Reliability Data Analysis of the KSNP Safety-related I&C Components from Operational Experience Data during the Period of 2003 through 2007

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1. Introduction

This study is the update of the previous work [1], which was the performance analysis of the safety-related I&C components based on the operating experience of the total 8.63 reactor years during a period of 1995 through the end of 1999 at four units of Korean standard nuclear power plant (KSNP). The paper mainly focuses on the estimation of the independent failure probabilities or failure rates for the safety-related I&C components, based on the operational data of the total 24.24 reactor years for a new period of 2003 through 2007 at six KSNP units. Recently, the results of the work was used to improve risk-informed surveillance test interval (RI-STI) of the KSNP safety-related I&C systems such as reactor protection system (RPS), engineered safety feature actuation system (ESFAS), and so on [2].

2. Operational Data Analysis Methods and Results

Generally, two reliability models – demand failure model (DFM) and time-related failure model (TFM) – have been used as the mathematical model to be able to explain component failure phenomenon in probabilistic safety assessment (PSA). Simply speaking, DFM means the estimation of component failure probability (p) under the assumption that the component failure occurrence follows a binomial process. Meanwhile, TFM means the estimation of component failure rate (λ) under the assumption of Poisson process. Simply p and λ can be estimated as the number of failure divided by the total number of demands and the total operating time, respectively.

Practically, however, the plant-specific estimation of p and λ from operational experience data is very complicated, time-consuming and tedious work as follows.

(1) Selection of components and failure modes to be analyzed
(2) Determination of prior distribution for each component
(3) Component failure experience data analysis
  - ✓ Estimation of the total number of demands or operating time
  - ✓ Estimation of the number of component failure
    - · Raw data collection
    - · Screening analysis
    - · Determination of failure counting scheme
    - · The detailed failure data analysis and classification
(4) Estimation of posterior distribution for each component (i.e., Bayesian update)

In addition, the variety of assumptions and ground-rules (see Appendix A in the reference [2]) for each step can be necessary to analyze reliability data for the safety-related I&C components. They are basically similar to those of the previous work [1], except some modifications such as failure count scheme of zero failure data, addition of I&C components (e.g., subgroup relay for auxiliary relay cabinet (ARC), safety-related component control cards for plant control system (PCS) or interposing logic system (ILS), power supplier, etc.), consideration of unplanned shutdown information, and so on.

The results of the failure probabilities or rates for the KSNP safety-related I&C components were summarized in Table 1. Finally, Fig. 1 shows the result of a comparison study between the performance analysis for the KSNP safety-related I&C components from this study and the previous work [1].

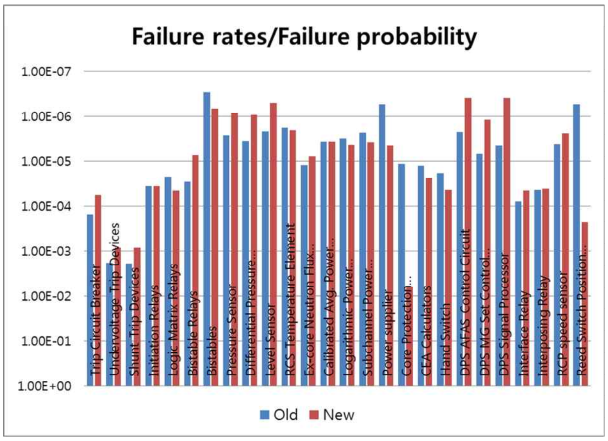

Fig. 1 Comparison of the performance analysis for the KSNP safety-related I&C components (Old: the previous work[1], New: this study[2])

3. Conclusions

The individual component failure probabilities or rates (Table 1) were derived from operating experience of the total of 24.24 commercial reactor years for the period of 2003 through 2007. They are generally comparable to the estimates listed in the previous study [1] as well as the foreign study for CE-type plants, such as the CEN-327 [3], NUREG/CR-5500 [4], etc. The results of the data analysis are similar to ones of the previous domestic and foreign studies. The results of the study can be useful for the risk-informed applications like the RI-STI for the KSNP RPS and ESFAS, including digital I&C systems.

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Table 1. The results of the failure probabilities or rates for the KSNP safety-related I&C components

Components	Code	Prior		Experience Data [1]				Posterior					비고
		MEAN	EF	Failure No.	Demand No.	Operating Time	Unit	MEAN	EF	5%	50%	95%	
Bistable	BI	4.39E-06	5.06	9		15,894,920	HR	6.60E-07	1.64	3.77E-07	6.39E-07	1.01E-06	
Bistable-Fixed	BI	4.39E-06	5.06	5.5		10,798,520	HR	6.51E-07	1.81	3.27E-07	6.21E-07	1.07E-06	
Bistable-VSP	BI	4.39E-06	5.06	3.5		5,096,400	HR	9.22E-07	2.02	4.00E-07	8.63E-07	1.64E-06	
Bistable Output Relay	BR	8.81E-06	3.16	0.5	106,876		D	7.20E-06	2.68	2.19E-06	6.13E-06	1.58E-05	
Bistable Output Relay-Trip	BR	8.81E-06	3.16	0.5	86,266		D	7.65E-06	2.73	2.28E-06	6.46E-06	1.70E-05	
Calibrated Average Power Calculator	--ED-LP	4.69E-06	1.61	0.5		849,400	HR	3.72E-06	1.53	2.35E-06	3.61E-06	5.47E-06	
Subchannel Power Calculator	--ED-SP	4.69E-06	1.61	1		849,400	HR	3.84E-06	1.53	2.43E-06	3.73E-06	5.65E-06	
Logarithmic Power Calculator	--ED-GP	4.69E-06	1.61	3		849,400	HR	4.37E-06	1.52	2.78E-06	4.24E-06	6.39E-06	
Neutron Flux Dectector	NE	9.59E-06	1.26	2		1,698,800	HR	7.70E-06	1.23	6.20E-06	7.61E-06	9.34E-06	
CEA	RD	1.70E-05	13.8	0.5	7,811		D	2.37E-05	9.31	1.01E-06	1.13E-05	8.77E-05	2)
Reed Switch Position Transmitter	OT	6.60E-04	5.6	1	7,078		D	2.31E-04	2.9	6.10E-05	1.97E-04	5.13E-04	
CEAC (integration)	RC	3.82E-05	1.76	6.5		424,700	HR	2.40E-05	1.47	1.58E-05	2.34E-05	3.39E-05	
CEAC CPU module	--PM-RC	3.82E-5	1.76	1		424,700	HR	1.74E-05	1.51	1.11E-05	1.70E-05	2.53E-05	
CEAC AI module	--IM-RC	3.82E-5	1.76	5.5		2,335,850	HR	7.91E-06	1.37	5.61E-06	7.80E-06	1.06E-05	
CPC	AP---	9.01E-04	3.2	11.5	1,164		D	6.22E-03	1.73	3.32E-03	5.97E-03	9.94E-03	
CPC CPU module	APPM-			6		849,400	E(HR)	7.06E-06	1.79	3.87E-06		1.24E-05	3)
CPC AI module	APIM-			5.5		849,400	E(HR)	6.48E-06	1.83	3.47E-06		1.16E-05	3)
CPC WDT	APWD-			0.5		849,400	E(HR)	5.89E-07	3.3	2.07E-07		2.26E-06	3)
DPS AFAS Control Circuit	DPSK-			0.5		1,274,100	E(HR)	3.92E-07	3.3	1.38E-07		1.51E-06	3)
DPS MG Set Trip contactor	DPTC-			0.5		424,700	E(HR)	1.18E-06	3.3	4.14E-07		4.52E-06	3)
DPS Signal Processor	DPSK-			0.5		1,274,100	E(HR)	3.92E-07	3.3	1.38E-07		1.51E-06	3)
Hand Switch	MW	4.33E-05	2.6	0.5	9,308		D	4.37E-05	2.45	1.52E-05	3.79E-05	9.16E-05	
Initiation Relay	KR	4.00E-05	3	0.5	17,453		D	3.59E-05	2.65	1.12E-05	3.06E-05	7.85E-05	
Interface Relay	XR	4.00E-05	3	1.5	24,435		D	4.46E-05	2.48	1.51E-05	3.90E-05	9.27E-05	
Interposing Relay_RPS	QR	4.00E-05	3	0.5	9,308		D	4.08E-05	2.77	1.20E-05	3.40E-05	9.20E-05	
Interposing Relay	QR	4.00E-05	3	0.5	1,140		D	4.84E-05	2.96	1.31E-05	3.90E-05	1.15E-04	
Subgroup Relay	SR	4.00E-05	3	0.5	9,059		D	4.09E-05	2.77	1.20E-05	3.41E-05	9.25E-05	
LM Output Relay	LR	8.17E-05	5.7	2	48,870		D	4.47E-05	2.64	1.35E-05	3.94E-05	9.36E-05	
Trip Circuit Breaker	RB	1.80E-05	3.2	3	10,984		D	5.55E-05	2.77	1.62E-05	4.68E-05	1.25E-04	2)
Shunt Trip Device	ST	4.93E-05	9.3	0.5	688		D	9.51E-05	8.31	5.05E-06	4.45E-05	3.49E-04	2)
Undervoltage Trip Device	UV	1.10E-03	5	0.5	688		D	8.47E-04	3.7	1.60E-04	6.49E-04	2.20E-03	2)
PCS & ILS control card	PM			23		195,646,723	E(HR)	1.18E-07	1.38	8.46E-08		1.61E-07	3)
Differential Pressure Transmitter	PT	4.30E-06	5.6	0.5		1,698,800	HR	9.29E-07	2.93	2.41E-07	7.91E-07	2.08E-06	
Level Transmitter	LT	4.30E-06	5.6	1		5,096,400	HR	5.06E-07	2.48	1.66E-07	4.53E-07	1.02E-06	
Level Transmitter-RWT	LT	4.30E-06	5.6	1		849,400	HR	1.77E-06	2.98	4.48E-07	1.49E-06	3.99E-06	
Level Transmitter-SG	LT	4.30E-06	5.6	0.5		4,247,000	HR	4.98E-07	2.66	1.49E-07	4.38E-07	1.05E-06	
Pressure Transmitter	PT	4.30E-06	5.6	3.5		5,521,100	HR	8.30E-07	2.06	3.52E-07	7.75E-07	1.49E-06	
Pressure Transmitter-CNT	PT	4.30E-06	5.6	0.5		1,698,800	HR	9.29E-07	2.93	2.41E-07	7.91E-07	2.08E-06	
Pressure Transmitter-PZR	PT	4.30E-06	5.6	0.5		2,123,500	HR	8.02E-07	2.86	2.16E-07	6.89E-07	1.77E-06	
Pressure Transmitter-SG	PT	4.30E-06	5.6	0.5		1,698,800	HR	9.29E-07	2.93	2.41E-07	7.91E-07	2.08E-06	
RCP speed sensor	SS	4.30E-06	5.6	8		3,397,600	HR	2.38E-06	1.75	1.25E-06	2.28E-06	3.82E-06	
Temperature Element	TE	1.95E-06	1.9	4		1,698,800	HR	2.05E-06	1.68	1.15E-06	1.96E-06	3.25E-06	
PPS power supply	CR	2.17E-06	4.09	9		1,698,800	HR	4.47E-06	1.75	2.35E-06	4.28E-06	7.18E-06	
ESF power supply	CR	2.17E-06	4.09	0.5		1,698,800	HR	8.72E-07	2.7	2.58E-07	7.53E-07	1.88E-06	
CPC power supply	CR	2.17E-06	4.09	8		1,698,800	HR	3.98E-06	1.8	2.01E-06	3.80E-06	6.52E-06	
PCS & ILS power supply	CR	2.17E-06	4.09	11.5		11,647,920	HR	1.04E-06	1.58	6.20E-07	1.01E-06	1.54E-06	

1) E=evidence only, HR=hour, D=demand, In the case of zero failure, the number of failure is assumed to be 0.5.
2) Unplanned outage and experience data for Ulchin Units 5&6 were included.
3) Excel function of 90% confidence interval: <5%, 95%> = <CHIINV(0.95, 2*(# of failure + 1))/(2*Op. time), CHIINV(0.05, 2*# of failure))/(2*op.. time)>