Preliminary Performance Evaluation of Coolant Distribution Blocks in the Upper Plenum of a Prismatic-core VHTR

Min-Hwan Kim*, Nam-il Tak
Korea Atomic Energy Research Institute, P.O.Box 105, Yuseong, Daejeon, Korea, 305-350, mhkim@kaeri.re.kr
**Corresponding author: mhkim@kaeri.re.kr*

1. Introduction

In the Very High Temperature Reactor (VHTR) for the Nuclear Hydrogen Development and Demonstration (NHDD) project [1], a cooled-vessel design is considered an alternative for the high-Cr steel reactor vessel such as 9Cr-1Mo-V steel. The cooled-vessel design selects the SA508/533 steel, ASME Section III code approved material for the Light Water Reactor (LWR), for the material of the VHTR pressure vessel.

One of the key features in the cooled-vessel design is an internal path of the inlet coolant flow which is routed through the permanent side reflector to increase thermal resistance from the core to the reactor pressure vessel (RPV), as shown in Fig. 1. To complete the internal flow path, coolant distribution blocks (CDBs) are introduced atop of the core, which connect the upper plenum to the coolant channels of the fuel blocks in the core.

In this study, two design options of the CDBs are suggested, and their performances are evaluated by CFD analysis.

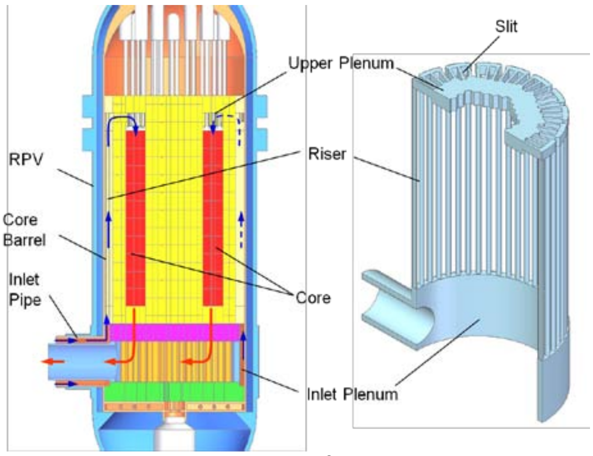


Fig. 1 RPV and reactor internals for a cooled-vessel design.

2. Design Options of Flow Distibution Blocks

The internal flow path for the cooled-vessel design includes an upper plenum in the top reflector region. As shown in Fig. 1, the upper plenum includes a plurality of mixing cavities and slits. Serveral open holes of the riser are bundled and connected with one mixing cavity and then lead to the core by passsing through more than 3 slits. In addition, a number of upper reflector supporting posts are provided for supporting the upper reflector located on top. A plurality of CDBs coupled with a bottom portion of a respective one of the supproting posts is located on top of the prismatic core in order to distribute the coolant, which is collected in a space formed by the upper reflector support, to the prismatic core. Fig. 2 shows the design concept for the upper plenum in the top reflector region.

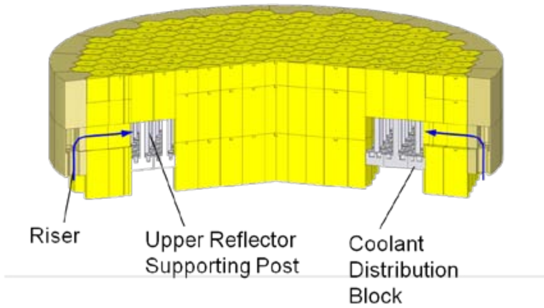
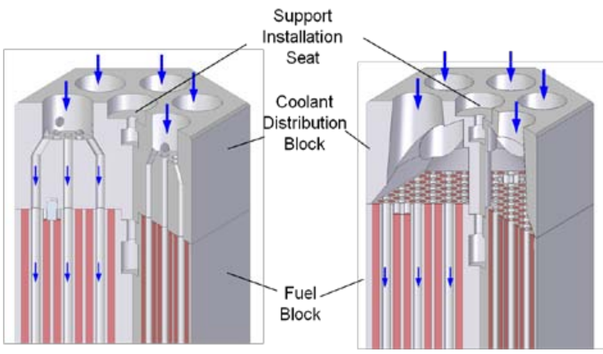


Fig. 2. Design concept for an upper plenum in the top reflector region.

The role of the CDB is to secure a space to install the upper refelctor supporting post and also provide a coolant flow channel connecting an upper plenum and coolant channels of the fuel block in the prismatic core. Two options are proposed for the present study, as shown in Fig. 3. In the first option, there are a number of small coolant flow channels connecting the passages with a coolant channel of the fuel block in the surrounding six coolant flow holes around the support installation seat. In the second option, a dome-structured cavity is directly connected to the coolant channel instead of the plurality of the holes which connect the coolant channel of the fule block in Option 1.



(a) Option 1 (b) Option 2
Fig. 3. Design options for the flow distirbution block.

3. Analysis Model

In order to investigate the performance of the CDBs, an analysis model is developed by using the ANSYS CFX code [2]. Since modelling all the CDBs in the upper plenum requires tremendous computational resource, the flow region corresponding to one fuel block is selected as the computational domain of analysis. Fig. 4 shows CFD models for each CDB.

Grid systems are obtained by combining two regions generated separately: one is the upper plenum consisting of tetra and prism meshes; and the other is the CDB and the fuel block consisting of tetra and prism meshes for the CDB, and a hexahedral mesh for the straight coolant channels. The grid systems are shown in Fig. 5.

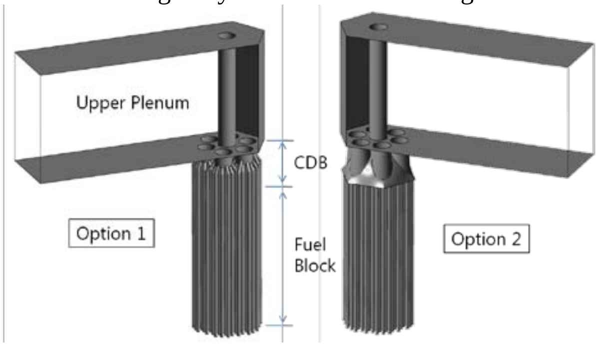


Fig. 4. Computatial models for each CDB.

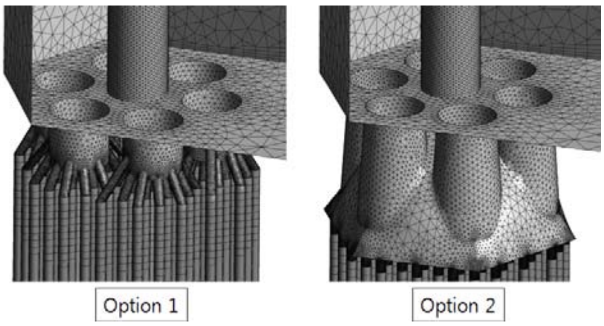


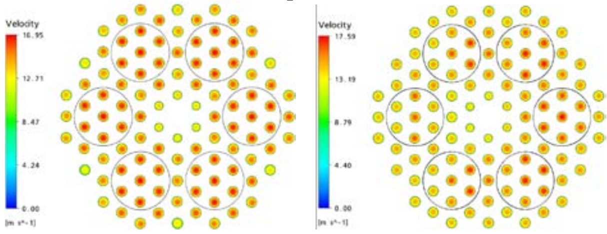
Fig. 5 Grid systems.

An iso-thermal flow is assumed because the coolant does not undergo perceivable temperature changes before encountering the fuel block. The inlet temperature and pressure are 490^{o}C and 70 bars, respectively. The inlet flow per fuel block is 1.246kg/s without bypass flow consideration. The symmetric condition is applied to the boundary surface except for the inlet and the wall in the upper plenum. A constant static pressure is applied at the outlet of coolant channels. To investigate the effect of the core pressure drop on the flow distibution, part of the coolant channel region in height is selected as a subdomain for applying the momentum source of a directional loss model.

4. Results

This section shortly describes a part of the present results. Fig. 6 shows outlet velocity distributions for both design options. In Option 1, the velocity distributions at the surrounding six coolant holes are neary similar to each other because they are independently connected to the coolant channels in the fuel blocks. Meanwhile, a high velocity in Option 2 appears in the coolant holes far from the inlet because the six holes are connected to a single cavity where the rotational intertia of the flow supplies more flow to those.

The effect of a postulated core pressure drop on the flow distirbution is shown in Fig. 7. The maximum velocity deviation is bigger in Option 1 than in Option 2. A core pressure drop of just 2.5 kPa may reduce the deviation from more than 20% to less than 8%. For the NHDD PMR 200 of which the core pressure drop is 5.9kPa, the deviation is expected within 5%.



(a) Option 1 (b) Option 2

Fig. 6. Velocity distributions at the outlet.

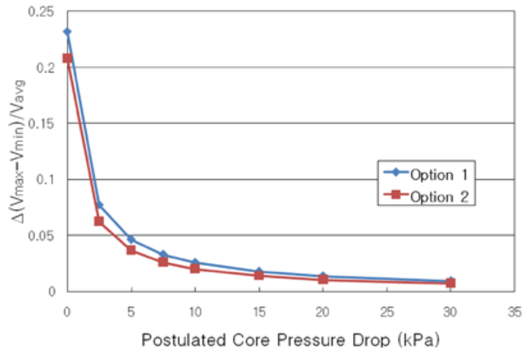


Fig. 7. Maximum velocity deviation at the outlet with a change in the postulated core pressure drop.

5. Conclusions

CFD analyses were performed to investigate the perfomance of the two design options of CDB. Results showed that the difference of the flow distributions between the two options is not so much. Without the cosideration of the core pressure drop, the velocity deviation is more than 20%. When applying the core pressure drop of NHDD PMR 200, however, the deviation drops to 5% which may be tolerable in the design of core thermal hydraulics.

Acknowledgements

This work was supported by the Nuclear Research & Development Program of the National Research Foundation of Korea (NRF) grant funded by the Korean government (MEST). (Grant code: 2009-006258)

REFERENCES

[1] J. Chang et al., “A Study of a Nuclear Hydrogen Production Demonstration Plant,” Nuclear Engineering and Technology, Vol. 39, No.2, April 2007.
[2] ANSYS CFX, Release 11.0, 2006