The Preliminary Phase Results of Seismic Margin Analysis in the APR1000

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1. Introduction

The Probabilistic Safety Assessment (PSA) based Seismic Margin Analysis (PSA based SMA) for the standard design of the APR1000 is performed as required in the EUR Rev.E Chapter 2.4 Section 6.7.1.

The purpose of the SMA is to demonstrate that the plant design has adequate safety margin to withstand seismic events as stated in Chapter 2.4 of EUR.

APR1000 has various advanced safety features which are very effective in the safety point of view. This paper discusses the design effectiveness by performing the PSA based SMA in the design phase PSA of APR1000. The scope of SMA analysis is Level 1 and 2 PSA for the At-power and Low Power Shutdown (LPSD) design stage.

2. PSA based SMA Methodology of APR1000

This section provides an overall PSA based SMA methodology that complies with EUR 2.4 in support of the design phase PSA.

The PSA is used to ensure that the Unit satisfies the requirements under all operational modes. PSA based SMA Requirements in delineated in EUR 2.4.6.7 are as follows:

- The objective of the SMA shall be to establish, with a high degree of confidence that sufficient margin exists with regards to cliff edge effects:
  - To avoid Core damage and to prevent Early or large Releases
- A seismic design, the free-field design response spectra for DBE are defined as 0.25g of Peak Ground Acceleration (PGA)
- The design of the Standard plant will be carried out using conservative design procedures. (Seismic levels up to 1.5 * Design Basis Earthquake (DBE))

The methodology for the PSA-based SMA is described in the recommendation of SECY-93-087 and ISG-020, which meets the requirement of EUR.

The analysis process of the PSA-based SMA is as below:

- Selection of the Review Level Earthquake (RLE)
- Development of Seismic Equipment List (SEL)
- Identification of seismic initiating event category
- Development of system models
- Fragility Analysis
- Evaluation of the plant level seismic capacity
- Demonstration of seismic margin in the design

3. Engineered Safety Features of APR1000

The active safety systems in the APR1000 are designed to be four (4) trains to ensure additional redundancy considering Single Failure Criterion (SFC) and unavailability due to on-line maintenance, which means an N+2 concept. These systems can reach and maintain a controlled state and a safe shutdown state after a Design Basis Accident (DBA). Each train and its components of Safety Injection System (SIS), Shutdown Cooling System/Containment Spray System (SCS/CSS) and associated supporting systems are physically separated into four (4) quadrants to secure vital safety functions from malicious and natural hazards.

APR1000 has various advanced Engineered Safety Features (ESFs) to provide protection in the highly unlikely events of an accidental release of radioactive fission products for DBA and Design Extension Conditions (DEC-A). The main systems of ESFs are Safety Depressurization and Vent System (SDVS), In-containment Refueling Water Storage System (IWSS), Passive Auxiliary Feedwater System (PAFS) with Alternative Auxiliary Pump (AAP), Diverse Safety Features (DSF), and so on.

The Diverse Containment Spray System (DCSS), which is designed for the containment heat removal for DEC-B conditions, also provides a means of long-term cooling to maintain the plant in a safe state in the event of DEC-A when the SCS or its supporting systems such as Component Cooling Water System (CCWS) and Essential Service Water System (ESWS) are not available.

The Mid-loop Level Control System (MLCS) is adopted to reduce the risk of mid-loop operation during shutdown modes by automatic Reactor Coolant System (RCS) inventory control during mid-loop operation in the LPSD.

4. PSA based Seismic Margin Analysis in APR1000

The PSA based SMA of At-power and LPSD has been performed for APR1000 standard design to identify potential vulnerabilities and demonstrate seismic margins beyond the design for the plant to maintain safe and stable conditions during and after the earthquake.

4.1 The major assumptions for SMA Model

- The PGA for DBE for the APR1000 standard plant are conservatively set to 0.3g from 0.25g of EUR 2.4.6.7
- The target for PSA based SMA is High Confidence of Low Probability of Failure (HCLPF) 0.45g, 1.5 times Design Basis External Hazards (DBEH) according to EUR 2.4.6.7
- The loss of offsite power from the earthquake occurs due to the failure of the switchyard or transformer stations outside the plant, because the HCLPF capacity of ceramic insulators is assigned to be 0.09g
- No credit is taken for non-safety-related systems
- If components are same, located on same building location and elevation, they are treated as the fully correlated
- No credit is given to recovery of the mitigation systems and seismic induced failures
- Human Failure Events (HEPs) for all operator actions are set to 0.1 to early identify human failure events in the cutsets. This is a conservative assumption considering internal event and performance shape factors from EPRI 2002000709 in service condition

4.2 Seismic Event Tree

Seismic event trees are developed to represent the accident progression and significant equipment failures that can be expected following a seismic event. A series of eleven event tree is developed to model all significant accident sequences. Modeling of all accident sequences begins with the Primary seismic event tree where the initiating event represents any seismic event that causes a loss of offsite power (LOOP), shown in Fig. 1.

Top events shown on the event tree are arranged, from left to right, by decreasing severity. Seismic events lead to direct core damage are S-DMG, S-LLOCA, S-MSLB, S-ATWS, S-LOIC, S-LODC and S-LOKV. The other event trees are entered by a transfer from sequences on the primary seismic event tree.

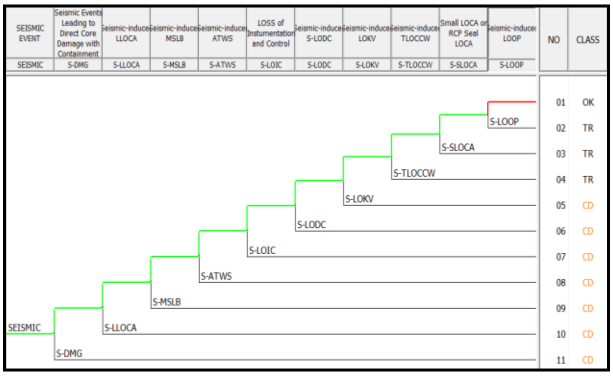

Fig. 1. Primary Event Tree

4.3 Plant level HCLPF

The objective is to demonstrate that there is sufficient seismic margin in the design. If the plant HCLPF earthquake is less than the RLE, modification of the design or the model is required.

The dominant cutsets for core damage or containment failure are derived through the system analysis in the PSA based SMA of the APR1000. The plant level HCLPF by seismic induced initiators not directly leading to core damage is calculated. The plant level HCLPF is 1.5 multiplied DBEH for withstanding Rare and Severe External Hazards (RSEH) to demonstrate that there is sufficient margin to avoid core damage and to prevent early or large releases. Therefore, it satisfies the requirements presented in Chapter 2.4 Section 6.7.3 of EUR.

5. Conclusion

The PSA based SMA in APR1000 as the external events of Chapter 2.17 is qualitatively analyzed because site-specific information is not available as standard stage. As results of quantification of PSA based SMA, the plant HCLPF for APR1000 is 0.45g. Therefore, it satisfies the requirements presented in Chapter 2.4 Section of EUR. The plant HCLPF is sufficiently higher than RLE. Therefore, any design change is not required.

The currently presented HCLPF is preliminary phase results based on assumption. When site specific is available in the detail design stage, the detail analysis will be performed quantitatively considering plant specific design information.

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