Preliminary Numerical Analysis of the Downcomer Boiling Test for APR1400 by Using the MARS Code

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1. Introduction

APR1400 adopts new safety injection concepts, such as the direct vessel injection(DVI), fluidic device, and elimination of the low pressure safety injection flow, etc. The new safety features are expected to increase the emergency core cooling capacity. The reflood rate in the core is an important parameter for the core cooling during the LBLOCA reflood period. It depends on the safety injection flow characteristic and multi-dimensional thermal hydraulics in the downcomer. Most of the best-estimate safety analysis codes show that the boiling phenomena from the downcomer structure can significantly affect the nuclear fuel cooling capacity during the late reflood phase. However, results of the safety analysis for the LBLOCA of the APR1400 plant are different according to the codes used.[1][2] It may be due to the difference in the various models composing the code. Therefore, it is necessary to investigate the boiling phenomena in the downcomer wall during the LBLOCA reflood period and to improve the code capability.

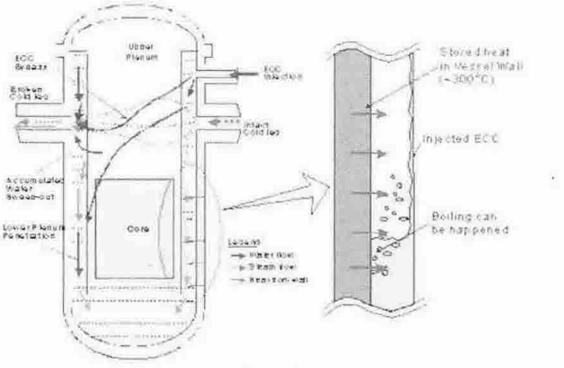


Fig. 1. Downcomer Boiling Phenomena of APR1400 under the LBLOCA

Based on this background, KAERI is performing the separate effect test program for simulating the phenomena in the reactor downcomer during the LBLOCA reflood period. The facility is designed so as to meet a full scale for the height and gap of the reactor downcomer. The facility simulates a 1/47.08 azimuthal part of the prototype downcomer section area.

To investigate the performance of the experimental facility and to find the requirements for the various instruments, a preliminary numerical test is performed in this study. The evaluation of the predictability for the boiling phenomena of the safety analysis code is another purpose. The version of the code used is MARS 2.1.

2. Methods and Results

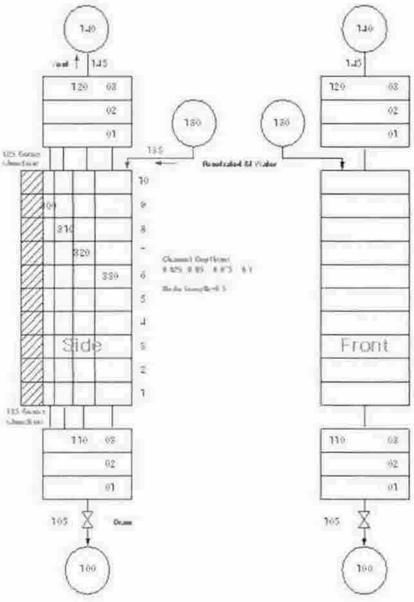


Fig. 2. MARS Model for Simulation

According to the preliminary tests performed separately in KAERI and KAIST, there observed definitely a bubbly boundary layer near the wall. The boundary layer is significantly thin except for the upper region of the test section. To reflect the void profile and to investigate the node size effect qualitatively, two kinds of downcomer gap model are applied. One is a single-channel model and the other is a four-channel model. For the four-channel test, the node size near the wall is set to be smaller than the other regions.(See Fig. 2) The boundary conditions are summarized as follows, which were deduced from the TRAC results.

- Penetrated SI Flow: 1.7kg/s
- SI Temperature in D/C: 95°C (5°C Subcooling)
- Heat Flux: 70kW/m2

The analyses are performed for the three cases, which are defined as follows:

Case 1: Single Channel Model for the Downcomer
Case 2: Four Channel Model for the Downcomer
Case 3: Applying the Lateral Equilibrium Momentum Equation in the Case 2 Model)

2-1. Case 1 Model

This model is a conventional type for a safety analysis of the nuclear reactor thermal hydraulics.

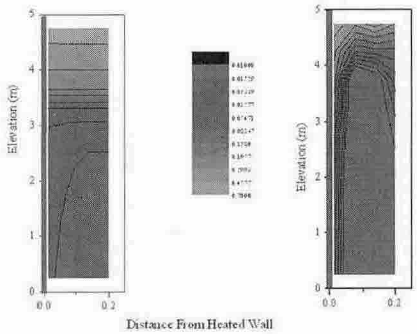
However, this model has a weak point in predicting the complicated local boiling phenomena such as the upward bubble motion near the wall and a downward liquid flow. Since there is no efficient steam vent path, most of the generated steam is condensed before it is vented. The results show that the bottom of the test section has a saturated condition. As the liquid temperature reaches a saturated condition, a numerical oscillation occurred and we could not achieve steady-state results. To get the convergent solution, we had to reduce the inlet water temperature slightly. These results show that the single-channel approach is very conservative.

2-2. Case 2 Model

The Case 2 model has four channels for the downcomer simulation. Figure 3(a) shows the void fraction profile in the test section. According to the figure, there is no significant variation in the void fraction in the lateral direction. This trend is different from the preliminary experimental tests. This discrepancy comes from the misleading flow regime at the lateral junction. The MARS sets the horizontally stratified flow regime for the low velocity condition to less than a critical velocity. Therefore, the lateral steam motion is active, which leads to a flat lateral void fraction profile. This should be corrected based on the experimental investigation. The profile of the liquid and steam velocities showed that there are highly upward fluid motions near the wall and an efficient steam vent path. The existence of the steam path means that a part of the wall heat can escape without an energy transfer to the fluid, which results in a lower drain water temperature rise. Table 1 shows that the case 2 model has an 8K subcooling at the bottom of the test section.

2-3. Case 3 Model

The Case 3 model has the same nodalization as the Case 2, but applies an equilibrium velocity option to the lateral connection, which means that the steam velocity is the same as the liquid velocity in the crossflow junction. Figure 3(b) shows a significant variation for void fraction in the lateral direction and a definite bubbly boundary layer near the wall. This trend is almost similar to the KAERI and KAIST preliminary test. The profile of the liquid and steam velocities shows a more upward fluid motion near the wall. The profile shows a definite escaping path of the generated steam at the heated wall. Therefore, the subcooling of the drain water is larger than the previous case models.



(a) Case 2(b) Case 3

Fig. 3. Void Profile in the Downcomer

Table 1. Results for the Analysis

	Case 1	Case 2	Case 3
Inlet Subcooling(K)	5	5	5
Drain Subcooling(K)	0	8.0	9.5
Inlet Flow(kg/s)	1.7	1.7	1.7
Steam Vent Flow(kg/s)	-	~0.028	0.031

3. Conclusions

A single-channel model for the downcomer boiling shows no efficient steam vent path, which leads to a numerical oscillation and a large condensation. However, the multi-channel model shows a definite steam vent path, which leads to a higher subcooling degree at the lower part of the downcomer. Therefore, the single channel model has a large conservatism for the safety analysis. Although the case 3 model has an assumption for the lateral momentum, the results are very feasible when referring to the experiment. The numerical oscillation shown in the single-channel model and the misleading cross flow regime of the multi-channel model should be improved in the safety analysis code.

Acknowledgement

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