Evaluation for Effect of Upper Head Nodalization and Temperature in OPR1000 Plant

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ABSTRACT

In the best estimate (BE) method with the uncertainty evaluation, the nodalization for LBLOCA calculation was determined by the comparative studies of the experimental data. Up to now, it was assumed that the temperature of the upper dome in OPR1000 was close to that of the cold leg. But, it was found by the evaluation of the detailed design data that the temperature of the upper head/dome might be a little lower than or similar to that of the hot leg. In this study, the LBLOCA analysis was performed to identify the effects of the upper head nodalization and the temperature. In conclusion, the high upper head temperature can affect the modification of nodalization for upper head, the blowdown quenching, the peak cladding temperature in the reflood phase, etc.

1 INTRODUCTION

Nowadays, the best estimate (BE) method with the uncertainty evaluation has been broadly used worldwide in licensing of Nuclear Power Plant (NPP). In Korea, the large-break loss of coolant accident (LBLOCA) analysis using the BE methods to replace the old conservative evaluation method (EM) was performed by the licensee in several plants such as Westinghouse (WH) type Units, OPR1000 and APR1400. In the BE method, the nodalization for base calculation was determined by the comparative studies of the experimental data and it could influence the prediction accuracy for specific phenomena such as emergency core cooling (ECC) bypass and blowdown quenching.

In OPR1000 and APR1400, as shown in Figure 1 Case(1), the nodalization of upper head including the upper dome was generally composed of axial several single volumes and the flow circulation between the upper plenum and the upper head/dome was not considered significantly since the circulation rate was much smaller than the primary coolant flow rate. However, there are actually the upward and downward flows in the upper head and this circulation flow can transfer the heat of the upper plenum to the upper dome. Up to now, the temperature of upper head/dome was difficult to confirm exactly for lack of design data. Therefore, it was assumed that the temperature of the upper dome was close to that of the cold leg in most LOCA analyses due to the effect of bypass flow from the downcomer into the upper dome. However, it was recently found that the temperature of the upper dome might be
larger than that of the cold leg according to the heat transfer from the upper plenum and the review of detailed design data. The maximum upper dome temperature could be ~ 600 K, which was almost the same as the temperature of hot leg. Therefore, the modification of nodalization for upper head could be needed to promote the heat exchange and predict exactly the temperature in the upper head. This could influence the blowdown quenching, the reflood peak cladding temperature (PCT) and final quenching behaviors.

In this study, the LBLOCA in OPR1000 was evaluated to identify the effects of upper head nodalization and temperature.

2 NODALIZATION OF UPPER HEAD

The upper head was generally defined as the region above the upper guide structure assembly as shown in Fig. 1. The upper head consists of the upper guide structure assembly and the control element assembly (CEA) shroud assembly. There are many holes in these assemblies to exchange the flow between the inner- and the outer-region. The conventional upper head nodalization is shown in Fig. 1 Case (1). The upper head was composed of three single-volumes and the guide structure was modeled separately from the upper head. In this study, two nodalization methods were considered for the sensitivity study. As shown in Fig. 1 Case (2), the guide structure was modeled as 5 single volumes and the single junction was connected from the upper guide structure to the upper head for more easily exchanging flow. In Fig. 1 Case (3), the upper head was separated into 2 axial volumes to simulate the actual circulation flow. Two axial volumes were connected each other with the cross flow junctions.

3 ANALYSIS RESULTS

The initial conditions for LBLOCA analysis were obtained from the steady state calculation of MARS code [1]. The input for OPR1000 considered the increment of linear heat generation rate and the reduction of reactor coolant system (RCS) flow according to the recent licensing experiences and the calculated initial conditions show a good agreement to the plant actual values for the major parameter such as a core power, pressurizer pressure and hot & cold leg flow rates.
3.1 Sensitivity Study for the Key-ways Bypass Rate

The upper head temperature was generally determined by the bypass rate (the key-ways bypass) from the downcomer into the upper head and CEA guide flow rate. The maximum design value of the key-ways bypass was usually ~ 0.5% and the best estimate value was ~ 0.4 % including the uncertainty. And the larger the key-ways bypass was, the colder the upper head/dome temperature was. Figure 2 shows the upper head temperature according to the key-ways bypass. The upper head volume number was plotted along the X axis and the volume number-128 represented the upper dome.

![Figure 2: Upper Head Temperature in Steady-state Condition](image)

Usually, as the key-ways bypass flow increased, the temperature of upper head/dome decreased due to the increment of cold water that flowed into the upper head. As shown in Figure 2 Case (1), the temperature of upper dome (node no. 128) was very low and close to that of cold leg because of no exchange flow with lower nodes in the upper head. In Case (2), the flow was circulated between the upper plenum and the upper dome and the hot water flowed into the upper dome along the guide structure. The highest upper dome temperature was shown in Case (3) and the temperature was constant in the upflow and the downflow region, respectively.

![Figure 3: Cladding Temperature for 0.3% Key-ways Bypass](image)

Figure 3 showed the cladding temperature when the key-ways bypass rate was 0.3%. Compared with Case (1) in Figure 3, the cladding temperature for Case (2) and Case (3) had the following characteristics, a) reduction of the depth for the blowdown quenching, b)
Increase of the reflood temperature, c) delay of the cladding final quenching, etc. Therefore, Case (3) has the highest reflood temperature and the latest cladding quenching.

3.2 Effect of Upper Head Temperature in the Uncertainty Analysis

The KINS (Korea Institute of Nuclear Safety) has also conducted the regulatory audit calculation by using the KINS Realistic Evaluation Methodology (KINS-REM) to confirm the validity of licensee’s calculation. The 22 uncertainty parameters were considered in KINS-REM evaluation for OPR1000 and the nodalization of Figure 1 Case (1) was used at that time [2]. 124 code runs were performed in KINS-REM according to 3rd order Wilks’ formula [2] and the third high-ranking PCT (3rd PCT) means the PCT95/95. In this study, the effect of upper head temperature according to the nodalization change was evaluated by using KINS-REM. The 9 sampling set, which had a high reflood temperature, were selected as the evaluation targets.

![Figure 3: Cladding Temperature for 9 sampling set](image)

As shown in Figure 3 Case (2) and (3), the blowdown quenching depth was reduced dramatically compared to Case (1). Case (2) showed the significant increase of reflood temperature which is ~ 100 K. Quenching behaviors for Case (2) and (3) were not much different from Case (1) due to characteristics of MARS code for uncertainty calculations. MARS applied the uncertainty value of each heat transfer model to the separate regions of the boiling curve. It could result in low CHF heat transfer rate in the reflood phase [3]. As a result, the high upper head temperature could increase the reflood PCT and the 3rd PCT could be showed in the reflood phase.

4 CONCLUSION

The LBLOCA calculation for OPR1000 was performed to identify the effect of the upper head nodalization. If the nodalization was changed to exchange the flow between the upper plenum and the upper head/dome, the temperature of the upper head/dome increased and the blowdown quenching finished at the higher temperature. Also, the modification of nodalization influences the best-estimate method with the uncertainty and the PCT behavior can be changed, especially in the reflood phase. The more detailed analysis for the effect of
nodalization would be needed to consider appropriately the temperature distribution in the core.

REFERENCES

