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Behaviour of Natural Circulation Flow in Uljin Unit 1&2 Plant

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1. Introduction

Since the TMI-2 accident, occurrence of severe accident natural circulation inside the RCS during in-vessel core melt progressions before the reactor vessel breach had been emphasized and analyses were performed to clarify its thermal-hydraulic characteristics [1, 2]. In general, the natural circulation occurs due to the density difference, which for a single phase flow, is typically generated by temperature difference. Three natural circulation flows can be formed during severe accident; in-vessel, hot-leg countercurrent flow and flow through the coolant loops. Each of these flows may be present during high pressure transients such as station blackout (SBO) and total loss of feedwater (TLOFW).

This natural circulation redistributes the heat energy generated in the core into the RCS structures. This energy redistribution will slow the heatup of the core, which in turn may affect the damage progression or the extent of the core damage. Slowing the core damage would allow more time for systems to be recovered to mitigate or terminate the accident. However, the energy removed from the core will be deposited on the other structures. This deposition of energy on the structure heats up the RCS and steam generator pipes which renders the occurrence of either the RCS creep rupture or the steam generator tube rupture faster.

The question of which one occurs first seems still in debate due to the uncertainties inherent in the calculation. Because the steam generator tube rupture provides a direct path of fission product release to the environment, an accident management of stopping the natural circulation is also conceivable and should be taken into account in developing the accident management guideline. In this paper we have analysed the behaviour of the natural circulation taking into account the accident management action during the SBO accident and found the way to stop the natural circulation. The analysis was performed using MELCOR 1.8.5 code[3] for Uljin unit 1&2 nuclear power plant.

2. MELCOR Modeling and Accident Management

In this section we describe the MELCOR 1.8.5 code [3] modeling used for the analysis and the action of accident management taken during the accident. The accident scenario considered is a SBO and we take the RCS depressurization action by opening the safety relief valves.

2.1 MELCOR RCS Model

Based on normal MELCOR1.8.5 simulation model developed for Uljin 1&2 RCS and related safety systems [4], detailed RCS natural circulation model was developed, as shown in Figure 1. The detailed model has two control volumes for hot leg and two control volumes for steam generator rising tubes and also two control volumes for downcoming tubes. This introduction of two control volumes in the hot leg and in the steam generator allows us to simulate the natural circulation flow. The core is not modeled in detail but the in-vessel natural circulation should also play quite an important role in the behaviour of flow.

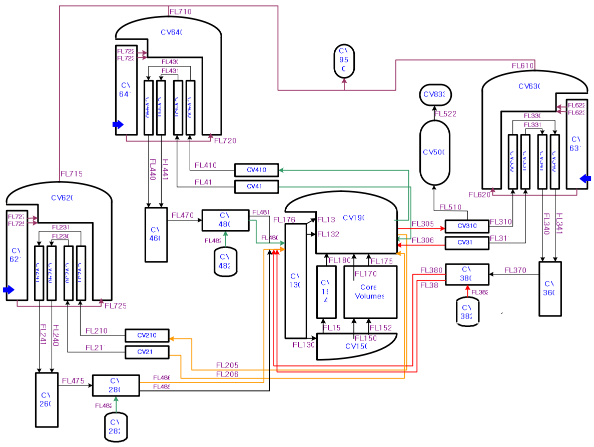

Figure 1. MELCOR modeling of Uljin unit 1&2 to simulate the natural circulation phenomena

2.2 Action of Accident Management

The accident scenario we have analysed is a station blackout. In case the power does not recover even after the core exit temperature exceeds 650 ^{o}C, then the only action operators could take is to depressurize the RCS. While the battery is available, operators could open the power operated safety relief valve (POSRV) and thus depressurize the RCS in Uljin plant.

2.3 Analysis Result of the Natural Circulation

The Figure 2 shows the flow behaviour in the hot leg for a SBO accident without recovery of battery until the vessel failure. In this case, operators do nothing until the vessel fails. This is the conceptual situation for a reference. We can see that until 7,500 seconds, only one directional flow out of the core is flowing in the hot leg, but after 7,500 seconds the natural circulation flow is developing. The negative flow rate in the flow path 306 means that the flow cooled down from the RCS heat structures are returning back into the core.

In the analysis of Figure 3 we have introduced the RCS depressurization action. As the core exit temperature exceeds 650 °C, operator has opened the POSRV and tried to reduce the pressure. As water and steam flow out through the valve, the pressure is reducing to such a value that the accumulator water begins to enter the RCS. This accumulator water cools the reactor core and now the density difference is also reducing. This makes the natural circulation flow to stop because the driving force of the natural circulation was the density difference.

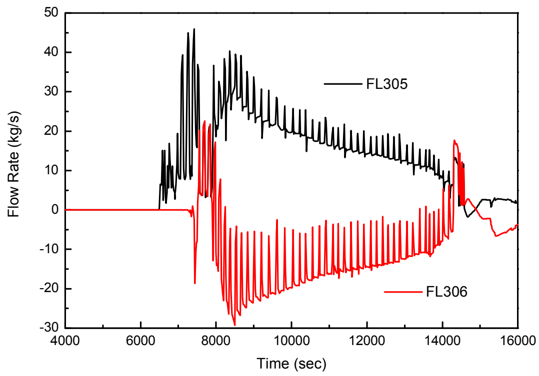

Figure 2. Formation of a natural circulation flow in the RCS during a SBO accident scenario. Reactor vessel fails at 15,300 seconds and the natural circulation stops only at the vessel breach.

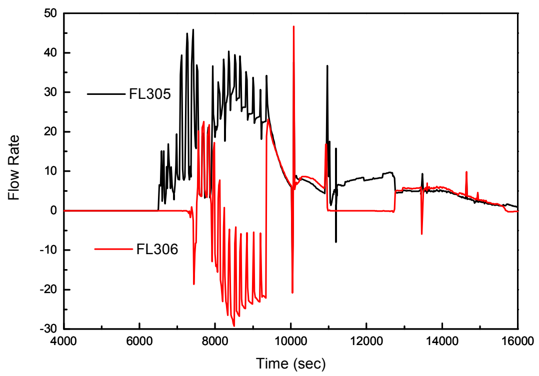

Figure 3. Behaviour of the natural circulation when the accumulator water enters the core in case the core exit temperature exceeds 650 °C. The accumulator water cools the core and the natural circulation stops.

We have checked the temperature of the hot leg during the accident progression. For a reference case of doing nothing until the vessel breach, the temperature of hot leg pipe increases up to 925 K. But in case the accumulator cools the core and stops the natural circulation, the maximum temperature of hot leg pipe was 670 K. This result clearly shows that stopping the natural circulation also makes the temperature of hot leg or steam generator to be reduced.

Until now the SAMG action of RCS depressurization was considered only taking into account the damage of fuel clad. But since the depressurization could stop the natural circulation and thus could help preventing the hot leg or steam generator tube rupture caused by the natural circulation, we should have another look on when to depressurize the RCS.

3. Conclusion

We have analysed the natural circulation phenomena for Uljin 1&2 plant using the MELCOR 1.8.5 code. The natural circulation redistributes the heat of core to the RCS heat structures, thus slowing down the heat up of core. But the heat redistributed to the heat structures could also make the steam generator tube rupture to occur fast and the accident management of stopping the natural circulation is conceivable in developing the strategy. The SAMG action of RCS depressurization makes the accumulator water to enter the core and this water cools down the core. But the RCS structures were heated by the natural circulation before the accumulator water cools the core, and now the density difference, which was the driving force of the natural circulation, inverted and the natural circulation stops. This was clearly proven by the MELCOR analysis. The result is still of conceptual one but we think this phenomenon should be taken into account in developing a new SAMG in near future.

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