Transactions of the Korean Nuclear Society Spring Meeting
Chuncheon, Korea, May 25-26 2006

Scaling Analysis and MARS Calculation of SNUF Experiment for the DVI Line Break SBLOCA in APR1400

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1. Introduction

APR1400 (Advanced Power Reactor 1400MWe) adopted the DVI (Direct Vessel Injection) system as the advanced feature of ECCS (Emergency Core Cooling System). It requires the safety analysis for the DVI line break SBLOCA and the conventional analysis model should be estimated or revised for application of the accident[1].

This study focuses on the experimental study for DVI line break SBLOCA in APR1400, utilizing the integral test loop, SNUF (Seoul National University Facility)[2]. In order to determine the experimental condition, the scaling study was conducted so that the experimental results can be reasonably scaled up to prototype. And the facility was simulated with the best-estimated code, MARS[3], for a pre-analysis of experiment.

2. Scaling Analysis

2.1 Determination of initial conditions

DVI line break accident in prototype was analyzed with MARS code to determine the initial conditions in SNUF. For the severe condition, it was assumed that the decay heat had 120% of normal power and the single failure of SI (Safety Injection) was occurred.

As depicted in Figure 1, the pressure in primary system reveals a plateau from 55 s to 100 s. During this period, the secondary system pressure shows the equilibrium with primary system and the downcomer seal is cleared. The phenomena of downcomer seal clearing is that the steam injected from cold leg penetrate through upper downcomer to the broken DVI. It is one of the important phenomena with respect to the depressurization of primary system. Therefore the test condition was determined as 55 s after the break.

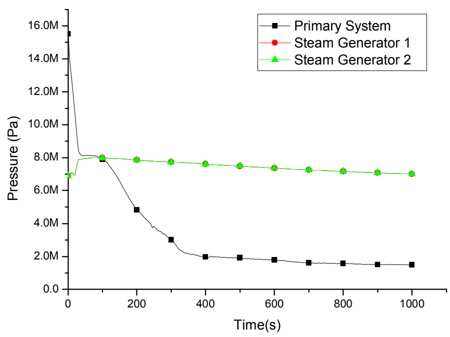

Figure 1. Pressure in APR1400

2.2 Power-to-mass scaling

SNUF is a kind of RHRP (Reduced-Height Reduced-Pressure) facility, so that an appropriate scaling methodology should be adopted. Among various ones, the power-to-mass scaling methodology from INER[4] was estimated to be applicable in SNUF. That methodology scales the heating power with respect to the mass of coolant inventory in facility. Accordingly, it can consider the variation in thermal properties of fluid for the reduced pressure condition. Considering the test capability of SNUF, the reduced pressure at initiation was determined as 8 bar.

Thermal power in test condition (*Q*) was scaled by the ratio of coolant mass (*M*) between the prototype and SNUF.

$$\frac{Q_{SNUF}}{Q_{APR}} = \frac{M_{SNUF}}{M_{APR}} \cong \frac{\rho_{SNUF}}{\rho_{APR}} \cdot \frac{V_{SNUF}}{V_{APR}} = 8.63\times10^{-4} \qquad (1)$$

In the other hand, the condition in secondary system should satisfy the following relationship about the temperature difference with cold leg.

$$\left(T_{CL} - T_{sat}\left(P_s\right)\right)_{SNUF} = \left(T_{CL} - T_{sat}\left(P_s\right)\right)_{APR} \qquad (2)$$

As shown in Figure 1, the secondary system pressure is nearly equivalent with primary one at 55sec in APR1400 and it decreases due to the reverse heat transfer in steam generator. However, the decreasing amount is negligible with respect to the transient of primary system. Therefore, the condition of secondary system was determined as the saturation at 8 bar, which is equal to initial condition of primary system.

The reference scenario in this study assumes the most severe case, so that the Guillotine-break is simulated and break area is scaled down according to the ratio of global scaling. The mass flow rate of SI water was calculated by the ratio of mass inventory. And the conservation of subcooling was considered for the temperature of SI.

$$\frac{\dot{m}_{SNUF}}{\dot{m}_{APR}} = \frac{M_{SNUF}}{M_{APR}} \qquad (3)$$

$$\left(\frac{C_p \Delta T}{h_{fg}}\left(\frac{\rho_f}{\rho_g}\right)^{1/2}\right)_R = 1 \qquad (4)$$

From the procedure described above, the initial conditions of APR1400 and SNUF were estimated as listed in Table 1.

Table 1. Test conditions of APR1400 and SNUF

Parameter	APR1400	SNUF
Pressure	80 bar	8 bar
Power	131 MW	113 kW
Broken DVI Area	3.66×10^{-2} m^2	2.06×10^{-4} m^2
SI Flow Rate	64.8 kg/s	0.056 kg/s
SI Temperature	48.9 ℃	54.6 ℃

3. Result of MARS Analysis

According to the above conditions, the code simulation for experiment was conducted with the best-estimate safety analysis code, MARS 3.0. The analysis results are expected to validate the experimental procedure and will be used to estimate the capability of the code for downcomer seal clearing phenomena.

The SNUF control system of electrical heaters and safety injection cannot simulate the exact decay heat curve in prototype. Therefore, the heater power in reactor vessel and SI flow rate were input in the code as integrated value during the transient.

SNUF does not simulate the transient before 55 s in prototype. So it is necessary to make a steady state corresponding to that time in the test facility. With supply of the constant thermal power, a relief valve was installed on the top of upper plenum and it released the steam in reactor vessel to make a system pressure constant as 8 bar.

Figures 2 to 4 shows the analysis results for transient after the break at 0 s, where the result of APR1400 was shifted in time and reduced to the scale of SNUF according to power-to-mass scaling methodology. As depicted in the figures, SNUF showed faster decrease in pressure and coolant inventory after the initiation of transient. It is due to the abrupt open of broken DVI after the steady state in SNUF, whereas the transient after break preceded in APR1400. After the pressure and break flow rate were sufficiently decreased around 100 s, the injected SI coolant effectively contributed to increase of coolant inventory. Because SI flow rate in SNUF was integrated value, which was lower than the realistic one after SIT injection in prototype, SNUF result revealed the late recovery of water level. In spite of these differences, the analysis results show that SNUF can reasonably simulate the behavior in APR1400.

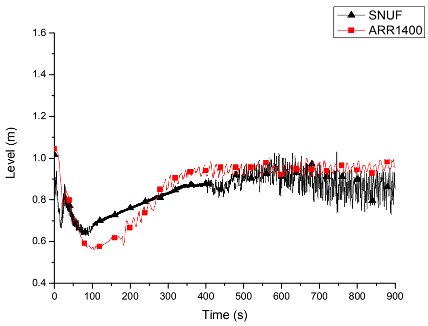

Figure 2. Collapsed Water Level in Core

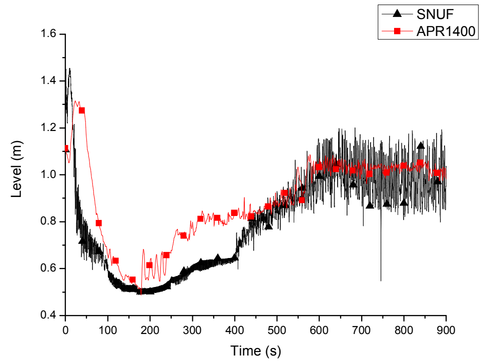

Figure 3. Downcomer Level

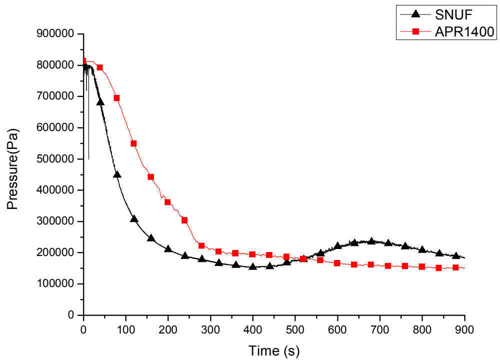

Figure 4. Pressure of Primary System

4. Conclusion

In order to study the thermal hydraulic phenomena in DVI line break SBLOCA, experimental conditions in SNUF have been determined according to power-to-mass scaling methodology. And pre-analysis of MARS code showed that the scaling procedure and test conditions were reasonable for predicting the behavior of APR1400.

In the future, based on this work, the experimental study will be conducted including the visualization of upper downcomer. These results will be utilized to estimate the validation and scale-up capability of MARS code for predicting the downcomer seal clearing.

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