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# Examination of risk significant configuration during low power and shutdown with ORION and PSA

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## 1. Introduction

Defense-in-depth is a safety philosophy in which multiple lines of defense and conservative design and evaluation methods are applied to ensure the safety of the public. Based on this philosophy EPRI developed Outage Risk Assessment and Management (ORAM) program as a qualitative assessment to better manage the risk during low power and shutdown event after the Vogtle loss of vital AC power and RHR event in 1990. Similar to U.S., KHNP has utilized ORION program [2] to manage risk during low power and shutdown period.

The ORION program is used during the outage planning to avoid risk significant configuration such as RED and ORANGE. With this ORION program, employee can notice the risk level of plant with color information representing the extent of DID, but can't know how much increased the risk level. And also, each risk level of RED, ORANGE color status caused by the degradation of each key safety function might be different depend on the importance of each key safety function. However we can't know how much different. If we know the quantitative information about the risk level represented by color, we can take and prepare concrete actions to reduce the risk level of the plant with rescheduling maintenance, strengthen surveillance for important safety function, and developing outage management strategy. The probabilistic safety analysis for low power and shutdown period can provide risk information with quantitative value related on the degradation of redundancy and diversity level for the safety functions during outage.

In this study, we calculated the increased Core Damage frequency (CDF) of each RED and ORANGE states in ORION program caused by the degradation of each key safety function by modifying LPSD PSA model. The result of calculation and analysis could be effective to check adequacy and find improvement for these two methods.

## 2. Qualitative Defense-in-Depth methods

The risk during LPSD period 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 [4].

- Green represents a very high or maximum level of DID and the lowest
- Yellow represents adequate DID and a slightly elevated (but still relatively low) risk level
- Orange represents reduced DID and an elevated risk level, but one that is tolerable for short durations
- Red represents an unacceptable DID, characterized by the inability to support the SF.

Figure 1. SFAT for DHR in POS 6-5

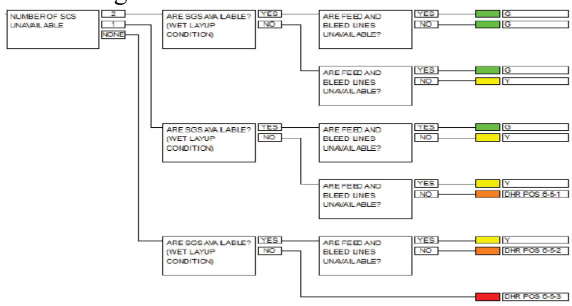


Figure 1 shows an example of SFAT. This example is a Decay Heat Removal (DHR) safety function for POS 6-5. If the number of available shutdown cooling system (SCS) train is one, and there are no available trains or methods for RCS heat removal using steam generator and feed & bleed operation due to maintenance or failure, then the extent of DID represents ORANGE. If there are no available trains in operable for safety functions, the extent of DID represents RED. The information of available trains for safety function are defined by maintenance orders schedule data from KHNP's ERP system.

Figure 2. The result of risk assessment by ORION

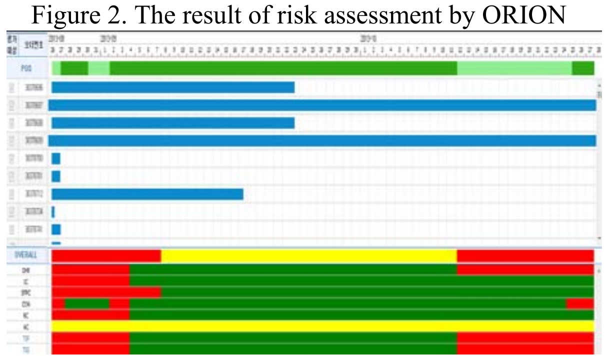

Figure 2 shows the result of risk assessment by ORION program for whole outage period. Employees in KHNP reschedule the maintenance order that leads to an increased risk and make safety states with the risk level information obtained by ORION program. Each safety function given in each POS can leads to ORANGE or

RED states. Only one RED state of 6 safety functions leads to RED state of overall plant risk level. Although each risk level of ORANGE and RED states caused by unavailability of different safety function might be different because impact of unavailable safety equipment to plant risk level are different, ORION program doesn't provide the information about the extent of increased risk caused by unavailability of each safety function and each related safety SSCs.

### 3. Procedure to calculate the increased CDF

Proposed procedure in this paper are using existing programs to manage risk during LPSD period in NPP that are ORION program and LPSD PSA model developed by SAREX. Mainly SFATs of ORION are utilized to define the configuration of Orange and Red states. SAREX program are utilized to modify and calculate the LPSD PSA model.

*Step 1. Matching ORION POSs to LPSD PSA POSs.*

Dividing POSs and developing each SFTAs in relevant POSs are necessary to evaluate risk because physical plant conditions and available SSCs for safety function are changed along with process of outage. Therefore, 9 POSs are defined to evaluate risk for Shin-kori units 3&4. The LPSD PSA of Shin-kori units 3&4, in common with ORION, has been divided into 17 POSs. System fault trees and event trees used in relevant POSs should be constructed to reflect its configuration changes according to the RCS operational mode changes. Due to differences between POSs of ORION and POSs of LPSD PSA, we needed to compare each POSs and match the ORION POSs to LPSD PSA POSs. The result of matching are summarized in Table 1.

Table 1. The result of matching POSs

| ORION POS | PSA POS | Description |
|---|---|---|
| 8-3 | 2 | Cooldown with SGs |
| 7-4 | 3 | Cooldown with SDC |
| 6-5 | 4A | Drain RCS (PZR manway closed) |
| 4-5 | 4B | Drain RCS (Manway open) |
| 5-5 | 5 | Midloop operation |
| 5-6 | 6 | Fill for refueling |
| 3-6 | 7 | Withdraw fuel |
| 2-6 | N/A | Fuel move prohibition |
| 1-0 | 8 | Drain and fill for maintenance |
| 3-6 | 9 | Reload fuel |
| 5-6 | 10 | Drain RCS to midloop |
| 5-5 | 11 | Midloop operation |
| 4-5 | 12A | Drain RCS (PZR manway open) |
| 6-5 | 12B | Drain RCS (Manway closed) |
| 7-4 | 13 | RCS heat-up with RCPs |
| 8-3 | 14 | RCS heat-up with SGs |

There are no significant differences between POSs of ORION and LPSD PSA, thus SFATs of ORION and LPSD PSA model are can be used in relevant POS to calculate increased CDF together.

*Step 2. Define analysis scope*

NUMARC 91-06 defines the key SFs that are applicable during shutdown conditions as decay heat removal (DHR), inventory control (IC), electrical power availability (PA), reactivity control (RC), and containment (CV). SFATs for each safety function are constructed separately based on required SSCs to prevent undesired consequences such core damage and radioactive material release. Required SSCs are changed along with POSs because available SSCs are different due to periodical maintenance and RCS states changes during outage. DHR, IC, and PA among 5 key SFs are considered in this paper because required SSCs for these SFs can be modified in LPSD PSA model and a loss of these key SFs can be associated with LPSD PSA consequence (for example, a loss decay heat removal SF can result in a core damage)

The loss of shutdown cooling (LOSC) is one of the most serious event types and can be initiated by the loss of flow in the shutdown cooling system [6]. And also, according to Shin-kori units 3&4 LPSD PSA report, three types of LOSC contribute to more than 50% of core damage frequency. For these reason, three different kinds of LOSC that are recoverable LOSC (S1), unrecoverable LOSC (S2) and over-drainage during midloop operation (SO) are utilized to calculate increased CDF as initial events (IE) by modifying LPSD PSA model in this paper.

*Step 3. Summarize SFATs of ORION evaluation criteria*

This step summarizes the available DID capability that are mainly available trains of system for each SF. Table 2 shows the result of summary. "N" in available DID capabilities column represents the number of trains or methods that are capable of satisfying the function. If "N" is one, the extent of DID represents ORANGE and if "N" is zero, represents RED for DHR and IC. If "N" is two, the extent of DID represents ORANGE and if "N" is less than 1, represents RED for PA.

Table 2. The available DID capabilities

| SF | ORION | PSA POS | Available DID |
|---|---|---|---|
| DHR | 2-6 ~ 5-6 | 4B ~ 12A, | N= 3 (SCS 2, F&B) |
| | 6-5 | 4A, 12B | N=4 (SCS 2, SG, F&B) |
| | 7-4 | 3, 13 | N=5 (SCS 2, SG 2, F&B) |
| | 8-3 | 2, 14 | N=3 (SG 2, F&B) |
| IC | 2-6 ~ 6-5 | 4A ~ 12B | N=8 (SCS 2, SI 4, CHG 2) |
| | 8-3, 7-4 | 2, 3, 13, 14 | N=6 (SI 4, CHG 2) |
| PA | All | All | N=5 (Offsite2, EDG2, AAC1) |

*Step 4. Methods to modify LPSD PSA model*

In this step, we suggest modification method to calculate the increased CDF value in case of ORANGE and RED status represented by ORION program. There are two ways of modification LPSD PSA model to correspond with ORANGE and RED status of ORION.

First way is to change house event value of fault tree. House event are necessary to set availability status of certain trains simply in LPSD PSA model. For example, In POS 9, shutdown cooling system train A in unavailable due to planned maintenance schedule, in other POSs, this train should be available. To reflect availability of certain trains in certain POS, house event database file should be changed along with maintenance schedule and plant status without making other fault tree for certain POS.

Figure 2. FT including house event

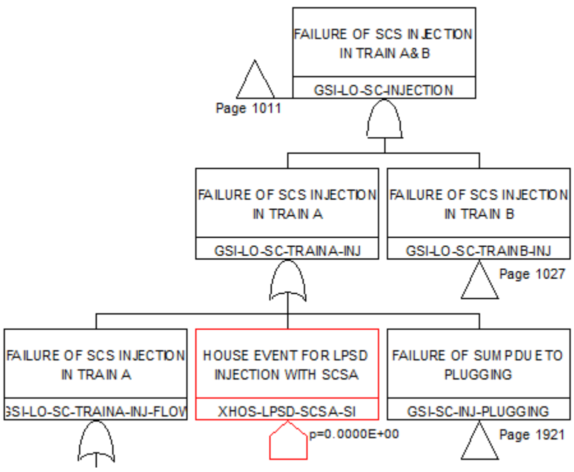


Figure 2 shows a part of fault tree including a house event. The hose event value is zero that means no influence to the availability of SCS train a. If we change this value to one, this SCS train A is not available in the POS. In LPSD PSA model of Shin-kori units 3&4, house events related to available DID capabilities were limited. Therefore, if we wanted to calculate increased CDF using only this way, we had to amend fault tree and create new gates to set availability of trains and methods that are capable of satisfying the function. But we didn't use only this way because we wanted to figure out that the other way can be applicable for calculation as well as it is more complex than the second way.

The second way is to change failure probability of a Minimal Cut Set (MCS) to one by using SAREX program. With this way, LPSD model can be changed to make same status with ORANGE and RED status of ORION in terms of availability of trains and methods. Selection criteria for MCS to be changed are as follows;

- MCSs whose unavailability lead to whole train's unavailability
- MCSs associated with available DID capabilities of ORION
- MCSs not related to human error and common cause failure

With these two ways, we modified LPSD PSA model to make condition that available trains and methods of PSA model are same with available DID capabilities of ORANGE and RED status in ORION program.

## 4. Analysis of the Result

Through this procedures suggested in previous chapter, we calculated the increased CDF caused by three initial events (S1, S2, and SO) for three SFs (DHR, IC, and PA) in several POSs.

The increased CDF for inventory control (IC) using suggested method was not meaningful. Among the available DID capabilities (SI, SCS, and CHG) for IC in ORION program, the capability of charging system (CHG) is not considered to be important in LPSD PSA model because the flow rate form charging system is much lower compare to flow rate of safety injection and shutdown cooling system. Therefore, the increased CDF for IC was excluded in the analysis.

Table 3. shows the result of increased CDF caused by unrecoverable loss of shutdown cooling accident (S2) in several POSs. The SFAT path for each SF and POS are as follows;

- Orange by DHR for POS 3, 4A, 13: 1 SCS available → No SG → No F&B
- Orange by DHR for POS 4B~12A: 1 SCS available → No F&B
- Orange by PA for all POSs: 1 EDG and 1 AAC DG available
- Red by PA for all POSs: 1 AAC DG available

## 3. Conclusions & Future Work

This paper suggests an approach to calculate the increased CDF corresponding to Orange and Red states in ORION program and analyzed the result of calculation. This approach is expected to be useful for checking the adequacy of the LPSD PSA. And also, the result of this calculation can provide the information about which SSCs for certain SF are more sensitive to risk in particular POS. This information can be used to develop more effective outage risk management tool associated with scheduling and operation action for better safety.

Methods presented in this paper could be further developed and be used to enhance safety of plant in a number of ways:

- Make up for the weak points in the current ORION program and LPSD PSA by using substantial difference between them defined by the result.

- Develop risk monitoring program providing the instantaneous CDF when a configuration of plant is changed by applying the methods.

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Table 3. The result of calculation

| POS | Original CDF | Orange by DHR | | Orange by PA | | Red by DHR | | Red by PA | |
|---|---|---|---|---|---|---|---|---|---|
| | | CDF | Increase Factor | CDF | Increase Factor | CDF | Increase Factor | CDF | Increase Factor |
| 3 | 2.09E-08 | 2.35E-06 | 112 | 2.83E-06 | 135 | 5.15E-04 | 24,608 | 3.40E-05 | 1,626 |
| 4A | 5.79E-10 | 2.55E-07 | 440 | 8.74E-08 | 151 | 1.58E-05 | 27,327 | 1.05E-06 | 1,812 |
| 4B | 9.09E-08 | 3.50E-06 | 39 | 1.67E-06 | 18 | 6.81E-06 | 75 | 1.67E-05 | 184 |
| 5 | 1.26E-07 | 6.86E-07 | 5 | 1.29E-06 | 10 | 1.25E-06 | 10 | 1.37E-05 | 109 |
| 6 | 5.32E-08 | 2.21E-06 | 41 | 3.85E-06 | 72 | 4.31E-06 | 81 | 4.44E-05 | 835 |
| 10 | 6.48E-08 | 8.22E-08 | 1 | 5.87E-06 | 91 | 2.06E-06 | 32 | 6.92E-05 | 1,068 |
| 11 | 1.34E-08 | 3.39E-07 | 25 | 2.08E-07 | 16 | 5.01E-07 | 37 | 1.10E-05 | 820 |
| 12A | 6.97E-09 | 4.27E-08 | 6 | 2.89E-07 | 41 | 7.26E-08 | 10 | 3.39E-06 | 487 |
| 13 | 1.42E-08 | 4.23E-07 | 30 | 2.23E-06 | 157 | 8.24E-07 | 58 | 2.70E-05 | 1,895 |