Development of LOCA Response Strategy during Shutdown Operation in Kori 3&4 and Ygn 1&2 Units

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1. Introduction

The abnormal transients and accidents during shutdown operation modes of pressurized water reactor, in contrast with those during full power operation modes, have been recently issued due to their potential risk for leading to a severe abnormal condition because the various safety-related systems and equipments may be unavailable [1]. The NRC issued Loss of Reactor Coolant Inventory and Potential Loss of Emergency Mitigation Functions While in a Shutdown Condition," on January 12, 1995, to alert addressees to an incident at the Wolf Creek plant involving the loss of reactor coolant inventory while the reactor was in a hot shutdown condition [2].

Considering those situations, abnormal response mitigation strategies in shutdown operation modes have been developed by evaluating the plant specific thermal hydraulic behavior following LOCA. The objectives of this study are: (1) to verify the effectiveness of abnormal operating procedure (AOP) and emergency core cooling system (ECCS) on reactor safety at shutdown operation, developing the operation strategy at the condition and abnormal operation guideline in the light water reactors; (2) to enhance understanding of the thermal-hydraulic phenomena during abnormal and accident conditions.

In this paper, some accident scenarios are analyzed to develop the abnormal operating strategy following LOCA in shutdown operation modes for Kori 3&4 and Ygn 1&2 units. This study shows the adequacy of operator action time to mitigate the LOCA, the thermal hydraulic behavior, reactor inventory distribution and possibility of cold overpressurization after SBLOCA during shutdown operation modes using computer code RELAP5 /MOD3.2[6].

2. Accident Scenario Analysis

For the plant specific evaluation of shutdown LOCA of Kori 3&4 and Ygn 1&2 units, various scenario cases were selected with a range of break sizes 0.4% to 4% of RCS diameter. It is used for investigating the plant response and accident mitigating strategy. Initial conditions and boundary conditions for RCS pressure were selected to be 7.0 MPa for mode 3 and 2.5 MPa for mode 4.

All the parameters obtained from the initialization process were appropriately within the LCO and operating data.

The plant including the primary system and the secondary system was modeled using RELAP5 with the condition defined above. The modeling includes all the components in reactor vessel, hot leg and cold leg at intact and broken loop, three steam generators, pressurizer and ECCS

3. Results and Discussion

3.1 Core Thermal Hydraulic Behavior

Following the initiation of the break in the cold leg, there was a rapid depressurization of the RCS. The PZR drained quickly and emptied at approximately 40 seconds. The liquid in the hot legs reached saturation at approximately 17 seconds at which time the depressurization stopped due to flashing.

Repressurization occurred as the volume of steam generated by the decay heat in the core exceeded the volume removed by the break.

The symptoms of loss of PZR level and loss of hot leg subcooling are assumed to be used by the operator to indicate that safety injection should be started. Both of these symptoms occurred within 1 minute. Assuming a 10 minutes operator action time, safety injection could have been established after 11 minutes in this analysis.

3.2 Inventory Behavior in PORV Stuck-Open

The behavior of the PZR collapsed water level during PZR PORV stuck open shows different trends compared to cold/hot leg small break LOCA. During the initial rapid depressurization of the primary system, the collapsed water level in the PZR dropped temporarily due to voiding in the PZR but rose again because water was pushed up into the PZR and was discharged into stuck opened PORV after safety injection initiated in the core. The collapsed water level in the PZR almost reached the top of the PZR at 30 minutes after the break and then maintained an almost constant level because the discharge mass flow rate from the PZR was almost equal to the mass flow rate into the PZR from the hot leg piping. PZR level fluctuation occurred due to mixing flow between liquid and vapor during discharging through PZR PORVs.

When the reactor coolant is discharged through PZR PORV, the symptom of hot leg level and PZR level may not provide an accurate indicator of inventory in the RCS.

3.3 Cold Overpressurization of Reactor Coolant System

The PORVs located near the top of the PZR, together with additional actuation logic from the wide-range pressure channels, are utilized to mitigate potential RCS overpressure transients if the RCS are inadvertently pressurized in low temperature. This Cold Overpressure Mitigation System (COMS) has been modeled in this transient to limit the RCS pressure. The set pressure required to open a PZR PORV was taken as 4.2 MPa, and the PORV remained open until pressure was reduced to 3.6 MPa.

This accident was selected for the accident scenario analysis to determine the applicability when cold leg rupture is isolated early and COMS is in service. In this case, HPSI is continued during eleven minutes after break isolation and then HPSI is terminated establishing normal charging. The result shows that it takes eleven minutes to reach the set pressure required to open COMS. Therefore, Operator should terminate HPSI within 11 minutes to prevent opening of COMS in inadvertent safety injection.

4. Operator Action Time

Successful operator actions were determined by how fast the plant transient was proceeding versus how fast the operator was moving through his procedure steps based on communication standards. In a LOCA during shutdown operation, the important operator actions are to verify the symptom associated with the safety injection, identify the LOCA, establish charging and SI flow to provide adequate RCS makeup, start a cooldown to build in extra subcooling margin, depressurize the reactor coolant system to reestablish indicated PZR level, and terminate safety injection.

This research shows that diagnosis to identify a LOCA can be performed within 1 minute by symptom of PZR level and pressure. Operator action time to actuate HPSI can be completed by pushing one button within several seconds. Operator action time in ANS/ANSI-58.8-1994 is 11 minutes. These criteria are used to determine whether safety related systems can be initiated operator action. The time response criteria ensure that adequate safety margins are applied to safety evaluations.

This study concludes that safety injection after 15 minutes delay can meet design criteria, 10CFR50 Appendix K, because temperature and pressure stay below design criteria. Therefore, this paper shows that the criteria for operator action time in ANS/ANSI 58.8-1994 can be met.

5. Conclusion

The results of this research demonstrate that the operating strategies are adequate for SBLOCA during shutdown operation modes. This conclusion is based on the results using a two-phase computer program, RELAP3.2, which addressed the full range of break sizes for the LOCA during shutdown operation. Conservative thermal-hydraulic analyses of the bounding small break LOCA (breaks equivalent to those of 12-inch diameter or smaller) demonstrated that the present ECCS design and operating strategies are adequate.

The analysis results indicate that high pressure safety injection should be initiated manually for core cooling within 15 minutes after SBLOCA during shutdown operation without automatic SI.

The core cooling can be adequately provided during PZR PORV stuck-open transient. However, in this transient this study also presents liquid holdup effect in the PZR. Therefore, termination of SI should be performed by using criteria of RCS subcooling and PZR level.

A LOCA event has been analyzed with a postulated scenario in which the cold overpressurization of the pressure vessel occurs and the pressure vessel integrity may be threatened. Cold overpressurization was evaluated by scenario analysis that operator early isolates the inappropriately opened valve as rupture and SI continued during extended period. In the postulated scenario, the pressure vessel is isolated on high radiation level. In such case the vessel pressure slowly rises due to its isolation. The vessel high pressure signal leads to COMS setpoint followed by depressurizing by opening the PZR PORV. The validity of the operating strategy to prevent the pressurized thermal shock during shutdown operation is verified by the results that pressure and temperature exist below limit of nil-ductility transition during the transients.

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