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Experiments and numerical analysis of a control method for natural circulation through helium gas injection

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A B S T R A C T

This study investigated a control method for natural circulation of air by helium gas injection. A depressurization accident is a design-basis accident of a very high temperature reactor. When a primary pipe rupture accident occurs, air is expected to enter the reactor pressure vessel from the breach. Thus, in-core graphite structures are oxidized. In order to predict and analyze the phenomena of air ingress during a depressurization accident, numerical analysis was carried out using a one-dimensional (1D) analysis code and three-dimensional computational fluid dynamics (3D CFD). An experiment was carried out regarding natural circulation using a circular pipe consisting of a reverse U-shaped channel. The channel consisted of two vertical heated and cooled pipes. The temperature difference between the vertical pipes was maintained at 40–80 K, and a small amount of helium gas was injected into the channel. The injected volume of helium was about 3.1–12.5% of the total channel volume. After injecting helium gas, each component gas moved through molecular diffusion and very weak natural circulation. After approximately 1180 s, ordinary natural circulation of air was suddenly produced. The numerical results of the 3D CFD code were in good agreement with the experimental results. The numerical results also showed that the natural circulation of air can be controlled by helium gas injection.

1. Introduction

The development of a very-high-temperature reactor (VHTR), which is a next-generation nuclear plant designs, is being pursued worldwide. The Japan Atomic Energy Agency (JAEA) has successfully built and operated a 30 MWt high-temperature engineering test reactor (HTTR) and has designed commercial systems such as GTHTR300C, which is a 300 MWe gas turbine high-temperature reactor for cogeneration (Yan et al., 2003). In order to deploy a commercialized high-temperature gas-cooled reactor, JAEA is also developing and validating analytical codes for design and safety assessment aimed at the development of an economical VHTR that has high inherent safety. These analytical codes will be verified using the experimental data from the HTTR and out-of-pile test facilities.

Fig. 1 shows a schematic of GTHTR300C, and its flow path is shown in Fig. 2. When a double coaxial duct connecting a reactor core to an intermediate heat exchanger (IHX) module breaks, air is expected to enter the reactor core from the breach. In a primary-pipe rupture accident, we have to consider the possibility of not only air ingress into the core through the breached pipe but also the fuel exposed by graphite oxidation. Air ingress into the VHTR is known to follow two sequential phases, starting with molecular diffusion and very weak natural circulation of the gas mixture, followed by the sudden development of natural circulation of air once sufficient buoyancy is established (Takeda and Hishida, 2000). On the other hand, under specific boundary conditions, the onset time for producing natural circulation is short (Oh and Kim, 2011; Oh et al., 2011).

A related study investigated the air ingress process and development of a passively safe technology to prevent air ingress. In order to clarify the safety characteristics of GTHTR300C in a pipe rupture accident, a preliminary analysis of air ingress was performed (Takeda et al., 2007). The previous paper described the influence of local natural circulation in parallel channels on the air ingress process during a primary-pipe rupture accident in a VHTR (Takeda, 2010). The duration of the first stage of the air ingress process was also discussed with analytical results of the reverse U-shaped passage with parallel channels.

Previous studies have mostly focused on molecular diffusion and natural circulation of the two-component gas mixture in a reverse U-shaped tube and in a simple test model of the HTTR (Takeda and Hishida, 1992). In order to investigate the basic features of the flow behavior of the multi-component gas mixture including

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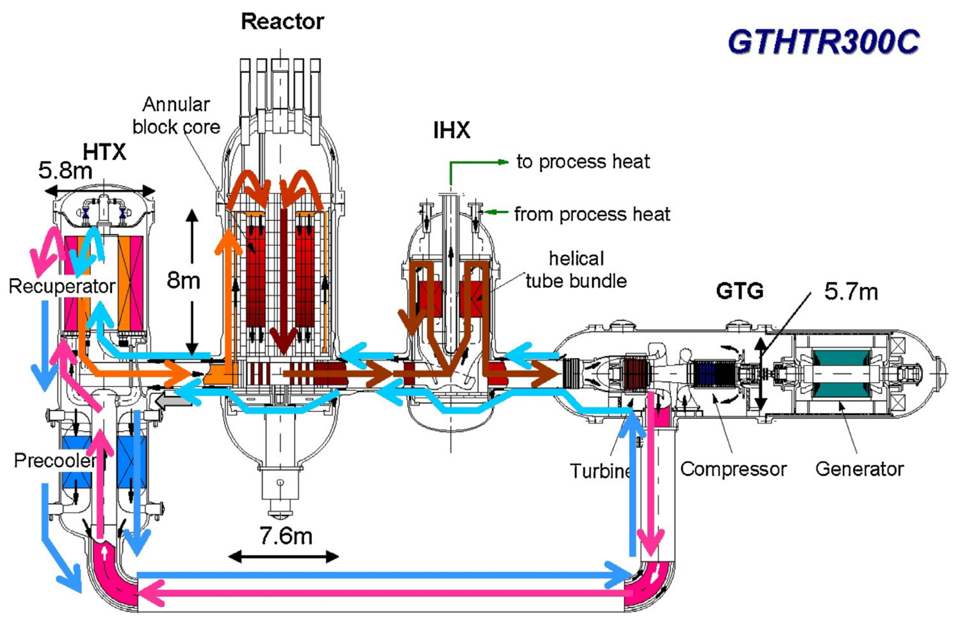

Fig. 1. Schematic of GTHTR300C.

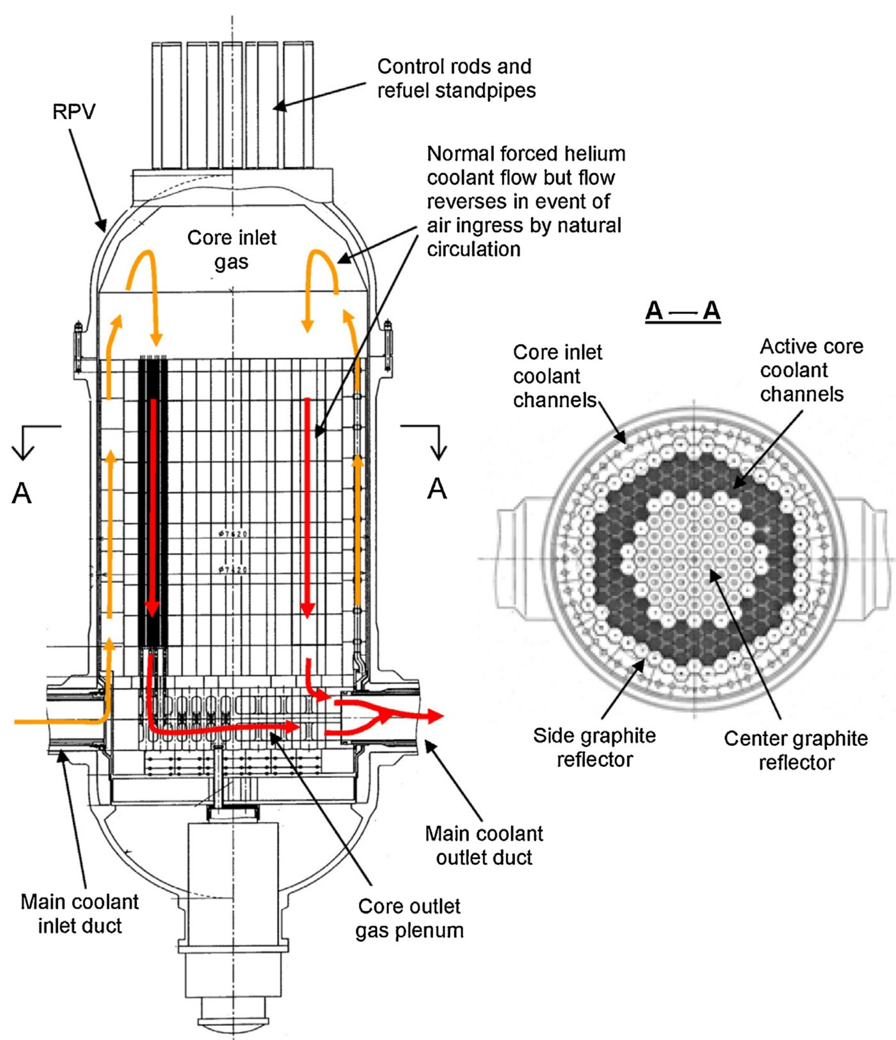

Fig. 2. Flow path in GTHTR300C.

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