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Feedwater Line Break Accident Analysis for SMART in the View Point of Minimum Departure from Nucleate Boiling Ratio

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1. Introduction

KAERI and KEPCO consortium had performed standard design of SMART(System-integrated Modular Advanced ReacTor) [1] from 2009 to 2011 and obtained standard design approval in July 2012. To confirm the safety of SMART design, all of the safety related design basis events were analyzed. A feedwater line break (FLB) is a postulated accident and is a limiting accident for a decrease in the heat removal by the secondary system in the view point of the peak RCS pressure. It is well known that departure from nucleate boiling ratio (DNBR) increases with the increase of the system pressure for conventional nuclear power plants. But SMART has comparatively lower RCS flow rate, and there is a possibility to show different DNBR behavior depending on the system pressure. To confirm that SMART is safe in case of FLB accident, the Korean nuclear regulatory body required to perform the safety analysis in the view point of minimum DNBR (MDNBR) during the licensing review process for standard design approval (SDA) of SMART design. In this paper, the safety analysis results of the FLB accident for SMART in the view point of MDNBR is described.

2. Description of the FLB accident

FLB accident occurs as a result of thermal stress or cracking in the feedwater pipe. A pipe break in the feedwater system causes an immediate decrease in feedwater flow rate, which causes a decrease in heat removal by the secondary system and an increase in RCS coolant temperature and pressure. The negative reactivity is inserted due to the negative moderator temperature coefficient (MTC), which causes a core power decrease. The reactor trip signal is generated by high PZR pressure, low speed of reactor coolant pump (RCP) in case of loss of offsite power or low steam line pressure. The passive residual heat removal actuation signal (PRHRAS) is generated by a low feedwater flow rate after the reactor trip signal generation and the RCS is cooled down by the natural circulation of passive residual heat removal system (PRHRS).

The followings are the acceptance criteria for FLB:

- Pressure in the RCS and main steam system should be maintained below 110% of the design values.
- A coolable core geometry should be maintained.
- The release of radioactive material shall not result in offsite doses in excess of the guidelines of 10 CFR Part 100.

3. Safety analysis

3.1 Methodology

TASS/SMR-S [2] code, which was developed at KAERI for the performance and safety analyses of an integral reactor, is used for the safety analysis. This code calculates the system thermal-hydraulic response, fuel rod DNBR, and fuel rod temperature under a full range of operating conditions.

A deterministic safety analysis method is used. By using the conservative model, initial boundary conditions and assumptions, conservative analysis results are calculated. The scram reactivity insertion curve is for the limiting bottom-skewed axial power shape, and the minimum shutdown rod worth with the most reactive rod stuck out is considered. The decay heat curve used is a conservative ANS-71 decay heat curve [3] with 1.2 multiplication factor. Three second turbine trip delay after reactor trip signal generation is not considered for the conservative calculation of the main safety parameters.

3.2 Sensitivity analysis

A sensitivity analysis was performed to select the limiting initial condition from the viewpoint of MDNBR among various initial condition ranges of core power, core inlet fluid temperature, PZR pressure, RCS coolant flow rate, PZR water level, axial offset and radial power distribution on the fuel rods. Moderator and fuel temperature coefficients were selected as a combination of the least or most negative ones for conservative results. Delayed neutron fraction and prompt neutron lifetime were also determined as a combination of the minimum or maximum values for the conservative results. Various break locations and sizes on the feedwater pipe were tested to select the limiting ones.

The inertia of RCP in SMART is comparatively lower than that in conventional nuclear power plants so that, if the power supply to the RCPs is lost, RCS flow decreases rapidly and the DNBR decreases due to a mismatch between core heat removal and nuclear power generation in the core. A sensitivity study to determine the limiting time of loss of offsite power was also performed.

The limiting initial conditions selected from the sensitivity analyses are summarized in table 1. Those conditions are at high initial core power, low initial core inlet temperature, high RCS flow, high initial RCS pressure, high PZR level, top-skewed axial power distribution, the minimum gap heat transfer coefficient, even radial power distribution, least negative MTC, least negative fuel temperature coefficient, the maximum delayed neutron fraction, and the minimum prompt neutron lifetime. The limiting time of loss of offsite power is 16 sec. after the occurrence of FLB accident. A guillotine break of feedwater pipe at the downstream of a main steam isolation valve is selected as the limiting one.

3.3 Results of the limiting case

The transient behaviors of system pressure and MDNBR during a limiting FLB are shown in Fig. 1. Upon the break the RCS pressure and temperature started to increase. Loss of offsite power was assumed to occur at 16.0s and the turbine was stopped at the same time. Simultaneously RCP speed, RCS flow and DNBR started to decrease. The PRHRAS is generated by a low feedwater flow rate. The reactor trip analysis set point was reached at 16.35s. The reactor trip signal was generated at 17.45s. MDNBR reached the minimum value at 19.01s, which is sufficiently higher than the specified acceptable fuel design limit (SAFDL) on DNBR. At 20.58s PZR safety valves (PSVs) were opened and PZR pressure was reached the maximum value, 101.6% of design pressure. After that the RCS pressure decreased. At 367.8s main steam pressure reached the maximum value, 57.2% of design pressure. At 1800 sec. the operator started to cooldown the plant. Due to the no fuel failure and the early isolation of secondary system by the PRHRAS, the radiation dose is well within the 10CFR100 limit.

4. Conclusions

Safety analysis of the postulated accident of the FLB in SMART was performed in the view point of MDNBR. The analysis results show that the MDNBR of the limiting case of the FLB accident, which is selected through the sensitivity analyses for various initial and boundary conditions, is sufficiently larger than the DNBR SAFDL.

REFERENCES

[1] *SMART Standard Safety Analysis Report*, KEPCO & KAERI, 2010.
[2] Kim et al., *TASS/SMR-S Code Technical Report*, KAERI, Daejeon, Korea, 2011.
[3] *Decay Energy Release Rates Following Shutdown of Uranium-fueled Thermal Reactors*, ANS-5.1, ANS, U.S.A, 1973.

Table 1. Limiting initial conditions for FLB

Parameter	Value
Initial core power, (% of rated condition)	103
Initial core inlet temp., (K, ΔT of nominal cond.)	-5.3
RCS flow, (% of nominal condition)	115
PZR pressure, (% of design press.)	92.2
PZR level, (%)	76.5
CEA worth at trip, (% Δρ)	-8.0
Axial offset	0.3
Fr	2.01
DNBR	2.45
Doppler coefficient multiplier	Least(-)
Moderate coefficient multiplier	Least(-)
Time of loss of offsite power (sec.)	16
Single failure	PRHRS 1 train

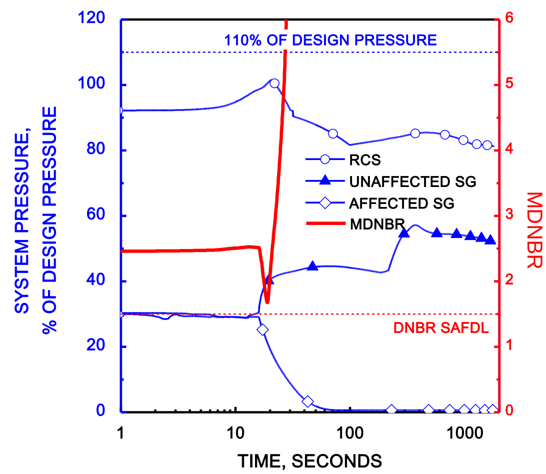

Fig. 1 System pressure and MDNBR during FLB transient