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Revisiting Ulchin 4 SGTR Accident – Analysis for EOP Improvement

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1. Introduction

The Steam Generator Tube Ruputure (SGTR) is an accident that U-tube inside the SG is defected so that the reactor coolant releases through broken U-tube and this is one of design basis accidents. Operating the Nuclear Power Plants (NPP), maintaing the integrity of core and preventing radiation release are most important things. The SGTR accident, however, causes radiation release and core uncovery due to break flow of primary-to-secondary.

Because of risks, many researchers have studied scenarios, impacts and the ways to mitigate SGTR accidents. The study to provide an experimental database of aerosol particle retention and to develop models to support accident management interventions during SGTR was performed. The scaled-down models of NPP were used for experiments, also, MELCOR and SCDAP/RELAP5 were used to simulate a design basis SGTR accident. This study had a major role to resolve uncertainties of various physical models for aerosol mechanical resuspension [1]. The other study which analyzed SGTR accident for System-integrated Modular Advanced Reactor (SMART) was performed. In this analysis, the amount of break flow was focused and TASS/SMRS code was used. It assumed that maximum leak was generated, and found that high RCS pressure, low core inlet coolant temperature, and low break location of the SG cassette contributed to leakage. Although the leakage was large, there was no direct release to atmosphere because the pressure of secondary loop was maintained below the safety relief valve set point [2]. Likewise, many studies related with SGTR accident were performed. The most cases were assumed, however, the NPP was operated in full power.

Recently, the necessity of accident analysis for shutdown mode has increased. Therefore, the Probabilistic Risk Assessment (PRA) during low power and shutdown mode was performed. It emphasized the importance of shutdown PRA so the event trees and fault trees were developed for major initiating events [3].

The SGTR accident occurred at Ulchin uint 4 and its condition was low power and shutdown for refueling test. In this paper, we set up a model for Ulchin 4 using MARS-KS code. The benchmarking was performed for actual plant behavior in SGTR accident situation. After that, the several cases were performed to check the safety evaluation about SGTR at Ulchin 4 and the effectiveness of EOP in shutdown condition.

2. Model Description

To analyze the SGTR accident at Ulchin 4, a MARS-KS ver.1.3 computer code model was set up incorporating the plant conditions at the time of accident and operator actions, using the Ulchin 4 NPP base deck. The MARS-KS code is a realistic multi-dimensional thermal-hydraulic system analysis code and the backbones of MARS-KS are RELAP5-MOD3 and COBRA-TF codes [4].

As shown in Fig.1, the plant model consists of broken loop with Steam Generator (SG) and Reactor Coolant System (RCS) nodalization. The intact loop with SG is modeled as the same way as the broken loop. The double-ended break of SG U-tube was modeled using two trip valves which are indicated by a red circle in Fig. 1. The Ulchin unit 4 was shutdown to test the refueling and the SGTR occurred 17 hours after the reactor shutdown. The plant was in Plant Operation Condition (POS) 2 at which the plant was cooled down by the S/G until the RCS temperature reaches 146 ºC, so that the RCS temperature was 291 ºC which was 20.5 ºC lower than the average RCS temperature at full power. The reactor power was assumed as 8.455 MW_{th} considering decay heat, reactor mass flow rate and temperature difference between hot/cold leg, etc. The plant configuration was identical to the full power conditions, except the set points of the safety system actuation were changed. The major sequence of events including the operator action is summarized in Table I [5].

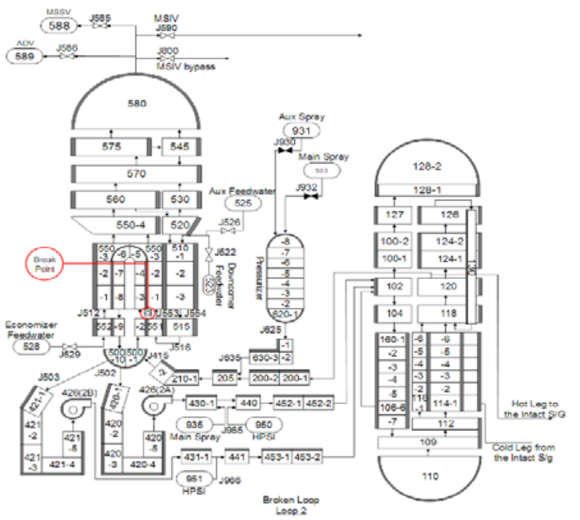

Fig.1 MARS-KS model of Ulchin 4 NPP

Table I : Major Sequence of Events

Time (sec)	Event
0	SGTR occurs
120	Charging pump on
780	SG #2 Isolation
960	HPSI on manually
1500	SG #1 Isolation
1740	Reactor Coolant Pump (RCP) 2B stop
2460	HPSI off
3480	Charging pump off
3960	HPSI on (restart)
5040	HPSI off
5160	RCS and SG pressure equalized

Benchmarking calculations were performed to validate the calculation possibility of accident and plant model, focusing on the pressure and water level of the pressurizer (PZR). The results are shown in Fig. 2. When SGTR occurred, the coolant of primary loop released to secondary loop through the broken U-tube, so the pressure and level of PZR decreased in the initial stage. After that, the preessure and level increased because operator turned on High Pressure Safety Injection (HPSI). It was, however, soon decreased once the HPSI is turned off until the pressure between the RCS and S/G became equalized, so that the break flow stopped.

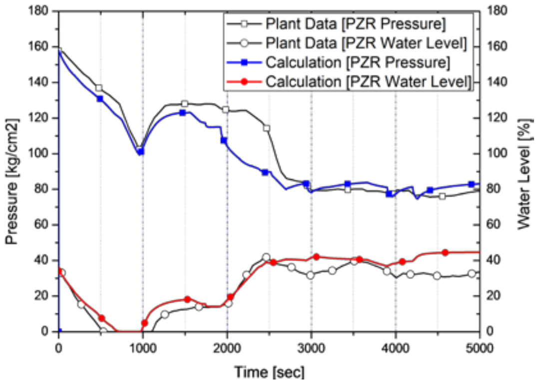

Fig.2 Pressurizer pressure and level behavior

3. Characteristics Analysis

When the SGTR accident occurs, there are two important things to protect; core water level and the integrated amount of break flow from primary-to-secondary loop. Therefore, we analyzed the way that mitigates the SGTR accident focusing on the above two factors. To protect the core uncovery, the core water level should be kept. Also, the total amount of break flow should be minimized. In SGTR accidents, there are two major mitigation actions; Emergency Core Cooling System (ECCS) injection and cooling through the Intact Steam Generator (ISG) operation. These impacts of actions were investigated in shutdown (SD) and full power (FP) condition, respectively.

Six cases were analyzed to find the best way to mitigate SGTR accident in SD condition and FP condition, respectively. Table Ⅱ represents the description of six cases.

Table II : Summary of the cases

Condition	Case	Description
Shutdown (SD)	Case1	No HPSI and no intact SG operation (worst)
	Case2	Automatic HPSI following EOP with intact SG operation
	Case3	Operation of the intact SG without ECCS
Full Power (FP)	Case4	No HPSI and no intact SG operation (worst)
	Case5	Automatic HPSI following EOP with intact SG operation
	Case6	Operation of the intact SG without ECCS

3.1 Shutdown Condition

To check the transient behavior and find the best way to mitigate in SD condition, case 1 to 3 were compared. The reactor power was assumed 8.455 MW_{th}. Also, the simulation time was set 5,000 seconds to follw the Ulchin 4 SGTR. Case 1 was assumed as worst case that there were no any actions to mitigate SGTR accdient. In case 2, the present EOP was applied operating HPSI with ISG cooling. Also, the auxiliary spray and main spray were operated to depressurize the pressure of primary loop. Case 3 was set as cooling with intact SG only; no ECCS and any spray systems. The purpose of case 3 is to check the effectiveness of cooling through the intact SG. The time for major sequence of event for these cases are reported on Table III. The character 'X' in table means that it was not operated.

TableIII: Major sequence of event in shutdown condition

Event	Case 1	Case2	Case 3
	Time (s)		
SGTR occurs	0	0	0
Charging Pump	X	120 ~	X
SG #2 Isolation	X	780 ~	780~
HPSI	X	1,048~2,700	X
SG #1 Cooling	X	1,048~	960~
Main Spray	X	1,500~2,000	X
Auxiliary Spray	X	2,000~	X

As shown in Fig.3, core water level and cladding temperature is represented. In shutdown case, the core water level is almost stable no matter what procedures are applied. It is because the reactor power is too low to affect the core water level. It was validated that core water level is stable until 60,000 seconds by long-term simulation.

The difference of temperature, however, can be shown depending on procedures. When no procedures are conducted after SGTR occurs, case 1, the cladding temperature increases slightly. If the HPSI is injected, in case 2, then the cladding temperature decreases continuously and is the lowest value among three cases. Comparing three cases, the effectiveness of cooling procedure is validated; HPSI and intact SG cooling. Because the core water level is stable for all cases, from this result, the amount of break flow becomes important factor for mitigating SGTR accident in shutdown mode.

The break flow rate of case 2 is the highest value because of HPSI injection as shown in Fig.4. The negative value can be checked in case 3 due to back flow. Because of continuous cooling through the intact SG, sometimes the primary loop pressure becomes lower than secondary loop so that the back flow is generated.

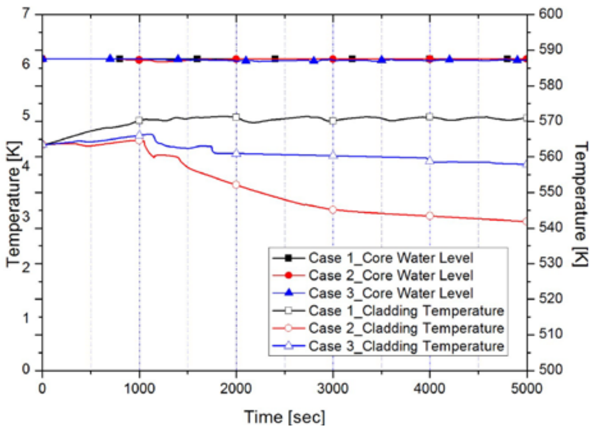

Fig. 3 Core water level and cladding temperature in shutdown condition cases

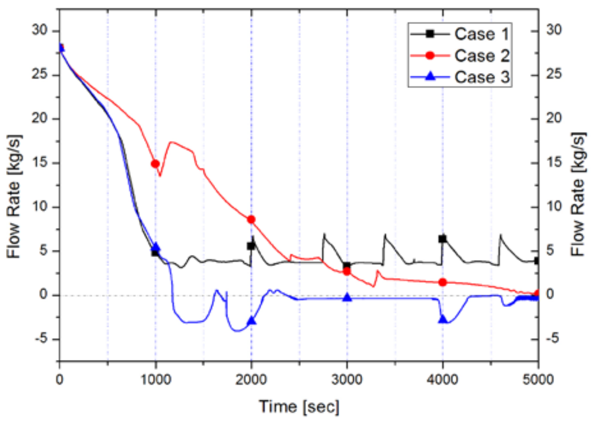

Fig. 4 Break flow rate in shutdown condition cases

Depending on break flow rate, the integrated amount of break flow changes as shown in Fig. 5. Due to HPSI injection, case 2 shows the highest integrated amount of break flow, otherwise, case 3 shows the lowest value.

As mentioned above, the integrated amount of break flow is important factor in shutdown case. Since the core water level keeps stable, so minimizing the integrated amount of break flow is essential. In this point of view, case 3 is appropriate to minimize the amount of break flow as keeping core water level.

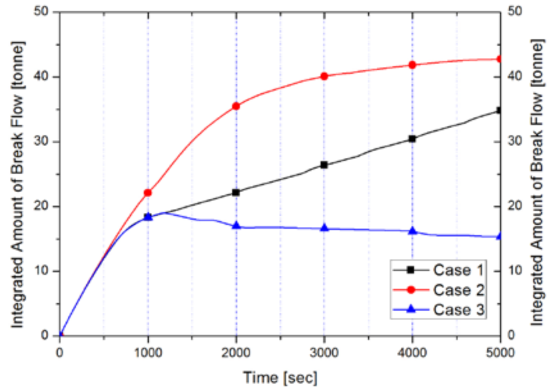

Fig. 5 Integrated amount of break flow in shutdown cases

3.2 Full Power Condition

To check transient behavior and find the best way to mitigate SGTR accident in full power conditon, case 4 to 6 were compared. The reactor power is set as 2815 MW_{th} and the simulation time was set 10,000 seconds considering its high reactor power. Case 4 was set for describing worst case as same as case 1. Case 5 was assumed that it followed the EOP applying HPSI, intact SG cooling and spray. The only intact SG cooling was applied to case 6. The major sequence of event is summarized in Table IV.

Table IV : Major sequence of events in full power conditon

Event	Case 4	Case 5	Case 6
	Time (s)		
SGTR occurs	0	0	0
Charging Pump	X	0	X
SG #2 Isolation	X	0	0
HPSI	X	0~3,000	X
SG #1 Cooling	X	0	0
Main Spray	X	1,500~2,000	X
Auxiliary Spray	X	0	X

As shown in Fig.6, the core water level is changed in all cases due to high reactor power. However, if the HPSI is injected, the core water level is kept. The cladding temperature increases rapidly when there are no actions to cooldown as shown in case 4.

Due to HPSI injection, the break flow rate and the integrated amount of break flow are the highest in case 5. However, the break flow rate of case 4 increases suddenly when the cladding temperature increases. Since increasing temperature of cladding makes the primary loop pressure high, the break flow rate and the integrated amount of break flow increase as shown in Fig.8.

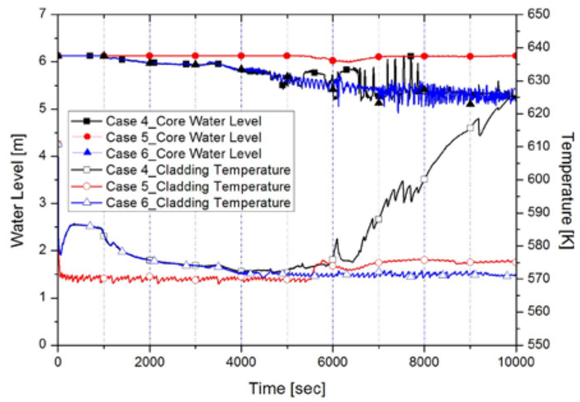

Fig 6. Core water level and cladding temperature in full power condition cases

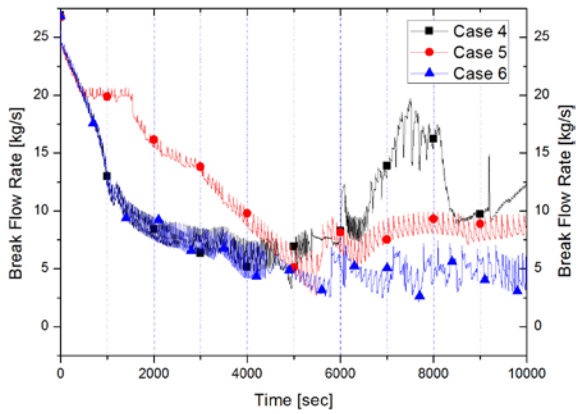

Fig. 7 Break flow rate in full power condition cases

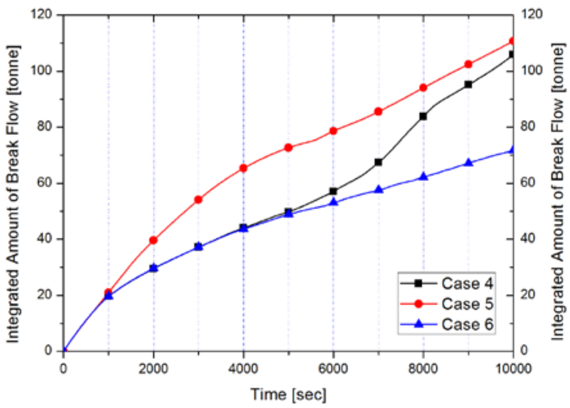

Fig 8. Integrated amount of break flow in full power cases

Differing from shutdown condition, the core water level decreases due to high reactor power. Therefore, in full power condition, the core water level should be considered fisrt to prevent severe core damage. In case 6, the cladding temperature becomes stable as time goes, because the 80 percent of fuel rods are sank in water and cooling through ISG continues. However, core uncovery can be checked. It has a possibility that causes the another accident releated with core so it is not suitable for mitigating SGTR accident in full power mode. Although the break flow is largest in case 5, it is suitable procedure to keep core water level. Therefore, injecting HPSI is inevitable to protect the core uncovery.

4. Conclusions

In this analysis, comparison of mitigating procedure when SGTR occurs between shutdown condition and full power condition was performed. In shutdown condition, the core uncovery would not take place in 16 hours whether the cooling procedures are performed or not. Therefore, the integrated amount of break flow should be considered only. In this point of view, cooling through intact SG only, case 3, is the best way to minimize the amount of break flow.

In full power condition, the core water level is changed due to high reactor power. The important thing to protect NPP is to keep core water level. Although the break flow rate is smaller when no HPSI is injected, the core water level decreases continuously so that HPSI injection is inevitable.

It is expected that SGTR EOP should be prepared for different mode of NPP, for instance, shutdown or full power.

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