The Analysis methodology of the APR1000 SFP PSA based on the EUR Chapter 2.17

Jae Gab Kim[a*], Ji Seung Yoon[a], Jeong Guk Song[a], Jin Kyoo Yoon[a], Ji Yong Oh[b]
[a] *KEPCO E&C, Gimcheon-si, Gyeongsangbuk-do, Korea*
[b] *KHNP CRI, Ltd. Yuseong-Gu, Daejeon, Korea*
[*] *Corresponding author: kjg@kepco-enc.com*

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1. Introduction

The purpose of this study is to discuss the methodology of a Probabilistic Safety Assessment (PSA) of the APR1000 Spent Fuel Pool (SFP) internal events.

The risk of SFP is associated with Loss of Cooling and Inventory which cause the damage of SFP by fuel assemblies overheating. These events have potential for leading to Fuel Damage and Inventory Boiling.

This assessment is developed in such a way the requirements set forth in the EUR and ASME/ANS PRA Standard. According to the EUR Chapter 2.17.3.3.1, “The event tree end states shall, besides the Core Damage (Fuel Damage) end state, also include end states with limited release of radioactivity.”

Therefore, this paper also discusses the end states with limited release of radioactivity by performing the analysis with separated end states such as the Fuel Damage Frequency (FDF) and the Boiling Frequency (BOF) in the APR1000 SFP PSA.

The scope of this analysis is the internal events during all operating modes including APR1000 SFP Risk. The APR1000 SFP PSA is performed by the following Methodology.

2. Analysis Methodology of APR1000 SFP PSA

This section provides an overall SFP PSA methodology that complies with EUR 2.17 in support of the design phase PSA. The APR1000 SFP PSA is performed following tasks by Methodology of Spent Fuel Risk report.

- Task 1: Operating Cycle Phase (OCP) Development
- Task 2: Initiating Event Analysis (IE)
- Task 3: Accident Sequence Analysis (AS)
- Task 4: Success Criteria Analysis (SC)
- Task 5: System Analysis (SY)
- Task 6: Human Reliability Analysis (HR)
- Task 7: Data Analysis (DA)
- Task 8: FDF and BOF Quantification (QU)

- Task 1: OCPs used in SFP PSA represent the various operating states of the SFP. The operating cycle is discretized into six OCPs which are developed on the basis of each Plant Operating States (POSs) used in Low Power and Shutdown (LPSD) PSA.
- Task 2: The SFP internal initiating events can be identified from methods such as master logic diagram, failure modes and effect analysis, generic initiating events, and/or operational experience.
- Task 3: The possible accident scenarios following events are identified by the event tree approach which is consistent with NUREG-1738 methodology. The possible end states are OK (safe stable state with cooling), FD (Fuel Damage), and BO (Inventory Boiling)
- Task 4: Success criteria defines the plant-specific measures of success and failure. This task presents definition of Fuel Damage, functional level success criteria, and success criteria for operations. The Fuel Damage is defined as reaching top of the fuel of the SFP water level after occurring initiating events which is compromised with the definition of EPRI report on SFP 3002002691 and NUREG-1738.
- Task 5: The SFP system stores the used fuel safely. It maintains pool temperature properly using two types of the function such as SFP Cooling and Makeup.
- Task 6: The methodology for identifying and developing a Human Failure Event (HFE) for SFP OCPs is same as that used for At-power Level 1 internal event HRA for reactor side such as Human Cognitive Reliability / Operator Reliability Experiment (HCR/ORE) and Cause-Based Decision Tree Methodology (CBDTM).
- Task 7: Data analysis is carried out for initiating event frequencies, component failure probabilities, common cause failure probabilities, and so on. They are followed by data analysis from the AT-power Level 1 internal events PSA. The specific events considered in SFP PSA are Failure of repair model using Mean Time to Repair (MTTR) in NUREG-1738 and Siphon Device Failure Data.
- Task 8: The event tree and fault tree models that are developed for the SFP internal events Level 1 PSA are quantified using SAREX computer code to identify potential accident scenarios for FDF and BOF.

3. Engineered Safety Features (ESFs) of APR1000 SFP

The SFP of APR1000 is designed to store spent fuel assemblies within the pool in accordance with various design criteria.

Fig. 1. shows the simple arrangement of APR1000 SFP and Refueling Pool. The SFP is housed in the Auxiliary Building, which contains essential SFP equipment, such as follows;

- Normal SFP Cooling and Cleanup System (FC)
- Fuel Tube Transfer System connection between containment and the SFP
- Diverse SFP Cooling System
- SFP Inventory Makeup System such as Chemical and Volume Control (CV), Makeup Demineralizer (WM) and Component Cooling (CC) system

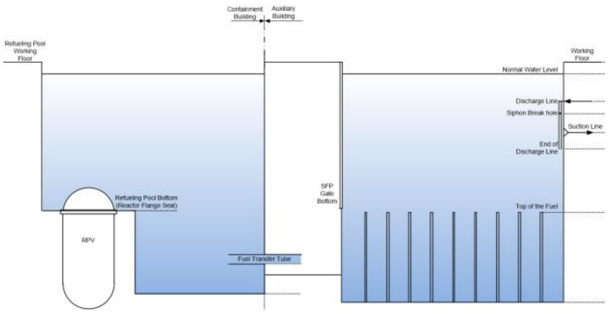

Fig. 1. Simple Arrangement of APR1000 SFP and Pool

3.1 Normal SFP Cooling and Cleanup System

The FC system consists of two safety-related, redundant pump trains and maintains SFP temperature within the limits. The system is designed such that a single train is normally in operation with the redundant in standby.

3.2 Diverse SFP Cooling System

One of the significant feature of APR1000 is Diverse System and the diverse SFP cooling loop consists of a 100% capacity cooling train. It is an independent cooling loop that composed to one diverse pump and one diverse heat exchanger. It is operating manually when all of SFP cooling pumps fail.

3.3 SFP Inventory Makeup System

The SFP makeup portion of the FC system constitutes an installed injection that can be used to provide SFP makeup in the event of a loss of SFP inventory. When SFP level falls to a predetermined set point, a signal is generated to initiate one of the SFP makeup pumps manually by operator. It consists of an external makeup system and three on-site makeup systems such as CV, WM and CC system.

4. Analysis in APR1000 SFP PSA

The PSA is conducted to assess not only FDF but also BOF of the APR1000 SFP when initiating is occurred as below;

- Loss of SFP Cooling in Normal Configuration (LOCN)
- Loss of SFP Cooling in Hydraulically Connected Configuration (LOCH)
- Loss of SFP Coolant Inventory in Normal Configuration (LOIN)
- Loss of SFP Coolant Inventory in Hydraulically Connected Configuration (LOIH)
- Loss of Offsite Power (LOOP)

The end state of the boiling condition of SFP inventory is defined as the Fuel Damage is prevented by maintaining the SFP inventory without recovery of SFP cooling. SFP integrity can be maintained by inventory makeup using onsite or external SFP makeup source.

Therefore, in the event trees of each events, each event tree sequence is assigned to an end state as BO, FD and OK. For example, the event tree of Loss of SFP Cooling in Normal Configuration is showed in Fig. 2.

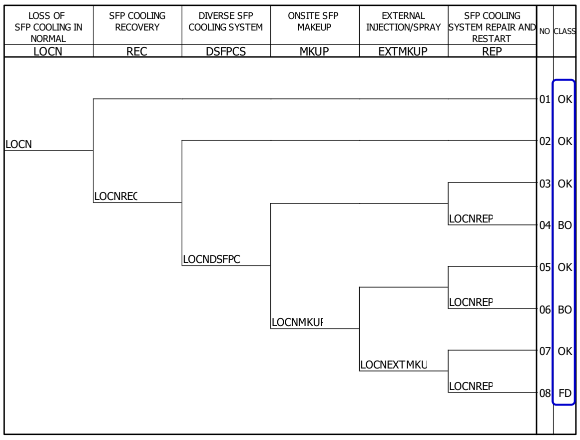

Fig. 2. The event Tree of Loss of SFP Cooling in Normal

5. Conclusion

This paper provides the analysis results of the FDF and BOF of the APR1000 SFP PSA according to the EUR 2.17.3.3.1 associated with initiating events such as LOC, LOI, and LOOP.

According to the results, the FDF of SFP PSA is very low as less than 1E-8/rcy, whereas the BOF of SFP PSA is a little higher than the FDF. The dominant initiating events for the total BOF are LOCH and LOOP, whereas the dominant initiating events for the total FDF are LOCH, LOCN, LOIH. The most significant initiating event for the FDF and BOF is LOCH. The closing gate valve is important in terms of containment integrity when loss of SFP cooling initiating event occurs because of hydraulically connected state between Reactor and SFP.

Therefore, it is expected that the probabilistic goals delineated in EUR 2.17.3.5 are achieved due to advanced ESFs of APR1000 as well as it is possible to provide insights and the effectiveness of safety features to address safety requirements in the APR1000 SFP.

REFERENCES

[1] European Utility Requirements for LWR Nuclear Power Plants, Chapter 2.17, Rev. E, December 2016.
[2] ASME/ANS Ra-Sa-2009, "Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications", The American Society of Mechanical Engineers, February 2009.
[3] IAEA, TECDOC-1791, "Considerations on the Application of the IAEA Safety Requirements for the Design of Nuclear Power Plants", May, 2016.
[4] "Plant Design Description of APR1000", KHNP, February 2021.
[5] NUREG/CR-6928, "Industry-Average Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants", 2015 Update
[6] "SAREX 1.3 User Guideline", KEPCO E&C. 2013
[7] EPRI, "PWR Spent Fuel Pool Risk Assessment Integration Framework and Pilot Plant Application," Report 3002002691, Final Report, June 2014.
[8] U.S. NRC, "Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants," NUREG-1738, February 2001.