Evaluation of Total Loss of Reactor Coolant Flow for an Advanced Integral Reactor, SMART

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1. Introduction

SMART is an integral type of pressurized water rector with a maximum thermal power of 365 MWt. Unlike the conventional loop-type of PWR reactors, the SMART contains major components of the reactor coolant system (RCS) such as the core, pressurizer (PRZ), 4 reactor coolant pumps (RCPs) and 8 helical types of steam generators (SGs). They are all integrated in a single reactor pressure vessel. SMART system has an integrated primary system, where the safety features are enhanced.

Total Loss of Reactor Coolant Flow (TLOF) is an event of losing forced circulation flow in the RCS following the failure of the entire four RCPs classified as anticipated operational occurrence (AOO). The event is related to simultaneously losing the power to all RCPs. The only cause of it is that loss of offsite power (LOOP) and a turbine trip following it.

There are various safety systems such as the Reactor Protection System (RPS), the Passive Residual Heat Removal System (PRHRS) to protect the TLOF accident in the SMART. The RPS generates the reactor trip signal to safely shutdown when process variables reach the safety system setpoints. The process variables provided to the RPS include the core power, PZR pressure, RCP speed, and so on. The PRHRS is designed to remove the residual heat after the reactor trip. It is actuated automatically when the signal is generated from passive residual heat removal actuation signal (PRHRAS). The PRHRAS is generated by the high and low main steam line pressure, high and low feedwater flow, and so on.

In this study, the thermal hydraulics behavior and the acceptance criteria during the TLOF were evaluated using the TASS/SMR-S computer program [1].

2. Analysis Methodology

2.1 TASS/SMR-S

TASS/SMR-S computer program is thermal hydraulic computer program developed at the Korea Atomic Energy Research Institute (KAERI) for the SMART. This program uses conservation equations for safety analysis and models a plant as a set of nodes and paths to calculate the thermal-hydraulic behavior of the plant such as core power, core heat flux, coolant temperature, coolant pressure, and flow rate.

2.2 Acceptance Criteria

The Safety Review Guide (SRG) classifies the TLOF as AOO [2]. The SMART presents the following acceptance criteria to conform to the requirements of the SRG in relation to a loss of reactor coolant flow event.

1. Pressure in the RCS and main steam system should be maintained below 110% of their design values required in KEPIC MN.
2. Fuel cladding integrity should be maintained ensuring that the minimum DNBR remains above the 95/95 of DNBR limit.
3. Anticipated operational occurrences should not propagate to postulated accidents without the other independent occurrence besides the initiating event. They should not cause the loss of the protection function of the RCS or the reactor containment

2.3 Initial Conditions and Assumptions

Conservative initial conditions and assumptions were used for this accident. The initial core power was assumed as 103 % of the normal power (365 MWt). The maximum RCS temperature, maximum PZR pressure, minimum RCS flow rate, minimum PZR level, and minimum main steam line pressure of the operating conditions were used. These initial conditions were selected by the sensitivity analysis.

3. Analysis Results and Discussion

When the TLOF was occurred, all RCPs and feedwater pumps failed simultaneously. The forced circulation of the coolant was not sustained and the reactor coolant flow rate rapidly decreased. The reactor trip signal is generated by a low RCP speed. Figure 1 shows the RCS flow behavior.

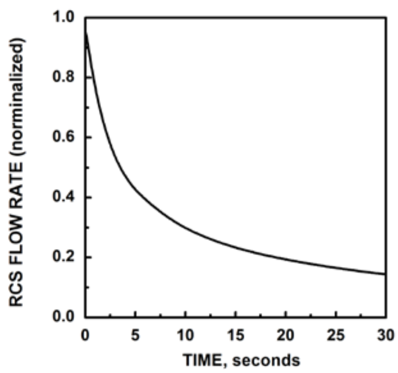

Fig. 1. RCS flow rate vs. time

The RCS heat would not remove as the loss of the normal heat removal function of the RCS and the decrease in the RCS flow rate. The residual RCS heat increased the RCS temperature and pressure before the decrease in the core power. Figures 2 and 3 show the RCS temperature and pressure.

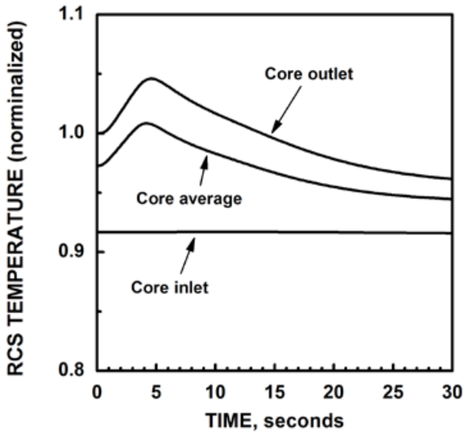

Fig. 2. RCS temperature vs. time

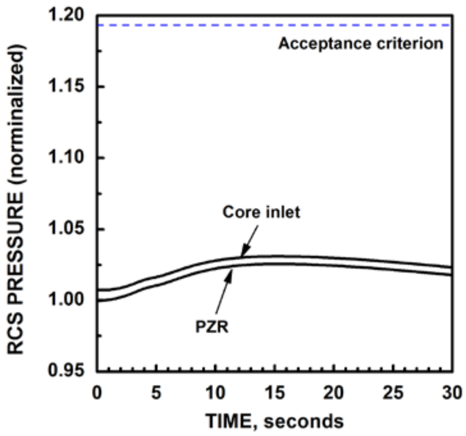

Fig. 3. RCS pressure vs. time

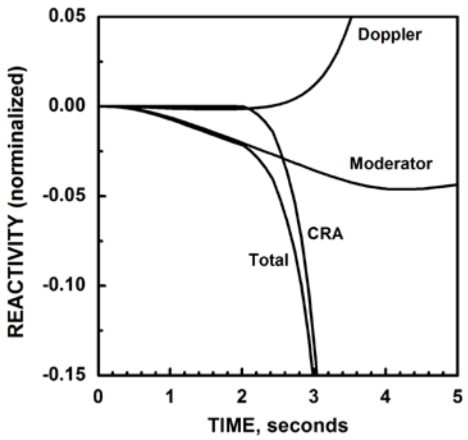

Fig. 4. Reactivity vs. time (5seocnds)

Figures 4 and 5 show the reactivity behaviors during 5 and 30 seconds. The total reactivity decreased because of the negative reactivity feedback by the increases in the moderator temperature and the fuel temperature before the insertion of control rod assemblies (CRAs). After the CRAs insertion, the reactivity and the core power sharply decreased. Figure 6 shows the core power behavior.

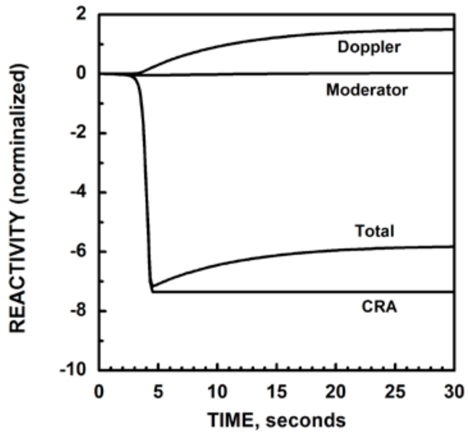

Fig. 5. Reactivity vs. time

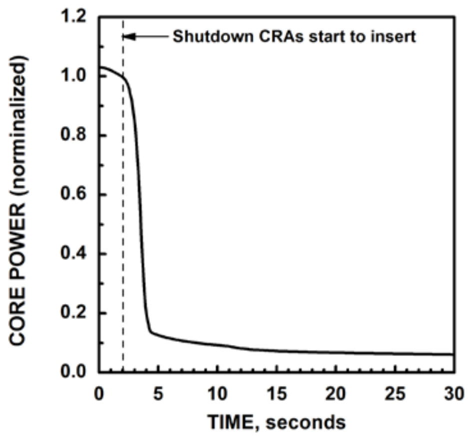

Fig. 6. Core power vs. time

Figure 7 shows the minimum DNBR behavior in this event. The minimum DNBR decreased as the increase in the RCS temperature and the decrease in the RCS flow rate. After the CRAs insertion, the core power and the core heat flux decreased. As the core heat flux decreased, the minimum DNBR increased.

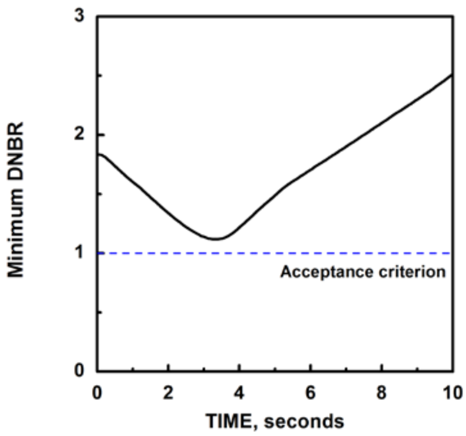

Fig. 7. Minimum DNBR vs. time

Figure 8 shows the behavior of RCS temperature during 8 hours. After the reactor trip, the PRHRS removed the residual heat. The RCS temperature decreased and reached the safe shutdown condition before 8 hours.

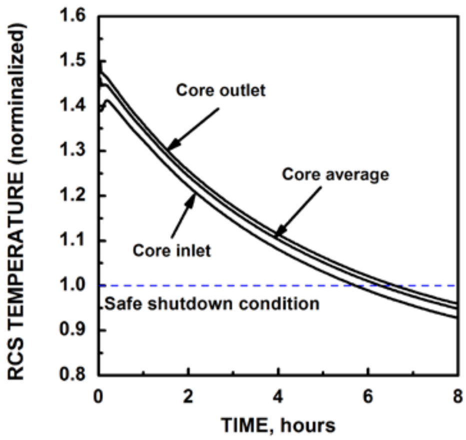

Fig. 8. RCS temperature vs. time (8 hours)

5. Conclusions

The thermal hydraulics behavior for the TLOF was evaluated. No fuel damage occurs during TLOF as the minimum DNBR is higher than the SAFDL. The integrity of the pressure boundary is maintained as the maximum pressures of RCS and secondary system are less than 110% of the design pressures.

ACKNOWLEDGEMENTS

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REFERENCES

[1] TASS/SMR-S Code Technical Report, KAERI, Daejeon, 2017.

[2] Safety Review Guidelines for Light Water Reactors, KINS/GE-N001, Rev.4, 2014