The Feasibility Study for Application of Risk-Informed Performance Indicators to Korean NPPs

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1. Introduction

The research for the development of risk-informed and performance-based regulatory inspection is ongoing in KINS. The risk-informed PI(performance indicator) is the one of the main components for risk-informed and performance-based regulatory inspection. Because the current KINS SPI (Safety Performance Indicator) is not a risk-informed PI, the feasibility study needs to be done on the application of risk-informed PI to Korean NPPs regulation.

As shown in table 1, KINS SPI does not include BRIIE (Baseline Risk Index for Initiating Events), USwC (Unplanned Scrams with Complications), SSFF (Safety System Functional Failure) and MSPI (Mitigating System Performance Index) used in the US industry. In this paper, the feasibility for application of BRIIE, USwC, MSPI to Korean NPPs is studied. SSFF is excluded from this study, because it counts simply a number of functional failures which does not account for risk information.

Table 1. The Comparison of PI used in NRC and KINS

NRC PI			KINS SPI
Program	Category	PI	
ITP	Initiating Event	BRIIE	Not Included
ROP	Initiating Event	Reactor Scram	Reactor Scram
		Power Change	Power Change
		USwC	Not Included
	Mitigation System	SSFF	Not Included
		MSPI – EAC	PI - EAC
		MSPI – HPSI	PI – HPSI
		MSPI – AFW	PI - AFW
		MSPI – RHR	Not Included
		MSPI – SW	Not Included

2. Analysis Method and Result

2.1 Initiating Event PI-Industry Level

BRIIE is used as one of the industry level initiating event PI in the US industry. It is a "risk-based" PI because it uses PRA results for NPPs. BRIIE includes two tiers. Tier 1 involves the monitoring of individual initiating events at the industry level against performance-based prediction limit, while Tier 2 involves an integrated, risk-informed indicator at the industry level that combines the risks from individual initiating events [1].

As a feasibility study of BRIIE PI for Korean NPPs, we preliminarily analyzed Tier 1 performance-based prediction limits of initiating events for Korean NPPs by using initiating frequencies described in the paper of Park Jin Hee, et al[2]. The derived prediction limits for Korean NPPs are almost 1/5~1/2 of the prediction limits for US PWRs, because the number of Korean NPPs (20) are smaller than the number of US PWRs (69). The Korean specific prediction limit as shown in table 2, which is different from that of US industry, should be determined if BRIIE is selected as initiating PI for Korean NPPs. The study on the Tier 2 risk-informed indicator will be performed in the future research.

Table 2. The Preliminary Results for Tier 1 Prediction Limit (95%) of Korean NPPs

Initiating Events	Mean Frequency	Baseline Year	Critical Year	Expected Occurrence Rate(/yr)	**95% Prediction Limit**	95% Prediction Limit (US PWRs)
GTRN	9.10E-01	229.82	195.51	16.38	**21**	59
LOCV	2.04E-01	229.82	195.51	3.67	**6**	10
LOFW	5.36E-02	229.82	195.51	0.96	**3**	15
LOOP	3.93E-02	229.82	195.51	0.71	**2**	8
LOAC	1.43E-02	229.82	195.51	0.26	**1**	3
LODC	1.06E-02	229.82	195.51	0.19	**1**	2
LOIA	1.78E-02	229.82	195.51	0.32	**1**	3
SLOCA	1.55E-03	459.64	391.02	0.03	**0**	2
SGTR	1.06E-02	229.82	195.51	0.19	**1**	2

2.2 Initiating Event PI- Plant Level

USwC is used as one of the plant level initiating event PI in the US industry. It is not "risk-based" PI because it does not use PRA results, but may be categorized as a "risk-informed" PI because it monitors scrams that may be potentially more risk-significant than "normal" scram. USwC indicator monitors unplanned automatic and manual scrams that require additional operator actions beyond that of the "normal" scram. Such events or conditions typically present more challenges to the operations staff and therefore may be more risk-informed than uncomplicated scrams[3]. The USwC PI monitors six conditions described in table 3 to determine if the scram requires additional operator actions beyond that of the "normal" scram. A threshold of greater than one complicated scram in the previous 4 quarters was selected as the Green/White threshold (increased regulatory response) for this indicator for USNPPs. This threshold was based on an evaluation of US industry performance data (collected during 1995 to 2000) which would result in approximately 5% of the plants exceeding the proposed threshold. No thresholds are provided for the Yellow or Red performance levels for US NPPs.

Table 3. The Category and Criteria of USwC

Category	USwC Criteria
Reactivity Control	Did two or more control rods fail to fully insert?
Turbine Trip	Did the turbine fall to trip?
Power available to Emergency Busses	Was power lost to any ESF bus?
Need to actuate emergency injection sources	Was a Safety Injection signal received?
Availability of Main Feedwater	Was MF unavailable or not recoverable using approved plant procedures following the scram?
Utilization of scram recovery EOPs	Was the scram response procedure unable to be completed without re-entering another EOP?

As a feasibility study of USwC PI for Korean NPPs, we preliminarily analyzed the scrams of Korean NPPs during

the recent 5 years (2002.10.1 ~ 2007.9.30) to determine whether the scram is USwC. A number of seven scrams was determined to be USwC of the 97 scrams during the 5 years, and one of the twenty plants(which is 5%) exceeded the Green/White threshold (more than one complicated scram in the previous 4 quarters). It may be able to use the similar threshold (greater than one complicated scram in the previous 4 quarters used in the US industry) if USwC is selected as initiating PI for Korean NPPs. Table 4 demonstrates the USwC PI results analyzed in this study and the KINS reactor scram SPI results in the third quarter 2007 for a comparison.

Table 4. The Result of USwC and Reactor Scram PI in the Third Quarter 2007

Unit	USwC	Reactor Scram (KINS)	Unit	USwC	Reactor Scram (KINS)
NPP1	N	N	NPP11	Green	Green
NPP2	Green	Green	NPP12	Green	Green
NPP3	Green	Green	NPP13	Green	Green
NPP4	Green	Green	NPP14	Green	Green
NPP5	Green	Green	NPP15	Green	Green
NPP6	White	Yellow	NPP16	Green	Green
NPP7	Green	Green	NPP17	Green	Green
NPP8	Green	Green	NPP18	Green	Green
NPP9	Green	Green	NPP19	Green	Green
NPP10	Green	Cyan	NPP20	Green	Green

2.3 Safety System PI- Plant Level

MSPI[4] is used as one of the plant level mitigating system PI in the US industry. It is a "risk-based" PI because it uses plant specific PRA result. MSPI of a given system is a simplified linear approximation of the change in CDF (Core Damage Frequency). MSPI can consider the dissimilarities in design and operation of NPPs by using plant-specific PRA results, while the current KINS SPI cannot. Therefore, if the current KINS SPI for safety system is replaced by MSPI used in the US industry, the significant change may be expected in the PI results.

As a feasibility study of MSPI for Korean NPPs, we did the sensitivity calculation of MSPI for five types of Korean NPPs (WH900, WH600, KSNP, Framatome, CANDU). The table 5 represents MPSI sensitivity results as a function of major component[1] failure numbers in three years of operation when only CDF is used as a MSPI threshold. The MSPI results including color coding (Green, White, Yellow, Red) for five types of plants are significantly different each other, even though the component failure numbers are the same.

MSPI results of many systems were remained "Green" even if a large number of failures occurred (ten failures in three years). This kind of indicator is defined as "insensitive indicator" in the US industry. This makes it possible for many failure to occur in a system having apparent regulatory significance, so it can be undesirable from general public's points of view. Therefore, the supplemental performance threshold (which is defined "backstop" in the US industry) must be used to limit the total number of failures of components. The table 6 represents MPSI sensitivity results when the supplemental performance threshold is used. The MSPI results change from "Green" to "White" before a number of ten failures occurred for all types of plants, so the problem of "insensitive indicators" can be solved by using this kind of supplemental performance threshold.

Table 5. MSPI (CDF Threshold Considered Only) Sensitivity Results

EAC – EDG

Number of Failure	WH900	WH600	KSNP	Framatome	CANDU
0	-4.54E-07	-5.44E-08	-2.78E-10	-5.76E-07	-2.59E-08
1	8.58E-07	2.60E-07	1.27E-06	5.09E-06	1.07E-07
2	2.20E-06	5.55E-07	2.61E-06	5.84E-06	2.55E-07
3	5.64E-06	8.54E-07	4.55E-06	1.04E-05	5.04E-07
4	4.88E-06	1.16E-06	5.91E-06	1.44E-05	5.00E-07
5	5.22E-06	1.47E-06	7.45E-06	1.82E-05	8.51E-07
6	7.57E-06	1.77E-06	9.00E-06	2.19E-05	7.62E-07
7	8.91E-06	2.08E-06	1.05E-05	2.57E-05	8.95E-07
8	1.02E-05	2.38E-06	1.21E-05	2.95E-05	1.02E-06
9	1.15E-05	2.69E-06	1.36E-05	3.33E-05	1.15E-06
10	1.29E-05	2.99E-06	1.52E-05	3.70E-05	1.29E-06

HPSI – MDP

Number of Failure	WH900	WH600	KSNP	Framatome	CANDU
0	-6.77E-11	-4.17E-09	-5.66E-08	-1.79E-10	-5.46E-10
1	1.74E-09	5.59E-08	5.40E-07	1.94E-10	7.46E-09
2	5.84E-09	1.11E-07	1.12E-06	5.05E-10	1.55E-08
3	5.50E-09	1.73E-07	1.70E-06	9.46E-10	2.55E-08
4	7.56E-09	2.40E-07	2.28E-06	1.13E-09	5.15E-08
5	9.21E-09	5.01E-07	2.56E-06	1.54E-09	5.95E-08
6	1.11E-08	4.04E-07	4.02E-06	2.01E-09	5.55E-08
7	1.29E-08	4.84E-07	4.80E-06	2.55E-09	6.35E-08
8	1.48E-08	5.46E-07	5.18E-06	2.59E-09	7.15E-08
9	1.66E-08	6.07E-07	5.76E-06	3.25E-09	7.95E-08
10	1.85E-08	6.67E-07	6.34E-06	3.24E-09	8.75E-08

RHR – MDP

Number of Failure	WH900	WH600	KSNP	Framatome	CANDU
0	-7.74E-09	1.56E-08	5.56E-08	1.02E-09	9.42E-09
1	1.95E-07	1.95E-07	2.52E-07	6.15E-09	5.56E-08
2	5.55E-07	2.76E-07	4.26E-07	1.15E-08	1.04E-07
3	5.01E-07	4.59E-07	6.22E-07	1.84E-08	1.51E-07
4	8.71E-07	5.58E-07	8.12E-07	2.16E-08	1.94E-07
5	8.45E-07	6.84E-07	1.01E-06	2.87E-08	2.45E-07
6	1.01E-06	PLE	1.20E-06	PLE	PLE
7	1.18E-06	PLE	1.56E-06	PLE	PLE
8	1.56E-06	1.05E-06	1.56E-06	PLE	PLE
9	1.62E-06	1.18E-06	1.78E-06	PLE	PLE
10	1.68E-06	1.51E-06	1.98E-06	PLE	PLE

AFW – MDP

Number of Failure	WH900	WH600	KSNP	Framatome	CANDU
0	-1.24E-08	-5.95E-09	-1.46E-08	-2.06E-09	-1.19E-09
1	2.60E-07	5.56E-08	1.09E-07	2.81E-08	1.65E-08
2	5.55E-07	1.11E-07	4.12E-07	5.62E-08	5.57E-08
3	5.04E-07	1.69E-07	6.20E-07	8.43E-08	5.12E-08
4	1.08E-06	2.26E-07	8.43E-07	1.12E-07	8.68E-08
5	1.55E-06	2.84E-07	1.05E-06	1.40E-07	8.91E-08
6	1.62E-06	5.61E-07	1.27E-06	1.74E-07	1.04E-07
7	1.61E-06	5.69E-07	1.48E-06	2.04E-07	1.21E-07
8	2.17E-06	4.57E-07	1.69E-06	2.54E-07	1.58E-07
9	2.44E-06	5.14E-07	1.91E-06	2.84E-07	1.56E-07
10	2.72E-06	5.72E-07	2.12E-06	2.84E-07	1.75E-07

Table 6. MSPI (CDF & Performance Threshold Considered) Sensitivity Results

EAC – EDG

Number of Failure	WH900	WH600	KSNP	Framatome	CANDU
0	-4.54E-07	-5.44E-08	-2.78E-10	-5.76E-07	-2.59E-08
1	8.58E-07	2.60E-07	1.27E-06	5.09E-06	1.07E-07
2	2.20E-06	5.55E-07	2.61E-06	5.84E-06	2.55E-07
3	5.64E-06	8.54E-07	4.55E-06	1.04E-05	5.04E-07
4	4.88E-06	1.16E-06	5.91E-06	1.44E-05	5.00E-07
5	5.22E-06	1.47E-06	7.45E-06	1.82E-05	8.51E-07
6	7.57E-06	1.77E-06	9.00E-06	2.19E-05	7.62E-07
7	8.91E-06	2.08E-06	1.05E-05	2.57E-05	8.95E-07
8	1.02E-05	2.38E-06	1.21E-05	2.95E-05	1.02E-06
9	1.15E-05	2.69E-06	PLE	3.33E-05	1.15E-06
10	1.29E-05	2.99E-06	PLE	3.70E-05	1.29E-06

HPSI – MDP

Number of Failure	WH900	WH600	KSNP	Framatome	CANDU
0	-6.77E-11	-4.17E-09	-5.66E-08	-1.79E-10	-5.46E-10
1	1.74E-09	5.59E-08	5.40E-07	1.94E-10	7.46E-09
2	5.84E-09	1.11E-07	1.12E-06	5.05E-10	1.55E-08
3	5.50E-09	1.73E-07	1.70E-06	9.46E-10	2.55E-08
4	7.56E-09	2.40E-07	2.28E-06	1.13E-09	5.15E-08
5	9.21E-09	5.01E-07	2.56E-06	1.54E-09	5.95E-08
6	1.11E-08	PLE	5.44E-06	PLE	PLE
7	PLE	PLE	4.02E-06	PLE	PLE
8	PLE	PLE	4.80E-06	PLE	PLE
9	PLE	PLE	5.18E-06	PLE	PLE
10	PLE	PLE	5.76E-06	PLE	PLE

RHR – MDP

Number of Failure	WH900	WH600	KSNP	Framatome	CANDU
0	-7.74E-09	1.56E-08	5.56E-08	1.02E-09	9.42E-09
1	1.95E-07	1.95E-07	2.52E-07	6.15E-09	5.56E-08
2	5.55E-07	2.76E-07	4.26E-07	1.15E-08	1.04E-07
3	5.01E-07	4.59E-07	6.22E-07	1.84E-08	1.51E-07
4	8.71E-07	5.58E-07	8.12E-07	2.16E-08	1.94E-07
5	8.45E-07	6.84E-07	1.01E-06	2.87E-08	2.45E-07
6	1.01E-06	PLE	1.20E-06	PLE	PLE
7	1.18E-06	PLE	1.56E-06	PLE	PLE
8	1.56E-06	1.05E-06	1.56E-06	PLE	PLE
9	1.62E-06	1.18E-06	1.78E-06	PLE	PLE
10	1.68E-06	1.51E-06	1.98E-06	PLE	PLE

AFW – MDP

Number of Failure	WH900	WH600	KSNP	Framatome	CANDU
0	-1.24E-08	-5.95E-09	-1.46E-08	-2.06E-09	-1.19E-09
1	2.60E-07	5.56E-08	1.09E-07	2.81E-08	1.65E-08
2	5.55E-07	1.11E-07	4.12E-07	5.62E-08	5.57E-08
3	5.04E-07	1.69E-07	6.20E-07	8.43E-08	5.12E-08
4	1.08E-06	2.26E-07	8.43E-07	1.12E-07	8.68E-08
5	1.55E-06	2.84E-07	1.05E-06	1.40E-07	8.91E-08
6	1.62E-06	PLE	1.27E-06	PLE	PLE
7	1.60E-06	PLE	1.48E-06	PLE	PLE
8	2.17E-06	PLE	1.69E-06	PLE	PLE
9	2.44E-06	PLE	1.91E-06	PLE	PLE
10	2.72E-06	PLE	2.12E-06	PLE	PLE

PLE : Performance Limit Exceeded

3. Conclusion

A feasibility study is performed on the subject of the risk-informed PIs (BRIIE, USwC, MSPI) application to Korean NPP's. The finding is that :

1) The Korean specific prediction limit as shown in table 2, which is different from that of US industry, should be determined if BRIIE is selected as initiating performance indicator for Korean NPPs.,

2) It may be able to use the similar threshold (greater than one complicated scram in the previous 4 quarters used in the US industry) if USwC is selected as initiating performance indicator for Korean NPPs.

3) The supplemental performance threshold must be added to limit the total number of failures of component if MSPI is selected as safety system performance indicator for Korean NPPs.

REFERENCES

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[3] NEI, "Regulatory Assessment Performance Indicator Guidline", NEI 99-09 Revision 5, 2007

[4] USNRC, "Independent Verification of the MSPI Results for the Pilot Plants", NUREG-1816, 2005

[1] *For a sensitivity study, 'major component' used in this study is 'Diesel Generators' for Emergency AC Power System, 'Motor Driven Pumps' for all the other MSPI systems. Only "Fail to Start" mode is considered as failure modes.*