Defense-In-Depth Evaluation Model Development Strategy for Pressurized Heavy Water Reactor Low Power and Shutdown Operations

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1. Introduction

The objective of defense-in-depth evaluation is to assess the level of defense-in-depth maintained during the various plant maintenance activities. Especially for shutdown and outage operations, the defense-in-depth might be challenged due to the reduction in redundancy and diversity resulting from the maintenance. Outage Risk Indicator of Nuclear Power Plants(ORION) which is a outage risk monitor for Korean NPPs is under development. ORION has the ability to assess the outage risk qualitatively using safety function assessment trees and deterministic margins such as time to boil. For pressurized heavy water reactors in Korea, defense-in-depth evaluation model development strategy to reflect the unique characteristics of pressurized heavy water reactors. The strategy and development steps were discussed in this paper.

2. Methods and Results

In this section, defense-in-depth evaluation model development strategy is described.

2.1 Defense-In-Depth Evaluation Model

The defense-in-depth philosophy is a fundamental concept of nuclear safety and three elements for defense-in-depth for nuclear power plant safety are redundancy, diversity and independence. The objective of defense-in-depth evaluation is to assess the level of defense-in-depth maintained during the various plant maintenance activities. Especially for shutdown and outage operations, the defense-in-depth might be challenged due to the reduction in redundancy and diversity resulting from the maintenance. To identify the configuration changes and assess risk resulting from the maintenance activities during shutdown and outage operations are the most important element to maintain the proper level of defense-in-depth and to develop risk management program during shutdown and outage operations.

The quantitative risk assessment, or probabilistic safety analysis can provide "Risk" related information on the quantitative risk level, major contributors to risk, and the sequences of specific risk contributors. Meanwhile, the qualitative defense-in-depth evaluation using deterministic trees such as Safety Function Assessment Trees(SFAT), can provide "Safety" related information on the levels of defense-in-depth according to the plant configuration including the levels of redundancy and diversity. Both quantitative and qualitative evaluation can provide the risk and safety significance information to maintenance rule program and based on this information, the functions can be scoped and monitored in maintenance rule implementation program.

It is general to assess at-power risk using PSA model and to assess shutdown and outage risk using defense-in-depth evaluation method. Nowadays, both approaches are being merged into the blended approach which utilizes the virtues of quantitative risk assessment and qualitative risk assessment because each risk assessment approach has unique value and each method can compensate each other by assessing different aspects of safety.

2.2 Development Procedure

Defense-in-depth evaluation model development procedure was presented in figure 1.

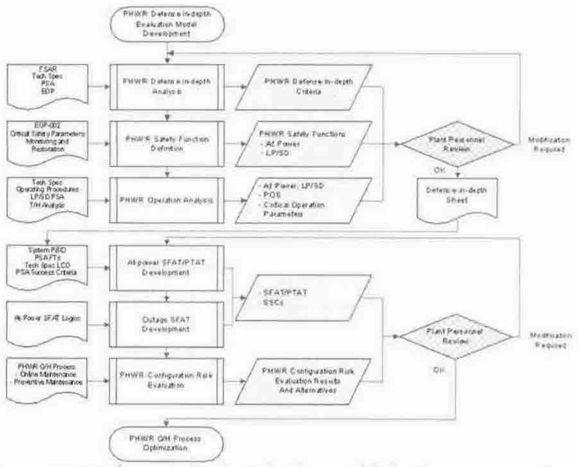

Figure 1. Defense-in-depth evaluation model development procedure

2.3 PHWR Defense-In-Depth Analysis Phase

PHWR defense-in-depth analysis phase includes PHWR defense-in-depth criteria determination, PHWR safety function definition, and PHWR operation analysis. In PHWR defense-in-depth criteria determination step, the PHWR defense-in-depth concept and multiple barriers to maintain defense-in-depth should be identified through the analysis on final safety analysis report, technical specifications, emergency operating procedures and probabilistic safety assessment report.

Based on the defense-in-depth analysis results, the safety functions to maintain the integrity of the multiple barriers should be recognized. These safety functions can be grouped into three categories, i.e., safety functions related to the integrity of nuclear fuels, primary heat transport system, and reactor building. The preliminary safety functions for PHWR were presented in table 1.

Low power and shutdown operation can be categorized various plant operating states(POSs) and each POS should be evaluated by different SFATs. To develop proper SFATs for each LP/SD POS, analysis on the PHWR operation is necessary for the defense-in-depth evaluation model development. Preliminary POS definition for PHWR LP/SD operations was illustrated in figure 2.

Table 1. Preliminary PHWR Safety Functions

Safety Function	Systems
1. Reactivity Control	Shutdown System No. 1 Shutdown System No. 2
2. Core Cooling	Emergency Core Cooling System Shutdown Cooling System Moderator System Emergency Water System
3. Secondary Heat Removal	Steam Generators Main Feedwater System Auxiliary Feedwater System Emergency Water System
4. Primary Heat Transport Inventory	Pressurizer Emergency Core Cooling Tank Dousing Tank
5. Essential Electric Power	Class IV Electric Power Supply Class III Electric Power Supply Standby Diesel Generator Emergency Diesel Generator
7. Cooling Water and Other Vital Support System	Recirculated Cooling Water System Raw Service Water System Emergency Water System
8. Containment Integrity and Cooling	Containment System Dousing System Local Air Cooler System Containment Isolation System

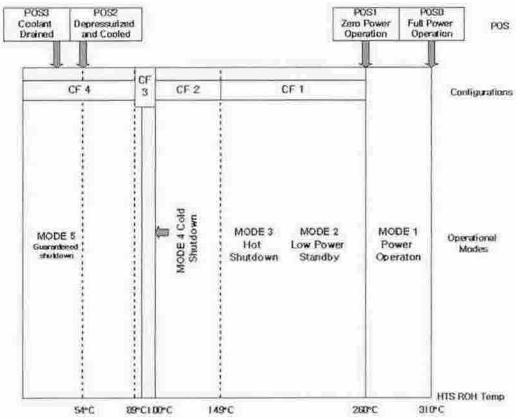

Figure 2. Preliminary POS definition for PHWR LP/SD Operations

2.4 Defense-In-Depth Model Development Phase

Based on the results from previous phase, the SFAT logics and internal SSC models should be developed. The color assignment rule should be decided based on the defense-in-depth evaluation criteria and review result form plant personnel.

To evaluate the defense-in-depth during preventive maintenance period, the maintenance processes should be evaluated and the translation matrix which enables to import schedules and match the imported schedules to the plant configuration database.

To verify the defense-in-depth model, the actual maintenance schedules should be evaluated by developed model. This pilot evaluation result should be reviewed by plant personnel, and review results should be reflected to the model logic and color assignment rule.

The planned schedules can be rearranged based on the defense-in-depth evaluation results and this process should be included in the preventive maintenance optimization process.

3. Conclusion

Because of the unique characteristics of PHWRs, the defense-in-depth model concept and development procedures for pressurized light water reactors cannot be applied to PHWR directly. More resources are required to analyze the defense-in-depth philosophy and safety functions for PHWR. Based on the strategy and development procedure presented in this paper, defense-in-depth evaluation model will be developed and this will contribute to the enhancement of safety during PHWR LP/SD operations and preventive maintenance periods.

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