Safety Analysis Results for the Control Rod Banks Withdrawal Event at a Full Power of the SMART-P

S.H. YANG[a], Y.J. CHUNG[a], H.C. KIM[a] , S.Q. ZEE[a]
[a] *Korea Atomic Energy Research Institute, 150, Dukjin-dong, Yusong-gu, Daejon, 305-353, yangsh@kaeri.re.kr*

1. Introduction

For the validation of the 330 MWt SMART (System-integrated Modular Advanced ReacTor), a detailed design for the SMART-P has been accomplished by KAERI. In the SMART-P design similar to the SMART design, the soluble boron free design is adapted. This concept results in a larger reactivity worth of the control rod bank compared to that of the commercial pressurized water reactor. Moreover, in the SMART-P design, the control rod banks are fairly well inserted into the core, even at a full power condition. Therefore, accidents related to the reactivity anomalies have been evaluated as crucial events when compared to the other initiating events.

In this paper, safety analysis for the control rod banks withdrawal event at a full power of the SMART-P has been accomplished by considering various initial conditions, different withdrawal times of the control rod banks and the reactivity feedback. To perform the safety analysis, the TASS/SMR (Transients And Setpoint Simulation/Small and Medium Reactor) code for a system response and SSF-1 correlation for a CHFR (Critical Heat Flux Ratio) have been used.

2. Configuration of the SMART-P Control Rods

The control rods of the SMART-P have the roles to offset an excess reactivity in the core, to control the core power and to shutdown the reactor. The SMART-P has 414 control rods. Each control rod is categorized into the control rod bank for a control (Regulating bank: 6) or the control rod bank for a shutdown (Shutdown Bank: 6) [1]. The control rods belonging to the same control rod bank simultaneously insert or withdraw. Since the SMART-P adapts the soluble boron free design, a reactivity control can be established by the control rods. Therefore, the regulating banks are fairly well inserted into the core at a full power, although the shutdown banks are fully withdrawn.

3. Analysis Method

To identify the system behaviors of the SMART-P and the CHFR for the control rod banks withdrawal event at a full power, the TASS/SMR code [2] and the SSF-1 correlation [3] have been used. In the case of the control rod banks withdrawal event, the possible reactor trip functions seem to be a low CHFR, high core power and high pressurizer pressure. For a conservative analysis, the CHFR trip function is not considered in this study. The trip setpoints of a high core power and high pressurizer pressure are 122.2% and 16.44 MPa, respectively.

In the SMART-P design, the control rod banks withdrawal event has been categorized into a moderate frequency event: the control rod banks withdrawal event can be shifted to an infrequent event by the adoption of a single failure and coincidence occurrence. In this study, mal-operation of 1 train of the PRHRs is considered as a single failure and a stuck of the most reactive rod in the fully withdrawn condition and a loss of offsite power are considered as coincidence occurrences. However, the control rod banks withdrawal event is not shifted to an infrequent event. Therefore, the safety criteria of this event are that the CHFR is not lower than 1.3 and the peak system pressure does not exceed 18.7 MPa.

4. Analysis Results

4.1 Event Description

The control rod banks withdrawal event at a full power condition results from mechanical failures of the control rod bank drives mechanism/control system or an operator's mis-operation. In the case of the control rod banks withdrawal event, the core power increases with time due to an excess (+) reactivity insertion into the core: however, a secondary flow into the steam generator remains at the value of the initial condition. This unbalance between the power generation in the core and the heat removal through the secondary system induces an increase of the primary coolant temperature and pressure. As time progresses, thermal hydraulic parameters including the core power, primary pressure and coolant temperature, change and approach the setpoints of the reactor trip functions. After one of the major thermal hydraulic parameters reaches the setpoint of the trip function, a reactor trip signal occurs and a reactor trip is established. In the SMART-P, the main feedwater and steam isolation valves are closed and the PRHRS isolation valves are opened to connect to the steam generator after a reactor trip. The long term cooling of the decay heat is accomplished by the PRHRS.

4.2 The Effect of the Initial Condition, Control Rod Withdrawal Time & Reactivity Feedback

Analysis on the control rod banks withdrawal event under various initial conditions, considering the core power (97~103%), system pressure (13.9~15.5MPa), core exit temperature (305~315^{o}C) and axial power shape (A.O. –0.6~0.15), have been performed to identify the limiting case from the viewpoint of the CHFR. In this case, the core inlet mass flow rate was assumed to be a thermal design flow and the withdrawal time of the control rod banks is assumed to be 1600 sec. The maximum bank worth including the uncertainty was 16179 pcm [1]. Considering the withdrawal time and maximum bank worth, the reactivity insertion rate can be calculated to be 10.11 pcm/sec. Fuel and moderator temperature coefficients (FTC & MTC) are also assumed as the most and least negative for conservative evaluation, respectively. The results show that the CHFR in the case of a 97% core power, 315^{o}C core exit temperature, 13.9 MPa PZR pressure and A.O. 0.15 is the minimum value, as shown in Fig. 1. The lower core power and the system pressure result in a delay in the reactor trip and further decrease the CHFR. On the other hand, as the core exit temperature increases, the core inlet temperature and CHFR can be higher and lower, respectively.

The minimum CHFR behavior with the control rod withdrawal time is shown in Fig. 2. The CHFRs have a tendency to decrease and increase with an increase of the withdrawal time. In the case of using the most FTC & the least MTC as the reactivity feedback, the CHFR at a 1600 sec withdrawal time is the lowest value compared to those at the other withdrawal times. Below 1600 sec, the core power sharply increases and the reactor trip time is shortened as the withdrawal time decreases. Therefore, the CHFR increases with a decrease of the withdrawal time. On the other hand, above 1600 sec, the reactor trip time is elongated with an increase of the withdrawal time. However, due to a decrease of the peak core power, the CHFR increases as the withdrawal time of the control rod increases. In the case of using different FTC & MTC as the reactivity feedback, the tendency of a decrease and increase with an increase of the withdrawal time can also be identified. On the other hand, the lowest CHFR can be observed at a different withdrawal time.

5. Conclusion

With the TASS/SMR code and the SSF-1 correlation, a safety analysis on the control rod banks withdrawal event at a full power of the SMART-P has been performed. According to the safety analysis results on the control rod banks withdrawal event, the SMART-P has a sufficient margin from the viewpoint of a CHFR and the system pressure.

REFERENCES

[1] S.Y. Park, "Core Design Interface Data for the SMART-P Safety/Performance/Containment Analysis," SMP65-CA-DD160-01, KAERI, 2003.

[2] H.Y. Yoon, H.C. Kim, Y.J. Chung, H.S. Lim, S.H. Yang, "Thermal Hydraulic Model Description of TASS/SMR," Technical Report, KAERI/TR-1835/2001, KAERI, 2001.

[3] D.H. Whang, "Development of CHF correlation systems for SMART-P fuel assembly," KAERI/TR-2943/2005, KAERI, 2005.

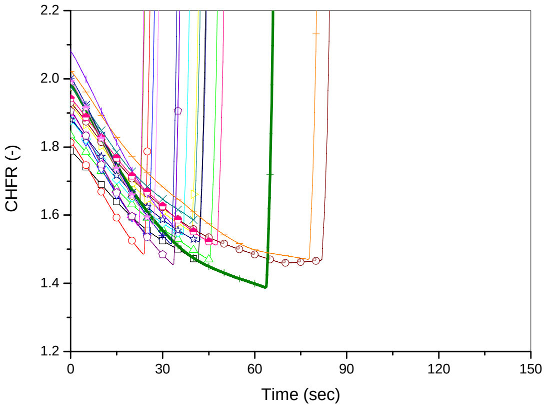

Fig. 1 CHFR Behavior for Different Initial Conditions

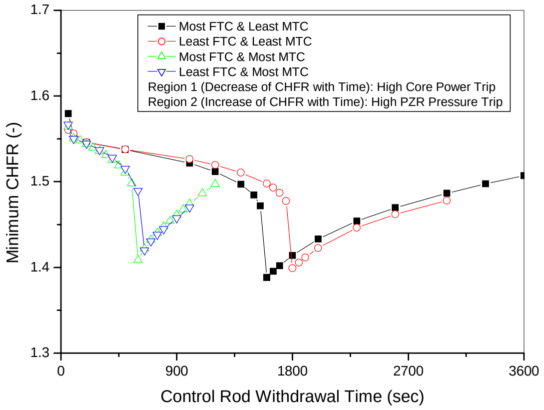

Fig. 2 Minimum CHF Behavior with Withdrawal Time