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Analysis on the Density Driven Air-Ingress Accident in VHTRs

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INTRODUCTION

Air-ingress following the pipe rupture is considered to be the most serious accident in the very high temperature gas-cooled reactor (VHTRs) because of its potential problems such as core heat-up, structural integrity and toxic gas release. Previously, it has been believed that the main air-ingress mechanism of this accident is the molecular diffusion process between the reactor core and the cavity. However, according to some recent studies,^{1,2} there is another fast air-ingress process that has not been considered before, namely density-driven stratified flow.

The potential for density-driven stratified air ingress into the VHTR following a large-break loss of coolant accident (LOCA) was first described in the Next generation Nuclear Plant (NGNP) Methods Technical Program² based on stratified flow studies performed with liquid.³ Studies on density-gradient driven stratified flow in advanced reactor systems has been the subject of active research for well over a decade since density-gradient dominated stratified flow is an inherent characteristic of passive systems used in advanced reactors.

Recently, Oh et al.⁴ performed a CFD analysis on the stratified flow in the VHTR, and showed that this effect can significantly accelerate the air-ingress process in the VHTRs when compared to diffusion driven process. Oh et al.¹ also proposed to replace the original air-ingress scenario based on the molecular diffusion with the air-ingress scenario based on the stratified flow. This paper is focusing on the effect of stratified flow on the results of the air-ingress accident in VHTRs.

In this study, density driven stratified flow were investigated in the new air-ingress scenario. Two different codes were used with GAMMA-FLUENT-GAMMA sequence. Finally, onset natural convection time, core hot spot temperature and graphite structure corrosion were predicted.

AIR INGRESS ANALYSIS INCLUDING STRATIFIED FLOW PHENOMENA

The main purpose of this paper is to understand the stratified flow effect in the progression of the air-ingress analysis. To achieve this goal, our analysis was divided into three parts; (1) depressurization, (2) stratified flow and (3) diffusion and natural convection. In this work, two different codes were used for analysis; GAMMA code⁴ and FLUENT code.⁵ For prediction of stratified flow, FLUENT code was used because GAMMA code does not have detail turbulence models to calculate complicated fluid field required for stratified flow. On the other hand, depressurization and diffusion/natural convection steps were solved by GAMMA code since the large model size resulted in the high computational cost. The results of each step have been used as initial and boundary conditions for the next step.

The reference reactor was GT-MHR 600 MWt⁶ adapting a direct cycle and a prismatic core. Figure 1 shows the schematics of the system.

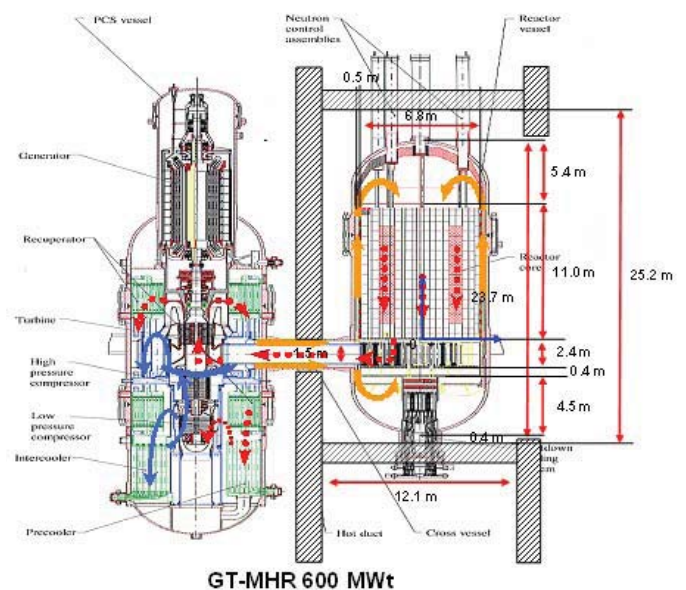


Figure 1. GT-MHR 600 MWt.⁶

a. Stratified Flow Simulation

The stratified flow in the VHTR has been predicted by FLUENT CFD analysis. The following is a summary of FLUENT options:

- 2D Segregated Solver (Unsteady)
- Non-iterative time advancement scheme
- Realizable k- ϵ model
- Energy and species (air/helium) transport equations
- Porous media assumption (core, lower plenum)
- Initial conditions were determined from depressurization calculation by GAMMA code.

Figure 2 shows some FLUENT calculation results. In our simulation, the onset of natural convection was predicted to be about 3~4 minutes after depressurization, and air filled the whole vessel within 10 minutes. It is much quicker than the previous predictions (~150 hrs) using diffusion driven flow assumption.^{4,7,8}

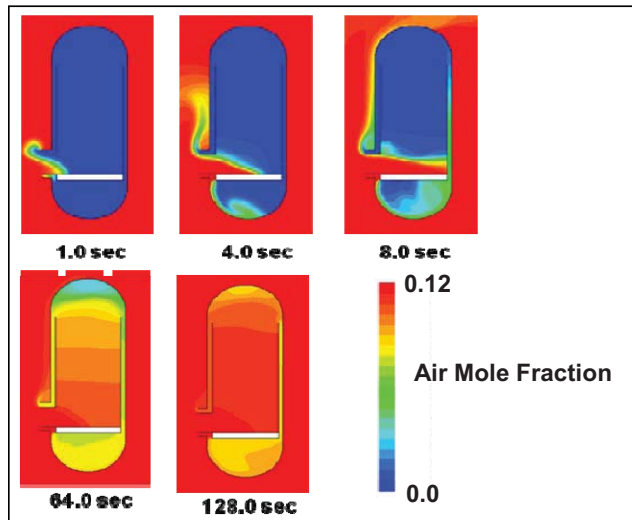


Figure 2. Stratified Flow Simulation by FLUENT.

b. Air-ingress Analysis

The next step of the air-ingress process after stratified flow has been predicted by GAMMA code. In this calculation, FLUENT code output data was implemented as GAMMA code initial values. The reactor vault size was assumed to be infinitely large to provide maximum air inventory.

Figures 3 and 4 show the results of core hot spot temperature and graphite corrosion at the lower plenum. As shown in Figure 4, the core hot spot temperature is not affected by the stratified flow effect. This is because most of oxygen is consumed at the bottom of the reactor core, so a chemical reaction is not generated at the core hot spot.

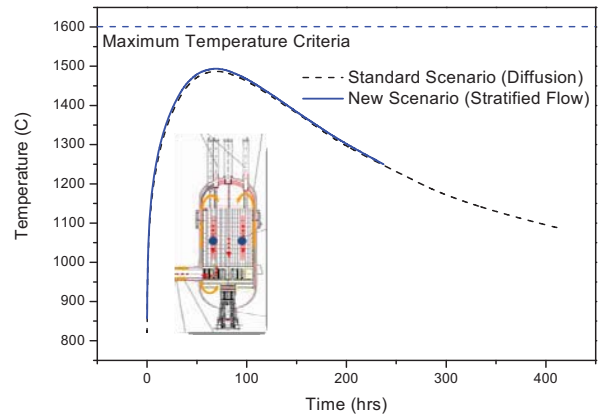


Figure 3. Core Hot Spot Temperature.

However, the oxidation of the graphite structure was highly accelerated because of significantly reduced on-set natural convection (See Figure 5).

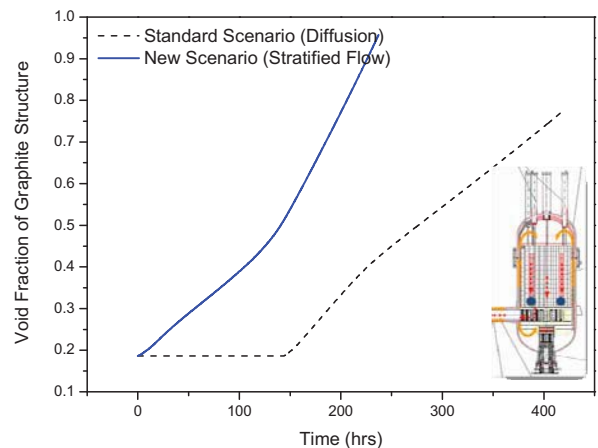


Figure 4. Void Fraction of the Graphite Core.

CONCLUSIONS

In the new scenario, the onset of natural convection was significantly accelerated by the stratified flow consideration leading to much faster oxidation in the graphite structure. This means that the previous

assumptions on the air-ingress accident will lead to the underestimation on their consequences. Therefore, it is highly recommended that the original air-ingress scenario based on molecular diffusion be replaced with the new assumption considering stratified flow. However, the core hot spot temperature was not changed by the new scenario because of the fast oxygen depletion at the lower plenum passing through the channels. However, the highly concentrated oxidation is predicted, making the potential core collapse problem at the lower plenum much more serious. Therefore, further investigation for the core collapse problem is highly recommended afterward.

ACKNOWLEDGMENT

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