Simulation of natural circulation on an integral type experimental facility, MASLWR

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1. Introduction

Oregon State University (OSU) has constructed a system-level test facility to examine natural circulation phenomena to integral reactors. Series of three tests have been conducted from 2002-2003 at the OSU MASLWR test facility in order to assess the behavior of this reactor concept in both normal and transient operation. After the test series, the OSU MASLWR test facility was reconfigured to eliminate a recurring grounding problem and improve facility reliability in anticipation of conducting an IAEA International Collaborative Standard Problem (ICSP). The purpose of ICSP is to provide experimental data on flow instability phenomena under natural circulation conditions and coupled containment/reactor vessel behavior in integral-type reactors, and to evaluate system code capabilities to predict natural circulation phenomena for integral type PWR, by simulating an integrated experiment.

2. MASLWR test facility and experiment

The MASLWR is an integral pressurized light water reactor relying on natural circulation during both steady-state and transient operations. The MASLWR's safety systems are designed to operate passively. There are no emergency cooling pumps and offsite power is not required for safety system operation. The reactor pressure vessel (RPV) is surrounded by a cylindrical containment partially filled with water. This containment provides pressure suppression and liquid makeup capabilities.

The OSU MASLWR test facility shown in Fig. 1, models the MASLWR design including reactor pressure vessel cavity and containment structure. It is scaled at 1:3 length scale, 1:254 volume scale and 1:1 time scale, and is designed for full pressure (11.4 MPa) and full temperature (590 K) prototype operation.

The test facility includes three components. The first is the primary circuit which includes the reactor pressure vessel with its internal components (core, hot leg riser, steam generators, pressurizer) and ADS blowdown lines. The second is the secondary circuit which includes the steam generator (internal to vessel), feed water pump, and associated feed water and steam valves. The third is the containment structure [1].

Power maneuvering was conducted to characterize the steady-state natural circulation in the primary side during various core powers. Power inputs of the core heaters were increased step by step from 10 percent of full power to 80 percent of full power, with a 10 percent increment at each step. For each power input, the primary side flow rate, hot leg and cold leg temperatures were measured. The primary side and steam generator pressures were maintained at 8.6 MPa and 1.4 MPa, respectively.

Fig. 1 OSU MASLWR facility

3. ANALYSIS RESULTS

3.1 Computer code and nodalization

For calculation of ICSP natural circulation, TASS/SMR code has been used [2]. TASS/SMR code is a thermal-hydraulic system analysis code that is developed by KAERI, focused on an integral PWR, SMART. The main purpose of the code is to simulate all relevant phenomena, processes and conditions of reactor coolant system that may occur during transients. Several conservative transient models are adopted to describe the thermal hydraulic behavior of plants conservatively.

The core is modeled by 6 nodes with same height. Core power fraction is evenly distributed to 6 core nodes. Steam generator is nodalized with 10 nodes with same height. Every structure of primary system such as vessel and barrel, and high pressure containment (HPC) are considered as heat structure. However, structures for secondary system and cooling pool vessel (CPV) system are not considered as heat structure except heat transfer plate between HPC and CPV. Ambient heat loss is given as boundary condition and proportionally distributed by node height to vessel-adjoining nodes.

2.2 Analysis results

For steady state calculation, thermal-hydraulic values such as core power and feedwater flow rate should be given as boundary condition. The steady state calculation is carried out using initial conditions with pressurizer water level of level 0.36 m, pressurizer pressure of 8.72 MPa and core heater power of 41.1 kW. The heat loss to ambient is assumed 12.25 kW from experimental results. The calculated results are compared with experimental values as shown in Table 1.

Table 1: Initial conditions

Parameter	Unit	Exp.	Cal.
PZR pressure	MPa	8.72	8.72
PZR level	m	0.36	0.36
Core power	kW	41.05	41.1
Primary flow	kg/s	0.50	0.67
Core inlet Temp.	℃	250.34	250.82
Core outlet Temp	℃	262.72	262.76
Steam pressure	MPa	1.46	1.46
Steam Temp	℃	255.94	261.43
Secondary flow	kg/s	0.0103	0.0102

The transient initiated by an increase of the core power heaters step by step. A natural circulation flow is developed as shown in Fig. 2 due to a density difference between a heat generation in the core and a heat removal through the steam generator. The flow rate increases with the core heater power. The TASS/SMR code over-predicts the primary natural circulation flow at the beginning of the 40 kW but the code under-predicts it at the end of 320 kW. The mass flow increases to 1.9 kg/s from 0.5 kg/s for the power of 320 kW from 40 kW in the experiment however the mass flow rate increases to 1.48 kg/s from 0.67 kg/s in the calculation. An increase rate of the calculated flow rate increased for the heater power is smaller than the experimental results. A sensitivity study is performed to improve the calculated natural circulation flow by the TASS/SMR code. The results are shown in Fig. 2. Fig. 3 shows the fluid temperature at the core inlet and outlet. The fluid temperature at the inlet and outlet is predicted well by the TASS/SMR-code although the temperature difference between the inlet and outlet sides is over-predicted owing to under-prediction of the primary mass flow by the code. To evaluate bypass heat transfer between the hot and cold sides in the reactor vessel, coolant temperatures of core outlet and SG inlet are compared. The code under-predicts the bypass heat transfer slightly.

3. Conclusions

A natural circulation in the primary side during various core powers is analyzed using TASS/SMR code for the integral type experimental facility.

The calculation results show higher steady state primary flow than experiment. If it matches the initial flow with experiment, it shows lower primary flow than experiment according to the increase of power. The code predictions may be improved by applying a Reynolds number dependent form loss coefficient to accurately account for unrecoverable pressure losses.

REFERENCES

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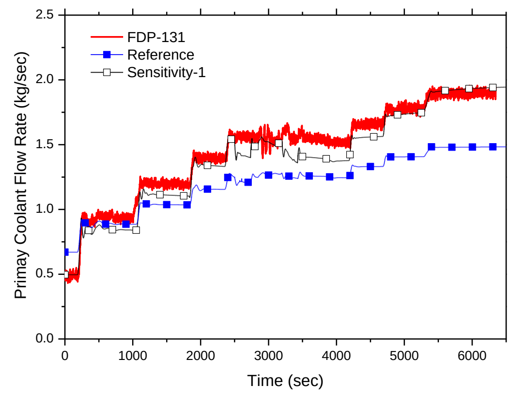

Fig. 2 Primary mass flow rate

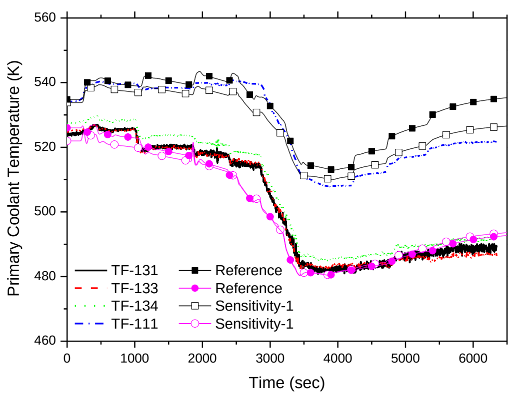

Fig. 3 Primary coolant temperature