Sensitivity studies on Semiscale natural circulation phenomena in degraded steam generator heat transfer area with SPACE code

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1. Introduction

SPACE (Safety & Performance Analysis Code for Nuclear Power Plants) has been developed by KHNP with the cooperation of KEPCO E&C, KAERI and KNF. SPACE code is expected to be applied to the safety analysis for LOCA (Loss of Coolant Accident) and Non-LOCA scenarios. SPACE code solves two-fluid, three-field governing equations and programmed with C++ computer language using object-oriented concepts [1]. To evaluate the analysis capability for the natural circulation phenomena in the integral test facility, a test of Semiscale was simulated with SPACE. To investigate the cause of discrepancies between the experimental data and the previous analysis results [2] in natural circulation (S-NC-3) case, the sensitivity studies of several conditions are carried out.

2. Analysis conditions and model

2.1 SPACE model

A full-height and 1/1705 volume scale of 4-loop PWR plant, Semiscale Mod-2A is modeled. S-NC-3 test is performed in single loop degraded heat transfer condition and with the variation of secondary level the change of steam generator heat transfer area is attained. Due to the decrease of SG heat transfer area, the natural circulation flow decreases. The 2.19 version of SPACE code is used in the analysis.

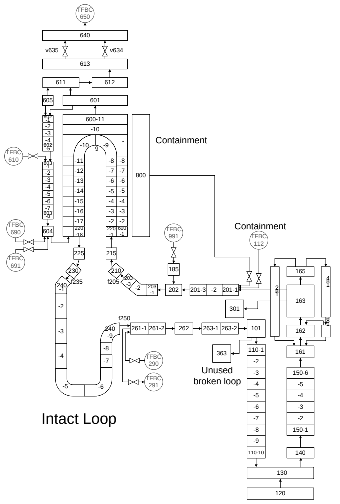

Fig. 1 Nodalization diagram of Semiscale Mod-2A

The nodalization diagram of Semiscale is depicted in Fig. 1. The plant is modeled with 105 fluid cells, 125 connections between cells and 69 heat structures. The power is 60kW, and the secondary inventory is varied about 15~100% of base condition.

2.2 Previous studies

The SPACE [2] and RELAP [3] analysis results showed overestimation of the mass flow rate in the dreaded SG heat transfer area as shown in Fig. 2. The possible cause of the discrepancy was considered that the calculated liquid entrainment carried more liquid over the top of the SG U-tubes and thus maintained the higher density difference to drive flow. The higher mass flow rate resulted in lower calculated fluid temperatures and a lower primary system pressure.

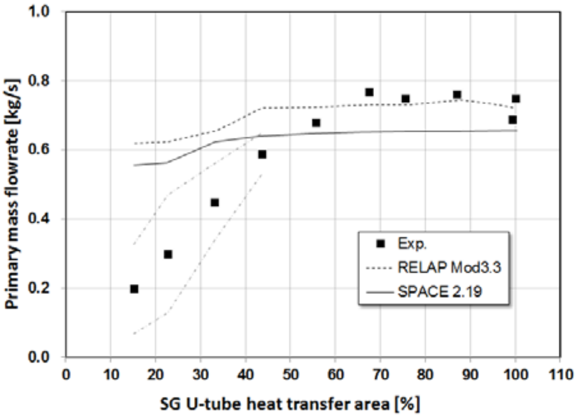

Fig. 2 Primary mass flow rate for S-NC-03

The measured mass flow rate at the primary side steam generator outlet in the region from 15% to 45% steam generator effective surface area was oscillatory [3]. The grey dash-dotted lines in Fig. 2, 3, 5~7, 9 present the minimum and maximum of the mass flow rate oscillations observed in experiments.

3. Analysis results

3.1 Sensitivity analysis results

Firstly, a sensitivity studies on interphase drag in primary system is carried out. Ten cases of equilibrium state are calculated for 2000 seconds respectively.

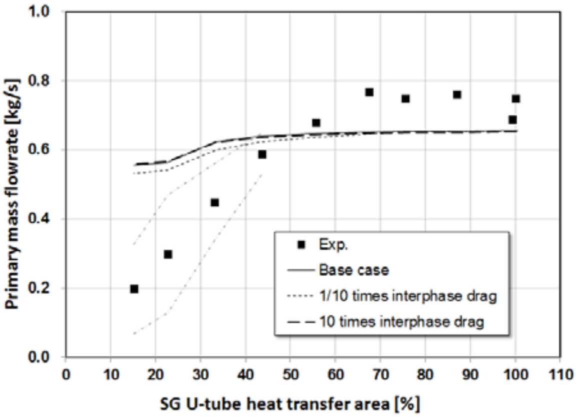

Fig. 3 Primary mass flow rate in varying interphase drag

The dialing factors of 1/10 and 10 on the interphase drag are applied in the calculations. As presented in Fig. 3, in the degraded heat transfer condition, maximum 4.2% of primary mass flow rate are changed for 1/10 times of the interphase drag case. This means vapor-liquid interphase drag looks not a major reason to explain the discrepancy in natural circulation mass flow rate.

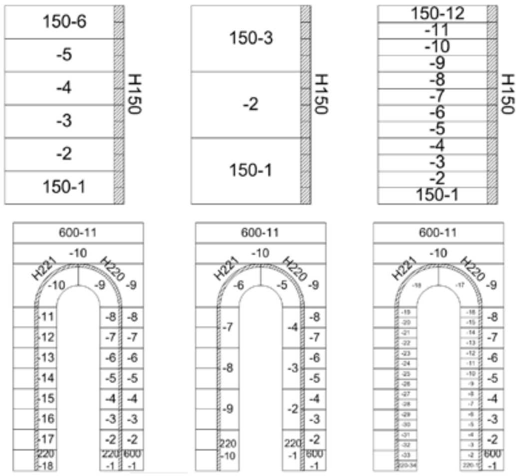

Fig. 4 6 cases of core and SG node for sensitivity study

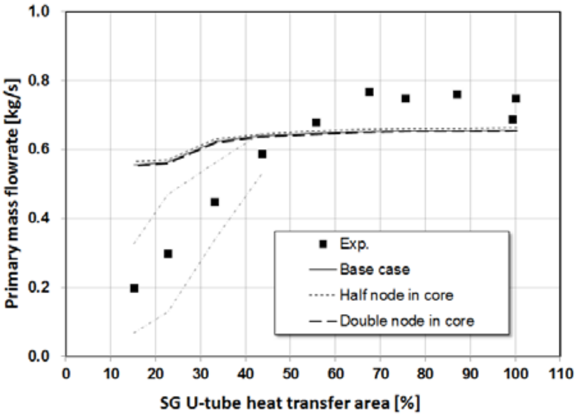

Fig. 5 Primary mass flow rate in core node sensitivity study

Secondly, the sensitivity studies on the core and steam generator node number are carried out. In the results of the 6 cases of node sensitivity calculation presented in Fig. 5 and 6, the maximum variation of the primary mass flow rate is 4.5%.

The third is the sensitivity study on the CCFL (counter-current flow limit) model in SPACE code. The calculation results show no dependency on the usage of the CCFL model, because there is no meaningful CCFL phenomenon in S-NC-3 test.

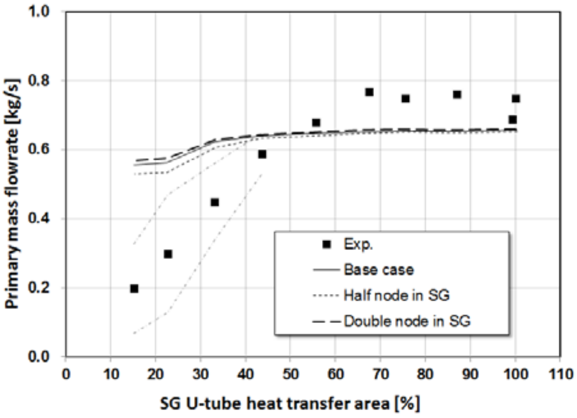

Fig. 6 Primary mass flow rate in SG node sensitivity study

In addition, the sensitivity study on the entrainment is performed. Because SPACE code calculates droplet field equation, the entrainment/de-entrainment phenomena can be analyzed more precisely. The calculation results show no dependency on the dialing on entrainment as depicted in Fig. 7.

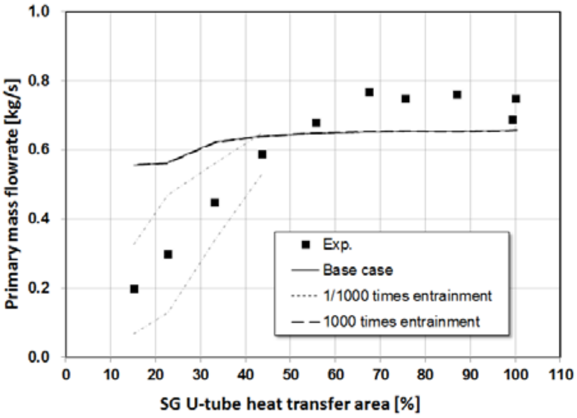

Fig. 7 Primary mass flow rate in entrainment sensitivity study

Finally, a sensitivity calculation for the primary inventory is carried out. The S-NC-2 test examined single-phase, two-phase, and reflux steady state modes by varying the primary side system mass with a constant steam generator secondary side condition. The S-NC-3 test examined primary side two-phase natural circulation behavior under varying steam generator secondary side mass inventory. In the S-NC-3 test, the primary inventory is selected where the primary loop mass flow rate is at its peak in the Semiscale natural circulation test S-NC-2 as presented in Fig. 8 [2]. Two-phase natural circulation was obtained by maximum density difference for 92% primary inventory. In SPACE and RELAP calculation results of S-NC-2, calculations give a peak natural circulation flow rate at a lower primary inventory than the experiment. The occurrence of this peak two-phase flow implies that bubbles are just reaching the top of the U-tubes and being pulled over into the downside [4]. At the same inventory, S-NC-2 calculations show all the bubbles condensing out lower in the upside of the U-tubes. The primary inventory must be dropped to 87% to simulate two-phase natural circulation flow peak which appears in maximum density difference condition [4].

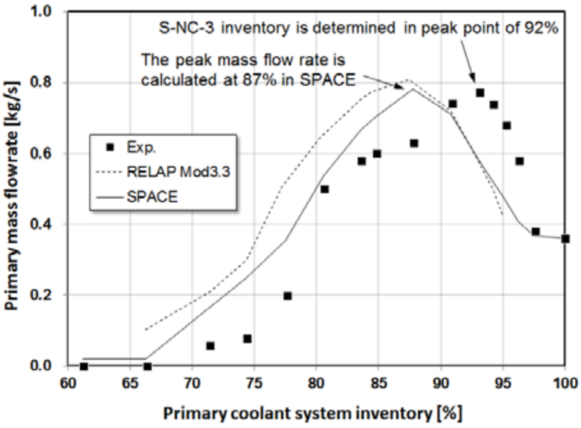

Fig. 8 Primary mass flow rate in S-NC-2

Matching the height and distribution of the two-phase mixture within the U-tubes relative to the height and distribution of secondary side liquid should be very important to predict correctly the degraded heat transfer phenomena observed in S-NC-3 [4].

Draining the primary inventory to 87%, where the peak mass flow rate is calculated in SPACE, the calculation result shows better qualitative and quantitative agreement with measured results as shown in Fig. 9.

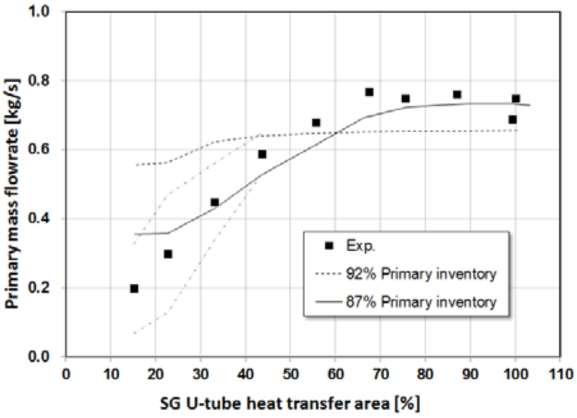

Fig. 9 Collapsed water level in reactor vessel

4. Conclusions

Sensitivity studies on Semiscale natural circulation test S-NC-3 in the degraded heat transfer condition test are performed. The quantitative agreement between calculated and measured primary flow rate have improved when the primary mass inventory used in the calculations is set to 87% rather than 92%. Equating the height and distribution of the two-phase mixture in calculation within the U-tubes with the experimental condition is essential to predict correctly the degraded heat transfer phenomena observed in S-NC-3.

Acknowledgement

This work was supported by the Nuclear Research & Development of the Korea Institute of Energy Technology and Planning (KETEP) grant funded by the Korea government Ministry of Trade, Industry and Energy (MOTIE).

REFERENCES

[1] SPACE 2.19 User's Manual, KHNP, 2016.
[2] Seyun Kim, et al., Preliminary assessment of SPACE code on natural circulation in Semiscale, KOSEE Autumn Meeting, Seoul, Korea, Oct. 2011
[3] RELAP5/Mod3.3 code manual, Volume III : Developmental assessment problems, ISL, NUREG/CR-5535/Rev 1-Vol III, Dec. 2001
[4] Wong, C. C. and Kmetyk, L. N., RELAP5 Assessment: Semiscale Natural Circulation Tests S-NC-3, S-NC-4, S-NC-8, SNL, NUREG/CR-3690, May 1984