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A Study on Baseline Period for Evaluating Frequency of Not Sparse Initiating Event Group

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1. Introduction

An initiating event (IE) is an unplanned event that occurs while a nuclear power plant (NPP) is in operation and requires that plant to shut down to achieve a stable state. The IE frequency is one of crucial input data for a probabilistic safety assessment (PSA). In the case of the U.S., the IE frequency indicates performance among plants and also several U.S. Nuclear Regulatory Commission (NRC) risk-informed regulatory activities such as plant inspections of risk-important systems.

NUREG/CR-6928[1] characterizing current industry-average performance for components and initiating events at U.S. NPPs established the parameter estimation process for component failure probabilities/ rates, maintenance unavailabilities, and IE frequencies for the Level 1 standardized plant risk analysis (SPAR) models based on NUREG/CR-6823[7] and INL reports[8-9]. Also, the report has been updated industry-average performance such as component failure probabilities/ rates and IE frequencies every five years to express the U.S. NPPs' current experiences[2-6].

For estimating IE frequency, the report selects a baseline period that resulted in the highest p-value through a trend analysis among potential baseline periods per each IE and then estimates IE frequencies with data in each selected baseline period. That is, a baseline period means a period with the least evidence of a trend.

In Korea, for the PSA of operational NPPs, they applied the results of NUREG/CR-6928 as the generic data and then performed a Bayesian update with the Korean-specific operational data for component failure probabilities/rates. On the other hand, to estimate IE frequencies, they utilize Korean-specific data through the entire data collection period without introducing a baseline period. Therefore, a method for IE estimation including the baseline period with Korean-specific operational data was proposed[10]. Recently, there have been attempts to evaluate component failure probabilities/rates and IE frequencies based on domestic operating experiences similar to NUREG/CR-6928 for domestic PSA.

The purpose of this paper is about IE frequency. This paper suggests considerations to be taken into account for the selection of a baseline period when statistically significant trend-free intervals do not exist through a trend analysis based on NUREG/CR-6928, 2020 Update.

2. Baseline Period for Evaluating IE Frequency by NUREG/CR-6850

As mentioned above, a baseline period is an interval with the least presence of trend. The purpose of the baseline period is not to include the early years with poorer performance in the baseline period since often the IE data indicate more events in the early years and fewer events in the latter years.

The concept of the baseline period for IE frequency assessment was first introduced in NUREG/CR-6928 and the process for choosing the baseline period has been utilized up to the 2015 Update version[4].

- Start from the end year of data collection (2002) and extend the period backward by one year at a time, with a minimum duration of five years until the starting year of data collection (i.e., 1998~2002, 1997~2002, 1996~2002…to 1988~2002).
- Perform statistical trend evaluations for potential baseline periods
- Choose a baseline period that resulted in the highest p-value

In the 2020 Update[6], the process is modified, however, the original intent of the baseline period remains unchanged. The process of the 2020 Update was based on INL/EXT-21-63577[11], which provides revised, historical frequencies for the occurrence of IEs in U.S. NPPs and reviews the operating data from an engineering perspective to determine the trends and patterns of plant performance for specific plants.

- For "not sparse" IE groups(the number of events during the data collection period≥20), the most recent ten-year period and fifteen-year period are investigated
- For "sparse" IEs, the starting years are not changed from the baseline periods in the 2015 Update, unless the trend and homogeneity criteria can't be met.
- The process for selecting a baseline period described in NUREG/CR-6928, 2015 Update is similar to those of NUREG/CR-6928.

3. Baseline Periods for GTRN-PWR: No Trend-Free Potential Periods

3.1. Status of the U.S.

The baseline periods resulted by NUREG/CR-6928, 2020 Update, and INL/EXT-21-63577 are the same except for the ‘general transient(GTRN)-Pressurized Water (PWR)’. The GTRN-PWR belongs to the Sparse group of IE based on the number of GTRN-PWR. INL/EXT-21-63577 uses an interval of ‘2016-2020’ as a baseline period of GTRN-PWR, while NUREG/CR-6928, 2020 Update uses ‘2011-2020’. INL/EXT-21-63577 describes that for the period of ‘2011-2020’, there is a statistically significant decreasing trend with a p-value of 0.021, and the period of ‘2016-2020’ was selected as it had the highest p-value (0.86). Therefore, the approach of INL/EXT-21-63577 can be considered to have applied the methodology of the original version of NUREG/CR-6928. However, in NUREG/CR-6928, 2020 Update, the reason for selecting the period of 2011-2020(the most recent 10-year period) is not explained. Figure 1 shows the occurrence status of GTRN-PWR in the U.S.

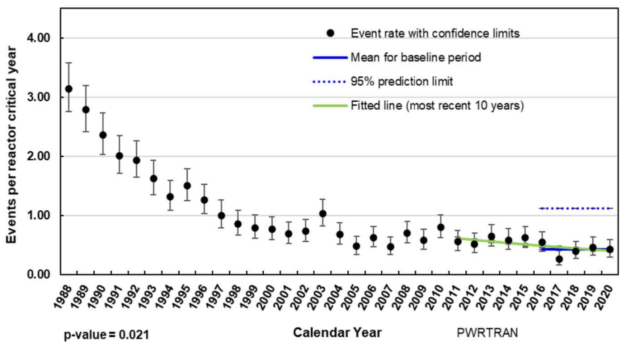

Figure 1. Occurrence of GTRN-PWR in the U.S.[11]

Table 1 presents the baseline periods and frequency estimation results with data within each baseline period in the U.S. The p-value(0.021) of Figure 1 is that of the period of ‘2011-2020’. From Table 1, It is shown that the mean from the baseline period(2011-2016) of a recent 10-year operation is larger than that with the baseline period(2016-2020) having the highest p-value, however, the former case has a smaller EF than the latter case. Generally, when the shapes of gamma distributions are similar, an increase in the mean leads to an overall increase in the distribution's height, resulting in a decrease in the difference between the 95th percentile and the 5th percentile. This can be considered as a factor that reduces the EF.

Figure 2 is a histogram of the gamma distribution for GTRN-PWR frequency in the U.S. based on NUREG/CR-6928, 2020 update[6] and INL/EXT-21-63577[11]. By displaying the y-axis in terms of relative probability density, it makes it easy to understand the variability of the data

Table 1. Frequencies of GTRN-PWR of the U.S.

Data Source	NUREG/ CR-6928[1]	2010 Update[2]	2015 Update[4]	2020 Update[6]	INL/EXT-21-63577[11]
Baseline Period	1998-2002	1998-2010	1998-2015	2011-2020	2016-2020
p-value		0.90	0.88	0.02	0.86
Reactor Critical Year (rcry)	304.0	803.9	1101.6	597	299.69
Number of events	228	553	743	300	126
Number of Plants	69	69	69	69	69
Estimation Method	EB(Empirical Bayes)	EB	EB	EB	EB
Mean	7.51E-01	6.90E-01	6.76E-01	5.18E-01	4.30E-01
5th-percentile	4.84E-01	3.47E-01	3.35E-01	1.39E-01	5.70E-02
9th-percentile	1.07E+00	1.13E+00	1.12E+00	1.09+00	1.09E+00
Error Factor(EF)	2.20	3.25	3.34	7.88	19.15
α parameter	17.77	8.19	7.86	2.94	1.62
β parameter	2.365E+01	1.187E+01	1.160E+01	5.68E+00	3.77E+00

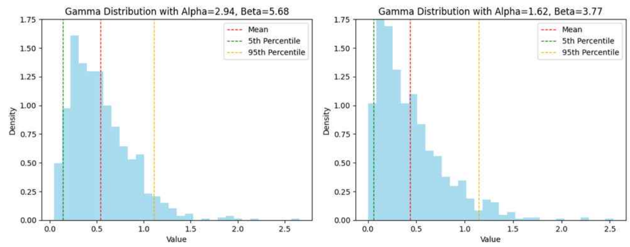

Figure 2. Histogram for Gamma Distribution Relate to GTRN-PWR frequency of U.S. by References [6] and [11]

3.2. Status of Korea

With the Korean-specific experience from 1993 to 2020 about the GTRN from the OPIS(Operational Performance Information System for Nuclear Power Plant) for 20 PWR NPPs, the estimation of IE frequency has been performed based on NUREG/CR-6928, 2020 Update. The selection results of the baseline period for GTRN frequency evaluation were similar to those in the U.S. That is, the number of GTRNs during the data collection period(1993-2020) for 20 Korean PWR NPPs is more than 200, falling into the ‘sparse group’ category. Therefore, a trend analysis using the Reliability Calculator software of NRC[12] for both the recent 10-year and 15-year periods showed all p-values below 0.05, indicating the presence of trends in both cases. As an alternative, based on the method of NUREG/CR-6928, the interval with the highest p-value was found to be 2016-2020 (p-value=0.27). In this paper, two kinds of baseline periods (‘2011-2020’ and ‘2016-2020’) were applied.

Table 2 shows the estimation results of GTRN frequency with data within each baseline period with the Reliability Calculator. From Table 2, for the evaluation of the GTRN frequency for 20 domestic PWRs, two kinds of options for the baseline period were derived based on the methods of NUREG/CR-6850 and its 2020 Update. It can be observed that in the former case, the mean decreased by approximately 50% compared to the latter case, while the EF increased by about twelve times.

Table 2. GTRN-PWR Frequency for Korean 20 PWRs

	1st Option	2nd Option
Baseline Period	2016-2020	2011-2020
References for baseline Period	NUREG/CR-6928	NUREG/CR-6928, 2020 Update
p-value	0.270	0.003
Reactor Critical Year (rcry)	70.04	146.87
Number of Events	5	27
Estimation Method	EB	JNID
Mean	7.09E-02	1.87E-01
5th-percentile	7.98E-03	1.33E-01
95th-percentile	1.86E-01	2.49E-01
Error Factor(EF)	23.45	1.88
α parameter	1.46	27.5
β parameter	2.07E+01	1.47E+02

EB: Empirical Bayes
JNID: Bayesian analysis with Jeffreys Non-informative prior Distribution

Figure 3 shows a histogram of the gamma distribution related to the GTRN frequency based on NUREG/CR-6928[1] and its 2020 Update[6].

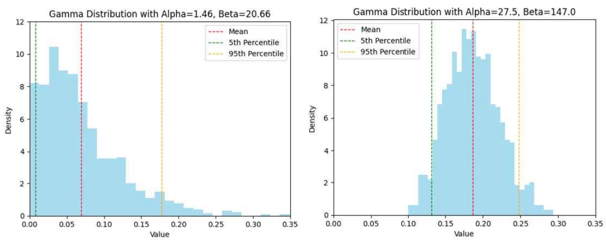

Figure 2. Histogram for Gamma Distribution Relate to GTRN frequency of Korean 20 PWRs by References [1] and [6]

The choice between the outcomes of two groups (baseline periods) with different means and EFs depends on what aspect is emphasized. In general, from a statistical standpoint, a smaller EF is preferred as it provides more reliable estimates. On the one hand, considering the original purpose of the baseline period, one may prefer selecting a period without trends in event occurrences as the baseline period, or considering a conservative stance towards the results, one may also prefer higher means.

4. Conclusions

This paper suggests considerations to be taken into account for the selection of a baseline period when statistically significant trend-free intervals do not exist through a trend analysis based on NUREG/CR-6928, 2020 Update. When choosing the baseline period for the GTRN-PWR frequency estimation, following the process described in NUREG/CR-6928, 2020 Update, it was noted that both in the U.S. and domestically, there are no potential baseline periods with p-values greater than 0.05 through the trend analysis with the Reliability Calculator. Considerations were derived regarding which baseline period to choose.

In this paper, GTRN frequencies were calculated for 20 domestic PWRs applying baseline periods derived by NUREG/CR-6928 and NUREG/CR-6928, 2020 update. Considering the size of EF, the basic purpose of the baseline period, and conservatism, the two types of GTRN frequencies were compared. In addition, the domestic operation experience is less compared to that of the U.S., so instead of choosing the highest p-value, another method could be considered, which is to select the longest period where the p-value exceeds 0.05. For future PSA applications, when there is no potential baseline period without trends, it should be noted that not only the considerations listed above but also the opinions of PSA experts should be taken into account to evaluate IE frequency.

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