Differences in LBLOCA Thermal-hydraulic Response Between 1D and 3D Calculations

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1. Introduction

Best-Estimate (BE) calculation of large break Loss-of-Coolant-Accident (LBLOCA) has been applied to the most of the domestic Nuclear Power Plants (NPP). One of the recent concerns in LBLOCA analysis of APR1400 design was a potential of the 'blowdown quenching', which drastically decreased the fuel cladding temperatures by the downflow of the water from the Upper Guide Structure (USG) of the reactor vessel to the core [1]. Depending on its extent, the cladding temperature response during reflood phase can change greatly, and then the uncertainty of reflood phenomena such as downcomer boiling may be more important. Due to the concern, a more specific analysis such as three-dimensional (3D) calculation, has been required for the LBLOCA thermal-hydraulic response. The present study is to discuss the 3D calculation and its result in comparison with that from 1D calculation. Several differences and their reasons are also discussed. MARS-KS code was used for the 1D and 3D calculation, and the hot channel whose flow area is not greater than area of one fuel assembly was used.

2. Code and Modeling

MARS-KS Version 1.2 [2] was used in this study. For the 3D calculation, the MULTI-D component was used for the reactor vessel.

Fig. 1 shows a comparison between 1D modelling and 3D one of reactor vessel. In 1D modeling, 6 azimuthal sectors having 10 axial volumes each were used for the downcomer with 60 crossflow junctions between the volumes in azimuthal direction. In 3D modeling, a MULTI-D component having 1×6×10 ($N_r \times N_\theta \times N_z$) array was used. The region from the core inlet to the UGS was modeled by a MULTI-D component of 4×6×27 array. Especially, each flow area of the 6 volumes of the Ring 1 of the core was the same as the flow area of one fuel assembly, which satisfies the requirement on hot and consistent with 1D modeling.

3. Results and Discussions

3.1 Steady State

Both the steady state from 1D modeling and the 3D one are almost identical and comparable with the licensee's calculation. Fig. 2 shows a distribution of coolant temperature and velocity vector over the volumes of the cross section of reactor vessel, which was from 3D calculation.

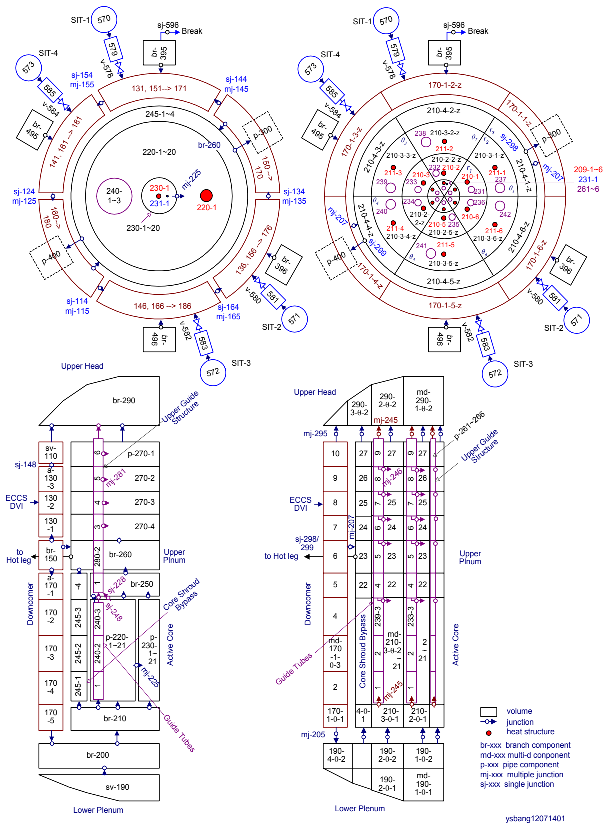

Fig. 1 Nodalizations of Reactor Vessel

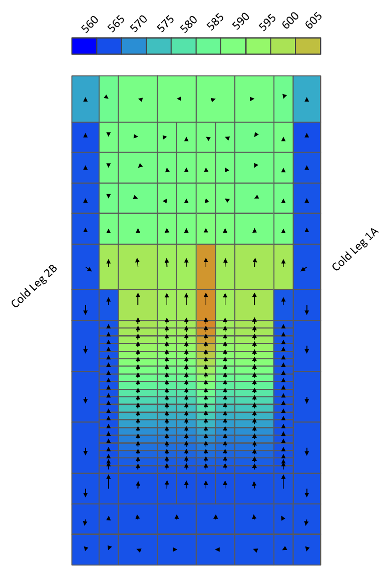

Figure 2 Distribution of Coolant Temperatures and Velocity Vectors

The coolant temperature was distributed including the hot channel as expected. Temperatures at the Upper Head and UGS region ranged from 585 to 590 K, a little lower than hot leg temperature, which was due to the bypassed water from the downcomer. The UH temperature was known to be an important parameter to the blowdown quenching.

3.2 Base Case Transient

Fig. 3 shows a comparison of fuel cladding temperature at the hot channel. After break, the blowdown PCT was observed at 10 sec, and then blowdown quenching found until 16 sec by the downward flow of water from the UGS region. It was re-increased by stopping of the downflow even though the injection of SIT was started at 17 sec.

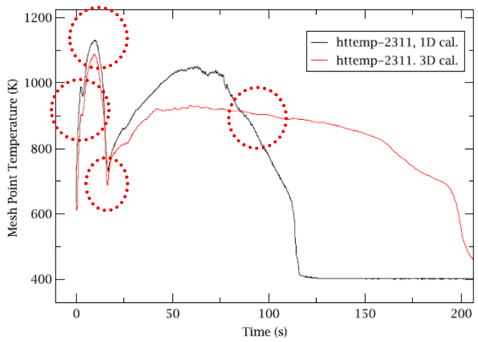

Figure 3 Comparison of Cladding Temperatures of Base Case

The comparison indicated some differences between 1D calculation and 3D one: (1) lower blowdown PCT in 3D calculation, (2) instantaneous stop of cladding heat-up, (3) extent of blowdown quenching, and (4) milder and longer reflood process in 3D calculation.

The reason for the blowdown PCT of 3D calculation lower than one of 1D calculation was due to the delay of initial heat-up in 3D calculation. It was due to the 3D flow acceleration in the core in a short time after break.

The reason for an instantaneous stop of cladding heatup at 3 sec in both cases was due to the local and temporal inflow from the downcomer to the core during blowdown process.

The extent of the blowdown quenching was also somewhat different between two cases. From the comparison of cladding temperatures along the positions, it was found that the 15-th spot was quenched in 3D calculation while not fully quenched in 1D calculation. It was due to the difference in amount of down flow induced by 3D flow distribution.

The reason for the steeper heat-up was the higher ECCS bypass ratio in 1D calculation at that time period. The reason for the later quenching may be related to 3D hydrodynamics. Fig. 4 shows liquid fraction and velocity vectors over the reactor vessel at 150 sec, which indicated the substantial portion of the core had a liquid fraction greater than 0.3 and the complex flow patterns was to distribute the water over the core. It is believed to have an effect to delay the reflooding.

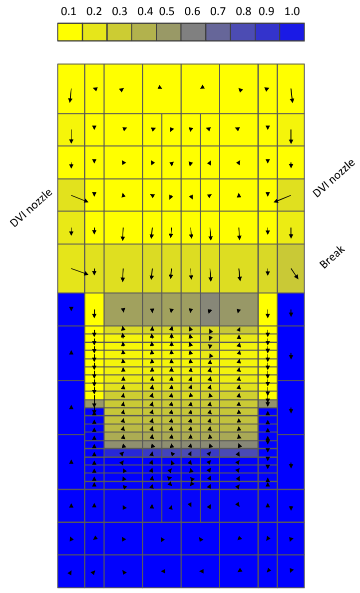

Fig. 4 Liquid Fractions and Velocity Vectors over Reactor Vessel at 150 sec

3.3 Sensitivity Study

Fig. 5 shows a comparison of cladding temperatures for the cases having various K-factors at the junctions between the downcomer and the UH. It can be shown that the reflood PCT can be changed about 280 K by changing the initial UHS temperature (4 K).

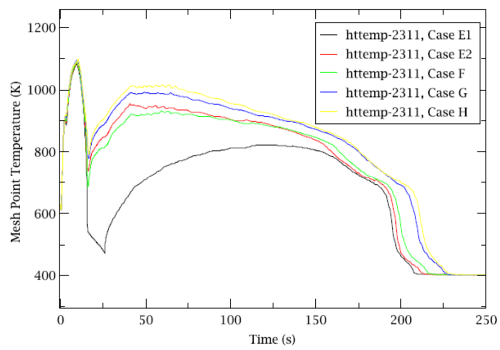

Figure 5 Comparison of Cladding Temperature of Sensitivity Study

4. Summary and Conclusions

Four kinds of differences were found in thermal-hydraulic response of LBLOCA between 1D and 3D calculations and their reasons were also traced. From the sensitivity study, the importance of initial upper head temperature and its impact on reflood PCT were identified.

REFERENCES

[1] KINS, RAI on LBLOCA Analysis, SKN Units 3, 4 FSAR, 2012.
[2] KAERI, "MARS Code Manual," KAERI/TR-2811/2004, 2009