reference 150 MWe SFR core [2] is loaded with a dual enriched U-10-Zr fuel. For cladding, lower shield, and radial reflector materials, D9 is used. For other components such as reactor vessel and support grid, SS316 is used. The detailed configurations are shown in Table. I.

Table I : Description of the 150 MWe small-size SFR

Number of pins in each assembly	271
Pitch of assembly	15.042
Outer diameter of fuel pin	0.74
Number of fuel assemblies	33 assemblies for 13.84 w/o, 90 assemblies for 19.28 w/o
Height of active core	100 cm
Pitch to diameter ratio	1.125
Height of lower shield	90 cm

The MCNP5 [3] model of the reference core for shielding calculation is shown in Fig 1. For the sake of simplicity, R-Z model for core and equi-volume models for other components (e.g., IHX, DHX, UIS and pump) are adopted [4].

For the accuracy of neutron source spectrum in shielding calculation, k-eigenvalue calculation was performed with 0.1 million histories per generation and 1,000 active generations based on the ENDF/B-VII.0 library.

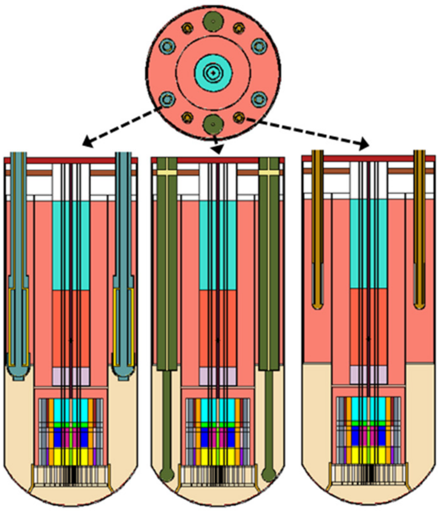


Fig. 1. Description of the MCNP5 model for reference small-size SFR

3. Reflector Material Effect in Shielding Analysis

The change of excess reactivity was investigated by replacing lower shield and radial reflector materials to MgO, SiC, and C. The eigenvalues in both of cold and hot conditions were shown in the Table II. Since the Doppler broadening effects in MgO, SiC, and C were less significant than that in D9, they showed larger excess reactivity gain in hot condition.

Table II : Eigenvalues of various reflector materials

Reflector Materials	k_{eff} in cold condition	Difference [pcm in $\Delta\rho$]	k_{eff} in hot condition	Difference [pcm in $\Delta\rho$]
Reference D9	1.07022	-	1.04020	-
MgO	1.09765	2335	1.08951	4351
SiC	1.07046	21	1.06303	2065
C	1.08210	1026	1.07448	3067

The DPA (Displacement Per Atom) of the support grid, reactor vessel, and IHX for BeO, MgO, SiC, and C reflector materials were calculated by MCNP5 tally [5] and shown in Table III. The maximum DPA was observed in the center of upper grid as in Refs. [5, 6], however, it was reduced by a factor of 4.5 for the MgO reflector.

Table III : The DPA values of various reflector materials

Reflector Materials	DPA in center of upper grid	DPA in RV	DPA in IHX
Reference D9	1.676E+00	3.115E-05	1.767E-05
MgO	3.764E-01	2.044E-05	1.025E-05
SiC	1.116E-02	2.363E-06	1.176E-06
C	1.266E-02	1.556E-06	7.376E-07

The significant DPA reduction was owing to the rapid neutron flux attenuation as shown in Figs. 2 and 3. Since ex-core detectors were in range of 10^{-2} #/cm^{2}sec to 10^{10} #/cm^{2}sec [7], the usage of MgO reflector provided an extended area for ex-core detector location without additional shielding configurations.

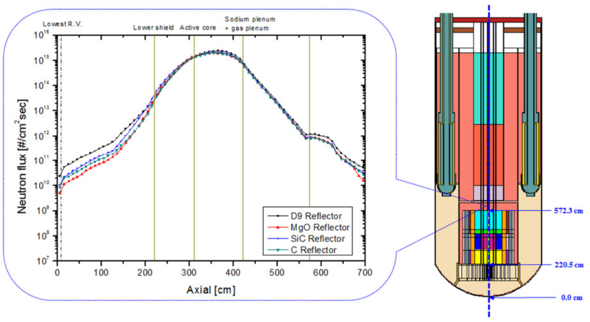
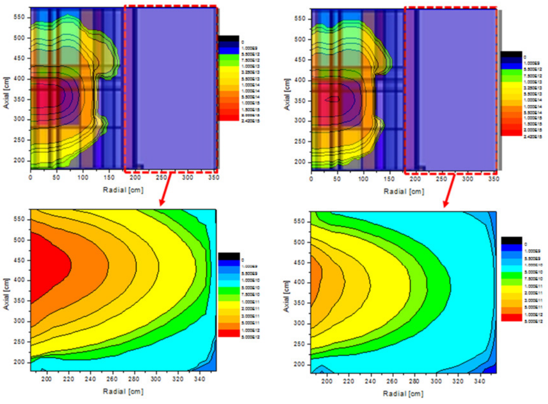


Fig. 2. Axial neutron flux distributions at center line for various reflector materials



(a) D9 reflector (b) MgO reflector

Fig. 3. Neutron flux distributions of D9 and MgO reflector

4. Determination of Lower Shield Length for MgO

In a past shielding design study [6], the value of 4.1 had been considered as the DPA limitation for SS316, however, the more conservative limitation (1.0 DPA) was selected in this study. The required MgO lower shield length was 77.64 cm for the 1.0 DPA limitation of SS316 as shown in Fig. 4. For the 77.64 cm MgO lower shield, negligible change in k_{eff} (1.08948) was resulted while the neutron flux at the lowest reactor vessel was increased by a factor of 2 (~1.23×10^{10} #/cm^{2}sec) compared to results of the 90 cm MgO lower shield (~5.11×10^{9} #/cm^{2}sec). However the neutron flux at the lowest reactor vessel was still lower than that of the 90 cm D9 reflector (~2.36×10^{10} #/cm^{2}sec)

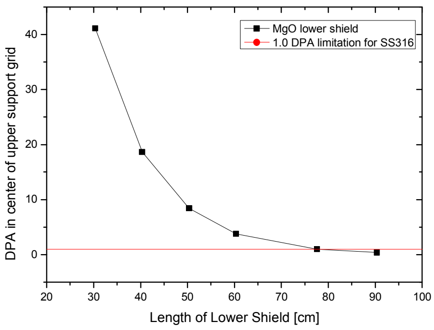


Fig. 4. DPA distributions in center of upper support grid for various sizes of MgO lower shield

5. Conclusions

The effects of reflector materials on the core and shielding characteristics were investigated. The MgO reflector showed significant improvement in excess reactivity gain (~4300 pcm at hot condition) and reduced maximum DPA (by a factor of 4.5). In addition, the sufficiently reduced neutron flux level at the reactor vessel facilitated an extended area for ex-core detector location.

For MgO, the minimum lower shield length, 77.64 cm, was proposed on the basis of the conservative DPA limit for SS316 with negligible change in k_{eff} and considerable change in the neutron flux at the lowest reactor vessel.

The effects of R-Z core model approximation and control rod position according to the burnup will be planned as further studies.

REFERENCES

[1] S. Yun, M. H. Baek, J. W. Yoo, and S. J. Kim, Effect of Reflector Material on the Neutronic Characteristics of the Small Sodium-cooled Fast Reactor, Proceedings of the Korean Nuclear Society Spring Meeting, Jeju, Korea, May 17-18, 2012.

[2] J. Y. Lim, Design Report of the Prototype SFR, SFR-DR111-WR12-2012, KAERI, 2012.

[3] X-5 Monte Carlo Team, “MCNP A General Monte Carlo N-Particle Transport Code, Version 5,” Los Alamos National Laboratory, 2003.

[4] M. H. Baek, S. Yun, and P. N. V. Ha, Shielding Design Report for Conceptual Prototype SFR, SFR-DR111-WR15-2012, KAERI, 2012.

[5] W. S. Park, et. al., Radiation Damage Estimation for Sodium-cooled Fast Reactor using MCNP and SPECTER, KAERI/TR-4400/2011, KAERI, 2011.

[6] J. W. Yoo, Y. J. Kim, Y. I. Kim, and C. M . Kang, A Preliminary Shielding Design of 150MWe Liquid Metal Reactor, Journal of Nuclear Science and Technology, vol. 37, p. 130, 2000.

[7] C. M . Kang, Ex-Core Detectors for SFR, internal seminar, KAERI, February 13, 2012.