Transactions of the Korean Nuclear Society Spring Meeting
Gwangju Korea, May 30-31, 2013

Simulation of loss of feedwater transient of MASLWR test facility by MARS-KS code

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1. Introduction

Since 2009, IAEA has conducted a research program entitled as ICSP (International Collaborative Standard Problem) on integral PWR design to evaluate current the state of the art of thermal-hydraulic code in simulating natural circulation flow within integral type reactor. For this ICSP, experimental data obtained from MASLWR (Multi-Application Small Light Water Reactor) [1] test facility located at Oregon state university in the US have been simulated by various thermal-hydraulic codes of each participant of the ICSP and compared among others. MASLWR test facility is a mock-up of a passive integral type reactor equipped with helical coil steam generator. Since SMART reactor which is being current developed domestically also adopts helical coil steam generator, KINS has joined this ICSP to evaluate performance of domestic regulatory audit thermal-hydraulic code (MARS-KS code) in various respects including wall-to-fluid heat transfer model modification [2] implemented in the code by independent international experiment database. In the ICSP, two types of transient experiments have been focused and they are 1) loss of feedwater transient with subsequent ADS operation and long term cooling (SP-2) and 2) normal operating conditions at different power levels (SP-3). In the present study, KINS simulation results by the MARS-KS code (KS-002 version) for the SP-2 experiment are presented in detail and conclusions on MARS-KS code performance drawn through this simulation is described.

2. Test facility description and its nodalization

Major components of MASLWR test facility are composed of core, PZR (Pressurizer), RPV (Reactor Pressure Vessel), HPC (High Pressure Containment), CPV (Containment Pool Vessel), HTP (Heat Transfer Plate), ADS (Automatic Depressurization System), SG (Steam Generator) and FWS (Feedwater System). In normal operation mode, primary coolant flows up within a chimney inside of the RPV by buoyancy force generated at the core which is located in bottom part of the chimney and then the coolant exchanges heat with the helical coil SG. After that, the coolant goes down through a downcomer and returns to the core again. In case of emergency, ADS operates and it relieves pressure build-up within the RPV by venting high pressure and temperature steam to HPC. Steam delivered to the HPC is condensed on the HTP which transfers heat from the HPC to the CPV through condensation heat transfer. That is, the CPV has a role of final heat sink in the MASLWR test facility when any accident happens. When the SP-2 transient begins as feedwater stops abruptly and then resulting heat-up of the RPV is relieved first through vent lines of the ADS by venting high temperature and pressure steam to the HPC. After equilibrium in pressure between the RPV and the HPC reaches, recirculation lines of the ADS are open additionally and long term cooling establishes. Nodalization for simulating the SP-2 experiment by the MARS-KS code is shown in Fig. 1. In this nodalization, multiple helical coil tubes of the SG is modeled as lumped one pipe, the HPC and the CPV are modeled partially two pipes, valves located in the ADS are assumed as trip valve. As for heat structures, only three components are considered in the model. (the core, the SG and the HTP) Additional assumptions made for the SP-2 transient simulation are: Non-condensable gas fills the upper part of the HPC and the CPV initially; Water temperatures of the HPC and the CPV are 300.15K, respectively; Heat loss is negligible; The CPV is open to atmosphere during whole the transient etc. Helical coil specific wall-to-fluid heat transfer model of the MARS-KS code is used and standard choked flow model (Henry-Fauske) with default parameters is used for the SP-2 simulation, too. Surface roughness of 3.0E-5m and heat structure material of stainless Steel are uniformly employed and control logic for the ADS is model according to the MASLWR test facility description report. [1] In developing the nodalization, SNAP tool (version 2.0.7, August 15, 2011) developed by the US NRC was used.

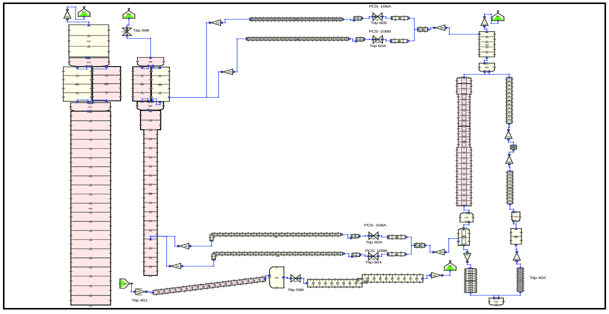

Fig. 1. Nodalization for MASLWR Test Facility.

3. Results of the MARS-KS code simulation

3.1 Steady state

Since the SP-2 transient is triggered from a steady state of which core power is 299kW by stopping feedwater, steady state simulation was performed first to establish initial condition of the SP-2 transient. In the steady state simulation, form loss coefficients within the RPV which were mostly determined with reference to CRANE handbook [3] are further tuned with respect to the steady state primary mass flowrate of the SP-2 experiment. Resulting steady state calculation is compared with experimental data in Table 1.

Table 1. Steady state comparison of the SP-2

Parameter	MASLWR	UNIT	EXP	CALC
Pressurizer pressure	PT-301	MPa(a)	8.718	8.718(BC)
Pressurizer level	LDP-301	M	0.3606	0.3434

Power to core heater rods	KW-101/102	kW	297.4	299(BC)
Feedwater temperature	TF-501	℃	21.2	21.39(BC)
Steam temperature	FVM-602-T	℃	205.4	203.85
Steam temperature	Avg. of TF-611 to TF-634	℃	203.1	207.21
Steam pressure	FVM-602-P	MPa(a)	1.411	1.411(BC)
HPC pressure	PT-801	MPa(a)	0.127	0.127653
HPC water temperature	TF-811	℃	26.7	27.0
HPC water level	LDP-801	m	2.820	2.813
Primary flow at core outlet	FDP-131	kg/s	1.734	1.734
Primary coolant temperature at core inlet	TF- 121/122/ 123/124	℃	215.1	214.97
Primary coolant temperature at core outlet	TF-106	℃	251.5	251.96
Feedwater flow	FMM-501	kg/s	0.106	0.1099
Steam flow	FVM-602-M	kg/s	0.106	0.1099
CPV water level	LDP-901	m	6.35	6.41
CPV water temperature	TF-815	℃	25.95	27.0

As can be shown the table, almost all variables calculated agree well with the experimental data. Especially, core inlet and outlet temperatures predicted by the code simulation show good agreement and steam temperature and feedwater mass flowrate also show reasonable agreement.

3.2 Transient state

Using the initial conditions established by the steady state run, transient simulation of the SP-2 experiment was performed in the following procedures. First, feedwater flow was shut off. Then, when the PZR pressure reached 1300psig, core heater was tripped and decay power mode was set. After that a vent valve in vent lines of the ADS operated automatically depending prescribed control logic to mitigate the transient. The PZR and the HPC pressures behaviors shown Fig. 2 display good agreement in pressure equilibrium time between the PZR and the HPC although higher pressure level is predicted in early phase of the SP-2 transient. Figure 3 shows core inlet temperature comparison between the transient calculation and the experimental data. As can be shown the figure, sudden core inlet temperature drop due to opening of valves in recirculation line of ADS for long term cooling is well predicted by the code.

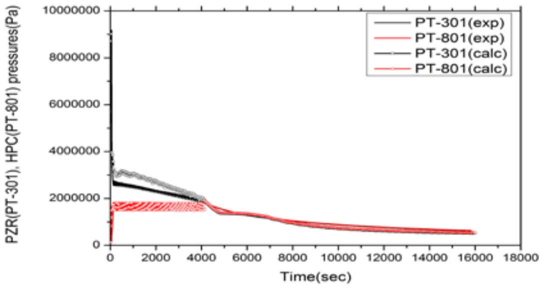

Fig. 2. Comparison of PZR and HPC pressures.

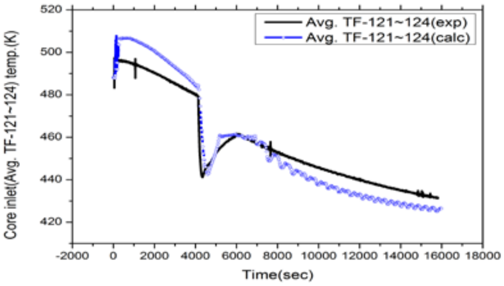

Fig. 3. Comparison of core inlet temperature.

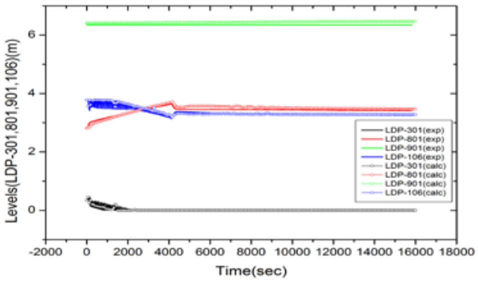

Fig. 4. Comparison of various levels.

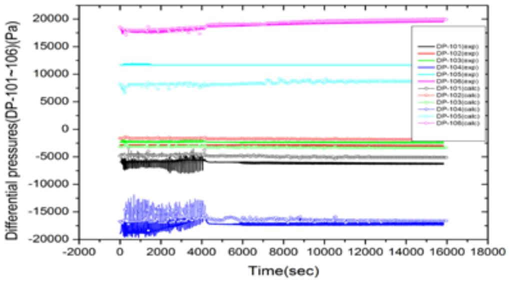

Fig. 5. Comparison of differential pressures.

Figure 4 shows various levels trends prediction for the RPV, the HPC, the CPV and the PZR agree well with the experimental data. Calculated pressure drops within the RPV also show reasonable trends and values compared with the experimental data. (See, Fig. 5.)

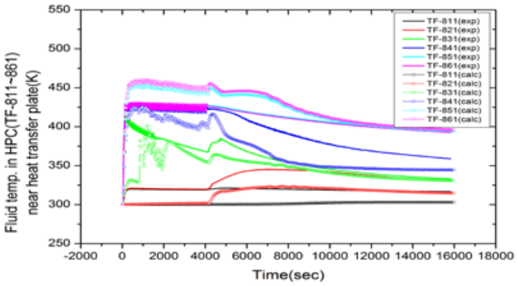

Fig. 6. Comparison of fluid temperatures in the HPC.

HPC fluid temperature prediction shown in Fig. 6 displays reasonable agreement with the experimental data but coincidence is not good as other parameters because three-dimensional effect within the HPC and axial conduction along the HTP are not well simulated.

4. Conclusion

Performance of the MARS-KS code is evaluated through the simulation of the loss of feedwater transient of the MASLWR test facility. Steady state run shows helical coil specific heat transfer models implemented in the code is reasonable. However, through the transient run, it is also found that three-dimensional effect within the HPC and axial conduction effect through the HTP are not well reproduced by the code.

REFERENCES

[1] Galvin, M. R. and Bower, C. J., OSU MASLWR Test Facility Modification Description Report, OSU-MASLWR-07002, 2010.

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[3] CRANE Co, Flow of Fluids through valves, fittings and pipe, Technical Paper No. 410, 2009.