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Effect of Sump Clogging in Post-LOCA Long Term Cooling Process

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1. Introduction

One of the important concerns on the safety analysis of nuclear power plant (NPP) is to confirm the adequacy of design provision and operational procedure related to the long term cooling (LTC) process following a loss-of-coolant accident (LOCA). The post-LOCA LTC capability of NPP is specified at the licensing requirements in most countries such as 10 CFR 50.46 in USA [1]. Recently a potential to loss of recirculation due to containment recirculation sump (CRS) blockage have been issued in regulatory review on the LTC in Korea [2]. In the course of LOCA, debris generated by the LOCA could accumulate and block the screen of the sump so that the flow to ECCS could be lost at the recirculation actuation signal (RAS) indicating the water of the refueling water storage tank (RWST) was emptied.

To evaluate if this issue is significant in Korean NPP and to provide the guidance to further in-depth analysis, an analysis has been performed for the LTC process for a selected plant. A LTC behavior in RCS and core following a double ended hot leg guillotine (DEHLG) break was calculated with RELAP5/MOD3.3[3], a best estimate system thermal-hydraulic analysis code. The DEHLG break is selected that could generate the largest amount of debris. The significance of the CRS blockage was evaluated through blocking the ECCS source after RAS.

2. Modeling

For the present analysis, the RELAP5/MOD3.3 code was used to simulate the LTC for the selected plant. The reactor core is modeled as one hot channel and one average channel. The core bypass flow between the lower plenum and upper plenum is modeled as one channel. The upper plenum is divided into two parts and the downcomer is modeled as two azimuthal sectors. The two reactor coolant loops are modeled with one cold leg, one hot leg and one steam generator respectively. The pressurizer is connected to the intact loop. The water which is spilled from the break and the containment spray is modeled to collect in the containment floor

The diagram for ECCS modeling is shown in Figure 1. Two trains of the RHR system which the RHR pumps take suction from the RWST are modeled to inject into the reactor vessel upper plenum. After recirculation signal, the suction of RHR pump is modeled to change from the RWST to the CRS. Also, the valve which the RHR pump outlet connects to the HHSI pump outlet is open and the recirculation water can be injected to the cold leg of each loop. Two trains of the HHSI system are modeled that the borated water in RWST is injected to the cold legs. In the recirculation mode, the valve which is located in the HHSI pump outlet is isolated. Two spray lines are modeled and the spray pump suction is transferred from the RWST to the CRS in the recirculation mode.

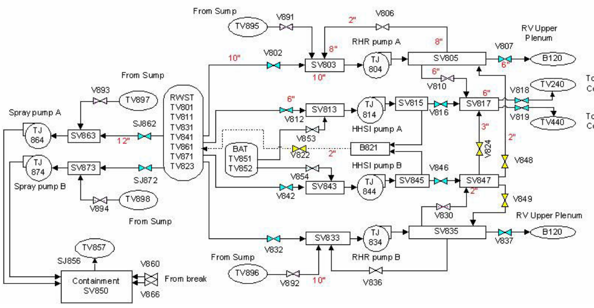

Figure 1. ECCS modeling for the selected plant LBLOCA calculation

The boundary condition is chosen conservatively in the present analysis. It is based on 102% reactor power, 15% steam generator tube plugging, the minimum safety injection flow and the maximum safety injection temperature. The containment temperature and pressure are given as the boundary condition and the containment backpressure is chosen from the result of containment pressure behavior in FSAR of Kori-1. The top-skewed axial power shape and ANS1973 decay curve is selected in this study. The total peaking factor of 2.35 is assumed, which is the same as in the reference plant. In addition, the single failure of the safety injection and the loss of off-site power (LOOP) are assumed. The safety injection signal is determine by the pressurizer pressure and the safety injection to the broken loop is not considered in this study. For the transient analysis, the initial condition is selected, which is same as the LOCA analysis in FSAR of the reference plant.

3. Results and Discussion

Using the RELAP5/MOD3.3 models described above, the transient calculation was performed up to 2000 or 3000 seconds. The DEHLG break is simulated as the base case. The Cases with 100% and 50% sump clogging for the base case are selected to consider the effect of CRS clogging. Additionally, the double ended cold leg guillotine (DECLG) break is considered for 50% sump clogging to evaluate the reheating time and the fuel cladding temperature.

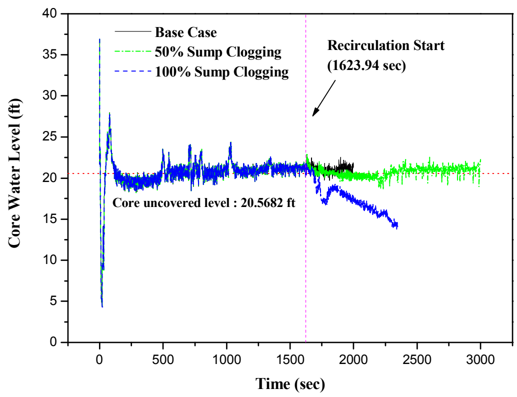

Figure 2. The Collapsed core water level

The collapsed core water level for DEHLG break is shown in Figure 2. In this study, the switchover from injection mode to recirculation mode occurs upon the low RWST level alarm (21.2%). The recirculation starts at 1623.94 sec including the time for valve alignment etc. Shortly after the break, since the liquid inventory continues to be depleted due to the vessel depressurization, the core water level decreases and the fuel cladding is heated up. After the safety injection begins to reflood the core at around 30 sec, the core water level is recovered. At around 65, the nitrogen in the accumulator injects into the cold leg. This added flow causes the core water level to substantially increase for a brief period. However, the increased flow is caused by the nitrogen injection forces the coolant out the break and the vessel water inventory is reduced. After that, the core water level is recovered up to the core uncovered level at around 500 sec due to the continuous safety injection. After 500 sec, the core water level maintains the similar value with the core uncovered level despite of the minor oscillation. For the 100% sump clogging case, the core water level decrease continuously below the core uncovered level in the recirculation mode as the recirculation flow is not injected for core cooling. For the 50% sump clogging case, the core water level decrease to some extent upon beginning the recirculation but it recovers up to the core water level at around 2250 sec.

The peak cladding temperature (PCT) variation is shown in Figure 3. In the early stage of the hot leg LBLOCA, the maximum PCT is approximately 900 K. However, after around 50 second, the PCT remain around 400 K in the base case and 50% sump clogging case as shown in Figure 3. For 100% sump clogging case, the fuel cladding reheats due to the loss of safety injection in the recirculation mode and thus the PCT increases continuously from around 2250 second. The reason for the difference between the time of RAS and the time of reheating can be considered as the water inventory remaining in the upper plenum. For cold leg LBLOCA, the PCT increases much more considerably than the hot leg cases due to the loss of large water inventory in early stage of LBLOCA.

The recirculation starts at 1642.04 sec which is somewhat earlier than the hot leg case. For 50% sump clogging of CL-LBLOCA, the reheating of the fuel cladding occurs at around 1900 second which is 300 seconds earlier than the hot leg case. This earlier reheating of the fuel cladding is caused by the latent heat which is more than the hot leg case.

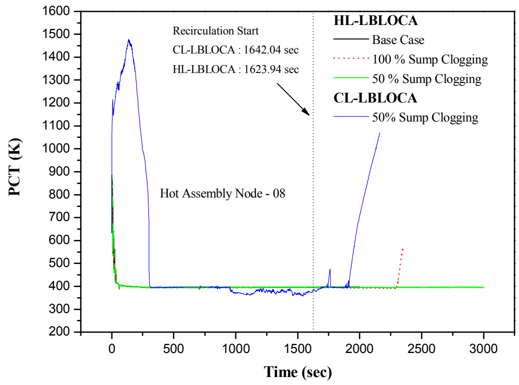

Figure 3. The peak cladding temperature (PCT) variation due to sump clogging

4. Conclusion

In this study, an analysis has been performed quantitatively for the LTC concerns that have been issued in regulatory review. From the analysis results, it is found that the core reheating was caused by the sump clogging and thus the core water level decreases due to the boil-off in the core region. For the DEHLG break, the core reheating occurs at around 2250 second in 100% sump clogging case. However, for the DECLG break, the core is reheated at around 1900 sec in 50% sump clogging case.

REFERENCES

[1] USNRC, 10 CFR 50.46, “Acceptance Criteria of Emergency Core Cooling System for Light Water Nuclear Power Reactors,” 1989.
[2] USNRC, Bulletin 2003-01, “Potential Impact of Debris Blockage on Emergency Sump Recirculation at Pressurized-Water Reactors,” June, 2003.
[3] Information System Laboratory, RELAP5/MOD 3.3 Code Manual, NUREG/CR-5535, Rev.1, 2001.