The Analysis of the Loss of Coolant Flow Accident of SMART-P

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1. Introduction

The SMART-P (SMART design verification program) has been developed for the purpose of the design verification of SMART. Most design features of SMART-P are the same as those of SMART except the thermal power reduced from 330 MWt to 65 MWt. SMART-P is designed to be operated under boron free condition. Adoption of the nitrogen filled pressurizer relieves the pressure oscillation during power changing operations. Passive Residual Heat Removal (PRHR) system removes the decay heat by natural circulation. SMART-P has two MCP (main circulation pump) which is a canned motor type axial pump. MCP coast down time from full speed to stop is 10 sec. Since the MCP cost down time is shorter than the conventional RCP, the loss of coolant flow may cause a severe critical heat flux conditions to the fuel rod. Two analyses are performed on the loss of flow accident, the total loss of flow due to the simultaneous failure of both MCP and the partial loss of flow induced by a locked rotor of a single MCP. The thermo-hydraulic analysis was performed with TASS/SMR code. This paper summarizes the results of the analysis on the loss of coolant flow of SMART-P.

2. Methods of Analysis

SMART-P is an advanced integral PWR (Pressurized Water Reactor) that produces 65.5MWt. The Major primary components are housed within a single pressure vessel. Newly, advanced and innovative features are adopted in the design to provide the reactor with significant enhancements in safety, reliability, performance, and operability. In this integral arrangement, there are no large size pipe connections and thus the possibility of the large break loss of coolant accidents is eliminated. The core design is characterized by an ultra long cycle, low core power density, soluble boron-free operation. This boron-free condition guarantees a large negative Moderator Temperature Coefficient (MTC) which makes a minimum rod motion feasible during power change operations. The main coolant pump (MCP) is a canned motor pump which does not require pump seals. This characteristic basically eliminates the small break loss of coolant accidents associated with a pump seal failure which has become one of the design bases events in the reactors using a conventional pump. The SMART-P has two MCPs vertically installed on the top annular cover of the RPV. Each MCP is an integral unit consisting of a canned asynchronous three phase motor and an axial-flow single-stage pump. The motor and the pump are connected by a common shaft rotating on three radial and one axial thrust bearings. The bearings use a specialized graphite-based material, and the axial bearing performs the function of a sealing too. The cooling of the pumps is accomplished with the component cooling water. The rotational speed of the pump rotor is controlled by a sensor installed in the upper part.

2.1 TASS/SMR code

TASS/SMR code [1] was used for the analyses of the loss of flow accidents in the SMART-P. In TASS/SMR, the governing equations are based on the drift-flux model so that the accidents or transients accompanying with tow-phase flow can be analyzed. Also TASS/SMR uses special models for a SMART reactor, such as, a helical tube heat transfer package, critical flow model with a non-condensible gas and a passive residual heat transfer model. For the critical heat flux calculation, the SSF-1 correlation is used.

2.2 Initial and Boundary conditions

The initial conditions of loss of flow accidents are selected with the considerations of conservatism. Within the LCO (Limiting Conditions of Operations) space of SMART-P [2], high core power, low core inlet flow rate, high RCS pressure and high RCS temperature are chosen as the initial conditions. Loss of off-site power (LOOP) is assumed to take place simultaneously with the core scram signal and the failure of one PRHR train is assumed as a single failure. For the reactivity feedback parameters, the least moderator temperature coefficients and the least fuel temperature coefficients are used.

2.3 Acceptance Criteria

The loss of coolant accident is one of the design bases events. Major safety parameters of this accident are the minimum CHFR, the maximum fuel temperature and the maximum coolant system pressure during the accidents progress. The safety limits of the SMART-P for these parameters are as follows, the minimum CHFR is above 1.3, maximum fuel temperature is below 606 ^{o}C and the maximum primary system pressure is below 18.7 MPa, which is 110% of the design pressure.

3. Results of Analysis

Loss of coolant flow can occur by the failure of both of MCP or a single MCP. The total loss of flow accident is initiated by the loss of off-site power and the partial loss of flow accident may be caused either of one MCP rotor seizure or one MCP shaft break. In the MCP shaft break accident, the reduction rate of coolant flow is bounded by the rotor seizure. Total loss of flow provoked by LOOP and partial loss of flow caused by the one MCP rotor seizure are analyzed in the study.

The decreased coolant flow SMART-P causes the coolant temperature increase and the deterioration of CHFR, LOOP is assumed to occur simultaneously with core scram, which results in feed water supply unavailable. Low feed water signal makes main feed water and steam isolation valves (MFIV/MSIV) close and PRHR isolation valve open. SMART-P design guarantees 3 sec prolonged operation of MCP after LOOP. Low MCP speed generates the core scram signal and CEA dropped into the core with delay time to curb the core power.

3.1 Total loss of flow accident

The total loss of flow is only caused by LOOP. Both MCPs starts to coast down after 3 sec delay time. At 3.15 sec, low MCP speed causes core scram signal. CEA dropped onto the core at 4.15 sec. MFIV and MSIV are fully closed and PRHE valves are fully open at 5 sec.

The core inlet flow rate decreases from 309 kg/s to 22 kg/s in 15 sec as shown in Fig. 1. The reduced flow causes a core coolant temperature increase in the initial period, but the negative reactivity insertion by a moderator temperature feedback effect suppresses the core power rise. The minimum CHFR occurs at 4.93 sec with a value of 1.34 (Fig. 2). The maximum primary pressure occurs at 7.2 sec with 16.18 MPa (Fig. 3).

3.2 Partial loss of flow accident

The partial loss of flow simulated in this study is caused by one MCP rotor seizure. The onset of rotor seizure generates MCP low speed core scram signal and LOOP takes place at the same time. CEA dropped into the core at 1 sec. The intact MCP starts to coast down at 3 sec. MFIV and MSIV are fully closed and PRHE valves are fully open at 5 sec.

The core inlet flow rate decreases from 309 kg/s to 135 kg/s within 2 sec and to 22 kg/s in 15 sec as shown in Fig. 1. The minimum CHFR occurs at 0.93 sec with a value of 1.38 (Fig. 2). The maximum primary pressure occurs at 2.76 sec with 15.84 MPa (Fig. 3).

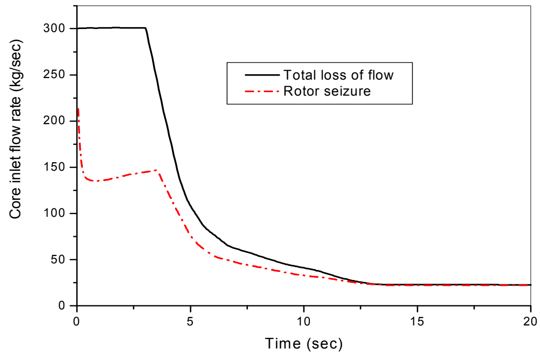

Figure 1. Core inlet flow rate of loss of coolant flow accidents.

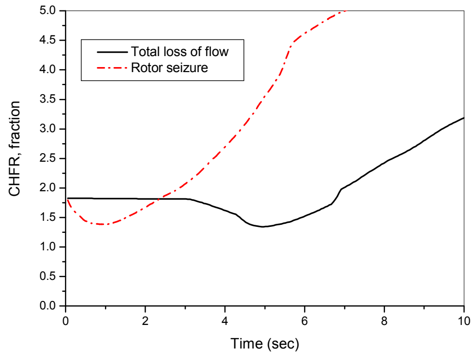

Figure 2. CHFR behavior of loss of coolant flow accidents.

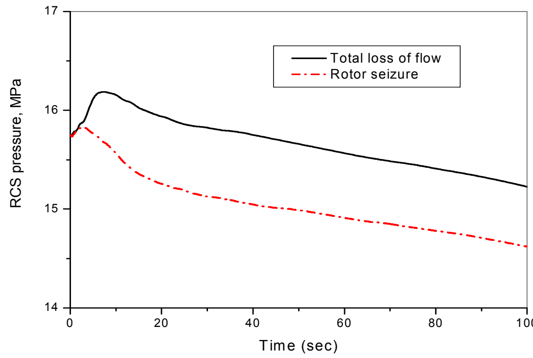

Figure 3. RCS pressure of loss of coolant flow accidents.

4. Conclusion

This analysis show that of SMART-P can be brought into a safe shutdown state by the actuation of the reactor protective for the total loss of flow and the locked rotor accident respectively. During the period of the postulated loss of flow accidents, the system parameters are maintained within the safety limits of the SMART-P.

REFERENCES

[1] Y.D. HWANG, et al., Model Description of TASS/SMR code, KAERI/TR-3028/2005, 2005.
[2] B. H. Cho, "Fluid System Design Data for SMART-P", SMP65-FS-DD012, 2004.