Effects of a Flow Mixing and Flow Path Configurations on an Air Ingress in a VHTR

Hong Sik LIM[a*], Won Jae LEE[a]
[a]*Korea Atomic Energy Research Institute, 150, Duckjin-Dong, Yusung-Gu, Deajeon, Korea, 305-353*
[*]*Corresponding author: hslim@kaeri.re.kr*

1. Introduction

The air-ingress event is a key safety issue encountered in a VHTR even with its inherent passive safety features. When the primary-pipe breaks, it is expected that the air entering the reactor vessel will chemically react with the high temperature graphite components, causing the temperature of the fuel elements to rise and the graphite components to be corroded. And thus the radioactive products that are to be released from the reactor core to the environment as well as the integrity of the graphite internals is to be loosened. It is generally accepted that there would be a grace period of time before a massive air-ingress because the air entering process is governed by a very slow molecular diffusion mechanism. However it is not clearly understood when some mechanisms accelerating an air transport are involved in the air entering process.

This study is to investigate the key major parameters affecting the air entering process, in particular the initiation time of a massive air-ingress. For the air-ingress analysis we use the GAMMA+ code [1] developed for this purpose, and we selected the prismatic-core GT-MHR [2] and its modified design [3] as reference plants.

2. Selection of Phenomenological Parameters Accelerating Air-ingress

The key parameters affecting the air-ingress process and the four analysis cases are listed in Table 1. Each case has its own system modeling to consider a specific phenomenon coming from the chosen parameters.

Table 1 Phenomenological parameters selected for the study

Key parameters	CC1	CC2	CC3	CC4
Flow mixing in the CB/RPV riser annulus	×	O	O	×
Flow mixing in the core	×	×	O	O
Shift of the inlet riser path toward the core	×	×	×	O
Reduction of fluid volume in the main flow path	×	×	×	O

The cases from CC1 to CC3 adopt the GT-MHR design having the core external flow-paths and the CC4 adopts the modified design having the internal flow-path configuration, as shown in Fig. 1.

The CC1 is to simulate the air-ingress process by a molecular diffusion only, thus it is expected that a grace period of time exists before a massive air-ingress by a natural circulation throughout the reactor system.

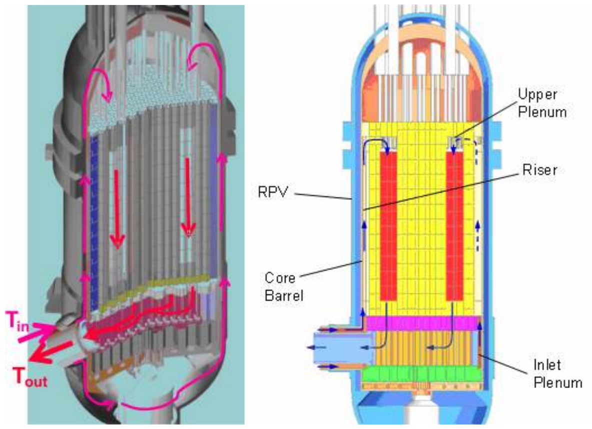

Figure 1. Flow path configurations: left (CC1-CC3) and right (CC4)

The CC2 has a two-dimensional domain at the riser annulus between the core barrel (CB) and the reactor pressure vessel (RPV) in order to consider a local circulation.

Together with a two-dimensional domain in the CB/RPV annulus, the CC3 has a detailed core flow network in order to consider a flow circulation in the core as shown in Fig. 2. The bypass flow paths modeled are those through the horizontal and vertical gaps between the graphite blocks, through the fuel coolant channels and through the reserved shutdown and control rod (RSC/CR) holes. The flow mixing in the core is caused by the lateral flows through the gaps between the graphite or fuel blocks, as shown in Fig. 3. The cross-flow model is applied between the vertical bypass channels for lateral flow.

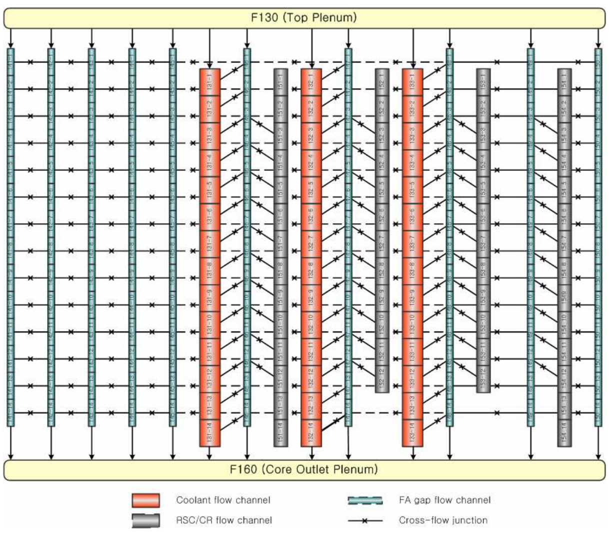

Figure 2. Core flow network model for the core coolant channels, FA gap bypasses and RSC/CR channels

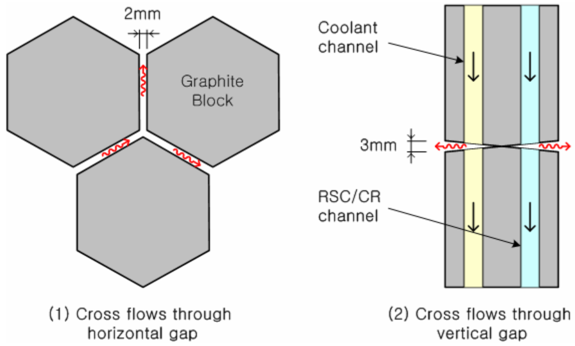

Figure 3. Cross-flow gaps between the graphite blocks in the prismatic core VHTR

The CC4 represents the modified design with cooled-vessel concept to reduce the RPV temperature. The modified configuration routes the inlet riser flow through holes in permanent side reflector to prevent a direct contact of high temperature coolant with the RPV. Therefore the coolant volume in the main flow path decreases thus increasing a stagnant volume.

3. Results and Discussions

The air-ingress event is initiated by a guillotine rupture of the primary pipe between the reactor vessel and the connected coaxial pipe. When the reactor vessel opens into the reactor cavity an infinite source of air is assumed in the analysis. Fig. 4 shows how much the initiation time of a massive air-ingress is affected by the selected parameters accelerating the air ingress.

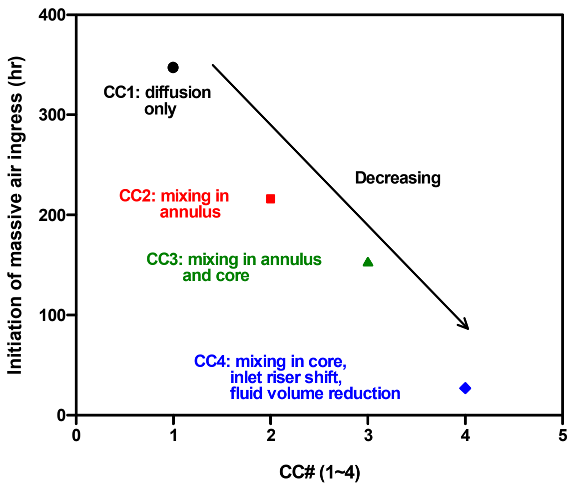

Figure 4. Initiation times of massive air-ingress for major phenomenological parameters

The CC1 governed by molecular diffusion only has the longest period of time (~15 days) before a massive air-ingress.

In the CC2 where the local circulation by the temperature difference in the CB/RPV riser annulus is considered, the period is reduced to 9 days. The air is transported much faster by a convection than by a diffusion. This mixing process by a natural convection was observed well in a vertical slot experiment [4].

In the CC3 where the flow mixing in the core is considered, the period further is reduced to 6 days by the same phenomenological reason as the local circulation in the riser annulus. In the CC2 and CC3 it is clearly indicated that in the local circulation region, a faster convection process replaces the diffusion process thus accelerating the air transport and eventually reducing the initiation of a massive air-ingress.

The CC4 contains two additional effects, shift of the inlet riser toward the core and a reduction of the coolant volume in the main coolant flow-path. When the inlet riser path shifts toward the hotter core side, the air diffusion becomes faster because the diffusion coefficient is proportional to the fluid temperature ($D_{air-He} \approx T^{1.75}$). In addition when the coolant volume in the main flow-path is reduced, it takes a shorter time for the incoming air to fill up the He-filled volume.

4. Conclusions

We investigate the key parameters affecting the initiation time of a massive air-ingress during the air-ingress event, the flow mixing and flow-path configurations. From the study, we found the following:

- In an ideal situation when the air entering process is governed by a very slow molecular diffusion only, a grace period of time before a massive air-ingress exists during the air-ingress events.
- In the real situation where the air transport is accelerated by the flow mixing in the local circulation region, however, the period before a massive air-ingress is much reduced. In particular, in the modified design with an internal flow-path configuration and thus an increased stagnant volume, the period becomes pretty much shorter.

ACKNOWLEDGEMENTS

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