Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 18-19, 2023

Analysis for 13% and 17% Break Sizes of Intermediate Break Loss of Coolant Accident in OPR1000 with MARS-KS

Hae-Yong Jeong [a*], Nihat Erdem Berber [a], Nguyen Huu Tiep [a]
[a]*Sejong University, Gwangjin-gu, Neungdong-ro, 209, Seoul*
[*]*Corresponding author: hyjeong@sejong.ac.kr*

1. Introduction

The Intermediate Break Loss-of-Coolant Accident (IBLOCA) was considered a realistic DBA by France's safety regulation, so the effect of this accident on the OPR1000 nuclear power plant (NPP) was examined [1]. Performing various thermal hydraulic analyses for the IBLOCA scenario can explain safety-related situations in line with emergency core cooling system (ECCS) acceptance criteria [2].

The aim of this study is to analyze the thermal hydraulic responses when the reactor coolant pump (RCP) is tripped in IBLOCA scenarios with two different break sizes in the Korean OPR1000.

2. Methods and Results

In this section, for the OPR1000, the thermal hydraulic analysis results of the double-ended Guillotine break (DEGB) cold leg IBLOCA scenario at 13% and 17% break sizes are examined.

2.1 IBLOCA Test Condition

The reference NPP at current analysis is 1000 MWe Korean OPR1000, which consists of two loops. Thermal hydraulic analysis modeling of the reactor in steady-state and transient states was done by Multi-dimensional Analysis of Reactor Safety KINS Standard (MARS-KS). Input model includes primary and secondary systems. Figure 1 shows MARS-KS nodalization for input model of OPR1000.

The DEGB model is located between the reactor pressure vessel (RPV) and the RCP in the cold leg, which is connected to the pressurizer in the first loop. Selected breaks are sized as 13% and 17% according to the flow area.

The test condition for the IBLOCA transient state can be summarized as follows.

1- Breaks (flow area) were happened 13% and 17% in the cold leg as DEGB at the beginning of the each transient analyses.

2- When the pressure decrease due to break reaches the determined value, the low pressurizer pressure (LPP) signal is activated, and the reactor scram signal is followed.

3- RCPs are tripped simultaneously after Reactor Scram signal.

4- The safety injection (SI) signal is activated after a delay time.

5- Accumulators (ACC) signal activated when primary pressure drops to set point.

Based on the experimental and analytic studies on the IBLOCA, it has been observed that the IBLOCA scenario consists of three distinct phases [3].

1- Blowdown & Rapid Depressurization
2- Crossover of 1st/ 2nd pressure & Core boil-off
3- Core recovery & Long-term cooling

In the first phase, critical flow occurs after the loss of inventory by rupture and rapid depressurization takes place. In this process, RCPs coast down, and reactor power starts to reduce. In the second phase, the high-pressure safety injections (HPSI) are activated, and loop seal clearing (LSC) takes place. The core begins to boil-off and the PCT increases due to the decrease in the liquid level. In the last phase, the uncovered core starts to fill up rapidly with the injection of the ACCs and the PCT reaches its maximum level. For long-term cooling continuation, low-pressure safety injections (LPSI) were activated, and reactor balance was provided [4].

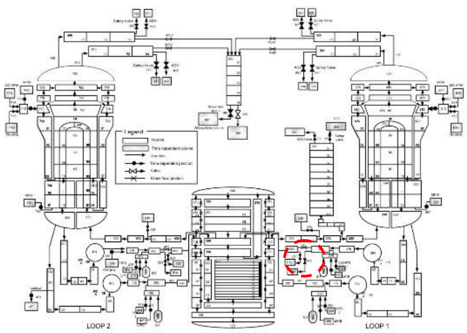

Fig. 1. MARS-KS nodalization for input model of OPR1000.

2.2 Results of Primary and Secondary System Pressure

In Figure 2, the primary and secondary system pressures are shown for two different break sizes. A sharp pressure drops are clearly observed after break within the two cases. During from the formation of flashing after rupture to two-phase flow, rapid depressurization ends with the closure of the main steam isolation valves (MSIV) and then pressure drop begins again. In this process, the primary and secondary side pressures remain in balance for a while. At 13% breakage size this took longer because inventory loss is less. After depressurization starts again, it continues to decrease until balanced pressure point. It is known that the flow discharged from break area and the primary system pressure are directly related to each other. The second system pressure increase occurred as the MSIVs closed and reached its maximum value, then, decreasing of pressure starts when the steam generator (SG) valves opened. As the primary system pressure falls below the secondary system pressure, SGs begin to lose their cooling effect. While depressurization of the primary system continues, ACC reaches its activation value and influences cooling due to vapor condensation caused by coolant injection.

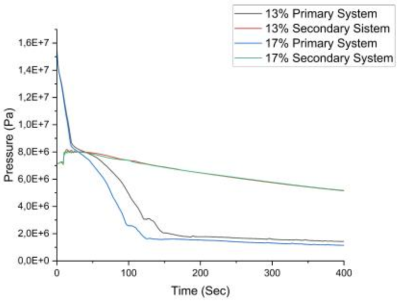

Fig. 2. Primary and secondary system pressures for 13% and 17% break sizes.

2.3 Results of Core Liquid Level

The comparison of the liquid level in the core is shown in figure 3. After the break begin, the active core was depleted with a large drop in liquid levels due to flashing. As the break mass flow rate begins to decrease, a temporary increase occurs and reaches a relative maximum, but this was less effective at 17% break. It has been interpreted that this situation is since the flow rate decreases much faster. Rapid recovery of the core liquid level occurred after LSC, and ACC injection and the fluid level was maintained the core. Injection of ACC into one of the cold legs condensed steam in the upper plenum, which affected core cooling.

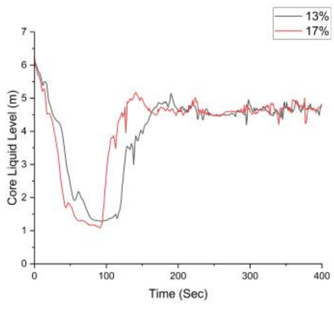

Fig. 3. Core liquid levels for 13% and 17% break sizes.

2.4 Results of Peak Cladding Temperature

The maximum cladding temperatures formed by two cases are shown in Figure 4. PCTs begin to rise when the core is dried out and the upper plenum gets empty. Since an accumulation of coolant in the lower plenum remains after the core is uncovered, the steam does not flow towards the downcomer, and there is no bypass for the ACC fluid, meaning it flows freely to the downcomer. The time differences between the cooling period of the PCT after reaching its maximum and the ACC injection is due to the time it takes for the downcomer to fill. As a result, increasing the break size also increases the maximum value of PCT and decreases the time to reach this value. Maximum PCT values in this analysis were 776.74 K and 817.74 K for 13% and 17% break sizes, respectively.

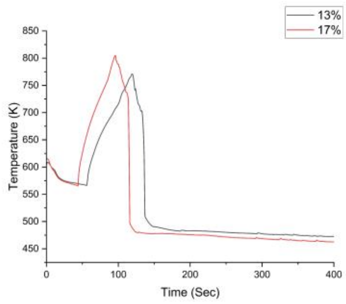

Fig. 4. Peak cladding temperatures for 13% and 17% break sizes.

3. Conclusions

For the OPR1000 pressurized water reactor (PWR), IBLOCA analyses were performed for 13% and 17% sizes relative to the DEGB model on the cold leg with the RCPs trip. The main purpose of these analyses is to compare the transient thermal hydraulic states of the break sizes in the cold leg IBLOCA scenario.

All phases have occurred in line with expectations. While the activation of the reactor scram signal, the RCPs were tripped simultaneously. Inside of the downcomer does not fulfill with steam flow because of lower plenum liquid level, therefore ACCs injection is not bypassed. A higher maximum PCT at 17% break size was observed due to the effect of break sizes on core liquid level. It was observed that the PCT values reached were well below the safety margins regarding to the calculated maximum fuel element cladding temperature shall not exceed 1477 K (2200F).

Single core uncovery occurs, and PCT starts to rise when the liquid at the vessel is not enough to cool while the core power is still high. These happens in time which is earlier than SBLOCA and later than LBLOCA responses. Increases of the cladding temperature and the core heat up were closely related to the behavior of the coolant inventory in the RPV. As in the IBLOCA scenarios, the core liquid level dropped to almost zero, and during the rapid refilling phase almost all of the core was quenched. It has been observed that the PCT value makes a single peak and the time interval when this occurs is similar to other IBLOCA scenarios. Hence, Core liquid level and PCT results of this analysis shows that these break sizes are in IBLOCA break range.

Examination of the accident scenario in different reactors or the trip signals of RCPs according to a conservative or realistic approach will contribute to making these issues more understandable.

REFERENCES

[1] Bae, B.-U., et al., 2017. Integral Effect Test on 17% Cold Leg IBLOCA for Investigation of Scaling Effect, Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea, May 18-19, 2017.
[2] Nuclear Energy Agency, "Nuclear Fuel Behavior in Loss-of-coolant Accident (LOCA) Conditions, OECD ISBN 978-92-64-99091-3, 2009.
[3] S. M. Bajorek, "Realistic Small- and Intermediate-Break Loss-of-Coolant Accident Analysis Using WCOBRA/TRAC", Nuclear Technology, 136, pp. 50-62, 2001.
M. Pérez-Ferrgut, J. Frexia, F. Reventós and I. Sol, "IBLOCA Analysis for Vandellós-NPP Using RELAP5/MOD3.3. Sensitivity Calculations to EOP Actions", NUREG/IA-0497, 2019.
[4] M. Lorduy-Alós, S. Gallardo and G. Verdú, Scaling analysis of an IBLOCA counterpart test between the ATLAS and LSTF facilities, Progress in Nuclear Energy Vol. 127, 2020.