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Investigation of Loop Seal Clearing Phenomena for the ATLAS SBLOCA Long Term Cooling Test using TRACE and MARS-KS

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1. Introduction

During Design Certificate(DC) review of the APR1400, USNRC raised a long term cooling safety issue on the effect of loop seal clearing during cold leg Small Break Loss Of Coolant Accident(SBLOCA) due to relatively deep cross-over loop compared to the US PWRs[1]. Using ATLAS test facility[2], Korea Atomic Energy Research Institute(KAERI) performed 4 inch cold leg break SBLOCA long term cooling test, LTC-CL-04R to resolve the safety issue.

The objective of this study is thus to investigate the loop seal clearing phenomena during cold leg slot break SBLOCA long term cooling and resolve the safety issue on the SBLOCA long term cooling related to the APR1400 DC. TRACE[4] and MARS-KS[5] were used to predict the test results and to perform sensitivity studies for the SBLOCA loop seal clearing phenomena.

2. Descriptions of ATLAS Test LTC-CL-04R

The LTC-CL-04R is top-slot cold leg break SBLOCA test during long term cooling[1]. In the experiment, a 7.12 mm nozzle was installed in upward direction at cold leg 1A of ATLAS to simulate a 4.0 inch top-slot break. To simulate best estimate conditions, 4 SIPs with maximum flow rate as well as 4 SITs were assumed to actuate and SI fluid temperature was ambient temperature[3].

3. TRACE and MARS-KS Analyses

2.1 Code and OS Environment

TRACE Code V5.0 patch 4[3] and MARS-KS V1.3[5] were employed for the prediction of the ATLAS Test LTC-CL-04R. The calculations were performed using an Intel Core i7 Processor under the Microsoft Windows environment

2.2 ATLAS Nodalization

ATLAS test facility has been simulated using TRACE and MARS-KS nodalizations as shown in Fig. 1 and Fig. 2. Thermal hydraulic models for both steady state and transient analyses were updated on the basis of the ATLAS steady-state model using TRACE and MARS-KS codes of previous research[2]. All setpoints were determined according to the test specifications [1].

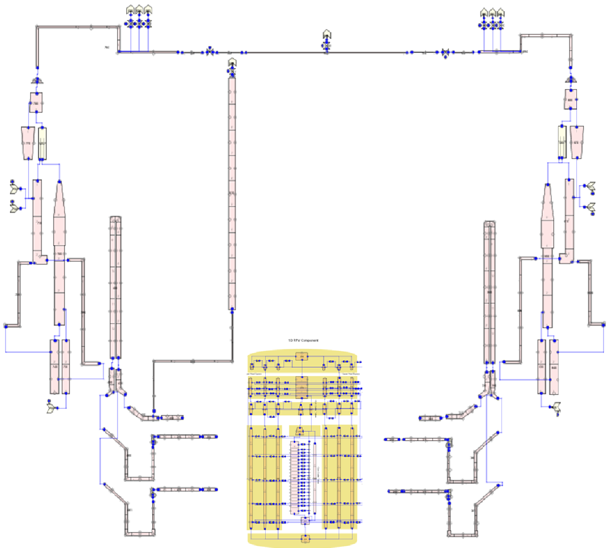

Fig. 1. ATLAS TRACE Nodalization

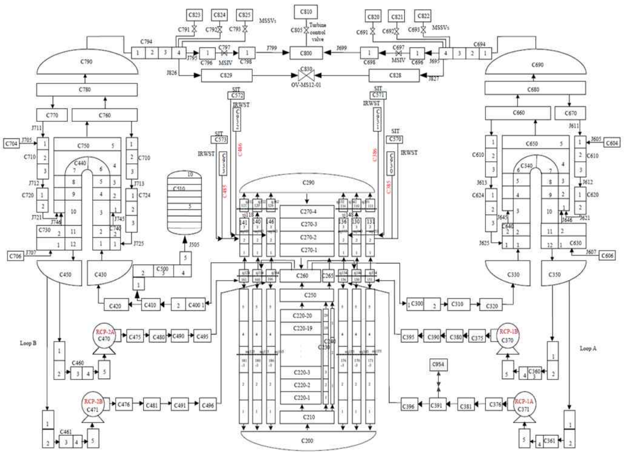

Fig. 2. ATLAS MARS-KS Nodalization

2.3 Initial and Boundary Conditions

Initial and boundary conditions are shown in Table 1. This result indicates that the TRACE and MARS-KS model well predicts overall steady-state conditions of the experiment within acceptable error ranges. The cold leg flow rate of MARS-KS was slightly under predicted as shown in Table 1.

Table 1. Initial Conditions for LTC-CL-04R

Parameter		**LTC-CL-4R**	**TRACE**	**MARS-KS**
Power, MW		1.64	1.64	1.64
Pressurizer Pressure, MPa		15.5	15.5	15.5
Core Inlet Temperature, K		564.15	564.54	564.29
Core Outlet Temperature., K		599.99	599.33	599.99
SG Steam Flow Rate, kg/s	SG 1	0.382	0.4577	0.466
	SG 2	0.425	0.4562	0.468
SG Feed Water Flow Rate, kg/s	SG 1	0.410	0.4574	0.467
	SG 2	0.413	0.4557	0.467
SG Feed Water Temperature, K	SG 1	507.05	507.05	507.05
	SG 2	506.15	506.15	506.15
SG Steam Pressure , MPa	SG 1	7.83	7.85	7.85
	SG 2	7.83	7.86	7.85
SG Steam Temperature, K	SG 1	568.75	566.9	565.28
	SG 2	568.75	567.0	565.28
Secondary Side Level, m	SG 1	4.99	4.99	4.99
	SG 2	4.99	4.99	4.99
CL Flow Rate, kg/s	CL 1A	1.98	2.0	1.94
	CL-1B	1.98	1.99	1.94
	CL-2A	1.98	1.99	1.94
	CL-2B	1.98	2.0	1.94

2.4 Results of TRACE and MARS-KS Analysis

The transient was initiated by opening the cold leg break valve at 300 seconds. When the cold leg break valve opened, the primary and secondary pressures immediately began to decrease and reached the trip setpoint of Low Pressurizer Pressure (LPP) of 12.48 MPa. LPP reactor trip occurred at 332 seconds in the LTC-CL-04R, 331 seconds in the TRACE and 318 seconds in the MARS-KS, respectively. MARS-KS predict earlier LPP trip because the break flow is higher than the test. The scram signal, RCP pump and turbine trip signals were generated simultaneously at LPP trip. Also, both the main steam isolation valve and main feedwater isolation valve were closed at LPP trip. The core power started to follow the programmed decay heat curve at 344 seconds after the LPP trip with a delay of 12.0 seconds in the LTC-CL-04R (TRACE : 343 seconds, MARS-KS : 330 seconds). Four SIPs were initiated at 381, 388 and 375 seconds in the LTC-CL-04R, TRACE and MARS-KS, respectively when the pressurizer pressure reached 10.7 MPa. The temperature of SIP is about 289 K. The PCT is not occurred in the experimental test as well as in TRACE and MARS-KS analysis results. Four SITs started to deliver the Safety Injection(SI) water at 1,066 seconds in the LTC-CL-04R when the upper downcomer pressure reached 4.03 MPa. TRACE predicts later SIT actuation time. The first loop seal clearing occurred in loop seal 1A in all cases. TRACE and MARS-KS showed a discrepancy in predicting the first loop seal clearing time. The event chronology is summarized in Table 2.

Table 2. Sequence of Event

Unit : sec

Sequence	**LTC-CL-04R**	**TRACE**	**MARS-KS**	**Remark**
Break	300	300	300	
LPP Trip	332	331	318	PT-PZR-01 < 12.48 MPa
MSSV first opening	336/340	336/333	324/324	SG Pressure
Decay power start	344	343	330	8% decay heat
SIP on	381	388	375	PZR P <10.7MPa + 28 sec delay
SIT on	1066	1378	1074	PC-DC-01 < 4.03 MPa
First Loop Seal Clearing	733(1A)	888(1A)	644(1A)	
LSC sequence	1A > 2A > 2B > 1B	1A > 2A > 2B > 1B	1A > 2A > 1B > 2B	

The break flow rate is shown in Fig. 3. The break flow increased rapidly as soon as the break valve opened. Both TRACE and MARS-KS codes used Ransom and Trapp critical flow model but the discharge coefficient of TRACE differs from that of the MARS-KS(TRACE : 0.6 MARS-KS : 0.9). TRACE under predicts and MARSKS over predicts the break flow rate until 1,000 seconds.

Fig. 4 shows the accumulated break mass. The accumulated break mass from the break valve were 13,681 kg and 13,406 kg in TRACE and MARS-KS results, respectively. However, TRACE under predicts and MARS-KS over predicts accumulated break mass until 1,000 seconds due to break flow predictions. The experimental date is absent during 4,497 to 5,453 seconds for the drain of accumulated break mass.

The behavior of primary pressure is shown in Fig. 5. As soon as the break opened, the primary pressure decreased rapidly due to sudden loss of coolant inventory from the system. It is decreased after the first loop seal clearing time. TRACE over predicts pressure and shows a pressure plateau at about 400 seconds. MARS-KS well predicts the primary pressure. LTC-CL-04R and MARS-KS show pressure plateaus at about 300 seconds and it decreases at 720 and 760 seconds, respectively.

The core level is shown in Fig. 6. In the beginning of the transient, the core level decreased due to the loss of coolant and it decreased continuously until the loop seal clearing due to pressure build up at the upstream of the loop seal. Core level at the active core was depressed consequently and then recovered after the loop seal clearing and finally with the start of the SIP. TRACE under predicts core level until 1,000 seconds and MARS-KS well predicts the core level.

The fuel cladding temperatures are shown Fig. 7. The PCT was not occurred after break and rather started to decrease because of the small break size initially and also increase in core level later due to loop seal clearing.

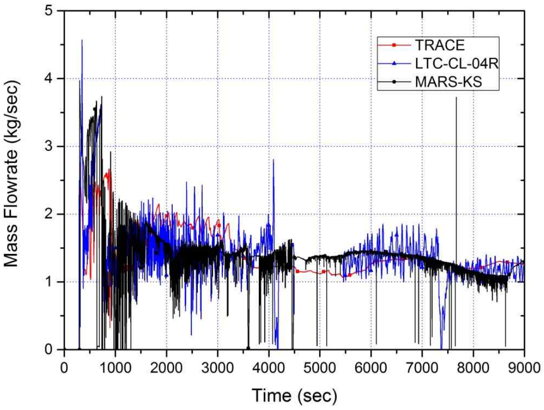

Fig. 3. Break Flow Rate

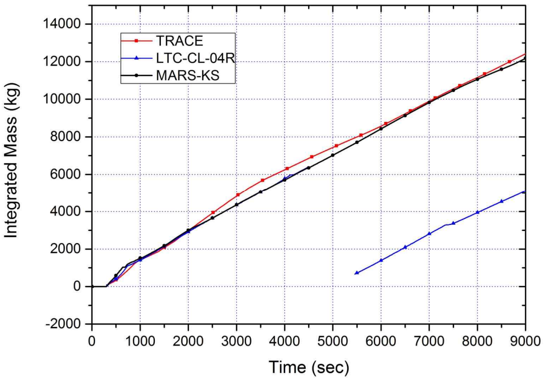

Fig. 4. Integral Break Flow

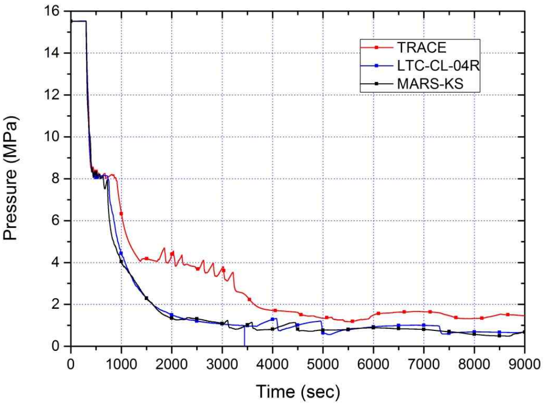

Fig. 5. Pressurizer Pressure

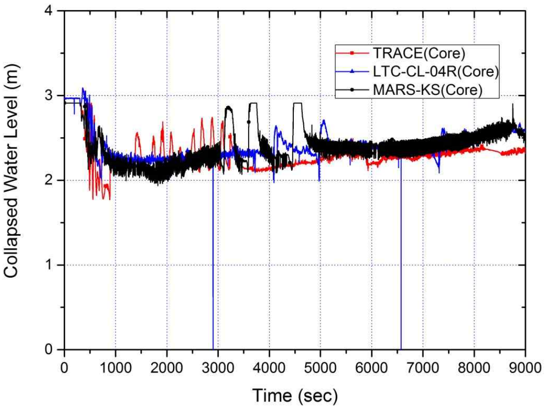

Fig. 6. Core Level

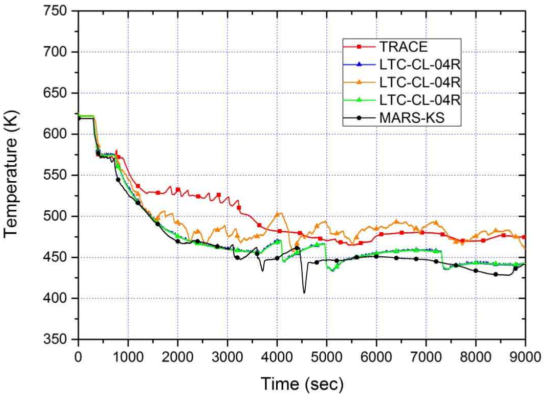

Fig. 7. Fuel Cladding Temperature

AS shown in Fig. 8 to Fig. 11, the loop seal water levels are quite different in the analyses compared to the experiment. Also, loop seal clearing and reformation sequences are quite different in LTC-CL-04R test, TRACE and MARS-KS analysis results as shown in Table 3. In principle, loop seal clearing phenomenon is a very complex in its nature, however, its pressure difference across the loop seal is believed to determine its clearing and the clearing sequences are quite dependent upon the flow resistances along the loop. Even though the first loop seal clearing times are different, both TRACE and MARS-KS correctly predicted the first clearing loop seal, 1A, and second clearing loop seal, 2A. TRACE even predicted correct loop seal clearing sequence, 1A-2A-2B-1B. Further study is needed to investigate loop seal clearing and reformation sequences and its effect on SBLOCA safety analysis.

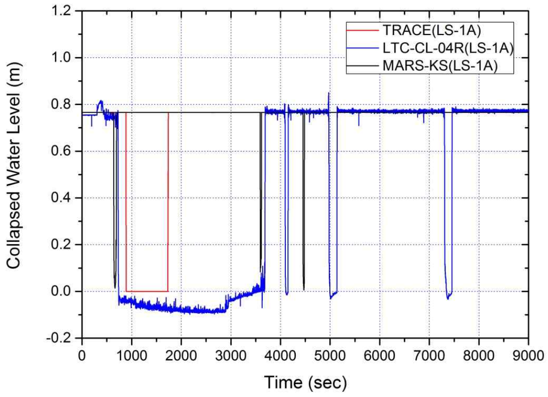

Fig. 8. Loop Seal Level – Loop 1A

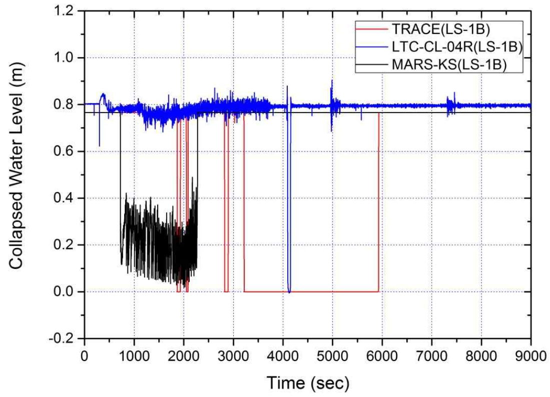

Fig. 9. Loop Seal Level – Loop 1B

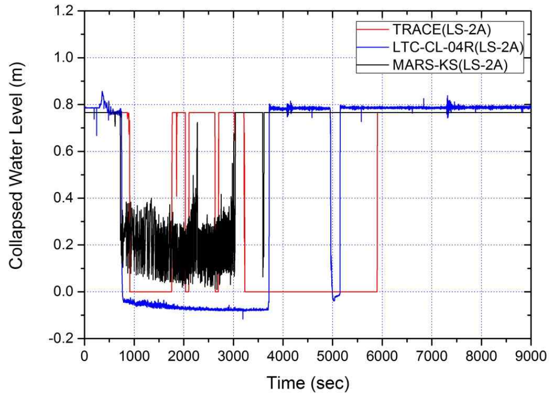

Fig. 10. Loop Seal Level – Loop 2A

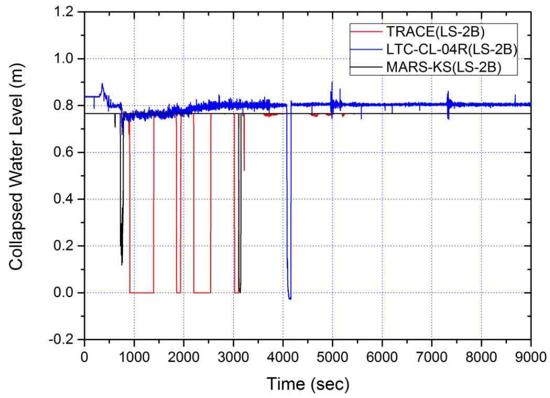

Fig. 11. Loop Seal Level – Loop 2B

Table 3. Loop Seal Clearing and Reformation Time

Unit : sec

LTC-CL-04R	TRACE	MARS-KS
733 ~ 3687 (1A) 754 ~ 3719 (2A) 4094 ~ 4160 (2B) 4097 ~ 4151 (1A,1B) 4982 ~ 5138 (1A) 4978 ~ 5150 (2A) 7322 ~ 7456 (1A)	888 ~ 1727(1A) 913 ~ 1755(2A) 914 ~ 1392(2B) 1855 ~ 1934(2B) 1869 ~ 1929(1B) 2034 ~ 2100(2A) 2053 ~ 2084(1B) 2202 ~ 2542(2B) 2632 ~ 2695(2A) 2824 ~ 2895(1B) 3023 ~ 3101(2B) 3217 ~ 5924(1B) 3230 ~ 5897(2A)	644 ~ 682 (1A) 869 ~ 3022 (2A) 936 ~ 2206 (1B) 3109 ~ 3150 (2B) 3594 ~ 3612 (2A) 4455 ~ 4480 (1A)

3. Conclusions

The calculation shows that the TRACE code well predict the sequence of Test LTC-CL-04R. However, compared to the experiment, the TRACE over predicts the primary pressure due to smaller break flow prediction. Thus, the TRACE results should be further investigated in detail and the TRACE model of the ATLAS SBLOCA should be improved for the break flow model. MARS-KS well predicts major thermal hydraulic parameters during the transient with reasonable agreement. MARS-KS better predicts ATLAS LTC-CL-04R test data with a good agreement than the TRACE due to better prediction of the break flow. Overall, compared to the experiment, the TRACE and MARS-KS Codes show a discrepancy in predicting the loop seal clearing and reformation time. However, it correctly predicts the sequence of the clearing loop seals. Moreover, both TRACE and MARS-KS correctly predicts core water level and fuel cladding temperatures. From this study, it can be said that even though APR1400 cross-over leg design has slightly deeper loop seals, the effect on the safety of the SBLOCA long term cooling is minimal compared to the SBLOCA cladding failure criteria. Further study on the SBLOCA loop seal clearing phenomena is needed.

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