SPACE Simulation of ATLAS-PAFS for FLB, SLB, SGTR and SBO

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1. Introduction

In recent reactor designs such as APR+, APR1000, and i-SMR, passive safety features have been incorporated as part of the safety design. Among these, the Passive Auxiliary Feedwater System(PAFS) is a representative passive safety system designed to remove decay heat through the steam generators under accident conditions[1, 2].

Unlike active systems that rely on mechanical pumps, PAFS operates based on natural circulation driven by gravity and density differences. Therefore, its thermal-hydraulic behavior is strongly influenced by heat transfer characteristics and system pressure response [2–4]. Accurate prediction of PAFS performance is thus essential for reliable safety evaluation.

In our previous studies, the ATLAS-PAFS integral effect tests were analyzed using the SPACE code with the default and PAFS heat transfer models for the PCHX. The predicted pressure behavior showed noticeable differences from the experimental data, and the default model generally resulted in higher system pressures than the PAFS model [5]. Therefore, in this study, the influence of modeling conditions, including facility heat loss and initial PCCT temperature, on the prediction capability of the SPACE code was investigated through analyses of ATLAS-PAFS under SLB, FLB, SGTR, and SBO [3, 6–8].

2. Modeling of ATLAS-PAFS Facility

2.1 Nodalization of ATLAS

The ATLAS-PAFS is an integral effect test facility designed to simulate the overall thermal-hydraulic behavior of a pressurized water reactor under prototypical pressure and temperature conditions. In this study, the ATLAS-PAFS experimental facility was modeled using the SPACE code for transient analyses.

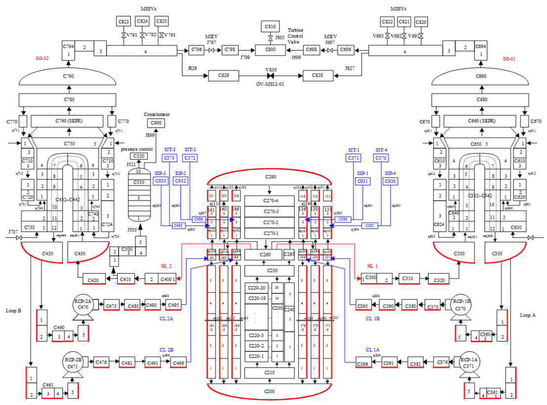


Fig. 1. Nodalization of ATLAS test facility [8]

2.2 Modeling Modifications

Compared to the previous analyses, several modeling conditions were modified in the present study to represent the experimental conditions[5]. The initial PCCT temperature, previously assumed to be near the saturation temperature (99 °C), was set to the experimental initial temperature of approximately 20 °C.

Facility heat loss from major components, including the steam generators (SG) and pressurizer (PZR), was incorporated based on experimentally evaluated values of approximately 5–10 W/m² [9].

In addition, dialing factors were applied to the nucleate boiling and condensation heat transfer coefficients based on the evaluation results of the PASCAL experiments to improve consistency with the experimental heat transfer behavior under natural circulation conditions.

The break configuration was modeled consistently with the experimental descriptions provided in Refs. [10–12].

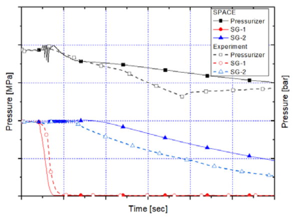
3. Results and Discussion

Figures 2–5 show the analysis results of the ATLAS-PAFS FLB, SLB, SGTR and SBO, including both the previous and modified conditions.

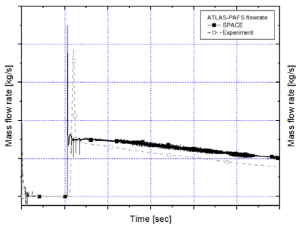
For the FLB test (Fig. 2), the previous analysis predicted lower pressure on the ruptured steam generator side, while the pressure on the intact SG and the pressurizer (PZR) remained higher than the experimental data. Because facility heat loss was not considered, the PZR pressure decreased more slowly and did not drop below the safety injection pump (SIP) actuation signal as observed in the experiment. When facility heat loss and the dialing factor were incorporated, the predicted PZR and SG pressures showed improved agreement with the experimental results.

For the SLB test (Fig. 3), the previous analysis reasonably captured the overall trend of the PAFS natural circulation flowrate. However, the predicted system pressure remained higher than the experimental data throughout most of the transient. When facility heat loss, the dialing factor, and the experimental initial PCCT temperature were incorporated, the predicted pressure showed improved agreement with the experimental results. In addition, the PCCT temperature behavior was better reproduced compared to the previous analysis.

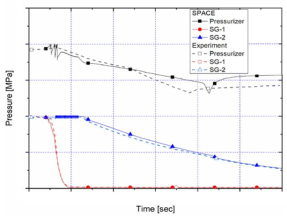
For the SGTR test (Fig. 4), the previous analysis predicted higher pressure on the ruptured steam generator side, whereas the pressure on the intact side was lower than the experimental data. In addition, the activation of the PAFS occurred earlier than observed in the experiment. The earlier PAFS actuation is considered to be influenced by the modeling of facility heat loss. Without accounting for heat loss, the secondary-side pressure increased more rapidly, leading to earlier opening of the main steam safety valve (MSSV) and consequently earlier initiation of the PAFS. When facility heat loss was incorporated, both the pressure behavior and the PAFS actuation time showed closer agreement with the experimental results.



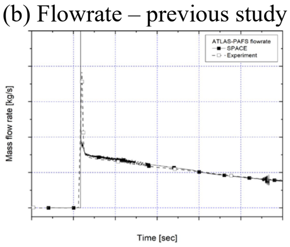
(a) Pressure – previous study



(b) Flowrate – previous study

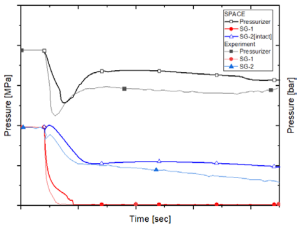


(c) Pressure – calculated results with experiments

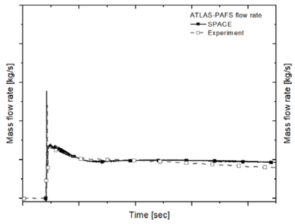


(d) Flowrate – calculated results with experiments

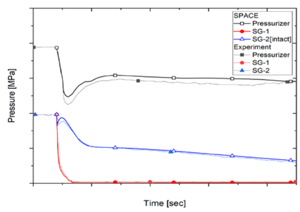
Fig. 2. Analysis results of ATLAS-PAFS feedwater line break test using SPACE code



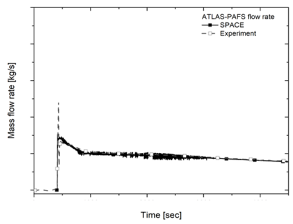
(a) Pressure – previous study



(b) Flowrate – previous study

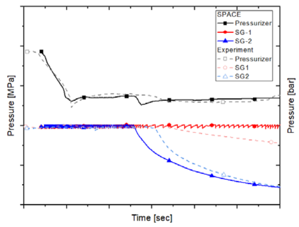


(c) Pressure – calculated results with experiments

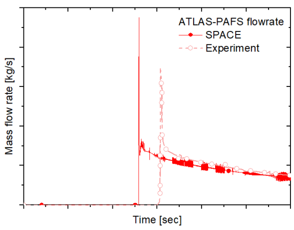


(d) Flowrate – calculated results with experiments

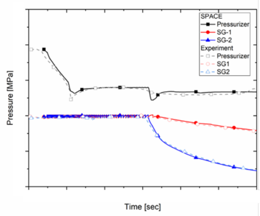
Fig. 3. Analysis results of ATLAS-PAFS steam line break test using SPACE code



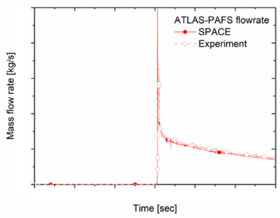
(a) Pressure – previous study



(b) Flowrate – previous study

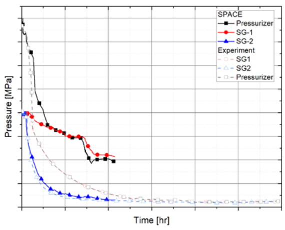


(c) Pressure – calculated results with experiments

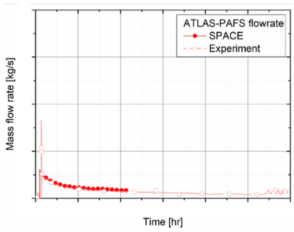


(d) Flowrate – calculated results with experiments

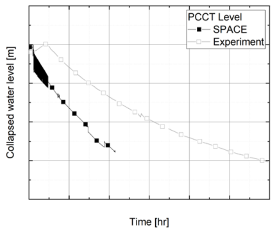
Fig. 4. Analysis results of ATLAS-PAFS steam generator tube rupture test using SPACE code



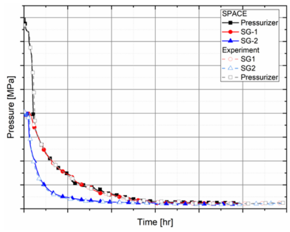
(a) Pressure – previous modeling approach



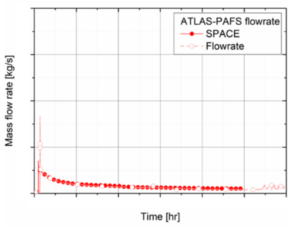
(b) Flowrate – previous modeling approach



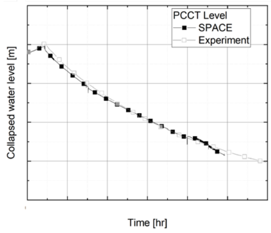
(c) PCCT level – previous modeling approach



(d) Pressure – calculated results with experiments



(e) Flowrate – calculated results with experiments



(f) PCCT level - calculated results with experiments

Fig. 5. Analysis results of ATLAS-PAFS station black out test using SPACE code

4. Conclusions

The influence of modeling conditions on the prediction capability of the SPACE code was investigated through analyses of the ATLAS-PAFS integral effect tests. The modified modeling conditions included the experimental initial PCCT temperature, facility heat loss, and dialing factors applied to the nucleate boiling and condensation heat transfer coefficients.

For the FLB, SLB, and SGTR tests, differences in pressure behavior were observed between the previous and modified modeling conditions, and the modified model showed closer agreement with the experimental trends while maintaining reasonable prediction of the PAFS natural circulation flowrate. A similar tendency was observed for the SBO test.

For the SBO test, the PCCT water level was identified as an important factor in long-term heat removal performance. Application of the experimental initial PCCT temperature and facility heat loss reproduced the heating-up phase and moderated the PCCT inventory depletion, resulting in improved prediction of pressure and flowrate during PCHX submergence.

Overall, improved agreement with the experimental data was achieved when the modified modeling conditions were applied.

ACKNOWLEDGEMENT

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