Analysis on Accident Sequences of SGTR Accident Considering the Status of Safety Valves

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Abstract: A method that classifies accident sequences within single Initiating Event (IE) depends on the status of safety valves in pressurizer and Steam Generators (SGs) to analyze accident sequences that cannot be found in current Event Tree (ET) was suggested in this research. Safety-grade automatic mitigation systems without operator intervention were only considered in accident sequences. Using this method, Steam Generator Tube Rupture (SGTR) accident which is relatively more complicated IE than others to mitigate for operator because condition of each SG is different was analyzed using MARS-KS-003, the thermal hydraulic system code. In the result, accident sequences which can prevent Core Damage (CD) only with safety-grade automatic mitigation systems in SGTR accident sequences was analyzed that cannot be analyzed in current ET.
Keyword: Event tree, Accident Sequence, Steam Generator Tube Rupture

1 Introduction

Probabilistic Safety Analysis (PSA) is an effective tool to estimate safety of Nuclear Power Plants (NPPs) as realistic as possible. Emergency Operating Procedure (EOP) which guides operators to mitigate accidents in NPP is developed based on Event Tree (ET) that includes possible accident sequences within Initiating Events (IEs) in at-power, internal events level 1 PSA area.

Operator errors are critical in accident situations, so EOP should provide enough information for operators to deal with accident situations within prediction and also minimize operator actions as much as possible to decrease operator errors. In other words, EOP should inform operators about all possible accident sequences that can prevent Core Damage (CD) only with automatic mitigation systems.

Because Pressurized Water Reactors (PWRs) are operated under high pressure condition, there are safety valves to prevent over-pressure failure of primary and secondary side, the pressurizer and the Steam Generator (SG) which are called Pilot Operated Relief Safety Valve (POSRV), and Main Steam Safety Valve (MSSV) each. These are spring-loaded valves to maintain passively system pressure high below specific pressure, but there are some possibilities to make these valves stuck open. When safety valves are stuck opened, system pressure decreases continuously and makes the accident progression wholly different, so this situation can induce operator errors. But accident sequences in current ET, not all possible status of safety valves are considered.

In this research, analysis on accident sequences only with safety-grade automatic mitigation systems of SGTR accident considering the status of POSRV and MSSV was done as a case study using a method that classifies accident sequences within single IE depends on the status of safety valves in pressurizer and SGs to analyze accident sequences that cannot be analyzed in current ET.

2 SGTR Accident sequence analysis

A method that classifies accident sequences within a single Initiating Event (IE) depends on the status of safety valves in pressurizer and Steam Generators (SGs) to analyze accident sequences that cannot be analyzed in current Event Tree (ET) was suggested in this research. Using this method, Steam Generator Tube Rupture (SGTR) accident was analyzed.

Even though SGTR accident is not a big contributor of total Core Damage Frequency (CDF), it is relatively complicated IE to mitigate for operator because condition of each SG is different. Also, accident scenarios include failure of Safety Injections (SIs) were recognized that additional operator actions are required because these are analyzed as CD from previous PSA reports [1].

Safety-grade automatic mitigation systems without operator intervention were only considered in accident sequences; SI to Direct Vessel Injection (DVI) line, Auxiliary Feed-Water Injection (AFWI) to damaged SG, and AFWI to intact SG. Other operations that require operator action are excluded in accident sequences such as isolation of damaged SG by closing all related valves, Normal Secondary Cooling (NSC) using AFWI and Atmospheric Dump Valve (ADV), Feed & Bleed (F&B) using POSRV, refill of In-containment Refueling Water Storage Tank (IRWST) & Auxiliary Feed-Water Storage Tank (AFWST), includes controlling the mass flow rate of SI, SI by Shutdown Cooling System Pump (SCSP) after depressurization of primary side. Non safety-grade systems such as charging pump, and Turbine Bypass Valve (TBV) are also excluded. Reactor trip, Turbine trip, Main Steam Isolation Valve (MSIV), and turning off Main Feed-Water System (MFWS) & Reactor Coolant Pump (RCP) are assumed as success in all accident sequences.

Total 64 cases are arranged by status of 3 safety valves and 3 safety-grade automatic mitigation systems. Table 1 shows set values and assumptions of safety valves and automatic mitigation systems. Accident sequences were analyzed using MARS-KS-003, the thermal hydraulic system code. Target plant is APR-1400, which is an evolutionary Advanced Light Water Reactor (ALWR) with two-loop, 3983 MWt [2]. SGTR was considered as a guillotine break of single u-tube with about 1,500 L/min leakage rate which is larger than maximum cover range of charging pump. Each accident scenario was analyzed for 72 hours from accident initiation, if Peak Cladding Temperature (PCT) exceeded 1477 K during accident progression, that sequence was regarded as CD. Effect of containment was not considered in this research.

Table 1 Set values and assumptions of safety valves and automatic mitigation systems

Parameter	Set value	Assumption
POSRV open pres.	~167.8 atm	Stuck opened at first open
POSRV close pres.	~146.2 atm	
MSSV open pres.	~80 atm	
SI mass flow	~18 kg/s to ~65 kg/s (~103 atm to 1 atm)	Continuous operation until IRWST exhaustion
AFWI mass flow	~40 kg/s	25 ~ 40% WR automatic operation until AFWST exhaustion

3 Results

From 64 cases which are arranged by status of safety valves; POSRV, MSSV on damaged SG (MSSV-A), and MSSV on intact SG (MSSV-B) with 3 safety-grade automatic mitigation systems; SI to DVI line, AFWI to damaged SG (AFWI-A), AFWI to intact SG (AFWI-B) in SGTR accident, 33 accident sequences are classified. Among these sequences, CD was analyzed to occur in 21 sequences. Fig 1 shows the ET of 33 accident sequences.

Whether any safety valves can be operated or not, accident sequences that all mitigation systems are shut down were analyzed as CD within about 4 hours. Except 2 scenarios which only SI to DVI line is possible under the condition that MSSV-A is operated and MSSV-B is stuck opened, all other scenarios are not depending on the status of POSRVs because POSRVs have no chance to open by high pressure of primary side until the end in these scenarios. In these 2 scenarios, SI stops after damaged SG dried out because primary side pressure increased continuously. If POSRVs are automatically operated, SI stops until CD because primary side pressure maintained higher than

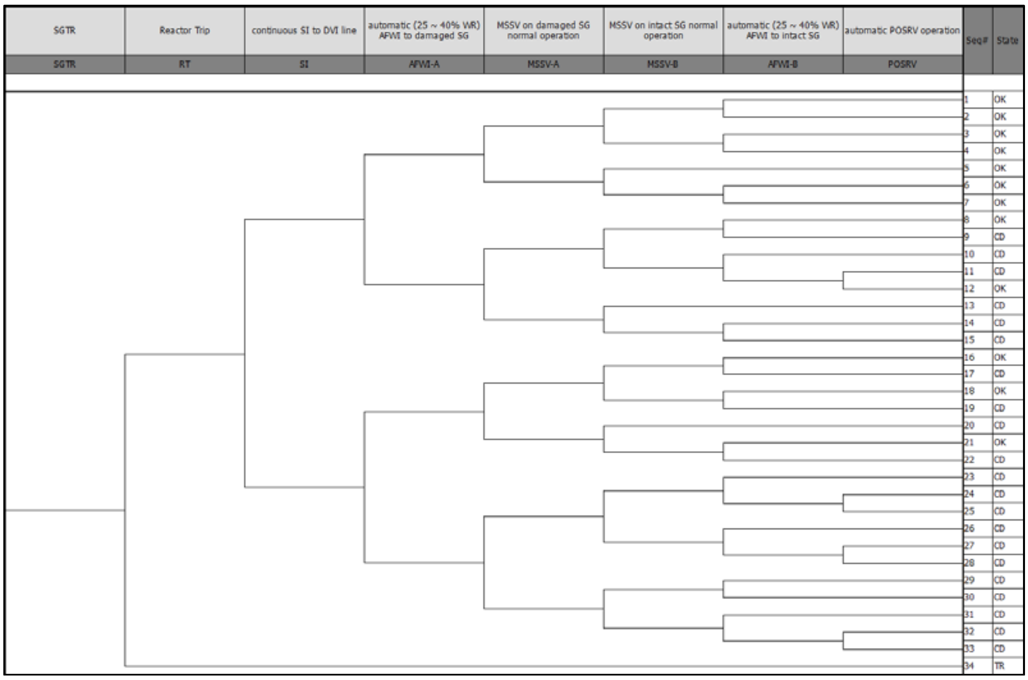

Fig.1 ET of SGTR considering the status of safety valves

maximum SI pump pressure. But if POSRVs are stuck opened, SI can be operated during 72 hours to prevent core damage by F&B operation without operator action, and this is the only scenario that prevent CD during 72 hours with only one mitigation system because IRWST is not exhausted. Also, AFWI-A and MSSV-A is operated without other mitigation systems, CD was analyzed to occur because core level decreased by pressure difference when MSSV-A is opened whether MSSV-B is stuck opened or not. In 10 scenarios except 11 scenarios including these scenarios and 2 scenarios that MSSV-A is stuck opened without SI and AFWI-A, CD was analyzed to occur because of IRWST or AFWST exhaustion before 72 hours.

In scenarios that all MSSVs on both SG are operated, CD was analyzed to be prevented with more than 2 mitigation systems. If only MSSV-A is stuck opened, it is analyzed that SI should be operated with at least 1 AFWI to prevent CD. But if MSSV-B is stuck opened, it is analyzed that AFWI-A should be operated with at least 1 other mitigation system whether MSSV-A is stuck opened or not.

4 Conclusion

In this research, analysis on accident sequences of SGTR accident considering the status of safety valves was done. Total 33 scenarios depending on the status of 3 safety valves with 3 safety-grade automatic mitigation systems are analyzed, and 12 scenarios are analyzed to prevent CD without operator action. 10 scenarios are analyzed that CD can be prevented only with enough supplement of IRWST or AFWST. It is expected that the method to minimize operator action in SGTR accident can be developed based on this research,.

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