Comparison of In-Vessel Shielding Design Concepts between Sodium-cooled Fast Burner Reactor and the Sodium-cooled Fast Breeder Reactor

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1. Introduction

An in-vessel shield to prevent secondary sodium activation (SSA) in the intermediate heat exchangers (IHXs) is one of the most important structures for the pool type Sodium-cooled Fast Reactor (SFR) [1, 2].

In our previous work, two in-vessel shielding design concepts were compared each other for the burner SFR [3]. However, a number of SFRs have been designed and operated with the breeder concept, in which axial and radial blankets were loaded for fuel breeding, during the past several decades [1,4]. Since axial and radial blanket plays a role of neutron shield, comparison of required in-vessel shield amount between the breeder and burner SFRs may be an interesting work for SFR designer.

In this study, quantities of in-vessel shields were derived and compared each other based on the replaceable shield assembly concept for both of the breeder and burner SFRs. Korean Prototype Gen-IV Sodium-cooled Fast Reactor (PGSFR) like SFR was used as the reference reactor and calculation method reported in the reference [3] was used for shielding analysis.

2. Calculation Model and Method

The configuration of the burner SFR was shown in the reference [3] while the configuration of the breeder SFR was shown in Fig. 1 through Fig. 3. In the breeder SFR, reflector assemblies were changed into radial blanket assemblies and 40 cm axial blankets were placed upper and lower part of core, respectively. Basic data of blanket assemblies were shown in Table I.

The analysis method was reported in the reference [5]. For shielding calculation, the MCNP6 code [6] was used with ENDF/B-VII.0 continuous energy cross-section library.

Table I : Data of blanket assemblies

	Radial blanket	Lower axial blanket	Upper axial blanket
Pin number	61	19	217
Pin radius	0.75	1.00	0.32

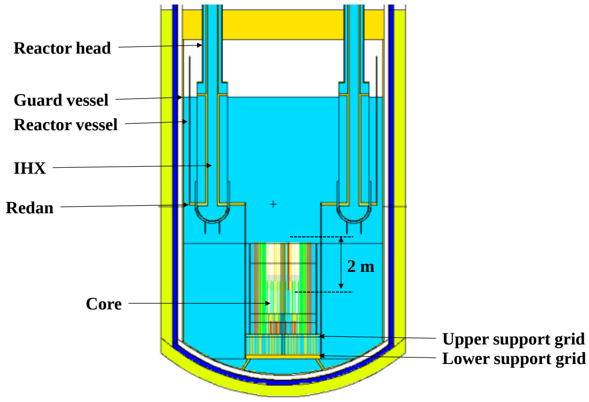


Fig. 1. Axial view of the breeder SFR model

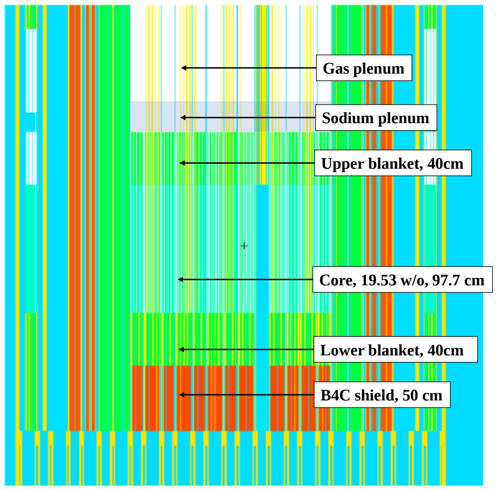


Fig. 2. Detailed axial view of the breeder SFR model

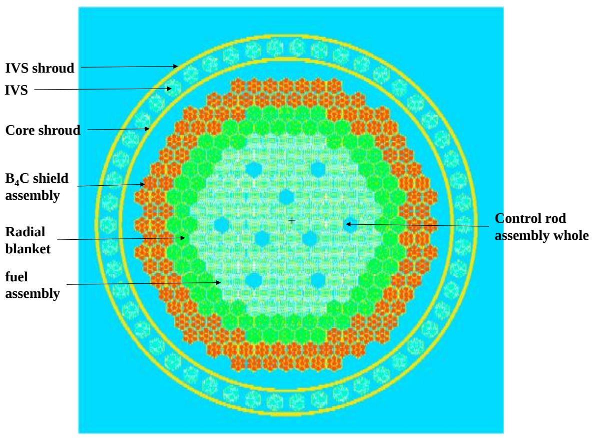


Fig. 3. Radial core configuration of the breeder SFR model

3. Analysis Results

3.1 Axial Shield

Similar to the our previous study, effect of axial shield height in the breeder SFR was evaluated and compared to that in the burner SFR as shown in Fig. 4. The detailed configuration and data of axial shield was shown in the reference [3]. Unlike the burner SFR case, the axial shield in the breeder SFR showed less efficiency.

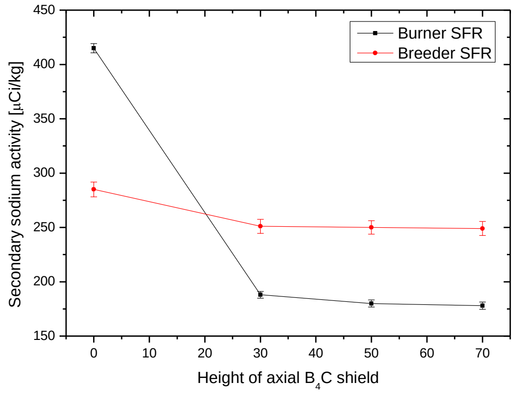
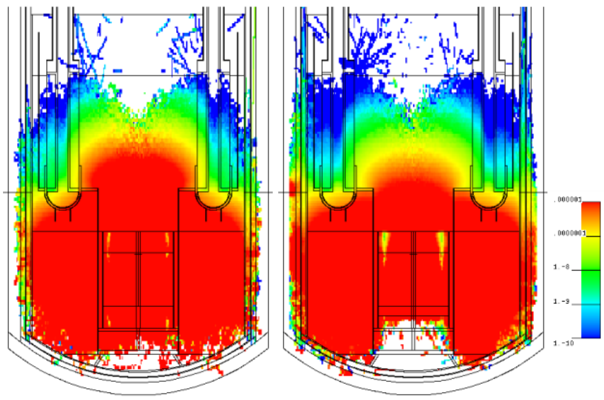


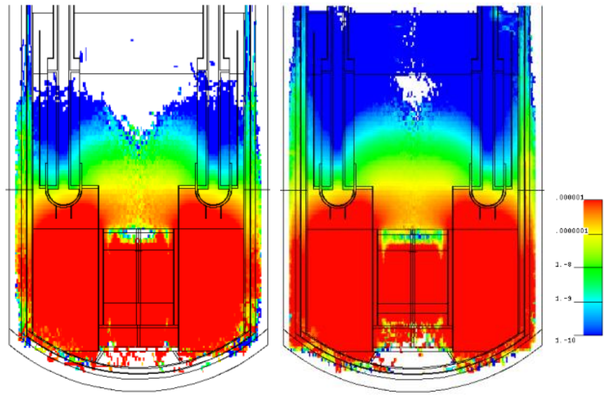
Fig. 4. SSA vs. height of axial shield

Fig. 5 showed sodium activation distributions for reference breeder/burner SFR cases while Fig. 6 showed sodium activation distributions for breeder/burner SFR with 70 cm axial shield cases, respectively.



(a) Burner SFR (b) Breeder SFR

Fig. 5. Sodium activation distributions for the reference burner and breeder SFRs



(a) Burner SFR (b) Breeder SFR

Fig. 6. Sodium activation distributions for the burner and breeder SFRs with 70 cm axial shield

Due to usage of the axial blanket, less sodium activation at the IHXs was shown in the reference breeder SFR case than that in the reference burner SFR case. However, since the axial B_4C shield could not absorb fast neutrons, considerable sodium activation at the IHXs were observed.

In radial direction, replacement of steel radial reflector to the radial blanket showed more sodium activation at the IHXs. Because steel reflector moderated neutrons and these neutrons were absorbed at the B_4C shield assembly more readily.

3.2 Radial Shield Assembly

Fig. 7 showed SSA at the IHXs in relation to number of B_4C shield assembly rings. For this analysis 30 cm height axial shield was adopted in both of breeder and burner SFRs. The breeder SFR showed higher SSA at IHXs than the burner SFR in case of two B_4C shield assembly rings (i.e., reference case), but the breeder SFR showed lower SSA at IHXs than the burner SFR in other cases (i.e., cases of increased B_4C shield assembly rings).

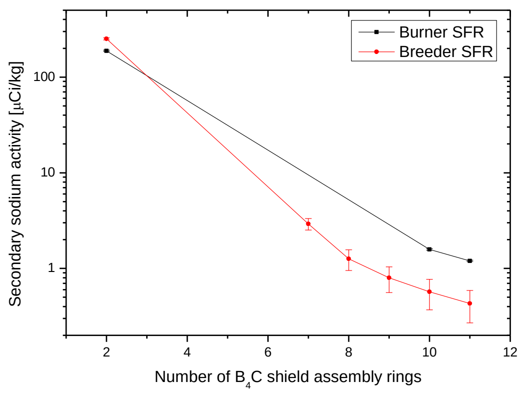


Fig. 7. SSA vs. number of B_4C shield assembly rings

For the design limit of SSA (1.6 $\mu Ci / Kg$) in the reference [1], eight B_4C shield assembly rings (corresponding reactor vessel diameter is 10.1 m) were required in the breeder SFR while ten B_4C shield assembly rings (corresponding reactor vessel diameter is 10.6 m) were required in the burner SFR.

Fig. 8 showed sodium activation distributions of the breeder and burner SFRs for the case of 10 B_4C shield assembly rings. In this case, diameter of reactor vessel was increased to 10.11 m. As discussed at the previous subsection, the breeder SFR showed worse performance in radial neutron shielding than the burner SFR. However, the breeder SFR showed better performance in axial neutron shielding due to axial blanket especially for fast neutrons. Therefore, the burner SFR required increased vessel diameter not for radial neutron shielding but for axial neutron shielding. And thus, the breeder SFR showed better performance in neutron shielding for SSA at the IHXs when more B4C shield rings were adopted.

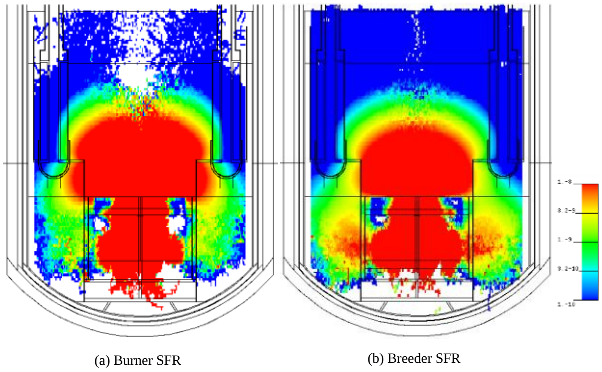


Fig. 8. Sodium activation distributions for the burner and breeder SFRs with 30 cm axial shield and 10 B_4C shield assembly rings

3. Conclusions and Discussions

In this paper, characteristics of in-vessel shielding design were studied for the burner SFR and breeder SFR based on the replaceable shield assembly concept. Due to the blanket, the breeder SFR showed better performance in axial neutron shielding. Hence, 10.1 m diameter reactor vessel satisfied the design limit of SSA at the IHXs.

In case of the burner SFR, due to more significant axial fast neutron leakage, 10.6 m diameter reactor vessel was required to satisfy the design limit of SSA at the IHXs. Although more efficient axial shied such as a mixture of ZrH_2 and B_4C can improve shielding performance of the burner SFR, additional fabrication difficulty may mitigate the advantage of improved shielding performance. Therefore, it can be concluded that the breeder SFR has better characteristic in in-vessel shielding design to prevent SSA at the IHXs than the burner SFR in the pool-type reactor.

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