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An Integral Effect Test Facility of the SMART, SMART-ITL

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1. Introduction

SMART (System-integrated Modular Advanced ReacTor) [1] is a 330-MWth integral pressurized water reactor (iPWR) developed by KAERI and had obtained standard design approval (SDA) from Korean regulatory authority on July 2012. In this SMART design main components including a pressurizer, reactor coolant pumps and steam generators are installed in a reactor pressure vessel without any large connecting pipes. As the LBLOCA scenario is inherently excluded, its safety systems could be simplified only to ensure the safety during the SBLOCA scenarios and the other system transients. An integral-effect test loop for the SMART (SMART-ITL), or called as FESTA, had been designed to simulate the integral thermal-hydraulic behavior of the SMART.

The objectives of the SMART-ITL are to investigate and understand the integral performance of reactor systems and components and the thermal-hydraulic phenomena occurred in the system during normal, abnormal and emergency conditions, and to verify the system safety during various design basis events of the SMART. The integral-effect test data will also be used to validate the related thermal-hydraulic models of the safety analysis code such as TASS/SMR-S [2], which is used for performance and accident analysis of the SMART design. This paper introduces the scaling analysis and scientific design of the integral test facility of the SMART, SMART-ITL and its scaling analysis results.

2. Scaling and Design of the SMART-ITL

The SMART-ITL has been designed following the three-level scaling methodology which consists of integral scaling, boundary flow scaling, and local phenomena scaling. Its height is preserved to full scale and its area and volume are scaled down to 1/49 compared with the prototype plant, SMART. The maximum core power is 2.0 MW, which is about 30% of the scaled full power. Design pressure and temperature of the SMART-ITL can represent maximum operating conditions, that is, 18.0 MPa, 350^{o}C, respectively. Figure 1 shows the schematic diagram of the SMART-ITL facility.

The SMART-ITL consists of a primary system, a secondary system, 4 trains of passive residual heat removal system (PRHRS), 4 trains of safety injection system (SIS), 2 trains of shutdown cooling system (SCS), a break simulator (BS), a break flowrate measuring system (BMS), and auxiliary systems. The primary system includes the reactor pressure vessel (RPV), steam pressurizer, four steam generators (SGs), four reactor coolant pumps (RCPs) in order to simulate asymmetric loop effects. An annular downcomer design is applied at the upper part to simulate a multi-dimensional effect. However, as the scaled-down annular downcomer of the SMART-ITL is not enough to contain the SGs, four SGs are installed outside of the RPV by two connecting pipes above and below each SG like hot and cold legs, which facilitates relevant measurements. Four secondary steam lines are lumped into a direct condenser tank where the steam generated by four SGs is condensed and the condensed feedwater is again injected into the SGs.

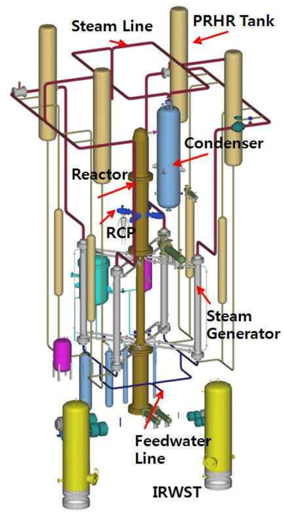

Figure 1 Schematic diagram of the SMART-ITL facility

The PRHRS is composed of four trains, each of which includes an emergency cooldown tank (ECT), a heat exchanger (HX), a makeup tank (MT), several valves, and connecting pipes. It is connected to feedwater and steam lines of the secondary system and the natural circulation flow path is formed by opening the isolation valve by the actuation signal. It is designed to have the same pressure drop and heat transfer characteristics and arranged to have the same elevation and position as those of the SMART. Also the diameter, thickness, pitch, and orientation of the heat exchanger tubes of the SMART-ITL facility are the same as those of the SMART. During the PRHRS operation, the superheated steam generated from the steam generator secondary side is directed to and condensed in the PRHRS heat exchangers by natural circulation. The condensed water flows downward through the PRHRS condensate line and returns to the feedwater line. The condensing heat is transferred to the ECT, which is an ultimate heat sink.

The SIS and the SCS can simulate several operation modes such as charging, letdown, spray, safety injection, long-term cooling, shutdown cooling, and recirculating operations. The BS consists of a quick opening valve, a break nozzle and instruments. The BMS has a function to collect the break flow and maintains a specified pressure in order to simulate the back-pressure of the containment. A separator in the BMS separates a liquid phase from a two-phase break flow and each separated flow rate in a single phase condition is measured by a different measuring technique. The separated liquid and gas flow rates are measured respectively by weighing a mass of accumulated water and by a dedicated flowmeter. The SMART-ITL is also equipped with some auxiliary systems such as a makeup water system (MWS), a component cooling water system (CWS), a compressed air system (CAS), a steam supply system (SSS), a vacuum system (VS) and a heat tracing system (HTS).

The control and data acquisition system of the SMART-ITL has been built with a hybrid distributed control system (DCS). The input and output modules are distributed into 5 cabinets and they are controlled by two central processing units (CPUs). The raw signals from the field are processed in a system server and the converted signals are monitored and controlled through the human-machine interface (HMI), which consists of 52 processing windows classified according to the SMART fluid system.

The number of instruments is up to 1,014 at present. Instrument signals can be categorized according to the instrument type, such as temperature, static pressure, collapsed water level, differential pressure, flow rate, power, and weight, etc. The core heater cladding temperatures are measured for several radial and axial locations with more than 260 thermocouples, and the fluid temperatures in the RPV are measured with more than 100 thermocouples.

3. Scaling Analysis of the SMART-ITL Design

Design of the SMART-ITL was assessed by scaling analysis as described in this section.

3.1 SMART-ITL Nodalization

The MARS-KS nodalization for the SMART-ITL is represented in Figure 2. The nodalization for MARS-KS analysis includes all the reactor coolant systems (RCSs), SIS and the secondary system including PRHRS.

3.2 Simulation Conditions

For the SBLOCA simulation, a safety injection line break is assumed and only one of the four safety injections is assumed to be operable based on a single failure assumption. The safety injection flow rate of the SMART-ITL is scaled down to 1/49 of that of the SMART. The break size is also reduced according to the area scale ratio of 1/49.

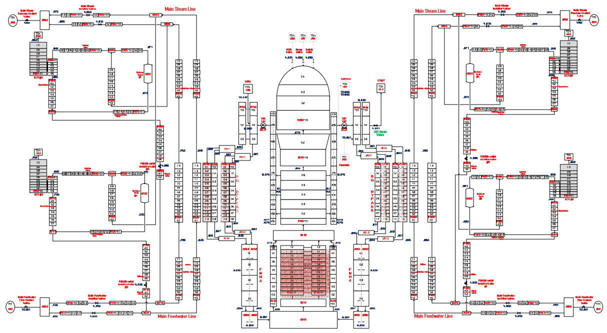

Figure 2 Nodalization diagram of SMART-ITL for MARS-KS model

3.3 Simulation Results

Initial steady-state condition is obtained to match with the full power operating conditions of the SMART. With it, scoping analysis was carried out to assess any scaling distortion of the SMART-ITL with the SMART reactor system using the same SBLOCA scenario. On the whole, the results for the SMART-ITL show a good agreement with those for the SMART in view of scaling distortion. Based on the results of the scaling analysis, detailed design of the SMART-ITL followed.

4. Conclusions

The design of the SMART-ITL facility and its scaling analysis results were introduced. The SMART-ITL can be used to understand the various thermal-hydraulic phenomena during normal and transients conditions and to verify the design safety of the SMART. With the SMART-ITL facility a series of thermal-hydraulic verification tests will be performed to demonstrate the design performance and safety of the SMART. The test results will be also be used to validate the system thermal-hydraulics analysis codes such as TASS/SMR-S and MARS-KS. The role of the SMART-ITL will be extended to examine and verity the normal, abnormal and emergency operating procedure required in the construction and export phases of the SMART.

ACKNOWLEDGEMENTS

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