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# Comparison of Qualitative and Quantitative Risk Results for Shutdown Operation

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## 1. Introduction

The Defense-In-Depth philosophy is a fundamental concept of nuclear safety. The objective of Defense-In-Depth (DID) 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. The qualitative defense-in-depth evaluation using deterministic trees such as SFAT (Safety Function Assessment Tree), can provide "Safety" related information on the levels of defense-in-depth according to the plant configuration including the levels of redundancy and diversity. For the more reasonable color decision of SFAT, it is necessary to identify the risk impact of degradation of redundancy and diversity of mitigation systems. The probabilistic safety analysis for the shutdown status can provide risk information related on the degradation of redundancy and diversity level for the safety functions during outage. Insights from the both methods for the plant status can be the same or different. The results of DID approach and PSA for the shutdown state are compared in this paper.

## 2. Shutdown Risk Assessment Models during refueling outage

### 2.1 Qualitative Defense-In-Depth Methods

The risk during refueling outages can be evaluated and controlled by using the qualitative Defense-In-Depth (DID) methods given in NUMAR 91-06. In this method, SFATs (Safety Function Assessment Trees) for key safety functions of plant are used, the risk is considered acceptable when key safety functions and plant activities are managed. The result of safety function assessment is a set of colors indicating the level of DID (the margin of safety). The following color definitions are typical for a SFAT.

- Green represents a high level of safety
- Yellow represents a slightly reduced level of safety
- Orange represents a cautionary level
- Red represents an unacceptable level of degraded safety features or violation of Technical Specifications.

Figure 1 shows an example of SFAT. This example is an Decay Heat Removal (DHR) safety function for POS B. In case of path 2 of this example, even though there are two SCS trains and two HPSI trains are available when there are no SG (steam generator) leads to a "Red" due to violation of LCO of Technical Specifications. These DID method provides no means to assess the level of risk and limited in there ability to provide an integrated safety assessment across safety functions that includes dependencies. These limitations can be assessed using a quantitative PSA model.

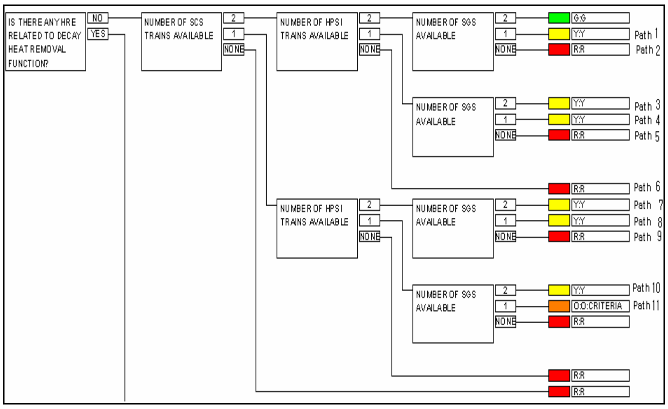


Fig. 1 Decay Heat Removal (DHR) SFAT for POS B

### 2.2 Quantitative Shutdown PSA methods.

Shutdown PSA model has been developed to quantify the impact of initiating events through to core damage frequencies during plant outages In this study, 15 POSs(Plant Operating States) have been defined and event trees for 8 POSs among these 15 POSs have been developed. Other POSs due to low level risk were screened from further quantitative analysis. The POSs represent the distinct plant configurations that affect the PSA success criteria. And POS are mainly differentiated by a set of physical parameters such as RCS water level, RCS integrity, and RCS temperature. Table 1 shows the POSs defined for DID and PSA. the POSs which are marked with blue and yellow colors in Table 1 have the PSA event tree and quantified.

The instantaneous core damage frequency and conditional core damage frequency were considered as the risk measures. The conditional CDF was considered to remove the impact of duration of POS. The LPSD PSA model like Yonggwang 5&6 and Ulchin 5&6 cover the combination of plant state and maintenance configurations.

For the purpose of comparison quantitative and qualitative model, the combined model was modified. First of all, the baseline risk was defined. The baseline risk is a function of the variables defining the plant operating state but does not include maintenance (i.e., all equipment is available). And the increase factor was defined as the instantaneous CDF of SFAT Path divided by baseline risk. The instantaneous CDF of SFAT path was evaluated as below. PSA surrogates which have the same effect for the SAFT path select.. And the surrogate events set the logic failure in this baseline risk.

Table 1. Plant Operating States at DID and PSA

| MODE | DID POS | PSA POS | Duration (hr) | POS Characteristics |
|---|---|---|---|---|
| 4 | B | 2 | 26 | |
| 4 | C | 3 | 35 | SG available |
| 5 | D | | | |
| 5 | E | 4A | 6 | SG available using CVCS |
| 5 | F1 | 4B | 8 | SG Unavailable Large Vent Path |
| 5 | G1 | 5 | 31 | Reduced Inventory |
| 6 | H1 | | | |
| 6 | I1 | 6 | 44 | RCS makeup is not required |
| 6 | J | 7 | 113 | Fuel Transferring POS |
| 6 | K | | | |
| 0 | L | 8 | 91 | Defuleld |
| 6 | K | 9 | 99 | Fuel Transferring POS |
| 6 | J | | | |
| 6 | I2 | 10 | 3 | Gravity Feed is possible |
| 6 | H2 | 11 | 30 | Reduced Inventory |
| 6 | G2 | | | |
| 5 | F2 | 12A | 8 | Similar with POS 10 |

### 2.3 Comparison of Results

The risk results are shown in table 2. The PSA results for the DHR SFAT path seem like similar results with DID colors. However, DID Sheets can never match PSA results 100% of the time, due to a number of issues like system dependencies. In case of path 9 of table 2, the DID based on the Technical Specs leads to a "Red" but the PSA result show a "Green" based on the increase factor. In case of path 11 of table 2, although DID SFAT has the same "Orange" color based on the number of SSC available, if the train of SSC is not same, the risk results can be different very extensively as shown 11b, 11c, 11d.

The risk results of supporting system SFATs such as the CCW, AC, DC are significantly higher than the other SFATs related to front line systems.

## 3. Conclusions

Risk insights have resulted in more accurate assessment of DID,and better control of outage work.

This ORION (Outage Risk Indicator of NPP) program which is blended with DID and PSA will be useful to maintain, or reduce, the shutdown risk as shorter outage are implemented

## REFERENCES


[1] NUMARC, Inc. 91-06 "Guidelines for Industry Actions to Assess Shutdown Management." 1991.12

[2]ORAM-SENTINEL TM, USER's Manual,Version 3.0, EPRI, Palo Alto, CA. TR-107018, 1997.

[3]KEPCO, The Ulchin5&6 LPSD PSA Report. 2002.


Table 2. The example of the comparison of DID and PSA results

| SFAT path | System | No of Tr. | Surrogate | CDF | CCDF | Increase Factor* | DID color |
|---|---|---|---|---|---|---|---|
| 1 | SCS | 2 | AFCVO1048A | 4.68E-7 | 1.172E-04 | 3.9 | Yellow |
| | HPSI | 2 | | | | | |
| | SG | 1 | | | | | |
| 2 | SCS | 2 | AVCVW104849 | 5.29E-6 | 1.323E-03 | 43.7 | Red |
| | HPSI | 2 | | | | | |
| | SG | 0 | | | | | |
| 3 | SCS | 2 | HSCVO0404A | 1.74E-7 | 4.365E-05 | 1.4 | Yellow |
| | HPSI | 1 | | | | | |
| | SG | 2 | | | | | |
| 4 | SCS | 2 | HSCVO0404A +AFCVO1048A | 1.27E-6 | 3.716E-04 | 10.5 | Yellow |
| | HPSI | 1(B) | | | | | |
| | SG | 1(B) | | | | | |
| 4b | SCS | 2 | HSCVO0404A +AFCVO1048A | 1.21E-7 | 3.028E-05 | 1.0 | Yellow |
| | HPSI | 1(B) | | | | | |
| | SG | 1(A) | | | | | |
| 5 | SCS | 2 | HSCVO0404A +AFCVW104849 | 8.50E-6 | 2.126E-03 | 70.2 | Red |
| | HPSI | 1 | | | | | |
| | SG | 0 | | | | | |
| 6 | SCS | 2 | HCVW40405+ +AFCVW104849 | 1.1E-4 | 2.753E-02 | 909.1 | Red |
| | HPSI | 0 | | | | | |
| | SG | 0 | | | | | |
| 7 | SCS | 1 | SCHXBHX1A | 1.95E-7 | 4.881E-05 | 1.6 | Yellow |
| | HPSI | 2 | | | | | |
| | SG | 2 | | | | | |
| 8 | SCS | 1(B) | SCHXBHX1A + AFCVO1048A | 1.37E-6 | 3.429E-04 | 11.3 | Yellow |
| | HPSI | 2 | | | | | |
| | SG | 1(B) | | | | | |
| 8b | SCS | 1(B) | SCHXBHX1A +AFCVO1049B | 7.46E-7 | 1.868E-04 | 6.2 | Yellow |
| | HPSI | 2 | | | | | |
| | SG | 1(A) | | | | | |
| 9 | SCS | 1 | SCHXBHX1A +AFCVO104849 | 1.95E-7 | 4.881E-05 | 1.6 | Red |
| | HPSI | 2 | | | | | |
| | SG | 0 | | | | | |
| 10 | SCS | 1(B) | SCHXBHX1A +HSCVO0404A | 9.27E-7 | 2.321E-04 | 7.7 | Yellow |
| | HPSI | 1(B) | | | | | |
| | SG | 2 | | | | | |
| 10b | SCS | 1(B) | SCHXBHX1A +HSCVO0405B | 2.30E-7 | 5.757E-05 | 1.9 | Yellow |
| | HPSI | 1(A) | | | | | |
| | SG | 2 | | | | | |
| 11 | SCS | 1(B) | SCHXBHX1A +HSCVO0404A +AFCVO1048A | 1.26E-5 | 3.154E-03 | 104.1 | Orange |
| | HPSI | 1(B) | | | | | |
| | SG | 1(B) | | | | | |
| 11b | SCS | 1(B) | SCHXBHX1A +HSCVO0405B +AFCVO1048A | 1.56E-6 | 3.904E-04 | 12.9 | Orange |
| | HPSI | 1(A) | | | | | |
| | SG | 1(B) | | | | | |
| 11c | SCS | 1(B) | SCHXBHX1A +HSCVO0405B +AFCVO1048A | 9.50E-7 | 2.377E-04 | 7.9 | Orange |
| | HPSI | 1(A) | | | | | |
| | SG | 1(A) | | | | | |
| 11d | SCS | 1(B) | SCHXBHX1A +HSCVO0404A +AFCVO1049B | 5.54E-6 | 1.388E-03 | 45.8 | Orange |
| | HPSI | 1(B) | | | | | |
| | SG | 1(A) | | | | | |