Assessment on Event Classification of One Steam Generator Tube Rupture in EU-APR

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1. Introduction

A Steam Generator Tube Rupture (SGTR) is a penetration of the barrier between the Reactor Coolant System (RCS) and the secondary system and results from the failure of a steam generator U-tube. The SGTR events can occur as the initial fault or as a consequence of another initiating event. A direct flow of primary coolant from the RCS to the steam generator secondary system during the SGTR event leads to contamination of the secondary system and a release of radiological materials to the environment. Separately, in Severe Accident analysis the loss of primary inventory due to SGTRs is considered as a possible scenario which may cause core damage.

For these reasons, SGTR has been deterministically included in postulated accidents and analyzed to ensure the plant safety with Defense-in-Depth (DiD) concept. The purpose of this report is to review regulatory practices and available information on SGTRs and derive reasonable event classification of one SGTR (1-SGTR) in conjunction with Loss of Offsite Power (LOOP) in EU-APR.

2. Event Category and SGTR

2.1 EU-APR Event Categories

Since 2009, the EU-APR has been developed as a modified design of the APR1400 to comply with the European nuclear requirements. EU-APR plant states are divided into operational states, which include normal operation and Anticipated Operational Occurrences (AOOs), and accident conditions, which include Postulated Accidents, Design Extension Conditions (DEC) and Severe Accidents (SA).

Normal operation within specified operation limits and conditions is addressed as DBC 1. An AOO is expected to occur one or more times during the life cycle of the plant and it is assigned to DBC 2. The lower bound of the DBC 2 frequency is established with a conservative value of 1×10^{-2} per year (/yr) considering more than 60-year design life of current Advance Light Water Reactors with the license renewal for additional period.

The postulated accidents are categorized into DBC 3 and 4 primarily on the basis of their expected frequency and their level of challenge to the physical barriers against the escape of radioactivity. While the lower frequency limit of 1×10^{-4} /yr is generally used for DBC 3, EU-APR sets the frequency of 1×10^{-3} /yr to identify complex sequences which may occur due to Common Cause Failure (CCF) with DBC 2 or 3 events. And, DBC 4 events includes limiting faults to verify the adequacy of DiD despite the low frequency of the postulated initiating events. DEC events comprise unlikely multiple failures as well as the DBC 2 or 3 events combined with CCF. The upper frequency limit of 1×10^{-4} /yr is used for DEC events to identify the need for implementation of diverse measures for those complex sequences. Besides, rare external events are regarded as DEC. SA is a certain unlikely event beyond the postulated accident condition involving significant core degradation.

2.2 SGTR and Regulatory Practices

The spectra of potential accidental radioactive releases from the plant are DBC 2-4, DEC and SA. As the purpose of this report is concerned, however, it is not necessary to discuss DEC and SA in detail. The postulated initiating events which lead to DBC 2-4 have been identified and classified using engineering judgment and a combination of deterministic assessment and probabilistic assessment as a supplementary instrument.

The initiating events were primarily selected from current practice of the reference plant which used top-down type event categorization imposed by RG 1.70 [1] and RG 1.206 [2]. To implement European practices, design basis initiating events and their frequency were reviewed referring to EUR Rev. D [3] Section 2.1.8.3, IAEA INES [4] Annex II and YVL B.3 [5]. The combination of the initiating event with the range of reactor operating modes specified in Technical Specification is taken into account in shutdown evaluation of the reference plant. The frequency of plant state is generally based on NUREG/CR-5750 [6], NUREG/CR-6928 [7] and its updates [8].

Regarding SGTR, the number of tube(s) ruptured is important for the event classification since the consequences of the event and their frequency strongly dependent on the number of tube(s) ruptured. Typical regulatory practices show that one SGTR (1-SGTR) is deemed a “possible” event, and two SGTR, multiple SGTR and events or accidents in combination with consequential SGTR are regarded as "unlikely” or “remote”. The characteristics in terms of frequency based on IAEA SSG-2 [9] are as follows:

- “Expected”: 10^{-2}/yr < f < 1 (expected over the lifetime of the plant)
- “Possible”: 10^{-4}/yr < f < 10^{-2}/yr (chance greater than 1% over the lifetime of the plant)

- "Unlikely": 10^{-6}/yr < f < 10^{-4}/yr (chance less than 1% over the lifetime of the plant)
- "Remote": f < 10^{-6}/yr (very unlikely to occur)

3. Consideration on 1-SGTR

3.1 Preliminary Event Classification for 1-SGTR

As mentioned in the section above, in typical examples 1-SGTR is assigned to the occurrence with frequency 10^{-4}/yr < f < 10^{-2}/yr which corresponds to DBC 3.

According to U.S. and Korean regulatory practices, LOOP is a basic assumption and all events are considered in connection with Loss of Offsite Power (LOOP) where this is unfavorable for the reference plant design. As a result, 1-SGTR with LOOP has been classified as DBC 3 in EU-APR by deterministic approach.

On the other hand, LOOP itself is generally addressed as DBC 2 event. In Europe LOOP is treated as an additional fault so that an initiating event with a LOOP (either caused by, or not caused by a turbine trip) can be relaxed to acceptance criteria for a higher level event category of low frequency. From the conservative interpretation of this approach, it was necessary to assume 1-SGTR without LOOP as a lower level event category than which 1-SGTR with LOOP case belongs to. In this context, 1-SGTR without LOOP was classified into DBC 2 at the beginning of the EU-APR design.

3.2 Past Experiences and Frequency Evaluation on 1-SGTR

SGTRs are usually divided into spontaneous rupture, which is an initiating event, and induced rupture, which is a consequence of other initiating events, by their characteristics.

Since the Point Beach accident in 1975, at least 14 SGTR accidents have been reported worldwide including Korea and they are all involved in 1-SGTR. Those 1-SGTR events were a kind of spontaneous ruptures caused by tube degradation mechanisms such as Primary Water Stress Corrosion Cracking (PWSCC), Outer Diameter Stress Corrosion Cracking (ODSCC), high-cycle fatigue, fretting, wastage, wear, etc. [10 and 11]. For information, the operating experiences of Korea show the frequency of 1-SGTR without LOOP is 5.18×10^{-3}/yr. The frequency of 1-SGTR from NUREG/CR-6928 series [7 and 8], which evaluated the initiating events at U.S. nuclear power plants for risk analyses, is presented in Table I.

In addition, analytic methods exist to quantify the frequency of occurrence of induced SGTRs. In NUREG/CR-6365 [10], historical steam generator tube leakage and rupture data were reviewed and the accidents that might challenge the integrity of the steam generator tubes were selected to estimate the expected frequency of the induced SGTRs. Among these accidents as the initiator of SGTR, LOOP is included and the evaluated frequency of 1-SGTR induced by LOOP is 1.7×10^{-6}/yr, which is "unlikely". Consequently, the frequency of occurrence 2.2×10^{-3}/yr was evaluated regarding induced 1-SGTR.

Table I: Design Data for Safety Analysis

	NUREG/CR-6928	Update of NUREG/CR-6928
Frequency	3.54×10^{-3}/yr	2.07×10^{-3}/yr

3.3 Re-classification of 1-SGTR and Effect

By the engineering judgment and these surveys, it was concluded that the frequency of 1-SGTR as the initiating event and/or the consequence of other initiating events is below the range of DBC 2. Therefore, it is reasonable to re-classify 1-SGTR without LOOP as DBC 3 instead of DBC 2.

Acceptance criteria have been established by safety authorities to be commensurate with the frequency of the event and the effectiveness of physical barriers. In the EU-APR design process, safety analysis and radiological consequence analysis have been performed on 1-SGTR with LOOP, which is more unfavorable than 1-SGTR without LOOP, and the results show that all acceptance criteria target for DBC 3 in EUR are satisfied.

By removing 1-SGTR without LOOP from DBC 2, this event could be excluded in the limiting event for Anticipated Transient without Scram (ATWS). This is acceptable since the occurrence of 1-SGTR is typically considered "possible" but not "expected" regardless of LOOP.

The number of tube(s) ruptured is deterministically selected as Table II.

Table II: Postulated SGTRs in EU-APR

Event Category	Postulated Event
DBC 2 (10^{-2}/yr < f < 1/yr)	(None)
DBC 3 (10^{-3}/yr < f < 10^{-2}/yr)	1-SGTR with or without LOOP
DBC 4 (f < 10^{-3}/yr)	2-SGTR
DEC A (10^{-7}/yr < f < 10^{-4}/yr)	(None)
DEC B (10^{-7}/yr < f < 10^{-4}/yr)	MSLB in combination with consequential 2-SGTR

4. Conclusions

Regulatory practices and summary of available information were reviewed focusing on 1-SGTR. As has been noted, 1-SGTR without LOOP was temporarily assumed as DBC 2 rather than DBC 3 which 1-SGTR with LOOP belongs to, only because of

concern for the frequency of occurrence. Based on past experiences and evaluation, however, the frequency of 1-SGTR without LOOP is below the range of DBC 2. In conclusion, it is reasonable to re-classify 1-SGTR without LOOP event into DBC 3 and this approach is also in consistent with the typical regulatory practices. Quantitative analyses for 1-SGTR are assessed to confirm that the acceptance criteria are met with the re-classification of 1-SGTR as DBC 3.

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