Evaluation of the Latest Generic Data for PSA Applications of Domestic Nuclear Plants

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1. Introduction

Generic data of domestic PSAs have mostly referred to "Advanced Light Water Reactor (ALWR) Utility Requirements Document (URD)[1]"issued by EPRI. Generally, current data of domestic PSA have been customized with the generic and plant specific data through Bayesian analysis. The generic reference has established by collecting US nuclear plant practices from mid 1980s to early 1990s. Over the decade, US plants had showed low performances and capabilities in operation. On the other hand, the current domestic nuclear plants shows world class performance in operation and maintenance compared with the corresponding US nuclear plants in URD. Therefore, it is necessary to apply proper generic sources which can represent the current domestic plant performances and status.

In 2007, the latest generic source (NUREG/CR-6928)[2] is published by US NRC, which deals with new types of failure modes and analysis methods. A fundamental improvement in NUREG/CR-6928 compared with previous data source is the distinction between standby and alternating/running component basic events, which shows different failure mechanisms. Significant differences were also noted running failure events occurred within and beyond the first hour for emergency diesel generators, cooling units, and pumps. This was done because the historical perspective on running failure rates [1] indicated approximately a factor of 15 differences between the two failure rates for several component types. ALWR URD uses lognormal distribution in the estimation of failure rates. On the contrary, NUREG/CR-6928 uses beta and gamma distributions for demand and running failures, respectively.

This work has proposed an approach to the application of NUREG/CR-6928 to current PSA practice by comparing it with URD data. Moreover, this attempt results in eliciting substantial insights of the establishment of the domestic generic database.

2. Method and Results

2.1 Comparison of ALWR URD and NUREG/CR-6928

ALWR URD and NUREG/CR-6928 provide various types of data, such as initiating event, component failure rate, common cause failure, component unavailability, etc. The scope of this work is limited to the comparison of component data in the two generic sources. The specific data are analysed with Kori #3&4 from 1991 to 2007 and used in statistical analysis with the generic data. Error factors of component failure distributions refer to NUREG-4550 and NUREG-5500. Since ALWR URD and NUREG/CR-6928 apply different analysis methods in raw data treatment, conversion rules about failure rates associating with failure modes should be defined, in advance, in order to data comparison.

On the perspective of statistical analysis, lognormal distribution is proposed as a probabilistic prediction model of failure rates in ALWR URD. NUREG/CR-6928, in a different manner, postulates different probability distributions in demanding and running failures with beta and gamma distributions, respectively. Generally, demanding failures in plant specific data are assumed to be binomial distribution and running failure rates in plant specific data are represented with Poisson distribution. Therefore, statistical compatibility between generic and specific data has been improved in NUREG/CR-6928 from Bayesian analysis[3] perspective. Table 1 lists an exemplary data comparison in case of essential chiller in ALWR URD and NUREG/CR-6928.

Table 1. Comparison of ALWR URD & NUREG/CR-6928 Data.

ALWR URD			
Component	Failure Mode	Failure Rate	Error Factor
Essential Chiller	Fail to Start	2.03E-02	3.0
Essential Chiller	Fail to Run	1.01E-04	10.0
NUREG/CR-6928			
Component	Failure Mode	Failure Rate	Error Factor
Essential Chiller	Fail to Start	1.00E-02	5.1
Essential Chiller	Fail to Run	9.00E-05	8.4
Essential Chiller	STBY FTR ≤ 1hr	2.50E-03	2.0
Essential Chiller	STBY FTR > 1hr	9.00E-04	8.4
Essential Chiller	STBY FTS	2.00E-03	8.4

Failure modes in ALWR URD are divided into fail to start (demanding failure) and fail to run (running failure). However, NUREG/CR-6928 established data in accordance with component operating status like standby and alternating/running. Particularly, running failure mode of standby components is classified into more detailed level depending on failure time (1 hr).

Since current data format adapts ALWR URD type, data format of NUREG/CR-6928 should be customized to that of URD. As a matter of fact, raw data of NUREG/CR-6928 are not released, so there is a limitation to establish more consistent data tables.

2.2 Evaluation of PSA data using the latest generic data and plant specific data

As we mentioned above, in order to apply NUREG/CR-6928 to current PSA, failure mode conversion should be performed beforehand. In addition, the data conversion should consider the operating characteristics of domestic nuclear plants depending on reactor types such as KSNP, WH, Framatome, and CANDU. Table 2 demonstrates the results of Bayesian update with NUREG/CR-6928 and Kori 3&4 specific data in essential chiller.

Table 2. Bayesian Update with NUREG/CR-6928 and Kori 3&4 Specific Data (Essential Chiller)

NUREG/CR-6928				
Component	Failure Mode	Failure Rate	Error Factor	
Essential Chiller	STBY FTS	2.00E-03	8.4	
Essential Chiller	STBY FTR ≤ 1hr	2.50E-03	2.0	
Essential Chiller	STBY FTR > 1hr	9.00E-04	8.4	
Bayesian Update Using Specific Data (KORI 3,4)				
Component	# of Fail	Dem.	Run.	Failure Rate (Bayesian)
Essential Chiller (STBY FTS)	4	233	-	9.28E-03 (Beta)
Essential Chiller (STBY FTR ≤ 1hr)	4	-	-	-
Essential Chiller (STBY FTR > 1hr)	4	-	2097	1.69E-03 (Gamma)

As can be seen from the examples above, running failure with the first hour of specific data are classified into demand failure (failure to start). And considering the practical operation mode, standby failure mode is selected to essential chiller in Kori. The final data are a result of Bayesian update with NUREG/CR-6928 and specific data using beta and gamma distribution as priors.

2.3 Historical Trend Analysis for Main Components

Figure 1 presents Bayesian update result of Kori 3&4 using NUREG-6928 and ALWR URD along with several generic data values. Combined unreliability is

$$\text{Combined UR} = P_{FTS} + P_{FTR} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (2.1)$$

where, P_{FTS} is probability of failure to start and P_{FTR} is probability of failure to run. In order to calculate P_{FTR}, mission time of emergency diesel generator is assumed to be 8hr. The historical trend implies that reliability of EDG has been improved gradually. Particularly, ALWR URD and NUREG/CR-6928 turn out significant differences in unreliability and demanding failure probability. Unreliability of Kori 3&4 can be different depending on sorts of generic sources. As shown in figure 1, the unreliability of Kori3&4 with the application of ALWR URD has higher than that of NURE/CR-6928. Generally, EDGs have high importance in PSA, this discrepancy in EDG basic event would arise a significant impact on CDF.

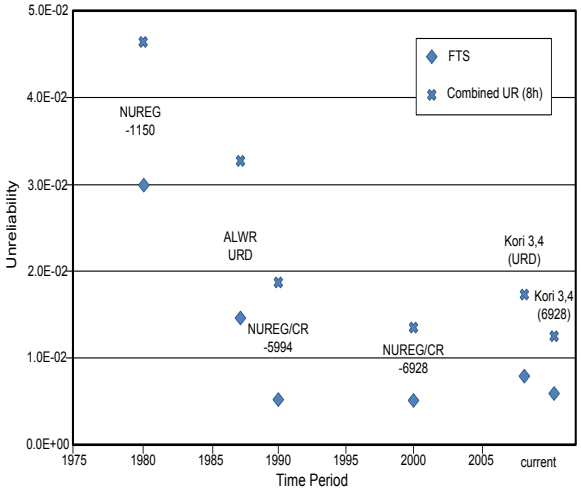

Figure 1. Historical Trend in EDG UR Performance Estimates

3. Conclusions

The fundamental differences in ALWR URD and NUREG/CR-6928 are identified and compared in this work. In addition, an attempt to customize failure modes of NUREG/CR-6928 has been done in order to fit into domestic PSA. Bayesian analysis is carried out with the postulated distribution such as beta and gamma. Moreover, historical trend are presented about EDG and tentative Bayesian analysis of Kori 3&4 using ALWR URD and NUREG/CR-6928 are demonstrated ensuring the legitimacy of proper generic sources.

REFERENCES

[1] "Advanced Light Water Reactor Utility Requirements Document (Volume II, ALWR Evolutionary Plant), Ch1, Appendix A, Rev 7," EPRI, 1995.
[2] "Industry-Average Performance for Components and Initiating Events at U.S Commercial Nuclear Power Plants," USNRC, NUREG/CR-6928, 2007.
[3] "Reliability Engineering and Risk Analysis (A Practical Guide)," M.Modarres etl, Marcel Dekker Inc, 1999.