A Study on the Frequency of Initiating Event of SGTR during Outage Periods

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1. Introduction

Low power shutdown probabilistic safety assessment (LPSD PSA) represents an extension of probabilistic safety assessment performed for other plant operating states, excluding power operation, which is covered in probabilistic safety assessment. The general objective when developing shutdown probabilistic safety assessment is to extend the probabilistic safety assessment performed for the plant full power operation. The extension is not straightforward, knowing that several specific matters are very much different in power operation state compared to the shutdown states.

In this study, we have improved the methodology of the initiating event identification for steam generator tube rupture (SGTR) to complement the deficiency obtained from review of accident management plan(AMP).

2. Methods and Results

2.1 Plant Operating States(POSs) of LPSD PSA

POSs will cover the LPSD evolution from full power operation to refueling conditions. During shutdown states initial conditions, such as decay power and primary pressure, differs significantly from conditions during power operation. The first step in evaluating each core damage sequence is the determination of POS. In the POS analysis, a thorough and systematic search was performed to define the spectrum of potential POS for NPP. The POSs are expected operating conditions. These states are based on established outage practices common to all PWRs. The task is to determine how to best characterize them for inclusion into the LPSD PSA.

The full power PSA is based on assumption that the plant power is 100%. But the POSs are various because the operational mode is changed as the process of planned outage. The LPSD operation encompasses low power operation, hot & cold shutdown process to cool RCS after reactor trip, disassembly work of reactor internals for refueling preparation, refueling, maintenance and test for equipment and components, assembly work of reactor internals. Plant equipment arrangements should be changed in order to do each process during LPSD. The success criteria of mitigating systems for abnormal accident like loss of Shutdown Cooling System (SCS) are dependent on the changing of plant arrangement. For example, for loss of SCS during LPSD operation, time to boiling and core damage are dependent on the level of decay heat and the area of RCS open part. Thus, in order to evaluate LPSD PSA, it needs to classify various plant configuration and operational conditions into several POSs. Table I summarizes the POSs for the APR1400 types of outages and their average durations(hr).

Table I. Plant Operational States for the APR 1400

POS	Description	Duration
POS 1	Reactor trip and subcritical operation	2.2
POS 2	Cooldown with steam generators	22.6
POS 3	Cooldown with shutdown cooling system	38.3
POS 4A	RCS draindown (pressurizer manway closed)	4.0
POS 4B	RCS draindown (manway open)	14.6
POS 5	Mid-loop operation	16.2
POS 6	Fill for refueling	43.6
POS 7	Fuel off load	92.2
POS 8	Defueled	190
POS 9	Fuel on load	84.4
POS 10	RCS draindown to reduced Inventory after refueling	56.7
POS 11	Mid-loop operations after refueling	19.3
POS 12A	Refill RCS (pressurizer manway open)	6.5
POS 12B	Refill RCS (manway closed)	37.7
POS 13	RCS heatup with shutdown cooling System	23.4
POS 14	Startup with steam generators	45.1
POS 15	Reactor startup	42.5

2.2 Steam Generator Tube Rupture (SGTR)

The SGTR accident is a unique small LOCA accident that has the potential to release primary coolant outside the containment. The pressure boundary of the primary system is breached by rupturing one or more tubes in one of the steam generators. The random or consequential rupture of the steam generator tubes initiates a small LOCA accident, where primary system volume leaks into the secondary system overpressurizing it. Overpressurization of the secondary side may cause the relief valves to open and potentially cause additional ruptures. An unmitigated leak of the primary system through a secondary side opening may result in a core damage scenario where the containment is bypassed and a direct pathway may exist to the outside environment.

In POS 2-4 and 12-14, the reactor is already scrammed and the Safety Injection (SI) signal is blocked and requires manual initiation. The normal feedwater flow is automatically terminated on SI signal, and auxiliary feedwater is delivered to all steam generators. Further action by the operator is required to adjust the auxiliary feedwater flow to maintain the water level in the unfaulted steam generators and terminate flow to the faulted generators. The operator is expected to follow the general procedures valid for operating states, and will attempt to identify and isolate the faulted steam generator. The isolation of the ruptured steam generator involves closing the MSIV, AFW inlet valve, isolating the blowdown line and the turbine driven AFW pump steam inlet valve. Complete isolation will not occur until the RCS pressure is reduced to equal or less than the faulted SG pressure.

The SGTR accident scenario is applicable to operating states with pressure in the primary system higher than the secondary system, POS 1 through 4 and 12 through 15. In general, in all the POSs, the operator must isolate the faulted steam generator, must introduce safety injection flow to maintain the primary system's volume, and must cooldown and depressurize the RCS to terminate the breakflow.

2.3 SGTR Initiating Frequency

After reviewing the existing LPSD PSA, the SGTR was excluded from the initial event selection because the steam generator was isolated from POS 3 and 13. However, before the reactor coolant temperature reaches 99℃, the SG prepares to steam. When steaming begins, the main steam isolation valve will be opened as the SG and main steam system will be prepared. Therefore, the SGTR accident scenario applies to operating conditions where the pressure of the primary system is higher than the secondary system, POS 1 through 4, and 12 through 15. The initiating frequency of SGTR accidents for full power operations were established in APR1400 AMP at

$$\text{SGTR} = 4.89\text{E-03/yr} \qquad (1)$$

which is based on one events over 291 reactor years of operation. This value is assumed to be valid for POS 1, 2, 14 and 15, due to the potential high differential pressures between the primary and secondary side. The other states, where the potential for tube rupture exists - POS 3, 4, 12, and 13, have operating pressures and temperatures of 28 kg/cm^2 and 65.5 ~ 99℃. In these states, the initiating frequency is adjusted to reflect the lower differential pressure by lowering the full power value by a factor of ten.

The final initiating frequencies are:

$$\text{SGTR(POS 1,2,14,15)} = 4.89\text{E-03/yr} \qquad (2)$$
$$\text{SGTR(POS 3,4,12,13)} = 4.89\text{E-04/yr} \qquad (3)$$

The initiating frequencies are given for a full year, which are adjusted by a relative time factor to take into account the relative length of each particular operating POS.

$$\text{SGTR-POS} = \text{SGTR(POS)/yr} * \text{Relative Time(POS)} \qquad (4)$$

Table II lists the final initiating frequencies in each POS with the respective relative time fractions.

Table II: SGTR Initiating Frequency(/yr)

	Initiating Frequency (full year)	Relative Time Fraction	Initiating Frequency (shutdown)
POS 1	4.89E-03	2.00E-04	9.78E-07
POS 2	4.89E-03	2.05E-03	1.00E-05
POS 3	4.89E-04	3.48E-03	1.70E-06
POS 4	4.89E-04	1.69E-03	8.27E-07
POS 12	4.89E-04	4.02E-03	1.96E-06
POS 13	4.89E-04	3.43E-03	1.04E-06
POS 14	4.89E-03	4.10E-03	2.00E-05
POS 15	4.89E-03	3.86E-03	1.89E-05

3. Conclusions

In this study, the initiating event which is considered during the LPSD SGTR accident are evaluated and the SGTR initiating frequencies of in each POS is also calculated. The study will provide input data needed to develop the LPSD PSA. It will also be useful for the review for the methodology of the initiating event identification of SGTR in the accident management plan.

REFERENCES

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