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Status of SMART PPE PSA

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1. Introduction

The SMART (System-integrated Modular Advanced ReacTor) Pre-project Engineering joint project has been performed with Korea and Kingdom of Saudi Arabia for three years. As a part of this project, the Probabilistic Safety Assessment(PSA) was performed. The scope of PSA project were Level-1 and Level-2 PSA for internal events, internal fire events & internal flooding events at full power operation mode. The seismic margin analysis was performed also for full power operation mode. In this paper, the results of SMART PSA are summarized.

2. Internal PSA

The SMART internal PSA was performed for full power operation mode based on two generic primary guidance. The total of 21 initiating events(IEs) for the SMART PSA were identified through the HBFT(Heat Balance Fault Tree) method by reviewing the specific design features of the SMART and by comparing it with the generic industry experience list of initiating events of NUREG/CR-5750 and the list of events analyzed in Chapter 6 and 15 of the SMART PSAR. The annual frequency of each IEs were calculated using the most recent generic estimates of initiating event frequencies for commercial NPPs such as NUREG/CR-6928 and NUREG-1829.

The event trees for each initiating event has developed to present the accident sequences that lead to core damage. Event trees for 19 among a total of 21 initiating events of the SMART PSA were developed, but not for the other two initiating events Excessive LOCA and Interfacing System LOCA because they are assumed to direct lead to core damage.

Data analysis was performed to collect and evaluate the reliability data required for the quantification of the core damage accident sequences such as initiating event frequencies, component hardware failure rates, common cause failure rates, human error probabilities, and component unavailability due to test and maintenance are assessed in this task. Since the SMART plant does not yet have any operational experience. Therefore, the failure data used in this analysis is solely based on generic sources.

FT models for a total of 15 systems including passive safety systems which are adopted to SMART such as passive safety injection system, passive residual heat removal system and etc., are developed considering their functions, description, operation of each system, and interfaces and dependencies among the systems.

Accident sequence quantification is to evaluate the CDF and dominant contributors via minimal cutsets for the SMART using AIMS-PSA. As a result of level 1 internal event PSA for the SMART, total CDF is meets the SMART probabilistic safety target of 1.00E-06/yr. There are no particular vulnerabilities to core damage in the SMART plant design.

3. Internal Fire PSA

The internal fire PSA methodology for SMART Units 1&2 is based on NUREG/CR-6850 and NUREG/CR-6850, Supplement 1. SMART Units 1&2 are divided into several rooms according to the fire protection standard and are shown in the fire barrier design basis drawing. SMART Units 1&2 are in the process of designing, and the building where the Room Number DBD is issued is Reactor containment / Aux building, Compound building. Turbine Generator Building, CW Intake Structure, and Standby DG Building. The buildings in the Yard area is placed in the site plan drawing. The number of defined fire compartments is 600. The qualitative screening is performed to identify the fire scenarios whose potential fire risk contribution can be judged negligible without quantitative analysis. According to the results of the qualitative screening analysis, 72 single compartment and 42 multi-compartment were not screened. Fire ignition frequency of SMART Units 1&2 is evaluated by applying the fire ignition frequency evaluation method of NUREG/CR-6850 and the fire ignition frequencies based on NUREG-2169 which reflects the recent fire event database. The total CDF from fire events is estimated as the sum of the core damage frequencies of the individual fire scenarios resulting in core damage that is well below the SMART Units 1&2 probabilistic safety goal of 1.00E-06/yr. The first significant compartment is ‘480V AC & MCC Room. This compartment contains all of the one train electrical bus and related cabinets such as 4.16KV bus, 480V load center, 480V motor control center and feed breakers for class 1E battery chargers.

4. Internal Flooding PSA

The SMART Plant are divided into the following broad area: RCAB (Reactor Containment and Auxiliary Building), compound building, SW (Service Water) intake structure, turbine generator building, fire pump & water/wastewater treatment building, and standby DG (Diesel Generator) building for flooding PSA. Reactor containment, compound building and fire pump & water/wastewater treatment building were not considered in this internal flooding analysis. Since the compound building and fire pump & water/wastewater treatment building do not contain any components used for accident mitigation and there were no propagation paths to other buildings. According to the qualitative screening analysis, the buildings needed quantitative analysis were the auxiliary building, SW intake structure, turbine generator building and standby DG building.

Safety-related equipment in each flood area that could be damaged by flooding were identified and documented. It shows that total flooding accident scenarios of 55 including 26 propagation scenarios require the quantitative analysis to estimate the risk caused by the internal flooding.

The flood scenarios were quantified using, the AIMS-PSA with a truncation value of 1.0E-15, as was done with the internal events PSA. Incorporating flooding damage terms into the one top model built by fault tree and event tree developed in the internal event analysis, the Core Damage Frequency was estimated for each area.

The total CDF from flood events is estimated as the sum of the core damage frequencies of the individual flood scenarios resulting in core damage. Total CDF from internal flood events is below the SMART Units 1&2 probabilistic safety goal of 1.00E-06/yr. The first significant flood area is 'Air Handling Unit (AHU) Room', F-B05-W06. This area contains all of the air handling units for service water pump rooms, B05-W02 and B05-W03. If these components in this AHU room are submerged due to flooding event, all of the service water pumps can lose completely their cooling functions, and lead to core damage.

5. Seismic Margin Analysis

The PSA-based SMA for SMART unit 1&2 was performed to satisfy the following objectives in consistent with SECY-93-087. The SSEL(Safe Shutdown Equipment List) for the SMA provides a documented list of the plant structures, systems, and components (SSCs) that could be used for responding to an earthquake or mitigating potential core damage initiated by a seismic event. The SSEL also includes items that may lead to an initiating event. The first step for developing the SSEL was to determine the potential initiating events that could occur as a result of a seismic event. Identification of potential initiating events used the internal events PSA for guidance.

The seismic fragilities are calculated for SSCs in the SSEL. A fragility analysis is performed to obtain the seismic margin of SSCs that could have an effect on safe shutdown of the plant following a seismic event. In this analysis, the seismic margin values of SSCs modeled in the accident sequences are obtained. The seismic margin is expressed in terms of HCLPFs.

Seismically-induced initiating events are identified from the internal events PSA. However, there are differences between seismic and internal events to identify the initiating event, because seismic events may damage structures and passive components that are not explicitly modeled in the internal events PSA. A series of event trees was developed to model accident sequences. Modeling of all accident sequences begins with the hierarchy event tree. The seismic margin of the SMART Units 1&2 is evaluated by using PSA-based SMA. The SMA has demonstrated that the sequence level HCLPF values for all sequences leading to core damage are greater than 0.5g. Therefore, the seismic margin of the SMART plant HCLPF is equal to or greater than 1.67 times the SSE.

6. Level-2 PSA

A set of six PDS parameters and their associated attributes were defined as followings for SMART Level-2 PSA: Containment Bypass (BYPASS); Containment Isolation (CONISO); Containment Rupture Before Core Melt (RBCM); RCS Pressure during Core Damage (RCSP); Status of Cavity Flooding System (CFS); Status of Containment Spray (CSPRAY). Six events are selected as top events in the general SMART CET: Containment Bypass (BYPASS); Containment Isolation (CONISO); Containment Rupture Before Core Melt (RBCM); RCS Failure (RCSFAIL); In-Vessel Corium Retention (INVRET); Containment Rupture (CF). The four grouping parameters selected to define the source term categories of SMART are as follows: Containment Bypass (BYPASS); Containment Isolation (CONISO); Containment Rupture Before Core Melt (RBCM); Containment Failure (CF).

Based on Level 1 PSA results, the overall PDS frequency and the containment failure frequency for were estimated for internal event of SMART. The overall conditional probability of a containment failure for a given core damage is estimated to be 0.108

meaning that 10.8% of core damage sequences would result in containment failure. The containment failure modes consist of over-pressurization failure (4.7%), RBCM (5.2%), Isolation Failure (~0.0%), and Bypass Failure (0.8%). Large Early Release Frequency (LERF) of internal events. The conditional probability of a LER failure for a given core damage is 0.008 (0.8%).

Based on Level 1 PSA results for fire event of SMART, the overall PDS frequency is estimated as a sum of individual PDS frequencies. The overall conditional probability of a containment failure for a given core damage is estimated to be 0.062 meaning that 6.2% of core damage sequences would result in containment failure. The containment failure modes consist of over-pressurization failure (3.4%), RBCM (2.8%), Isolation Failure (~0.0%), and Bypass Failure (~0.0%). LERF of fire events. The conditional probability of a LER failure for a given core damage is about 0.0%.

Based on Level 1 PSA results for flood event of SMART, the overall PDS frequency is estimated as a sum of individual PDS frequencies. The overall conditional probability of a containment failure for a given core damage is estimated to be 0.007 meaning that 0.7% of core damage sequences would result in containment failure. The containment failure modes consist of over-pressurization failure (0.7%), RBCM (~0.0%), Isolation Failure (0.0%), and Bypass Failure (~0.0%). LERF of flood event is estimated to be 0.0%.

7. Conclusions

The PSA for internal events, internal fire events and internal flooding were performed to confirm the safety and to find the vulnerability for SMART plant. The quantification results show that no vulnerable point in SMART design but some detailed analysis is needed to reduce uncertainty and conservatisms.

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