Simulation of 50% DVI Line SBLOCA in the ATLAS Integral Test Facility Using MARS-3D Code

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1. Introduction

For a thermal-hydraulic integral effect test facility, ATLAS (Advanced Thermal-hydraulic Test Loop for Accident Simulation) [1], a 50% break of a DVI line of the APR1400 (named SB-DVI-07) [2] was carried out and selected as the 50th international standard problem exercise (ISP-50) by OECD/CSNI on November, 2008 due to its technical importance.

Since the multi-dimensional peak cladding temperature (PCT) behavior in the core was observed in the SB-DVI-07, the 3-dimensional (3-D) core model is used for the MARS-3D [3] simulations.

2. MARS-3D Modeling

MARS-3D (MARS-KS version 002) used for the present simulation is started with a consolidated code of RELAP5/MOD3 and COBRA-TF. Then, MARS-KS has been equipped with multi-D component to model a three dimensional component with Cartesian and cylindrical coordinate system.

Overall nodalization diagram is shown in Fig. 1. For this nodalization the number of volumes, junctions and heat structures are 1096, 2435, and 406, respectively.

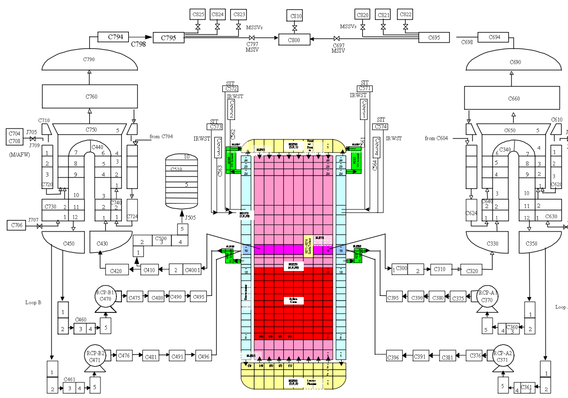
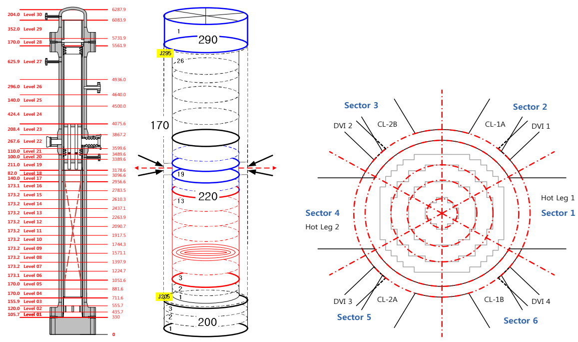


Fig. 1. Nodaization of the ATLAS facility.

2.1 Multi-Component Model

The reactor pressure vessel component is modeled as 3-D components (as shown in Fig. 2): 30 axial, 5 radial, and 6 azimuthal sectors. The active core region has 10 axial sub-volumes, each 4-heater group is located at 1st, 2nd, 3rd, and 4th radial ring, respectively.



(a) axial nodalizations (b) radial rings and azimuthal sectors

Fig. 2. MARS multi-D component for reactor vessel.

2.2 Bypass Modeling

- 2 hot leg bypass lines connecting the downcomer region and the inlet of 2 hot legs
- 2 upper head bypass lines connecting the upper head and the neighboring downcommer region

2.3 Heat Structure Model

Every heat structure is modeled to account the stored energy and heat loss to the ambient. For the active core region 24 heat structures are modeled to each 4-heater group

- 1 heat structure for each sector of the ring
- Uniform heat capacity for each heater rod and heat loss is considered : 3.98 kW/rod.

Table I: Number of heater rods for each sector / ring

	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6	No.	kW / rod	kW
Ring 1	4	3	3	4	3	3	20	3.980769	79.6
Ring 2	16	12	13	16	12	13	82	3.980769	326.4
Ring 3	21	24	24	21	24	24	138	3.980769	549.4
Ring 4	25	25	25	25	25	25	150	3.980769	597.1
	66	64	65	66	64	65	Total No. 390		Total power 1552.5 kW

2.4 Choked Flow Model

Trapp-Ransom model is used to match to test break flow.

2.5 Turbine Boundary Pressure

Turbine boundary pressure is set to ambient pressure. And turbine flow area is adjusted to get a test flow rate.

3. Calculation Results

3.1 Steady-state Results

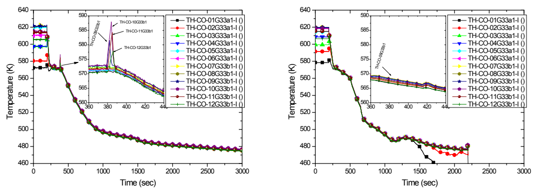
The 3-D model in the reactor vessel component by MARS-3D well predicts the steady state results of ISP-50 as shown in Table II.

Table II: Comparison of steady state results

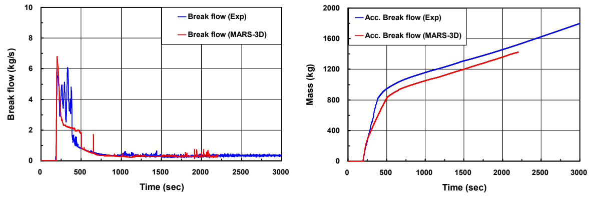
Parameter	Measured value	MARS	Instruments
Primary system			
- Core power (MW)	1.535	1.535	Including heat loss
- PZR Pressure (MPa)	15.596	15.596	PT-PZR-01
- Core inlet temp. (K)	563.2	565.5	TF-LP-02G18
- Core exit temp.(K)	598.2	599.2	TF-CO-07-G14, G18, G21, G25
- Hot leg temp. (K)	597.6	598.2	TF-HL1-03A
	598.5	598.3	TF-HL2-03A
- Cold leg temp. (K)	565.4	563.2	TF-CL1A-04A
	565.3	563.2	TF-CL1B-04A
	565.0	563.2	TF-CL2A-04A
	565.2	563.2	TF-CL2B-04A
- RCS flow rate (kg/s)	2.2	1.964	QV-CL1A-01B
	±5%	1.964	QV-CL1B-01B
		1.966	QV-CL2A-01B
		1.966	QV-CL2B-01B
- Pressurizer level (m)	3.32	3.38	LT-PZR-01
Secondary system	(SG1/SG2)		
- Pressure (MPa)	7.83/7.83	7.91/7.91	PT-SGSD1-01/PT-SGSD2-01
- Steam temp. (K)	568.6/568.8	567.4/567.4	TF-SGSD1-03/TF-SGSD2-03
- FW temp. (K)	507.6/508.4	507.6/508.4	TF-MF1-03/TF-MF2-03
- FW flow rate (kg/s)	0.431/0.435	0.45/0.45	QV-MF1-01/QV-MF2-01
- Water level (m)	2.03/1.97		LT-SGSDDC1-01/LT-SGSDDC2-01
ECCS			
- SIT pressure (MPa)	4.19/4.21/4.23	4.19/4.21/4.23	PT-SIT1,2,3-02

3.2 Transient Results

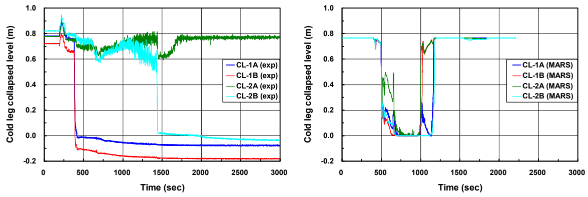
Initial and transient behavior of cladding temperatures is well predicted except the over-cooling of the cladding temperatures at the 1st and 2nd measurement location at the end of the test (Fig. 3). However the 3-D effect of PCTs in the core region is not captured by the MARS-3D, whereas the heater rods located in the 4th quadrant of the cross sectional view showed a higher increase in the PCT than those in other quadrants from the experimental results. The break flow during the two-phase discharge is under-predicted, while the plateau of the primary pressure is not predicted during this period. Accumulated mass of break outflow is under-estimated (Fig. 4) due to the under-estimation of break mass flow rate during the two-phase discharge. As we can see in Fig. 5, the loop seal clearing is predicted in all intermediate legs in calculation results, whereas the loop seal were cleared only in CL-1A and CL-1B (2 out of total 4 cold legs) intermediate legs in experiment.



(a) experiment (b) MARS-3D
Fig. 3. Cladding temperatures in the heater sub-group G33.



(a) instant break flow (b) accumulated break flow
Fig. 4. Comparison of break flow between prediction and measurement data.



(a) experiment (b) MARS-3D
Fig. 5. Collapsed level in the CL intermediate leg.

Experiment - 1st loop seal clearing: 383 s (CL-1A & CL-1B) - 2nd loop seal clearing: 1236 s (CL-2B)
MARS-3D - 1st loop seal clearing: 271 s (all)

4. Conclusions

The 3-D model in the reactor vessel component by MARS-3D well predicts the steady state results of ISP-50. However present MARS-3D simulation cannot show the non-uniformity of PCTs. The break flow during the two-phase discharge is under-predicted, while the plateau of the primary pressure is not predicted during this period. The loop seal clearing is predicted in all intermediate legs in calculation results, whereas the loop seal were cleared only in CL-1A and CL-1B intermediate legs in experiment

For the future study the optimization of the number of multi-components (900 cells in the present model) should be investigated to enhance the calculation efficiency (about 91,000 s of CPU time is used for 2,200 s of the transient simulation).

REFERENCES

[1] K.H. Kang et. al, "Detailed Description Report of ATLAS Facility and Instrumentation", KAERI/TR-4316/2011.
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[3] B.D. Chung et. al, "MARS CODE MANUAL VOLUME II: INPUT REQUIREMENTS", KAERI/TR-2811/2004.