OECD-NEA ATRIUM Activity: 2nd Exercise of post-CHF tests

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1. Introduction

SPACE code development team has participated in the OECD-NEA project of ATIRUM (Application Tests for Realization of Inverse Uncertainty quantification and validation Methodologies in thermal-hydraulics), which is practice for SAPIUM IUQ guideline. In the ATIRUM project, IBLOCA is selected as a test scenario. In addition, we defined two major phenomena of critical flow and post-CHF with separated effect tests [1]. The final target experiment is LSTF Test No.1 (LSTF IB-HL-01) of IBLOCA with hot-leg break. The first exercise was a critical flow phenomenon, and it was already analyzed [2]. During the IBLOCA scenario, the peak cladding temperature depends on several variables, including the critical heat flux (CHF), the minimum film boiling temperature, and the heat transfer on post-CHF(film boiling). For simplicity, the second exercise focuses only on the physical models related to the post-CHF. In this study, we will discuss status of 2nd exercise of the ATRIUM project.

2. Post-CHF Experimental Database

Proposed experimental database for post-CHF are Becker [3], Stewart [4], THTF [5]. Table I shows a summary of the experimental database with a target test of LSTF IBLOCA (LSTF IB-HL-01).

Table I: Summary of the 2nd exercise experimental database

ED	Type	No. tests	P [bar]
Baker T/S 1	Tube	281	30-200
Baker T/S 2	Tube	102	30-200
Baker T/S 3	Tube	38	150-200
Stewart	Tube	312	20-90
THTF FB	Bundle	22	40-130
THTF UB	Bundle	6	40-75
LSTF	**Bundle**	**1**	**20-50**
	G [kg/m²s]	**q” [W/m²]**	**$T_{sub,in}$[K]**
Baker T/S 1	500-3000	100-1250	10
Baker T/S 2	500-3000	90-850	10
Baker T/S 3	780-2475	290-940	5-10
Stewart	115-2833	65-460	9-56
THTF FB	226-806	320-940	8-46
THTF UB	3-30	74-480	46-103
LSTF	**0-600**	**500-2000**	**0**

To evaluate the adequacy of the experimental database, adequacy analysis was conducted with SAPIUM guidelines. From the results, the Stewart experiment is deleted due to the low capability of physical phenomena of interest required for the simulation [6].

The Beker experiment [3] was performed in the Royal Institute of Technology (RIT), so sometimes this test called as RIT test. They consist of a heated cylindrical tube delimited by two copper rings. It has three kinds of test sections with different diameter sizes and heated lengths. They measured flow rate, local wall and fluid temperatures, inlet and outlet pressure, and temperature. The wall temperature from this result, we can estimate burn-out occurs when a significant increase in wall temperature. Fig. 1 shows a schematic diagram of the Beker test facility.

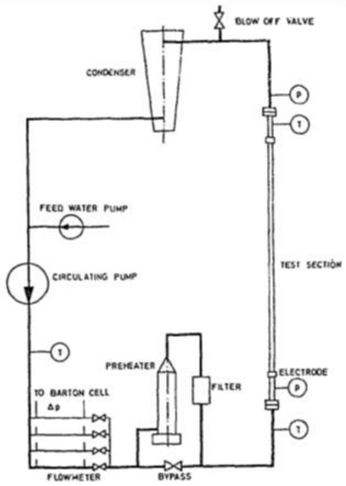

Fig. 1. Becker experimental facility [3].

The THTF (Thermal-Hydraulic Test Facility) is a heavily instrumented pressurized-water loop built at ORNL [5] to investigate the heat transfer phenomena during small and large break LOCA. Fig. 2 shows a simplified LSTF facility [5]. The test section consists of a cylindrical barrel containing 8x8 electrically heated rods enclosed in a shroud box (in Fig. 3). The 60 rods are heated structures, but 4 rods are used for instrumentation. The shroud box holds 6 grid spacers along the heated length and 1 grid spacer located before the beginning of the heated length. There are 14 axial measurement locations for rod temperature and fluid void fraction. In this study, two kinds of tests in THTF are considered. The first experiment is the Film Boiling (FB) test and the second experiment is the Uncovered Bundle (UB) test. In the film boiling tests, the bundle power was increased until the dry-out point was obtained at the desired level. A steady state was reached when pressure and rod temperature were stabilized. In the uncovered bundle tests, a certain collapsed level was obtained in the bundle thanks to the connection lines between the pressurizer and the annulus and the annulus and the outlet section. After stabilization, the power of the bundle increased to produce the peak cladding temperature safety limit of 740 °C.

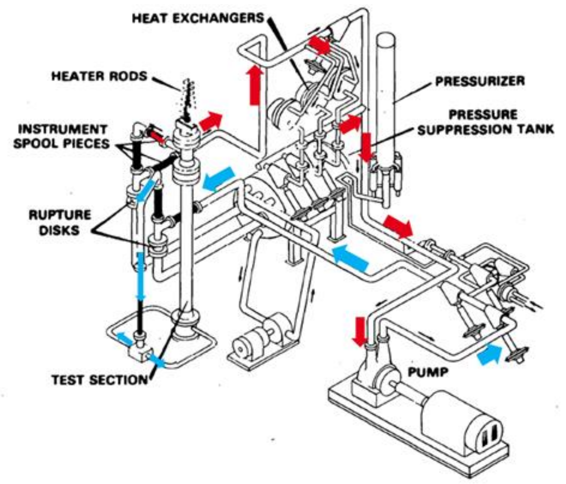

Fig. 2. THTF experimental facility [5].

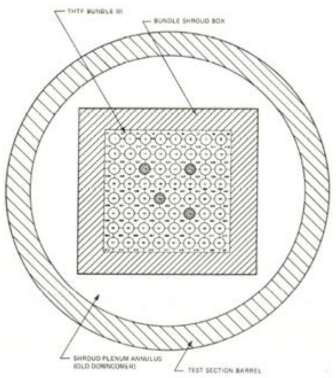

Fig. 3. THTF cross section of test section [5].

3. Preliminary Calculation for Experimental Database

Using the SPACE code, preliminary calculation for the post-CHF experimental database is conducted. These input models will be nominal calculations for future Inverse Uncertainty Quantification (IUQ) with selected input parameters.

3.1 Baker Test

In the Baker test, a total of 510 runs are available: 334 runs are performed with test section 1, 138 with test section 2, and 38 with test section 3. In this study, all tests are not explained. Fig. 4 shows representative results for test section 2. The predicted dry-out location is slightly lower than the experiments. And the wall temperature after dry-out is over-estimated. This trend is easily observed in overall tests.

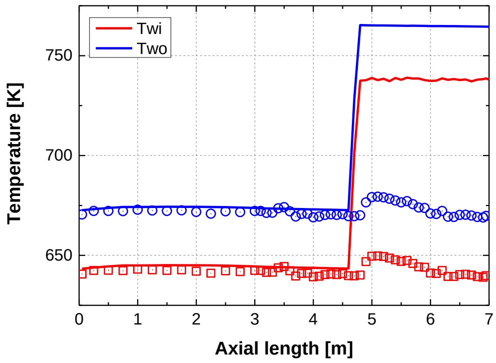

Fig. 4. Wall temperature for Baker test section 2 run no.336.

3.2 THTF Tests

In the THTF tests, the film boiling test has 22 runs, and the uncovered bundle has 6 runs. Fig. 5 shows representative results of wall temperature for the film boiling test B. The test section of THTF is rod bundle type with grid spacers. Thus, there must be grid spacer effects, such as single-phase vapor heat transfer enhancement, droplet breakup, radiation heat transfer, rewetting, and so on. To consider these effects, the grid spacer model, single-phase vapor heat transfer enhancement model, and IAT (interface area transport) model are applied. Moreover, different combinations of models are applied to check the contribution of each model in the wall temperature prediction. In the legend of Fig. 5, the Vertical green line indicates the grid spacer location. The measured wall temperature is dropped after passing through a grid spacer due to heat transfer enhancement. 'wo GS' indicates calculation without a grid spacer model. GS, IAT, and SP indicate grid spacer, IAT, and single-phase vapor enhancement models, respectively. In case 2, all grid spacer related models are applied, and the wall temperature is well predicted like experiments. When the SP model was not applied (case 3), the wall temperature generally appeared similar to the experimental results, but the effect of the grid spacer was not significant. However, when only the IAT model was not applied (case 4), the effect of the grid spacer appeared weak, but the overall wall temperature was higher. This indicates that the IAT and SP models are complementary to each other.

Fig. 6 shows the representative void fraction of UB test run J. All results show a reasonably well-predicted void fraction. In this study, the Chexal-Lellouche drift flux model, which is developed for rod bundle type, gives a better prediction.

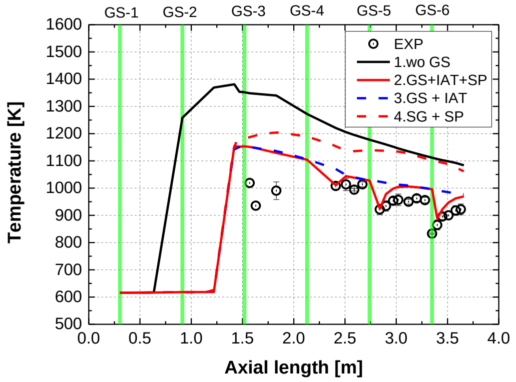

Fig. 5. Wall temperature for THTF Film boiling test run B.

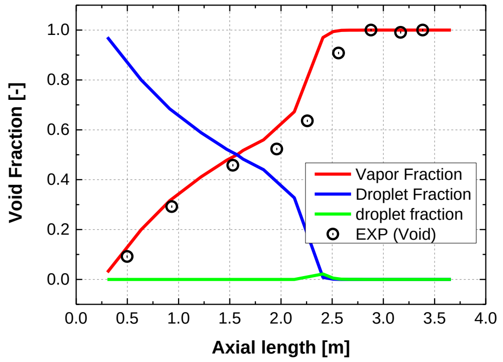

Fig. 6. Void fraction for THTF Uncovered Bundle test run J.

4. Summary

SPACE code development team has participated in the OECD/NEA ATRIUM Project. Currently, 2nd exercise of post-CHF is working. The post-CHF experimental database of Baker and THTF tests is selected through adequacy analysis. In this study, preliminary calculations of Baker and THTF tests are carried out. All prediction shows reasonable results for post-CHF phenomena in terms of wall temperature and void fraction. In particular, grid spacer models in SPACE show very good performance in predicting the heat transfer enhancement through a grid spacer. In the next step of the SAPIUM guideline, the input parameters related to post-CHF phenomena will be selected to analyze inverse uncertainty quantification (IUQ). Finally, all updated uncertainty distributions of all input parameters will apply to the target IET test of LSTF IBLOCA test No. 1.

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REFERENCES

[1] Specification for the ATRIUM Project- 2nd exercise Rev.1, CEA-Saclay, 2024.

[2] C. CHOI, J. Heo, and S. Lee, Inverse Uncertainty Quantification using SPACE in ATRIUM (Application Tests for Realization of Inverse Uncertainty quantification and validation Methodologies in thermal-hydraulics), 10th Korea-China Workshop on Nuclear Reactor Thermal-Hydraulics (WORTH-10), November 26-29, Jeju, South Korea, 2023.

[3] K. M. Becker, C. H. Ling, S. Hedberg and G. Strand, "An experimental investigation of post dry-out heat transfer," Departement of Nuclear Reactor Energy, Royal Institute of Technology, Stockholm, 1983.

[4] J. C. Stewart, "Low quality film boiling at intermediate and elevated pressures," PhD Thesis, University of Ottawa, Ottawa, 1981.

[5] C. B. Mullins, D. K. Felde, A. G. Sutton, S. S. Gould, D. G. Morris and J. J. Robinson, "ORNL Rod Bundle Heat Transfer Test Data Volume 7. Thermal-Hydraulic Test Facility Experimental Data Report for Test Series 3.07.9—Steady-State Film Boiling in Upflow, NUREG/CR-2525, Vol. 7," Oak Ridge National Laboratory, Oak Ridge, 1982.

[6] C. CHOI, J. Heo, and S. Lee, Adequacy Results of 2nd exercise in OECD/NEA ATRIUM Project for SPACE, KNS Spring Meeting, Jeju, South Korea, May 9-10, 2024.