

Effect of CCFL at the top of core during ATLAS IBLOCA tests

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1. Introduction

To improve the phenomenological understanding for the intermediate break loss-of-coolant accident (IBLOCA), the phenomena identification and ranking table (PIRT) [1] was developed based on the analyses for integral effect tests (IET) simulating IBLOCA. For the Advanced Thermal-Hydraulic Test Loop for Accident Simulation (ATLAS), the DVI line break test (ATLAS B3.2) and cold leg break tests (ATLAS A4.1 and A5.2) were simulated via using the safety and performance analysis code for nuclear power plants (SPACE). The reference plant of ATLAS B3.2 test was APR1400, and the ATLAS A4.1 and A5.2 tests were the counterpart tests for large scale test facility (LSTF). To investigate IBLOCA transient for OPR1000 which is operating in Korea, the IBLOCA-OPR-01 test, which simulate an upward break of the cold leg with 10.1% of cold leg flow area for OPR1000, was conducted via using ATLAS facility. In this study, the SPACE code analysis was conducted for IBLOCA-OPR-01 test. Especially, the effect of the counter-current flow limitation (CCFL) between core and upper plenum/head was investigated.

2. CCFL correlation

The SPACE uses the Bankoff CCFL correlation [2], expressed as:

$$(1) H_g^{1/2} + M H_f^{1/2} = C$$

$$\text{where } H_k = j_k \left(\frac{\rho_k}{g_{cw} \Delta \rho} \right)^{1/2}$$

$$w = D^{1-E} L^E$$

C : slope

M : abscissa intercept.

In equation (1), for $E=0$, the Wallis CCFL correlation can be applied, and for $E=1$, the Kutateladze CCFL correlation can be applied.

In the previous study [3], the effect of CCFL between core and upper plenum/upper head was investigated via the sensitivity analysis. In this study, based on the experimental studies of Bankoff et al. [4] and NO et al. [5], the values of E , M and C for each flow path between core and upper plenum/head were suggested as given in Table I.

Table I: CCFL correlation at flow path between upper plenum/head and core

Location	Value of constants
UGSSP flow holes (upper plenum – upper head)	$E = 0.0433$ $M = 1.0$ $C = 2.0$
FAP flow holes (core – upper plenum)	$E = 0.0$ (Wallis) $M = 1.22$ $C = 0.88$
CEA guide tube holes (core – upper head)	$E = 0.0$ (Wallis) $M = 1.22$ $C = 0.88$

3. SPACE code analysis for IBLOCA-OPR-01

The IBLOCA-OPR-01 test simulated the IBLOCA transient in OPR1000. Therefore, the cold leg injection type of safety system in OPR1000 was simulated via revision of the ATLAS facility. The SPACE code input model for ATLAS facility was also revised as shown in Fig. 1. Using this SPACE code input model, the steady state analysis was conducted and the initial condition for the IBLOCA-OPR-01 test was obtained, as shown in Table II. The initial condition for the transient analysis was well agreed with the experimental conditions.

Table II: Steady state for IBLOCA-OPR-01 test and SPACE analysis

System parameter	IBLOCA-OPR-01	SPACE
Primary system		
Power (MWt)	1.64	1.641
PZR pressure (MPa)	15.52	15.54
PZR level (m)	4.175	4.177
Core T_{in} (°C)	291.71	290.64
Core T_{out} (°C)	327.43	325.88
Cold leg flowrate (kg/s)	1.98	1.98
Secondary system		
Steam flow rate (kg/s)	0.404	0.425
FW flow rate (kg/s)	0.421	0.427
Steam pressure (MPa)	7.83	8.01
Steam temperature (°C)	296.3	294.88
FW temperature (°C)	232.75	232.75
SG level (m)	4.99	4.97

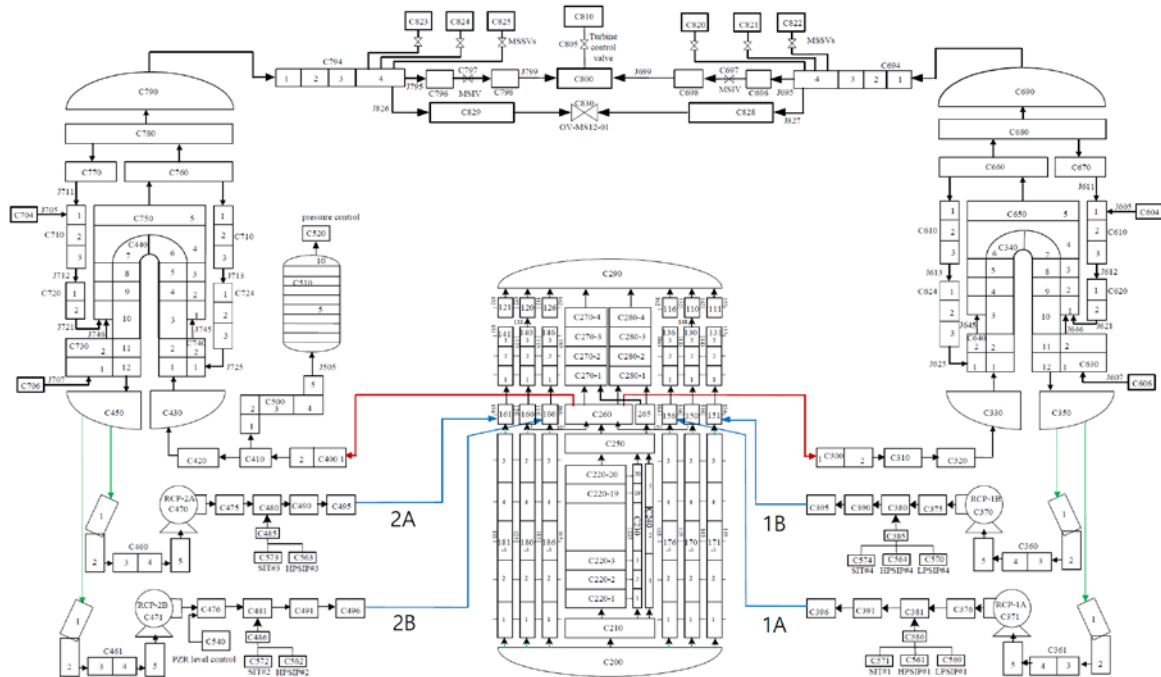


Fig. 1. Nodalization of SPACE code input model for IBLOCA-OPR-01 test

Based on the initial condition, a cold leg break was simulated, and the Henry-Fauske model was used at the break location with a discharge coefficient of 0.7, 0.7 and 1.0 for subcooled liquid and two-phase and vapor conditions, respectively.

3.1 Base case

In the IBLOCA-OPR-01 test, the accumulated break flow was measured and compared with the SPACE analysis results, as shown in Fig. 2. The accumulated break flow of the SPACE code analysis results was well matched with that of the experimental results. Also, the RCS pressure for the SPACE code analysis results was quite well matched with the IBLOCA-OPR-01 test results, as shown in Fig. 3.

The collapsed core water level and cladding temperature are shown in Figs. 4 and 5, respectively. The SPACE code predicted a late decrease of core water level in comparison with the experimental results. Accordingly, the delayed core heat-up appeared in the SPACE code analysis results.

The comparison of water level in upper plenum and upper head is shown in Fig. 6. The SPACE code analysis results show that the core water level decreased after depletion of water level in upper plenum. However, in the IBLOCA-OPR-01 test, the early decrease of core water level was observed before depletion of water level in upper plenum. To properly simulate those trends of water level change, the CCFL correlation was applied in the SPACE code analysis.

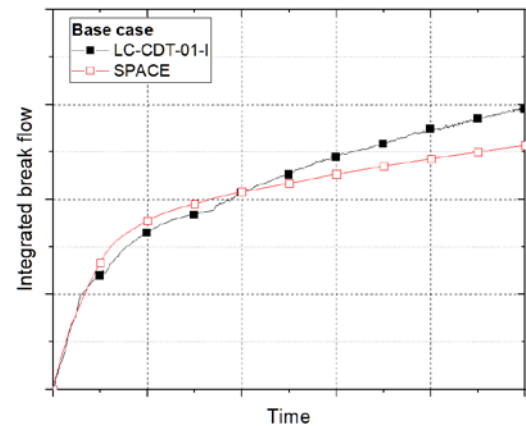


Fig. 2. SPACE prediction of accumulated break flow

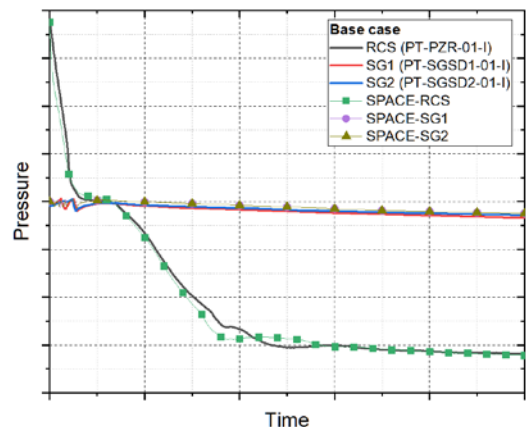


Fig. 3. SPACE prediction of system pressure

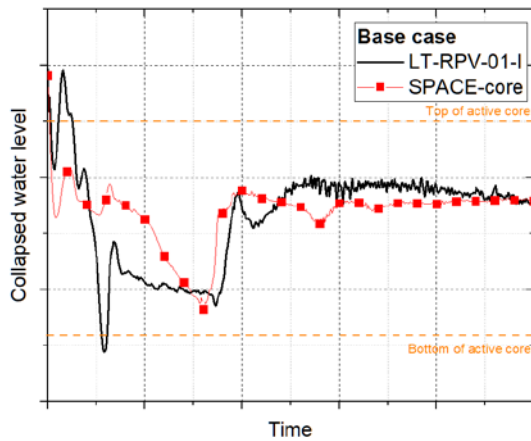


Fig. 4. SPACE prediction of core collapsed level

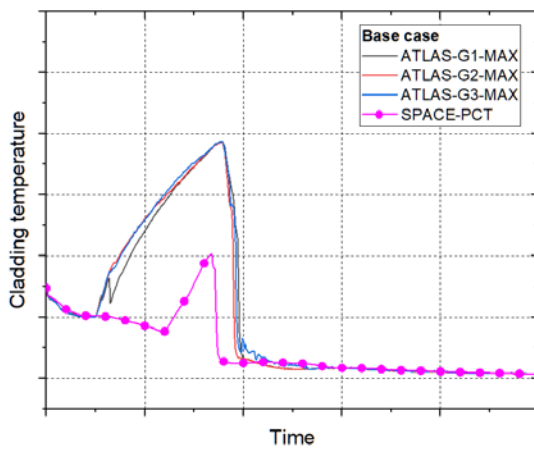


Fig. 5. SPACE prediction of cladding temperature

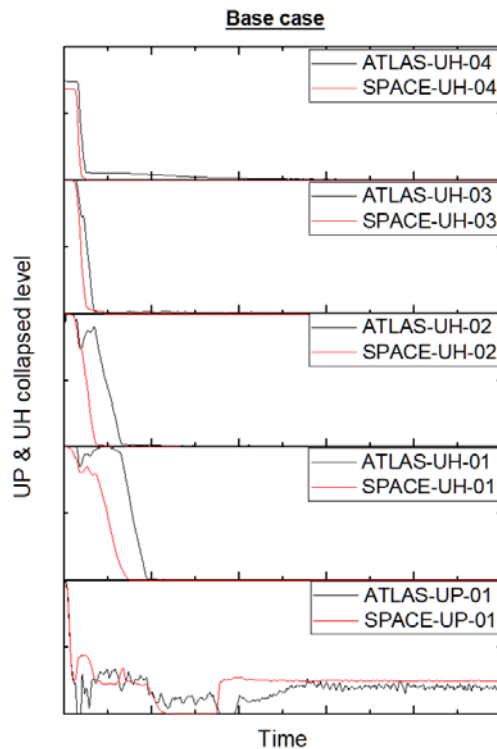


Fig. 6. Water level comparison for upper plenum/head

3.2 Effect of CCFL on core water level

At the flow path between core and upper plenum/head, the CCFL correlations with the constants, which are given in Table I, were applied. For the CCFL applied case, the SPACE code analysis results are shown in Figs. 7 to 11. Similarly with the base case, for the CCFL applied case, the SPACE code predicted well the accumulated break flow and system pressure. Owing to the application of CCFL correlations, the SPACE code properly simulated the early decrease of core water level. Consequently, the cladding temperature was well matched with the IBLOCA-OPR-01 test results.

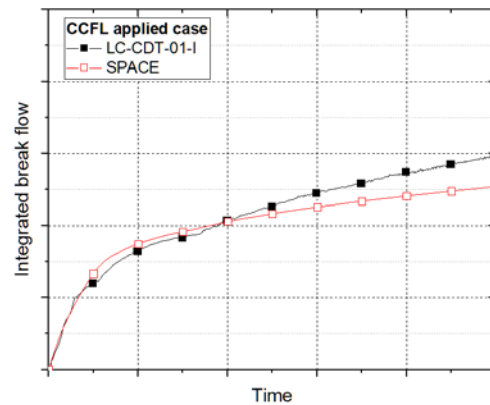


Fig. 7. Accumulated break flow – effect of CCFL

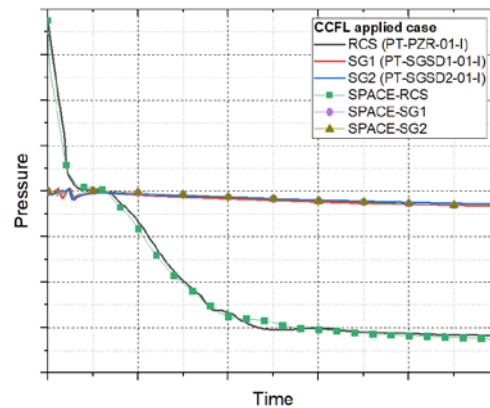


Fig. 8. System pressure – effect of CCFL

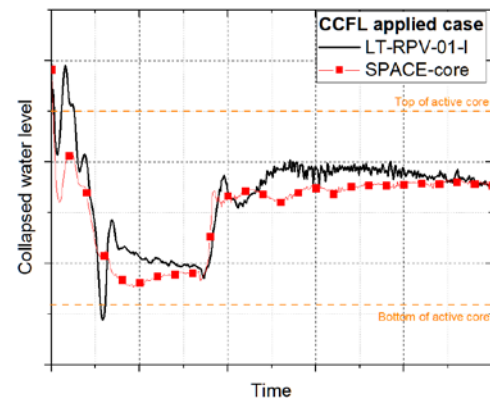


Fig. 9. Core water level – effect of CCFL

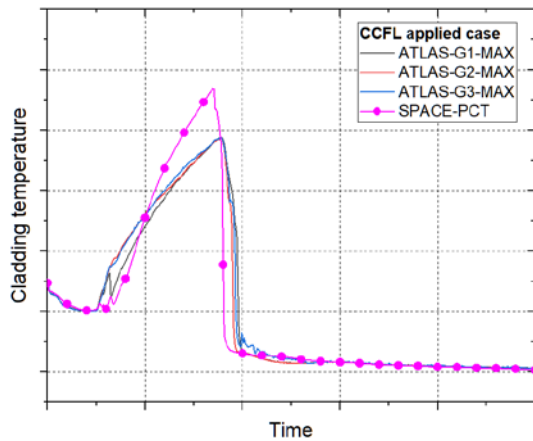


Fig. 10. Cladding temperature – effect of CCFL

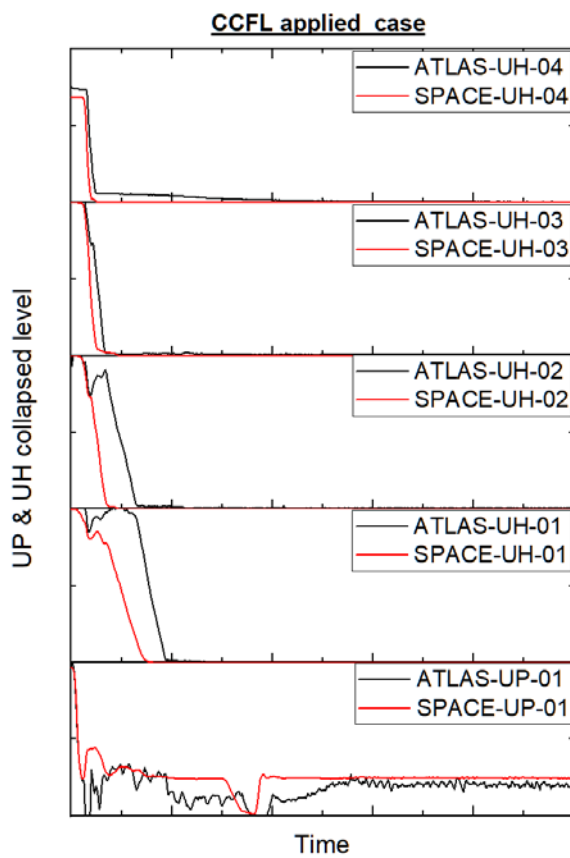


Fig. 11. Water level of upper plenum/head – effect of CCFL

4. Conclusion

In the previous study, the effect of CCFL between core and upper plenum/head was investigated for the DVI line break test, and for the ATLAS facility the constant values of CCFL correlations were suggested. Using suggested CCFL correlations, the effect of CCFL on core water level was investigated for the cold leg break test (IBLOCA-OPR-01).

For the base case, the SPACE code predicted the delayed decrease of core water level, whereas the early

decrease of core water level was observed in the IBLOCA-OPR-01 test. Through the application of CCFL correlation with the constants suggested in the previous study, the SPACE code properly simulated the early decrease of core water level.

As a further study, the effect of offtake model is needed to be investigated because the IBLOCA-OPR-01 test simulated an upward break of cold leg. Especially, the increase of break flow during safety injection was observed in the experimental results. The possible effect of offtake phenomenon on break flow increase should be investigated.

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