A Study on Applications of the MSPI Methodology to Ulchin Unit 3

Dae-Il Kang[1], Kil-Yoo Kim[1], Jin-Hee Park[1], and Key-Yong Sung[2]
[1]*Korea Atomic Energy Research Institute,150 Deogjin-Dong, Yuseong-Gu, Daejeon, 305-353, dikang@kaeri.re.kr*
[2]*Korea Institute of Nuclear Safety, 19 Kuseong-Dong, Yuseong-Gu, Daejeon, 305-338*

1. Introduction

As one of the efforts to improve the current Korea Institute of Nuclear Safety (KINS) performance indicator (PI), we performed a pilot study on the applications of the Mitigating System Performance Index (MSPI) methodology to the safety systems of Ulchin Unit 3 (UCN 3) [1, 2]. The MSPI has been developed to replace the current safety system unavailability performance indicator (SSU PI) of the USNRC reactor oversight process (ROP) [3].

2. Methods and Results

2.1 *MSPI Methodology*

The MSPI is the sum of changes in a simplified core damage frequency evaluation resulting from the differences in the unavailability and unreliability relative to industry standard baseline values [3]. It is supplemented with system component performance limits. The pressurized water reactor (PWR) systems for MSPI calculation are emergency AC power system, high pressure safety injection system (HPSIS), auxiliary feedwater system (AFWS), residual heat removal system (RHRS), and cooling water support system (essential service water system and component cooling water system: ESWS and CCWS).

The equation for MSPI can be represented as Eq. (1) [3].

$$MSPI = UAI + URI \quad \text{......................(1)}$$

where,
UAI: unavailability index,
URI: unreliability index

Calculation of System UAI due to a train unavailability is as follows:

$$UAI = \sum_{j=1}^{n} UAI_{tj} \quad \text{.....................................(2)}$$

$$UAI_t = CDF_p \left[\frac{FV_{UAp}}{UA_p} \right]_{max} (UA_t - UA_{BLt}) \quad \text{....(3)}$$

where,
UAI_t: unavailability index for a train.
CDF_p: plant-specific Core Damage Frequency,
FV_{UAp}: train-specific Fussell-Vesely value for unavailability,
UA_P: plant-specific PRA value of unavailability for the train,
UA_t: actual unavailability of train t, and
UA_{BLt}: historical baseline unavailability value for the train

Calculation of system URI due to changes in the component unreliability is as follows:

$$URI = CDF_p \sum_{j=1}^{m} \left[\frac{FV_{URcj}}{UR_{pcj}} \right]_{max} (UR_{Bcj} - UR_{BLcj}) \quad \text{.........(4)}$$

where,
CDF_p: plant-specific Core Damage Frequency,
FV_{URc}: component-specific Fussell-Vesely value for unreliability,
UR_{Pc}: plant-specific PRA value of component unreliability,
UR_{Bc}: Bayesian corrected component unreliability for the previous 12 quarters, and
UR_{BLc}: historical industry baseline calculated from unreliability mean values for each monitored component in the system.

Component performance limits for each system are calculated as a maximum number of allowed failures (F_m) from the plant specific number of system demands and run hours. Actual numbers of equipment failures (F_a) are compared with these limits. The decision rules for assigning a performance color to a system are as follows:

- If MSPI ≤ 1.0E-6 and $F_m \geq F_a$, then performance is GREEN.
- If MSPI ≤ 1.0E-6 and $F_m < F_a$, OR 1.0E-5 < MSPI ≤ 1.0E-5, then performance is WHITE.
- If 1.0E-5 < MSPI ≤ 1.0E-4, then performance is YELLOW.
- If MSPI > 1.0E-4, then performance is RED.

2.2 *Results*

We selected the monitored components for unreliability according to the guidance of NEI 99-02 appendix F [3]. Table 1 shows the identified components that should be monitored. As the RHRS for UCN 3 includes a shutdown cooling system and containment spray system, the number of the monitored components of UCN 3 is greater than that of the Braidwood nuclear power plant (NPP) in the USA.

Table 1. Components to be Monitored for Unreliability

Systems	UCN3		Braidwood	
	No. of Train	No. of Component	No. of Train	No. of Component
EDG*	2	4	2	4
HPSIS	2	18	4	21
RHRS	2	28	2	13
AFWS	4	8	2	10
CCWS	4	~0	5	8
ESWS	4	~0	4	4
Sum	n/a	58	n/a	60

*: Emergency Diesel Generator

Based on the operation experiences of UCN 3, we selected the EDG and AFWS for the MSPI pilot study. The EDG and AFWS MSPIs of UCN 3 were evaluated for a 5 quarter period ending December 31, 2002. We also performed sensitivity analyses for the cases without common cause failures, using the Year 2000 baselines failure probabilities, etc.. Figure 1 shows the calculation results of AFWS MSPI. Table 2 shows the calculation results of AFWS SSU PI using the KINS and NRC SSU PI approaches.

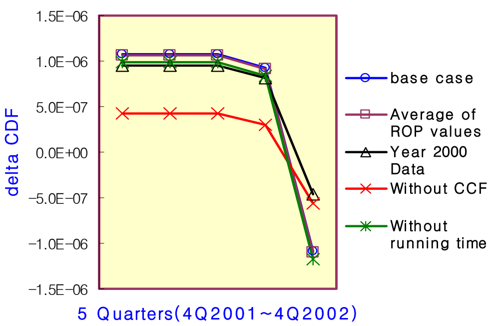

Figure 1. Calculation Results of AFWS MSPI

The study results show that the EDG MSPI drops below 1.0E-6/yr for the three years and the AFWS MSPI is greater than 1.0E-6/yr for the three quarters. However, the SSU of the AFWS estimated by the current KINS PI approach is Green. A noticeable result from the sensitivity analyses is that the MSPI values of both systems calculated using the Year 2000 baseline failure probabilities are lower than those calculated using the NEI 99-02 baseline failure probabilities. From Table 2, we can see that the estimated AFWS SSU PI using NRC SSU PI with the fault exposure time is comparable to the domestic threshold of the Green/Cyan for AFWS.

Table 2. Calculation Results of AFWS SSU PI

Items	4Q2001	1Q2002	2Q2002	3Q2002	4Q2002
Use of current KINS SSU PI	5.36E-3	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Use of current NRC SSU PI	1.86E-3	1.86E-3	1.83E-3	2.16E-3	1.51E-3
Use of current NRC SSU PI including fault exposure time	1.49E-2	1.49E-2	1.47E-2	2.19E-3	1.51E-3

KINS SSU based on one quarter system performance. NRC SSU based on 12 quarters system performance. Domestic threshold of Green/Cyan (White) for AFWS is 0.015

3. Conclusions

As the results of applying the MSPI methodology to UCN 3, it was found that the number of components within the scope of the MSPI would be 58, and the AFWS MSPI could be above the base threshold (i.e., △CDF > 1.0E-06) for the three consecutive quarters. In this case, the AFWS system performance could have been graded as "White" in terms of the USNRC ROP's color indications, but graded as "Green" by the evaluation of the current KINS PI approach.

For the implementation of the MSPI for the domestic NPPs, first above all, it is expected that the following studies be performed: 1) the establishment of components reliability databases for all domestic nuclear power plants and their analyses, 2) the establishment of a reliability data reporting system for the safety systems, 3) the assurance of an adequate PSA quality.

REFERENCES

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[3]. NEI, Mitigating Systems Performance Index, NEI 99-02, Appendix F, Revision N, January, 2005