Achievement of Design Improvement by Use of PSA in the SMART

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1. Introduction

An integral reactor SMART (**S**ystem integrated **M**odular **A**dvanced **R**eac**T**or) developed by Korea Atomic Energy Research Institute (KAERI), is under regulatory review now. The thermal power of SMART is 330 MWth and a pressurizer, 4 reactor coolant pumps (RCPs), and 8 steam generator cassettes (S/Gs) are located in a single reactor vessel [1]. This reactor has substantially enhanced its safety with an integral layout of its major components, 4 trains of safety injection system (SIS), and an adoption of 4 trains of passive residual heat removal system (PRHRS), instead of an active auxiliary feedwater system.

The possibility of a severe accident in SMART has been determined during the design stage. The preliminary PSA results showed that a total core damage frequency (CDF) was 1.47E-6/ry [2]. This value did not satisfy the top tier requirement of SMART. The CDF should be less than 1.0E-6/ry for the internal event at full power. So the various ways were searched to reduce CDF. These include the design changes, the operating procedure changes, or both. This paper introduces a part of these efforts.

2. Design Improvement Suggested Through Preliminary PSA Results

As mentioned above, the preliminary PSA was done during the first year of SMART development project. The total CDF was determined as 1.47E-06/ry. One of an important contributor to the high CDF was determined a small loss of coolant accident (SLOCA). The CDF for SLOCA was 2.36E-7/ry and the most important sequence for SLOCA was sequence 5 (SLOCA-5) in Fig. 1 and its frequency was 2.30e-7/ry. At that time there was no means to supply the water into the reactor coolant system (RCS) except SIS. In order to reduce the frequency of this core damage sequence, an alternative injection tools should be provided. The use of shutdown cooling system (SCS) pump is suggested as a viable means to inject the water into the RCS when a SIS is unavailable.

SMART has two trains of SCS. The normal function of SCS is that it cools down the RCS from a hot shutdown state to a cold shutdown state and operates during the refueling stage. The SCS entry condition is that the RCS pressure is below 2.8MPa and the RCS water temperature is below 200 ^{o}C.

There are prerequisites for the use of the SCS pump to inject the water into the RCS. These are following;

1. There should exist a path way from in-containment refueling storage tank (IRWST) to the RCS via SCS pump.
2. RCS pressure should allow the operation of a SCS pump when required and the IRWST water should be always subcooled and the temperature is lower than 200 ^{o}C .
3. There should be enough time to align this path way by the operator.
4. There should be procedures for this job in the Emergency Operation Procedure (EOP) or Emergency Response Guideline (ERG).

3. Thermal Hydraulic Analysis to Support Design Improvement

Various thermal hydraulic calculations had been done to support the development of an event tree for SLOCA and to estimate the allowable time to the operator to diagnose the plant state and execute the proper actions. MIDAS/SMR code was used in this analysis. A part of these calculation results are summarized in Table 1 and 2[3]. For 13 mm break, the RCS pressure did not reduced below 10 MPa before the core was damaged, when PRHRS did not work. So the operator should open a Safety Depressurization System (SDS) valve when he/she noticed PRHRS did not work. This operator action was requested to be described in ERG.

4. Change of Emergency Operation Guideline

Originally, there was no procedure which uses a SCS pump to inject the water into the RCS. PSA team asked this procedure to ERG development team and this procedure was developed in the current ERG. The actions which open a SDS valve and align a path from the IRWST to the RCS via a SCS pump are described in the ERG.

5. Results and Conclusion

The event tree for SLOCA and SGTR were modified to reflect the use of SCS when SIS is unavailable. The new event tree for SLOCA is shown in Fig. 2. As expected the CDF of SLOCA was reduced 1.82E-7/ry. But this reduction does not rely on the alternative injection provision entirely. The effect of a SCS pump was evaluated by using the final SLOCA event tree. When we assumed that the water injection using a SCS pump is not available all the time(e.g., there is no ways to use a SCS pump), the summed frequency of SLOCA-7, 9, 10, 11 of the final PSA increases to 6.59E-7/ry from 1.82E-7/ry and the total CDF increased to the 9.92E-07/ry from 5.15E-7/ry. This means that an alternative injection means to the RCS is very important in SMART.

After Fukushima accident, the preparations of an alternative injection means which does not require an AC power, is under the consideration in SMART. The provision may be prepared which enables to inject water into RCS through SIS piping by a fire pump or a fire engine. When a new injection means is provided and its success probability to inject the water into RCS when required is assumed to be 0.9, then the total CDF is reduced to the 3.52E-7/ry.

REFERENCES

[1] SMART Reactor System Description, KAERI, 2010
[2] Preliminary Evaluation Report of Level 1 PSA, 916-NS301-020, Rev.0, KAERI, 2010
[3] Thermal Hydraulic Calculation to Support Event Tree for LOCA, 916-NS301-031, Rev.0, 2010

Table 1 Important Events Times for no SIS, no PRHRS, and no operator action

(time in seconds)

	50mm Break	13mm Break
Break occurs	200	200
Reactor trip	254	1,024
SIS signal from High Cont. P	254	1,024
RCP P reaches SIS injection P (10 MPa)	596	30,947
Core uncover	3,320	3,320
RCP P reaches SCS entry P (2.8 MPa)	**3,486**	**-**
Peak cladding T 1225K(1800^{o}F)	14,062	46,837
Core water depleted	28,775	53,501
Calculation ends	30,000	80,000

Table 2 Important Events Times with operator action of a SDS valve open for no SIS, no PRHRS conditions

(time in seconds)

	13mm Break	
	2 Hour	3 Hour
Break occur	200	200
Reactor trip	254	1,024
SIS signal from High Cont. P	254	1,024
SDS Valve Open	***8,225***	***11,825***
RCP P reaches SIS injection P (10 MPa)	8,874	10,251
Core uncover	8,484	11,865
RCP P reaches SCS entry P (2.8 MPa)	**19,783**	**17,640**
Peak cladding T 1225K(1800^{o}F)	21,511	21,081
Core water depleted	28,613	27,962
Calculation ends	50,000	50,000

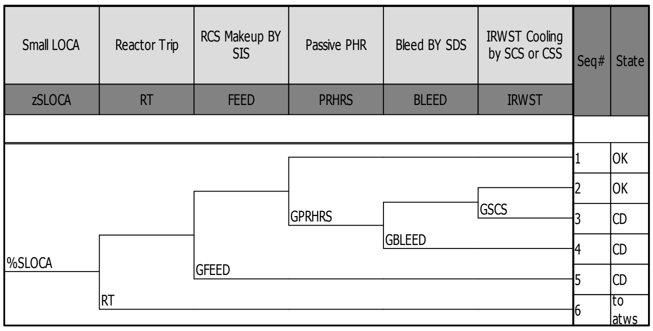

Fig. 1 Small LOCA event tree used in the preliminary PSA

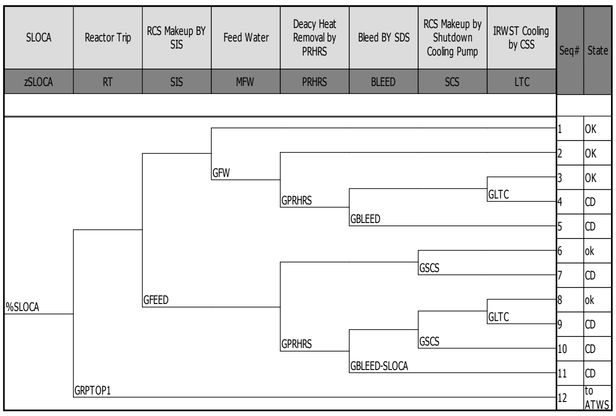

Fig. 2 Small LOCA event tree used in the final PSA