Analysis of ATLAS LTC-04R Test for Loop Seal Reformation Phenomena using RELAP5

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1. Introduction

US-NRC issued about the loop seal reformation and their consequences of APR1400 in APR1400 Design Certification project [1]. They requested the technical basis to show that the reactor core cooling will be maintained before and after the potential loop seal clearing and that the peak cladding temperature remains within acceptable limits.

The 4th domestic standard problem (DSP-04) exercise was started on February 27, 2015. The loop seal reformation issue was selected to be the analysis topic of the DSP-04 based on the technical discussion between the participants and the operating agencies (KAERI and KINS) and domestic experts meetings. After that, KAERI performed LTC-04R test which is 4inch top-slot cold-leg break test using ATLAS facility in December 27, 2015.

KHNP CRI, as a participant of the DSP-04, performed the blind calculation and open calculation using RELAP5/Mod3.3 patch 3. This paper deals with the results of open calculation for ATLAS LTC-04R test. The results of several sensitivity analyses such as the critical flow modeling sensitivity and break flow system modeling sensitivity will be discussed.

2. Results of Open Calculation

2.1 Steady-state results

The base nodalization is modified from the ATLAS-MARS-SS-REV04 input which is provided by the operating organization. As shown in Fig. 1, the ECCS configuration is made as four SIPs and four SITs. The SI pipe lines are modeled as pipe components and their hydraulic volumes and heads are considered. The SI line is modeled as 5 sub-volumes. In sensitivity analysis, loop seals nodalization effect is analyzed as shown in Fig. 2. The bypass flow paths through the upper head and downcomer are removed, which is same with an experimental condition.

To model the top slot break, an off-take junction and off-take volume are modeled in the steady state input. The off-take junction is 564 component and the off-take volume is 565 component as shown in Fig. 3.

Table I shows the results of steady-state calculation. Major variables in the primary and secondary are well predicted with the experimental data.

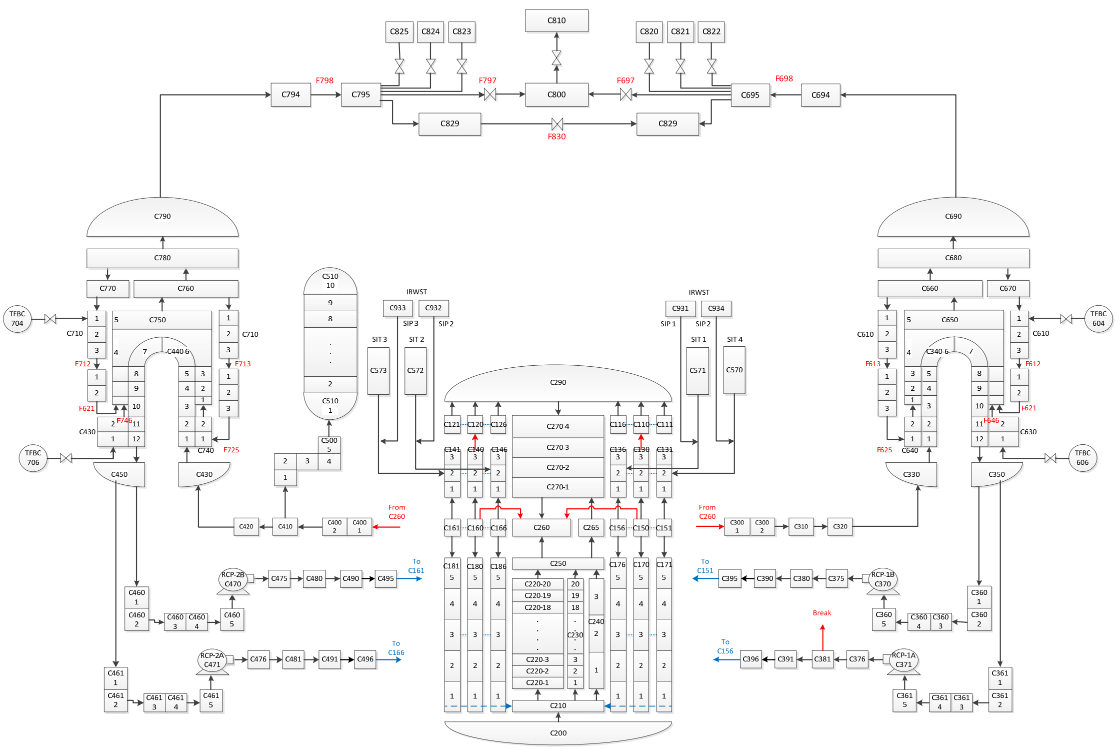

Fig. 1. Nodalization of ATLAS

Table I : Result of Steady-State Calculation

Parameter	Exp.	Cal.	Diff. %
Core Power (MW)	1.65533	1.65533	0.0
Heat Loss (kW)	88.67	89.59	1.0
PZR Pressure (MPa)	15.56	15.56	0.0
Core Inlet Temp. (K)	564.15	562.54	0.3
Core Outlet Temp. (K)	599.99	599.99	0.0
RCS Flow Rate (kg/s)	1.98	1.89	4.6
PZR Level (m)	-	5.51	-
SG Dome Press. (MPa)	7.83	7.82	0.15
SG Steam Temp. (K)	568.75	566.56	0.39
FW Temp. (K)	507.05/ 506.15	507.05/ 506.15	0.0
FW Flow Rate (kg/s)	0.410/ 0.413	0.438/ 0.438	6.8
SG Water Level (m)	4.99/ 4.99	4.99/ 5.00	0.0
Circulation Ratio (-)	-	-	-
Heat Removal (MW)	-	0.78/ 0.78	-
Heat Loss (kW)	-	58.62	-

2.2 Summary of Blind Calculation

In the blind calculation, Henry-Fauske model is used in the critical flow model. The discharge coefficient is 0.85 and the non-equilibrium factor is 0.14.

The blind calculation was focused on the off-take modeling sensitivity, fine nodding of loop seals and CCFL model sensitivity as shown in Table II.

However, there are no meaningful tendencies in the clearance time and reformation time. At around 2500sec, all loop seals are reformed because the water is enough to cover the RCS due to maximum SI flow. Though all loop seals are reformed, the increase of cladding temperature is not observed.

After the test data are opened, we knew that the break flow modeling is important and safety injection pump logic has error in the test specification. After that, operating agency corrects this variable [2].

At around 200 ~ 500 seconds, the break flow is under-predicted from the test data as shown in Fig. 5 and the choking flag of HF model shows choking flag repeats on and off. Hence, depressurization rate of PZR after loop seal clearance is far away from the test data as shown in Fig. 4.

Table II : Sensitivity Analysis Matrix in the blind calculation

Cases	Offtake Modeling	Break system Modeling	Fine nodding of loop seals	CCFL model
Basecase	O	O	O	Wallis
Case1	X	X	X	Wallis
Case2	O	X	X	Wallis
Case3	O	O	X	Wallis
Case4	O	O	O	Kutateladze

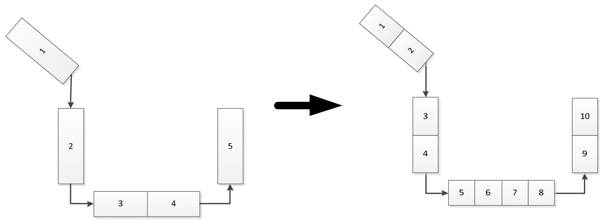

Fig. 2. ATLAS Loop Seals Nodalization

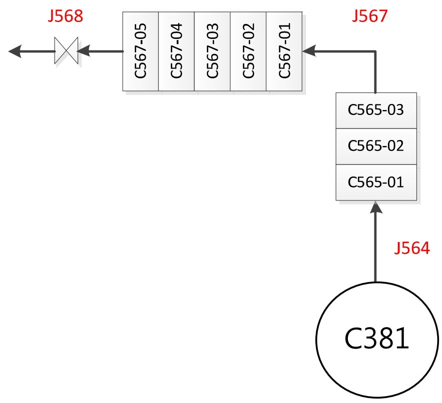

Fig. 3. Break system nodalization

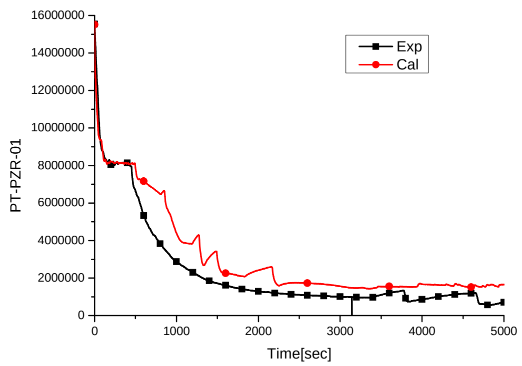

Fig. 4. PZR pressure in Blind Calculation

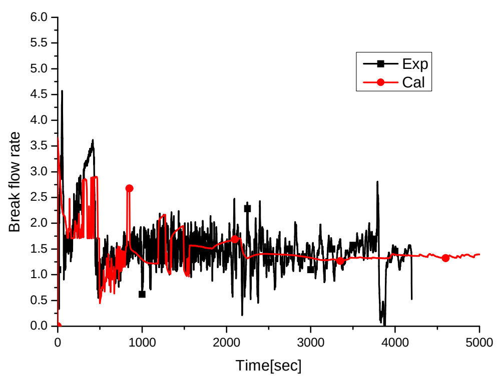

Fig. 5. Break flow in Blind Calculation

2.3 Results of Open Calculation

In the open calculation, Ransom-Trapp model is used in the critical flow model. Sub-cooled discharge coefficient is fixed as 0.8 and two-phase discharge coefficient is varied from 0.8 to 0.2.

As shown in Fig. 6 and 7, RT model shows better results in the system pressure behavior compared with HF model (Fig. 4). Below the 0.6 in the two-phase discharge coefficient, primary pressures are well predicted. But if the fixed sub-cooled discharge coefficient is changed, best combination of discharge coefficient may be changed. In this paper, we deal with the fixed sub-cooled discharge coefficient.

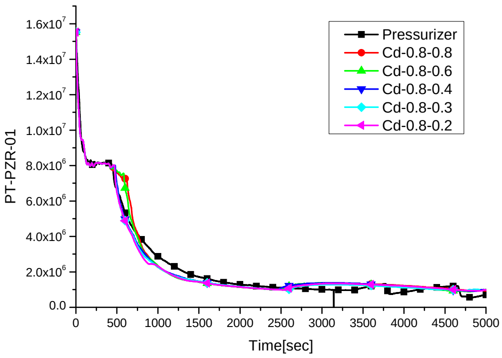

Fig. 6. PZR pressure

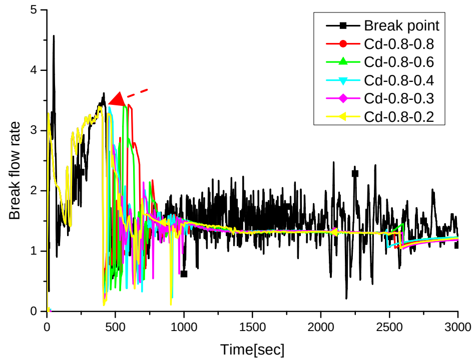

Fig. 7. Break flow

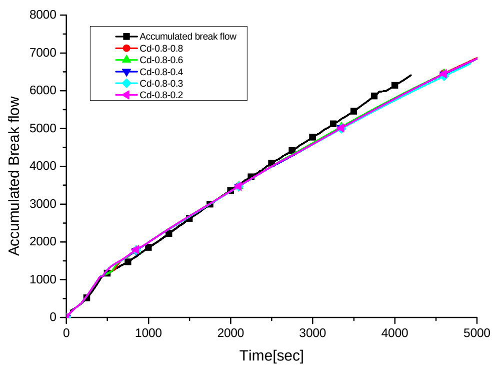

Fig. 8. Accumulated break flow

After 500 seconds, break flow is changed by varying the two-phase discharge coefficient as shown in Fig. 7. However, this is very small difference in the accumulated break flow as shown in Fig. 8.

After 1,000seconds, all cases show the linear break flow rate but the test results are bigger than the calculation results. This is because the SIT flow rate as shown in Fig. 9. At around 1,000 seconds, SIT flow rate in the calculations shows discontinuous flow rate but the test results shows the continuous flow rate until 3,500 seconds. Therefore, accumulated total SI flow in the calculation starts to under-predicted at 1,500 seconds.

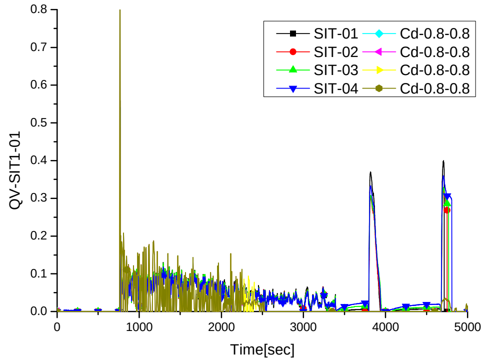

Fig. 9. PZR pressure

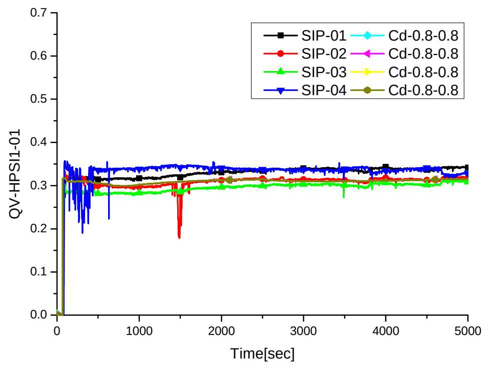

Fig. 10. SIP flow-Cd0.8-0.8

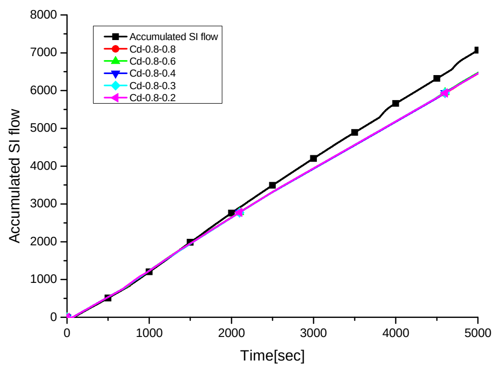

Fig. 11. Accumulated Total SI flow

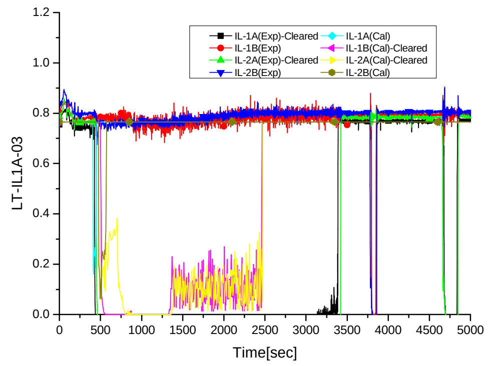

Fig. 12. Loop Seal Level (Cd-0.8-0.4)

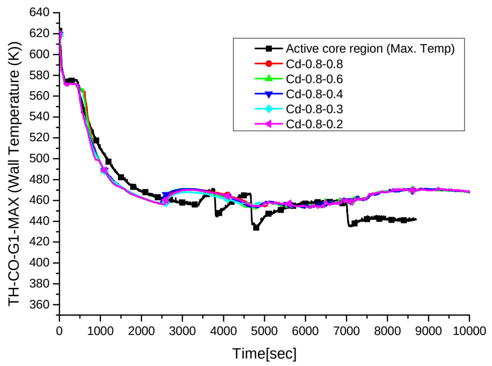

Fig. 13. Loop Seal Level (Cd-0.8-0.4)

As shown in Fig. 10, SIP flow rate in the calculation is similar with the test data after the correction of SIP flow logic which is provided by the operating agency. SIPs flow rate in the test data are different with each other but SIPs flow rate in the calculation are same with each other. This leads under-estimation of accumulated SI flow as shown in Fig. 11.

In the calculation, loop seals clearance time is almost same with the test data but reformation time in the calculation is predicted earlier than the test as shown in Fig. 12.

After the loop seals reformation, cladding temperature is slightly increased but it is not significant as shown in Fig. 13.

3. Conclusions

Several possible factors in the loop seal reformation behavior are examined in the sensitivity analysis. Heat loss modeling, fine break system modeling, fine loop seal nodalization and off-take modeling are not significant factor in the loop seal reformation. Still critical flow model and discharge coefficient are dominant factors. Based on the ATLAS LTC-04R, Ransom-Trapp model shows better prediction in the break flow than the Henry-Fauske model.

However, they cannot change the impact of this analysis in terms of the increase of cladding temperature above the regulatory criteria due to the loop seal reformation.

REFERENCES

[1] NRC, APR1400 Loop Seal and Its Impact on Long Term Cooling During a Postulated Loss-of Coolant Accident, ML14134A347, NRC, 2015.
[2] J. R. Kim et al, Analysis Report on the Long Term Cooling Test for Cold-leg Top Slot Break, KAERI, 2016.