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Application of direct passive residual heat removal system to the SMART reactor

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ABSTRACT

A feasibility study on the application of the DRHRS to the SMART reactor was performed, using the MARS code. As a limiting event for the evaluation, an SBO event was used. From the MARS analysis on the DRHRS evaluation, most of the thermal hydraulic behaviors showed reasonable trends in pressure, temperature, and water levels. During the simulation, it was found out that mass transfer takes place between regions in the reactor vessel, especially from 2500 s to 11,000 s. Most of the mass transfer occurred from the outer regions in the reactor vessel, e.g., RV-outer1 and RV-outer2 regions, to the RV-inner region. The cooling flowrate in the CHX of the DRHRS was maintained between 7 and 8 kg/s for the simulation time. From this feasibility study, it can be concluded that the adoption of the DRHRS to the SMART reactor is reasonable at least from the view point of an SBO event.

1. Introduction

The Korea Atomic Energy Research Institute (KAERI) launched a project to develop an SMR in 1997 and developed an integral type pressurized water reactor (PWR) with a rated thermal power of 330 MWt (electric power of 100 MWe), called a system-integrated modular advanced reactor (SMART). For the overall philosophy of the SMART reactor development, refer to Nuclear Engineering International Magazine (2010).

The single reactor pressure vessel contains all primary components such as the reactor core, steam generators, reactor coolant pumps, and a pressurizer, as shown in Fig. 1. This integral arrangement of the reactor vessel assembly makes it possible to remove the large-size pipe connections between major components, thus essentially preventing the occurrence of large break loss of coolant accidents. The in-vessel pressurizer was designed to control the system pressure at a nearly constant level over the entire range of design basis events.

Another important design feature in SMART is the introduction of simplified and improved safety systems. SMART employs passive safety systems such as a passive residual heat removal system (PRHRS) to accomplish the inherent safety functions and mitigate the consequences of postulated accidents. The PRHRS prevents overheating and over-pressurization of the primary system in the case of emergency events by removing the core decay heat through only natural circulation.

Engineered safety systems that are designed to function automatically on demand consist of a reactor shutdown system, a safety injection system, a passive residual heat removal system, a shutdown cooling system, and a containment spray system. Additional safety systems include a reactor overpressure protection system and a severe-accident mitigation system. Under any circumstances, the reactor can be shut down by inserting control rods or injecting boron.

The core is maintained undamaged for 72 h without any corrective actions by the operator. The reactor overpressure at any design basis event can be reduced through the opening of the pressurizer safety valve. The main design data of the SMART-330 reactor are summarized in Table 1.

2. Overview of DRHRS

A conceptual design of a PRHRS connected to the pressurizer (PZR) and direct vessel safety injection nozzles, called a direct PRHRS (DRHRS), used to remove decay heat during an accident was preliminarily suggested and found feasible based on the thermal hydraulic behaviors of the primary system by the authors (Kim et al., 2013). In this paper, as a further study, a further feasibility of the DRHRS to the SMART reactor was investigated in detail using the MARS-KS code (Chung et al., 2010).

A DRHRS is a kind of decay heat removal system directly from the primary system. Like in a SMART reactor, DRHRS can be connected with the top of the pressurizer as an inlet line and direct

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Nomenclature

ANS	American Nuclear Society
CHX	condensation heat exchanger
CS	core shroud
CSB	core support barrel
DRHRS	direct passive residual heat removal system
ECT	emergency cooling tank
FA	fuel assembly
FMHA	flow mixing header assembly
KAERI	Korea Atomic Energy Research Institute
KINS	Korea Institute of Nuclear Safety
MARS-KS	multi-dimensional analysis of reactor safety – KINS
PRHRS	passive decay heat removal
PZR	pressurizer
RCP	reactor coolant pump
RV	reactor vessel
SBO	station black out
SG	steam generator
SL	surge line
SMART	system-integrated modular advanced reactor
SMR	small modular reactor
UGS	upper guide structure

Symbols

ΔH	height difference (m)

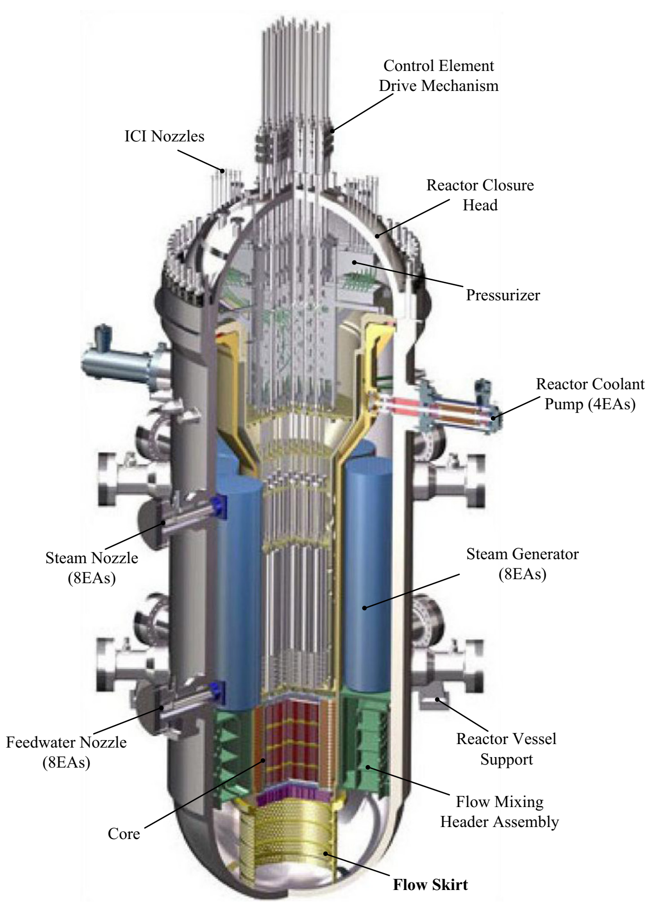

Fig. 1. Configuration of the SMART reactor.

vessel safety injection nozzles as a return line. Typically, a DRHRS consists of an emergency cooling tank (ECT), a condensation heat exchanger (CHX), and connected pipes, and its application to the SMART reactor is depicted in Fig. 2. The inlet line of the DRHRS is connected to the top of the pressurizer, and the return line of the condensate is connected to one of the safety injection nozzles. Steam from the pressurizer flows to the heat exchanger in the cooling tank, where the steam is condensed into water. This condensed water is returned to the reactor vessel through one of the direct vessel safety injection nozzles. Typical design data of the DRHRS used in this analysis are summarized in Table 2. As shown in the table, the height difference between the center of the core and that of the CHX is 14.3 m.

Table 1
Summary of main design data of SMART-330 reactor.

Reactor type: integral PWR	
Thermal power	330 MWt
Electric power	100 MWe
Desalination	40,000 ton/day
Design life	60 years
Fuel and reactor core	
Assembly type	17 × 17 square FA
Fuel material	UO_2
Maximum enrichment	5% wt%
Active core length	2.0 m
Refueling cycle	36 months
Reactor coolant system	
Design pressure	17 MPa
Operating pressure	15 MPa
Design temperature	360 °C

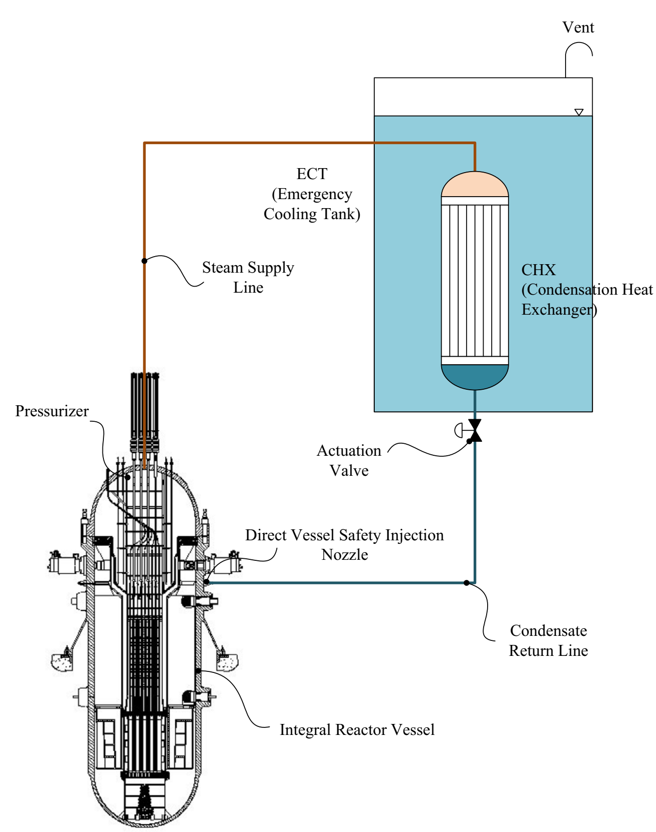

Fig. 2. Application of DRHRS to SMART reactor.