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Thermal-hydraulic analyses of passive reactor vault cooling system (RVCS) in PGSFR using MARS-LMR

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A B S T R A C T

KAERI has developed a prototype Gen-IV sodium cooled fast reactor (PGSFR), which is a pool type and metallic fueled fast reactor in Korea. Recently, a reactor vault cooling system (RVCS) was designed as a mitigation feature for severe accidents in the PGSFR. The RVCS which is located between the concrete and containment vessel is a passive cooling system which utilize an air natural circulation. The major goal of the RVCS is to keep the intactness of structures such as containment vessel and reactor vessel and to confine the radioactive materials inside of the vessel. The system has an influence on the reactor vessel temperature and the reactor vessel is an important structure in a reactivity feedback during a transient, since a control rod position is changed by the reactor vessel expansion. In this study, a performance test for the designed RVCS was conducted using an individual RVCS model. In order to check the effect of the RVCS performance under accident conditions, unprotected loss of heat sink (ULOHS) and total heat removal system failure (THRSF) accidents were analyzed with and without RVCS. The RVCS has a favorable effect on the reactivity feedback during the ULOHS because the RV expansion is reduced by enhanced cooling through the RVCS and the current RVCS design has enough capacity for mitigation of a severe accident condition. In addition, in terms of internal structure integrity, the damper opening time effect is also evaluated during the THRSF.

1. Introduction

A prototype Gen-IV sodium-cooled fast reactor (PGSFR) has been designed at the Korea Atomic Energy Research Institute (KAERI) (Kim et al., 2013). The PGSFR is a pool type sodium-cooled fast reactor (SFR) with metallic fuel. Recently, a reactor vault cooling system (RVCS) has been designed for heat removal during a severe accident. The RVCS is a passive air cooling system installed between the concrete and containment vessel. The major goal of the RVCS is to cool the internal structures, such as a concrete, containment vessel, and reactor vessel in the plant.

Based on the event classification for the PGSFR, unprotected events, accompanied with a reactor protection system (RPS) failure, are categorized as the design extended condition (DEC) class. In other words, a core during an unprotected event is not scrammed by the engineering system, but by reactivity feedback. Therefore, inherent safety characteristics such as the reactivity feedback are very important in a DEC event. In addition, a severe accident is also classified in the DEC category. And when a sodium coolant boiling is basically initiating of a severe accident. In general, sodium density, Doppler, fuel axial expansion, core radial expansion, control rod drive-line and reactor vessel (CRDL/RV) expansion reactivities are considered in a sodium cooled fast reactor (SFR) (Yun et al., 2017). In particular, the RV expansion reactivity can be influenced by the RVCS since its heat transfer path is directly connected to the reactor vessel. The RVCS can provide mitigation measures for a severe accident situation including core melting. In order to evaluate the performance of the RVCS, a modeling of the RVCS with current design parameters is developed using MARS-LMR (Choi and Ha, 2016). Moreover, to evaluate the performance of the RVCS under accidents, an unprotected loss of heat sink (ULOHS) for an unprotected event and total heat removal systems failure (THRSF) for a severe accident condition with and without the RVCS are analyzed using MARS-LMR.

2. Description of PGSFR

2.1. Major systems and components

The designed thermal power of the PGSFR is 391.6 MWt (Yun et al., 2016). Fig. 1 shows a schematic of the PGSFR, and Table 1 shows the major components in the PGSFR. The components of

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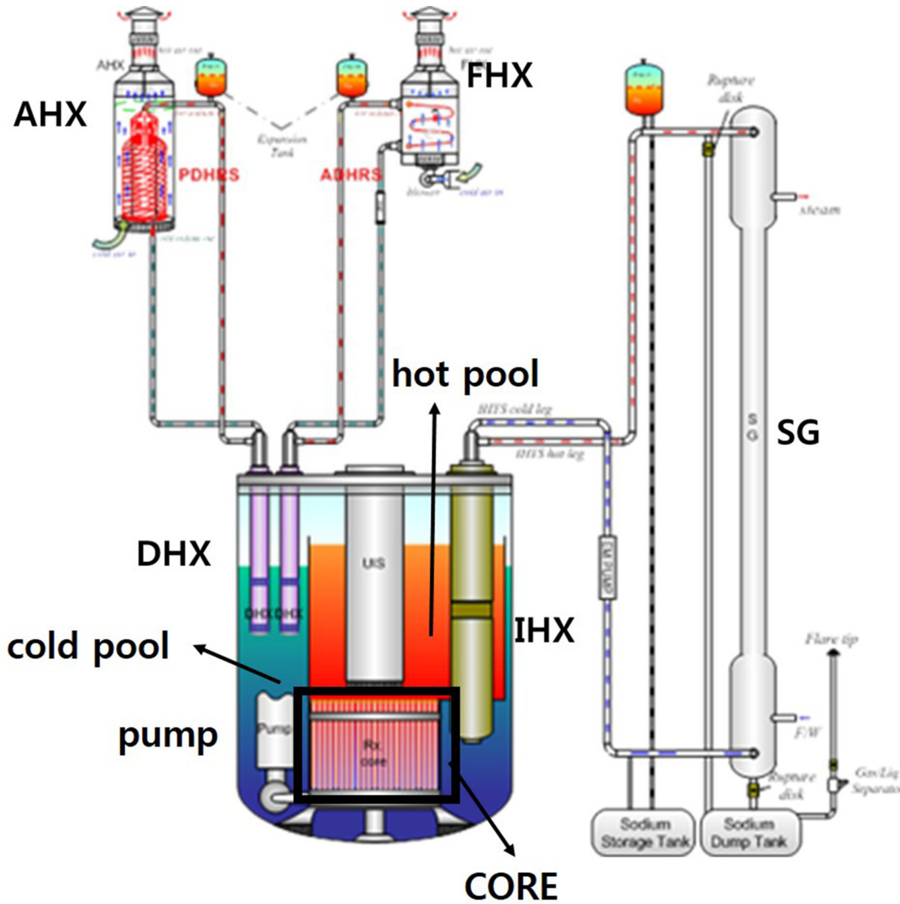

Fig. 1. Schematic of the PGSFR.

Table 1
Summary of PGSFR Systems and Components.

System	Component	The number of component	Remark
PHTS	PHTS pump	2	Mechanical pump
	Inlet plenum	1	Connection between pump and core inlet
	Subassembly	313	Multiple fuel pins, control rods, shields
	IHX	4	Inlet in the hot pool, outlet in the cold pool
	DHX	4	Into the cold pool
IHTS	Cold/hot legs	2 each	Connecting tube between IHX and SG
	SG	2	
	EM-pump	2	Driving flow in the tube-side of the IHTS
DHRS	Cold/hot legs	4 each	Connecting tube between DHX and AHX or FHX
	AHX	2	Air-sodium heat exchanger
	FHX	2	Finned air-sodium heat exchanger
	EM-pump	2	Only in active DHRS loops
	Blower	2	Only in active DHRS loops

the primary heat transport system (PHTS) are submerged in sodium pools, which are composed of cold and hot pools with free surfaces. There are two mechanical pumps to drive coolant into the core. Therefore, the core flow is determined with the pump head and pressure losses in the primary heat transport system.

The sodium coolant driven by the two PHTS pumps flows into an inlet plenum and is distributed to the individual subassemblies by a receptacle and orifices. A schematic of the core configuration is shown in Fig. 2. The core consists of five kinds of subassemblies including a fuel driver, primary control rod, secondary control rod, reflector, and B_4C shield. The total number of subassemblies is 313. The subassemblies are classified with 12 flow groups based on the designed flow rate. The fuel driver subassembly is a shape of hexagonal duct, in which many fuel pins are integrated. A single pin consists of an upper fission gas plenum, metal fuel, sodium bond, and clad. A helical wire spacer is welded in each fuel pin to prevent contact between the fuel pins. The shield structures are installed at the bottom and top regions of the fuel pin bundle region.

An intermediate heat exchanger (IHX) and decay heat exchanger (DHX) are located in the hot and cold pools, respectively. The hot sodium from the core outlet is cooled and discharged to the