# Power-to-Energy Scaling Methodology in the SNUF for DVI line Break SBLOCA Using the MARS Code

K.H. Lee*, B.U. Bae, G.C. Park
*Department of Nuclear Engineering, Seoul National University, Seoul, 151-742, Korea,*
** E-mail : snulkh99@snu.ac.kr*

## 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].

The integral test loop, SNUF (Seoul National University Facility) is utilized for this study. It has been constructed to be scaled down to 1/6.4 in length and 1/178 in area from APR1400[2]. And it is RHRP (Reduced-Height and Reduced-Pressure) system. Therefore, an appropriate scaling methodology in the RHRP facility is indispensable to observe the key thermal-hydraulic transient phenomena. Thus the major task of this paper is to propose a suitable scaling method in the SNUF for DVI link break SBLOCA using the best-estimate safety analysis code, MARS[3].

## 2. Scaling Method

### *2.1 Analysis of APR1400 Model*

The DVI line break accident in the prototype, APR1400, was calculated with MARS to determine the conditions in SNUF. For conservative conditions, it is assumed that core power has 120 % of normal power and 102 % of decay heat according to the ANS73 model. Also single failure of SI (Safety Injection) is assumed and the Guillotine-break of DVI line was postulated for the most severe case.

### *2.2 Power-to-Energy Scaling Methodology*

SNUF is a kind of RHRP facility, so that an appropriate scaling methodology should be applied. Basically, to preserve the timing of the event, the change rate of the coolant mass inventory should be conserved during the transient[4]. And a power-to-energy scaling was proposed to determine the core decay power. Also some specific scaling methods are applied to simulate the APR1400 model more similarly.

Considering the test capability of SNUF, the reduced primary system pressure at initiation was determined as about 8 bar. This pressure is scaled down from the prototype by the scaling factor of pressure, 1/20. The secondary system pressure is also scaled down with the same ratio.

To preserve cold-leg subcooling, the initial cold-leg fluid temperature $T_{CL}$ should satisfy the following relationship.

$$[T_{CL} - T_{sat}(P_s)]_R = 1 \tag{1}$$

Hot-leg fluid temperature $T_{HL}$ is determined by the specific enthalpy difference between the primary saturated temperature, the hot-leg fluid temperature and the cold-leg fluid temperature ratio.

$$\begin{aligned} &[h_f(T_{sat}(P_p)) - h(T_{HL}, P_p)]_R \\ &= [h_f(T_{sat}(P_p)) - h(T_{CL}, P_p)]_R \end{aligned} \tag{2}$$

This concept is from that the energy change rate of each part in the primary system should be same between the SNUF and the APR1400.

For conservation of the timing, the change rate of the coolant mass inventory ($M$) should be same between the SNUF and the APR1400. Therefore, the mass flow rate of SI water was calculated by the ratio of mass inventory. The ratio can be obtained from the initial coolant mass inventory difference.

$$[M]_R = [\rho((T_{HL} + T_{CL})/2, P_p) \cdot V]_R = [\dot{m}_{SI}]_R \tag{3}$$

And the temperature of SI water is determined as considering the conservation of subcooling.

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

The thermal power ($Q$) in the core is determined by the difference of coolant energy between at core inlet and core outlet coolant. This difference of energy can be calculated by specific enthalpy and mass flow rate of the coolant. To preserve the timing of the event, the ratio of coolant mass flow rate in core should be same as that of the initial coolant inventory. That gives the ratio of thermal power as follows.

$$[Q]_R = [M \cdot (h(T_{HL}, P_p) - h(T_{CL}, P_p))]_R \tag{5}$$

The broken DVI area was scaled based on the Henry-Fauske critical flow model. To preserve the primary mass inventory in both the SNUF and the APR1400 model, the ratio of the critical mass flow rate should be same as the ratio of the initial coolant mass inventory.

$$[A]_R = [M]_R / [G_c]_R \tag{6}$$

The ratio of critical mass flux ($G_c$) was determined by the MARS calculation case which adopts the Henry-Fauske critical flow model option. As the result, the broken DVI area is needed to be changed as the primary system pressure in the SNUF. It should be increased as the primary system pressure decreases in almost reciprocal proportion.

## 3. Results and Discussion

The SNUF model is calculated with MARS code. The results are compared to the calculation results of the APR1400 model. The key parameters of the ideal model are very similar with those of the APR1400 model. The primary system pressure in Figure 1 shows good agreement in each other behavior during the transient.

As shown in Figures 2 and 3, the void fraction of upper downcomer and the downcomer collapsed level show similar trends in the models. These behaviors are related with downcomer seal clearing phenomenon that steam injected from cold leg penetrates through upper downcomer to broken DVI. Downcomer seal clearing phenomenon is observed between 0 s and 150 s in the APR1400 model. But, in the SNUF model, the phenomenon is occurred more rapidly at about 100 s. This difference is probably because the downcomer boiling phenomenon[5] is not simulated exactly in the SNUF. However, the timing of the sequence is almost equivalent. Therefore, it can be said that the phenomenon is simulated reasonably with the MARS code.

Figure 4 shows that the trend of the integrated break flow is almost same between the SNUF model and the APR1400 model. It means that the timing of events is conserved during the transient, because the timing is very closely related with the primary coolant inventory as the scaling method.

According to these results, the scaling method suggested in this study is verified with the code analysis. Also, the scale-up capability of MARS code is verified.

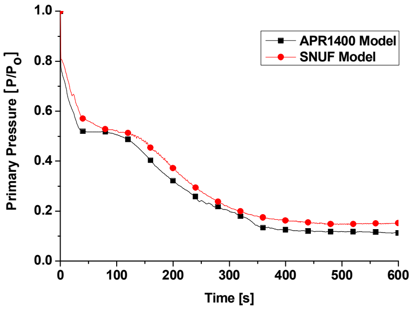

Figure 1. Primary System Pressure of SNUF Model and APR1400 Model.

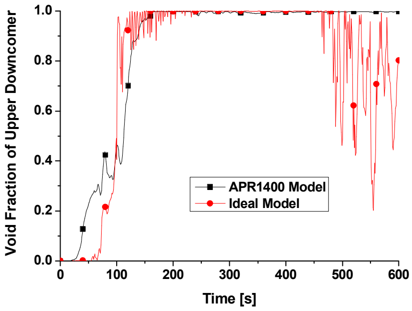

Figure 2. Void Fraction of Upper Downcomer of SNUF Model and APR1400 Model.

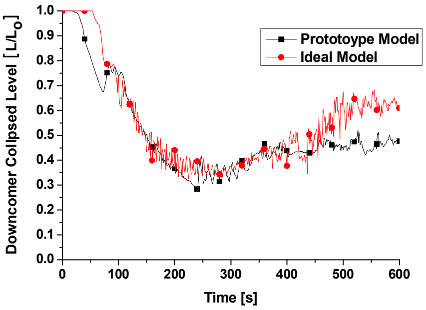

Figure 3. Downcomer Collapsed Level of SNUF Model and APR1400 Model.

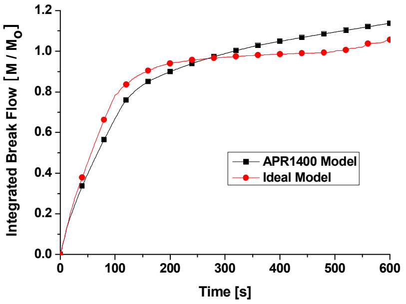

Figure 4. Integrated Break Flow of SNUF Model and APR1400 Model.

## 4. Conclusion

In order to study the thermal hydraulic phenomena in DVI line break SBLOCA, the conditions in SNUF have been determined according to the proposed scaling method. The analysis of MARS code showed that the scaling procedure and conditions were reasonable for predicting the behavior of the prototype, 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.

## REFERENCES

[1] K. H. Bae et al., Best Estimate Small Break Loss of Coolant Accident Analyses for Korean Next Generation Reactor with DVI ECCS, KAERI/TR-1235/99, 1999

[2] Y. S. Kim et al., RELAP5/MOD3.3 Analysis of Coolant Depletion Tests after Safety Injection Failure During a Large-Break Loss-of-Coolant Accident, Nuclear Engineering and Design, vol. 235, pp. 2375-2390, 2005

[3] KAERI, MARS3.0 Code Manual Input Requirements, KAERI/TR-1235/99, 2004

[4] C. J. Chang et al., IIST Small Break LOCA Experiments with Passive Core Cooling Injection, Nuclear Engineering and Design, vol. 236, pp. 19-34, 2006

[5] D. J. Euh et al., Investigation of the Boiling Phenomena in a Reactor Downcomer during a LBLOCA Reflood Phase, Proc. of the 11th International Toical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-11), Avignon, France, October 2-6, 2005