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A Sensitivity Analysis for Modified Surveillance Test Interval of EDG by Considering Failure due to Demand Stress

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1. Introduction

US Nuclear Regulation Committee (USNRC) declared a Probabilistic Risk Analysis (PRA) policy statement that PRA results would be applied for a future nuclear regulation in 1995 [1]. This paradigm was called a Risk-informed Regulation (RIR). As a result, NRC published several regulation guides to address the NRC's attitude to their activities when nuclear industries performed a Risk-informed Applications (RIA) on various issues. An amendment to Technical Specification (TS) is one of the RIA issues [3].

In order to estimate the probability of a failure on demand for a modified STI, Hickman et al. considered the demand failure probability due to only standby failures [3]. For the case of some components like an Emergency Diesel Generator (EDG), however, failures by demand stresses as well as standby failures have occurred. The number of failures due to demand stresses by tests can be obtained for an EDG from a published document [4]. To improve the method by Hickman et al., we proposed an estimation method for the probability of a failure on demand by taking into account a failure by a demand stress as well as a standby failure for the quantification of the risk impact of a modified STI [5].

In this research, we performed a sensitivity analysis for a risk impact on a modified STI of an EDG of Ulchin (UCN) Units 3 and 4 by considering failures by demand stresses as well as standby failures.

2. Methods and Results

2.1 Estimation of Probability of a Failure on Demand Based on a Modified STI by Considering a Demand Stress

Hickman et al. proposed an expression for the estimation of a demand failure probability by a modified STI which was derived under the assumption that all failures on demand were standby failures occurring between successive tests.

Assuming that a standby failure follows a Poisson process with a occurrence rate λ, a tested component becomes as good as a new one after a test, and successive tests are independent, the number of failures on demand, X, has a Binomial distribution with parameters N and p, abbreviated as $B(N,p)$. N is the total number of tests and p is the probability of a failure on demand. By Hickman et al., p was defined as follows:

$$p = 1 - e^{-\lambda\tau} \tag{1}$$

where τ is an STI.

To reflect failures due to demand stresses as well as standby failures for the demand failure probability when an STI is modified, we derived an estimation method [9].

Let $Z_i = 1$, if the i-*th* test ends in a failure and $Z_i = 0$, otherwise. Then

$p \equiv P(Z_i = 1)$
$= P$(the component fails during the standby time between (i-1)-*th* and i-*th* tests or during the i-*th* test)

$$= p_s + (1 - p_s)p_d \tag{2}$$

where p_s is the probability of a standby failure and p_d is the probability of a failure by demand stress. We proposed the Maximum Likelihood Estimator (MLE) of the probability of a failure on demand with the modified STI τ', is

$$\hat{p}' = \hat{p}_s' + (1 - \hat{p}_s')\hat{p}_d$$
$$= 1 - \left[1 - (1-\alpha)\frac{x}{N}\right]^{\frac{\tau'}{\tau}} + \left[1 - (1-\alpha)\frac{x}{N}\right]^{\frac{\tau'}{\tau}-1} \alpha\frac{x}{N} \tag{3}$$

where α denotes the probability of a failure having occurred during the test rather than the standby time.

$$\alpha = \frac{(1-p_s)p_d}{p_s + (1-p_s)p_d} \tag{4}$$

For real application, we need to obtain an estimate for α with the existing plant operation data. For an EDG, an estimate of α can be obtained from a NUREG report [4]. The estimate of α, however, should also be changed when the STI is modified. So we proposed the estimation of α', the changed parameter corresponding to α under the STI modification, as follows [5]:

$$\hat{\alpha}' \approx \frac{1}{1 + \frac{1-\hat{\alpha}}{\hat{\alpha}}\frac{\tau'}{\tau}} \tag{5}$$

With Equation (5), we calculated an estimate of α' for the modified STI of an EDG based on the assumption that the ratio of demand-related failures to standby time-related failures is 2:3 from the NUREG report.

Table 1. Estimate of α'

STI (month)	1	2	3	4
	2/5	1/4	2/11	1/7

Table 1 shows the estimate of α' decreases with increasing STI.

2.2 Quantification of Risk Impact of EDG due to Modified STI

In this section, we performed a sensitivity analysis for a risk impact due to a modified STI of EDGs of UCN Units 3 and 4 based on the method described in the previous section. Basic events related to the STI modification of an EDG and their existing failure probabilities are described in Table 2.

Table 2. Basic Events related to STI Modification of EDG

Basic Event	Description	Prob.
EGDGS01A	EDG A Fail to Start	4.49E-2
EGDGS01B	EDG B Fail to Start	
EGDGS01E	EDG E Fail to Start	
EGDGW01ABD	EDG A & B Fail to Start	2.27E-4
EGDGW01BED	EDG B & E Fail to Start	
EGDGW01AED	EDG A & E Fail to Start	
EGDGW01ABET	EDG A & B & E Fail to S tart	5.39E-4

For the risk quantification, we took into account three different values of α for the estimation of the probability in Table 2 with a modified STI; α of zero by Hickman et al. (Case 1), estimate of α with EDG monthly test data from the NUREG report (Case 2), and an estimate of α' due to the modified STI which is arranged in Table 1 (Case 3). We performed a sensitivity analysis based on the STIs of two, three, and four months. Table 3 shows the estimated probability of a failure on demand with the modified STI for the basic events in Table 2.

Table 3. Estimate of p'

Basic Event	STI	Case 1	Case 2	Case 3
EGDGS01A EGDGS01B EGDGS01E	2M	8.78E-2	7.06E-2	7.71E-2
	3M	1.29E-1	9.57E-2	1.14E-1
	4M	1.68E-1	1.20E-1	1.51E-1
EGDGW01ABD EGDGW01BED EGDGW01AED	2M	4.43E-4	3.57E-4	8.48E-4
	3M	6.52E-4	4.83E-4	1.15E-3
	4M	8.45E-4	6.06E-4	1.44E-3
EGDGW01ABET	2M	1.05E-3	3.89E-4	9.25E-4
	3M	1.55E-3	5.75E-4	1.37E-3
	4M	2.01E-3	7.63E-4	1.81E-3

The estimated probability of failure on demand due to the modified STI of an EDG increases with STI for all kinds of cases. For each STI, the estimated probability becomes large in ascending order of α when the STI is larger than one month by Equation (3).

Using the probabilities of Table 3, a relative CDF due to the modified STI of EDGs of UCN Units 3 and 4 are calculated with a PRiME-U34i which is a PSA model developed by KAERI for internal events PSA of UCN Units 3 and 4.

Table 4. Relative CDF due to Modified STI of EDG

STI	2M	3M	4M
Case 1 (without α)	1.38	2.01	2.95
Case 2 (with α for all STI)	1.10	1.22	1.37
Case 3 (with α' due to modified STI)	1.16	1.47	1.99

Table 4 shows that (1) when the standby failure is predominant (Case 1), the relative CDF becomes largest for each STI (2) when the probability of a failure having occurred during the test rather than the standby time is estimated with monthly test data (Case 2), the relative CDF becomes smallest for each STI. Therefore compared to Case 3, the CDF may be overestimated for Case 1, while it may be underestimated for Case 2.

3. Conclusions

The purpose of this paper was to perform a sensitivity analysis for modified STIs of EDGs of UCN units 3 and 4. We applied the estimate of p', the probability of a failure on demand with a modified STI which took into consideration failures due to demand stresses as well as standby failures and the estimate of α', the probability of a failure having occurred during the test rather than the standby time under the STI modification.

In this research, we used α from a NUREG report. However, α is strongly component-specific. Therefore we need to obtain an estimate for α with the existing plant specific operation data. However, it is not easy to estimate α from the plant operation data since most of the component reliability databases of a nuclear power plant do not recognize whether a component failure occurs during a standby time or a test. For the implementation of the proposed model, it is required to construct a component reliability database containing information on the failure occurrence type based on a plant expert's knowledge.

REFERENCES

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