Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 9-10, 2024

Effect of CCFL in Upper Plenum for ATLAS DVI Line Break Test

Hae Min Park, Seung Wook Lee*
Korea Atomic Energy Research Institute, 111 Daedeok-daero 989 been-gil, Yuseong-gu, Daejeon, 34057, Republic of Korea
**Corresponding author: nuclist@kaeri.re.kr*

***Keywords : CCFL, ATLAS, SPACE, Upper plenum**

1. Introduction

Recently, the loss-of-coolant accident (LOCA) acceptance criteria have been revised more strictly. To satisfy the strengthened criteria for LOCAs, re-classification of LOCAs for PWRs operating in Korea is being conducted to exclude the large break LOCA (LBLOCA) and include the intermediate break LOCA (IBLOCA) in the design basis accident (DBA) category. To improve the phenomenological understanding for the IBLOCA, the code analysis [1] was conducted for the DVI line break test (ATLAS B3.2) with the Advanced Thermal-Hydraulic Test Loop for Accident Simulation (ATLAS). However, there were differences of the water level in the core and peak cladding temperature (PCT) between prediction and experiment although the predicted transient behavior for system pressure and break flow was well matched with the experimental results. This study was focused on the counter-current flow limitation (CCFL) between core and upper plenum as a reason of water level difference. In this study, the sensitivity analysis for CCFL was conducted based on the preliminary analysis results using the safety and performance analysis code for nuclear power plants (SPACE) for the ATLAS B3.2 test.

2. Summary of preliminary analysis [1]

The ATLAS B3.2 test simulated a DVI line break corresponding to 8.5-inch break in APR1400 [2]. In the SPACE input model, a break of the DVI-3 line was simulated via connecting the time dependent volume having the atmospheric condition, as shown in Fig 1. At the break path, the Henry-Fauske model was used with a discharge coefficient of 1.0 for the critical flow. Fig. 2 shows the accumulated break flow. The accumulated break flow of the SPACE analysis was well matched with that of the experimental results. As shown in Fig. 3, the RCS pressure for the SPACE analysis was well matched with the experimental results as well.

However, the SPACE did not predict accurately the core water level, as shown in Fig. 4. During the early period, the core water level was decreased and the heat-up of core was observed in the experiment. SPACE predicted well the decrease of the core water level during the early period. However, the heat-up of the core was not appeared in the SPACE analysis due to less decrease of the core water level than the experimental results, as shown in Fig. 5.

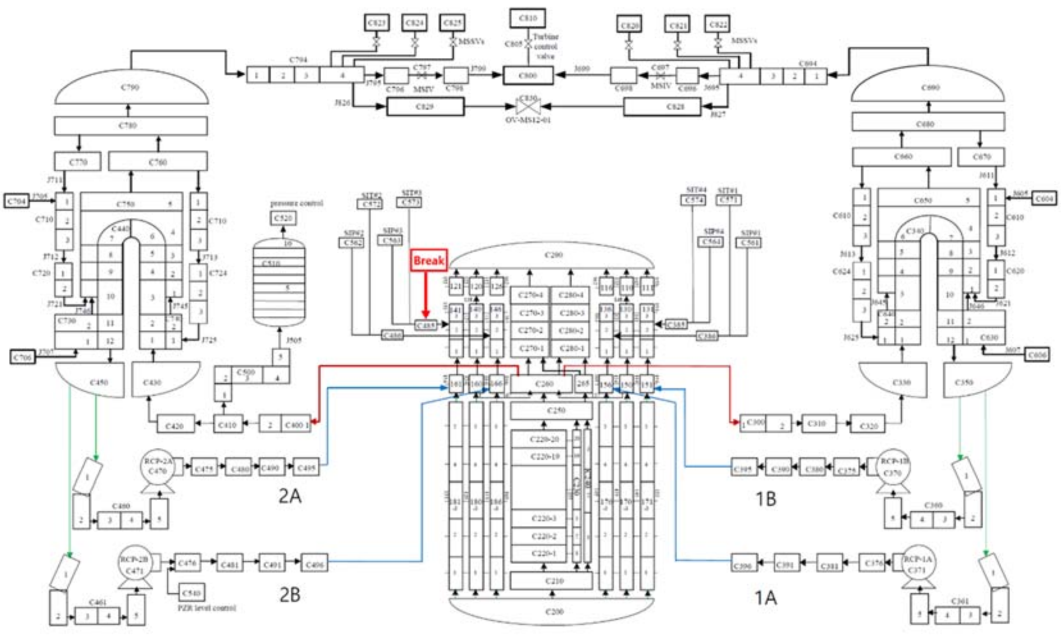

Fig. 1. Nodalization of the SPACE input model for ATLAS test facility

After the loop seal clearing, the core water level was increased due to the injection of the residual coolant from the intermediate leg. The core water level was decreased again owing to the boil-off. However, SPACE overestimated the water level decrease in the core. Depending on these behaviors of the core water level caused by the boil-off, the heat-up of core was appeared only in the SPACE analysis results.

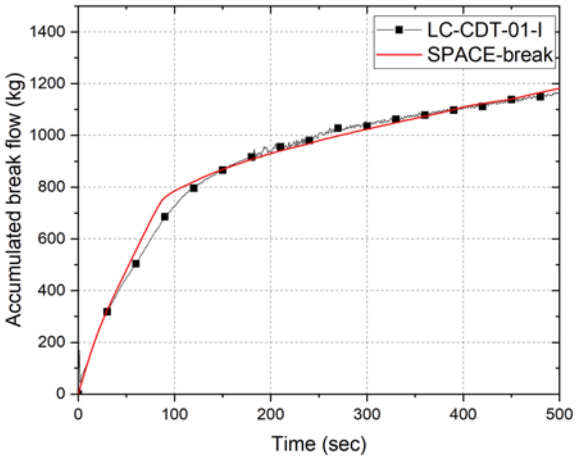

Fig.2. SPACE prediction of the accumulated break flow

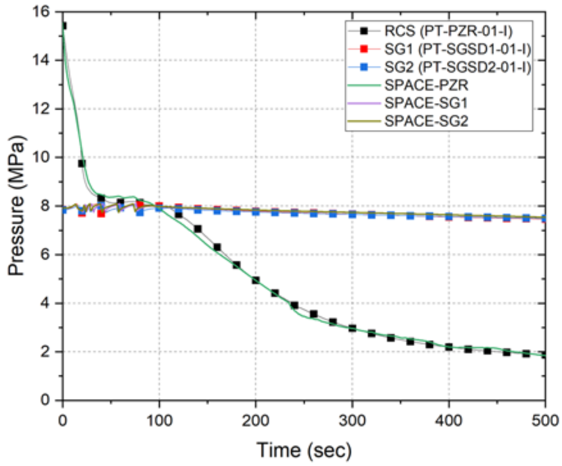

Fig. 3. SPACE prediction of system pressure

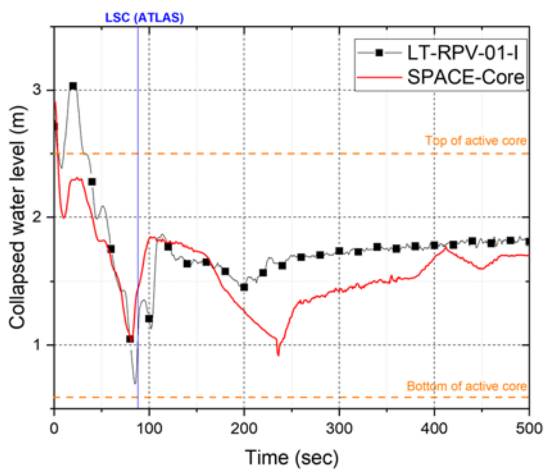

Fig. 4. SPACE prediction of core collapsed level

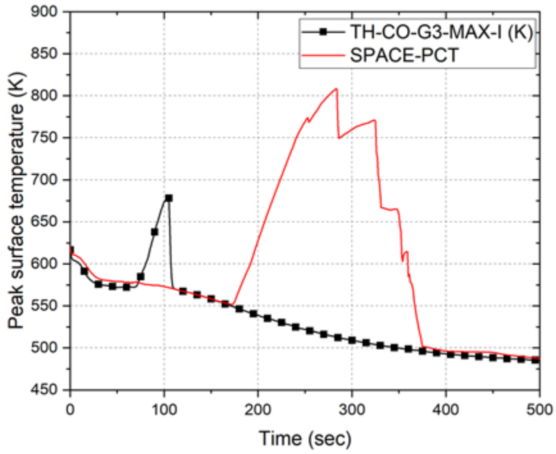

Fig. 5. SPACE prediction of peak surface temperature

3. Sensitivity analysis for CCFL

During the early period of IBLOCA, the flow may be complex between the core and the upper plenum. It can be caused by boiling in the core and flashing owing to the rapid depressurization. Under this condition, the CCFL between downward liquid flow and upward vapor flow can be important, and it can affect the core water level. The effect of this possible CCFL phenomena on the core water level and PCT was investigated.

3.1. CCFL model in the SPACE

The SPACE uses the Bankoff CCFL correlation [3], as given in equation (1).

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

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

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

$C: slope$

$M: abscissa\ intercept.$

In equation (1), for E=0, the correlation reverts to the Wallis CCFL correlation, and for E=1, it reverts to the Kutateladze CCFL correlation. In equation (1), M and C can be given differently depending on the shape of flow channel.

3.2. Case 1 (M=1.22, C=0.88)

For the upper plenum in the PWR, the values of M and C are recommended in the SPACE manual to be 1.22 and 0.88, respectively. Specifically, these values are applicable to the upper plenum injection type of the safety injection during the LBLOCA.

For the case 1, the transient behaviors, such as system pressure and break flow, were similar with the those of the preliminary analysis. However, the core water level (Fig. 6) became much lower during the early period in comparison with the preliminary analysis. Consequently, the PCT was highly increased, as shown in Fig. 7.

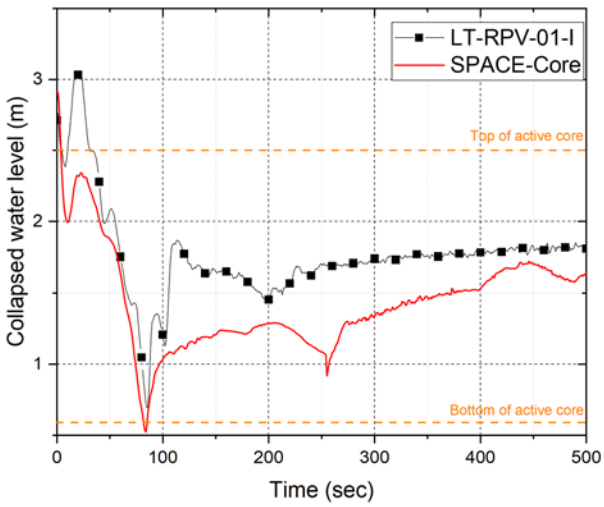

Fig. 6. Core collapsed level (Case 1, M=1.22, C=0.88)

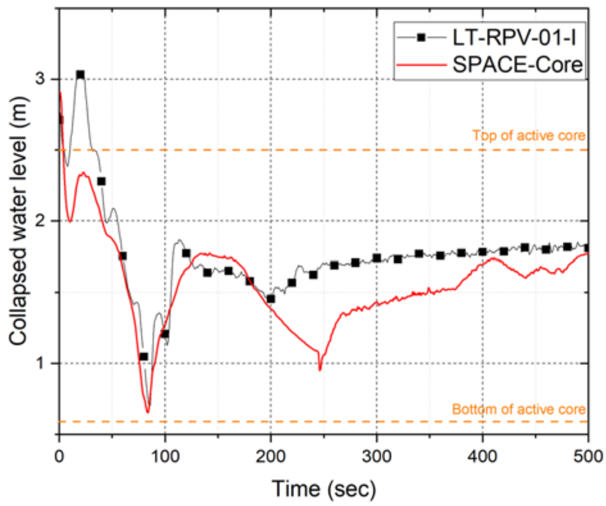

Fig. 8. Core collapsed level (Case 2, M=1.0, C=1.0)

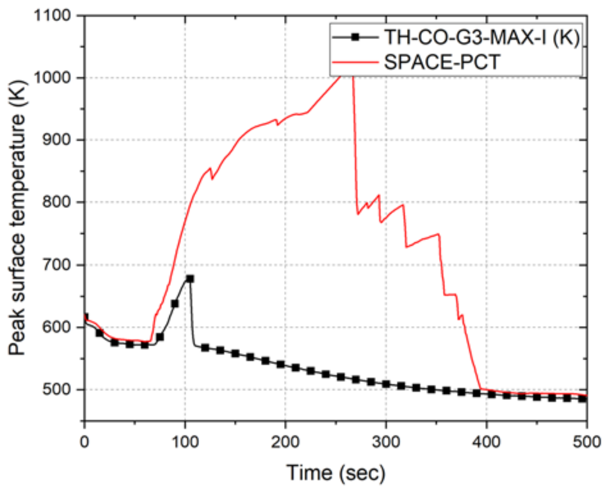

Fig. 7. Peak surface temperature
(Case 1, M=1.22, C=0.88)

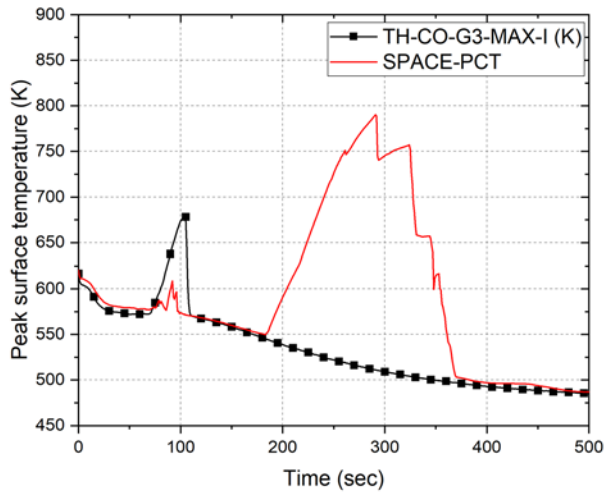

Fig. 9. Peak surface temperature
(Case 2, M=1.0, C=1.0)

3.3. Case 2 (M=1.0, C=1.0)

To investigate the sensitivity of M and C for CCFL model, the case 2 for M, C=1.0 was considered. For this case, the transient behaviors, such as system pressure and break flow, were also similar with the those of the preliminary analysis. The analysis results for core water level and PCT are shown in Figs. 8 and 9. For the case 2, the core water level during the early period was also lower than that in the preliminary analysis, consistently with that for the case 1. The core heat-up was also observed during the early period for the case 2. However, the PCT for the case 2 was much lower than that for the case 1.

For the case 2, the second core heat-up was observed, being similar with the trend of core heat-up caused by boil-off in the preliminary analysis.

4. Conclusion

In the preliminary SPACE analysis for ATLAS B3.2 test, there were some limitations of prediction for core water level and PCT. This study was focused on the CCFL phenomenon between core and upper plenum as a reason of water level difference, and the sensitivity analysis for the CCFL model was conducted.

The effect of the constants, M and C, in CCFL model was investigated via two test calculations. From the sensitivity results, it is found that the CCFL model with various combination of M and C constants bring a big difference of the core water level during the early period. This difference of core water level resulted in a cladding temperature difference.

In the future, the values of M and C, which are applicable to ATLAS B3.2 test condition, should be proposed. The recommended values from the SPACE manual are not proper in this condition because the test condition of ATLAS B3.2 is much different from that of the upper plenum injection type.

ACKNOWLEDGEMENT

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) and the Ministry of Trade, Industry & Energy (MOTIE) of the Republic of Korea (No. 20224B10200020)

REFERENCES

[1] H.M. Park, S.W. Bae, S.W. Lee, Predictability evaluation of SPACE for DVI line break with ATLAS, Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea, May, 2023.
[2] B. U. Bae, S. Cho, K. H. Kang, Test Report on the OECD-ATLAS2 B3.2 Test: Direct Vessel Injection (DVI) Line Intermediate Break Loss-of-Coolant-Accident (IBLOCA) Test with ATLAS, OECD-ATLAS2-TR-19-02, KAERI, Korea, 2019.
[3] KHNP, SPACE 3.0 Manual Volume 1 Theory Manual, Korea Hydro & Nuclear Power, 2017, TR-KHNP-0032.