

Time Margin Analysis of Reactor Trips Using Operating Experience

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1. Introduction

In nuclear power plants (NPPs), a reactor trip is considered as an essential element of safe operation because it represents the successful actuation of safety functions. When an accident occurs during plant operation, a reactor trip is the primary safety procedure. However, it is not desirable from an economic point of view. The electric power research institute (EPRI) estimates that a single plant trip results in an economic impact of approximately 10million USD [1]. Therefore, investigating reactor trips is important to improve plant economics and performance. In this study, we analyzed reactor trip events by reviewing all trip events over the last 20 years (2006~2025) in the operational performance information system (OPIS), based on actual operational experience. We reconstructed the trip path and derived a two-part indicator that distinguishes immediate trips from non-immediate trips. Based on the results, we identified events which should be targeted for future analysis to reduce trips.

2. Methods and Results

2.1 Data and event selection

We extracted data from the OPIS, which is operated and maintained by the Korea institute of nuclear safety (KINS). OPIS systematically records operational experience, including events and incidents that are required to be reported under the nuclear safety act of Korea. To ensure data timeliness, the analysis period was limited to the most recent 20 years. We selected only events that occurred during on-power operation and resulted in a reactor trip. Reactor trip initiated by external hazards like earthquake and fire were excluded. Accordingly, the data was limited to trip-related events, and industrial safety incidents without relevance to plant system such as worker's fall accident were omitted.

2.2 Pathway construction

The progression of OPIS events leading to reactor trips was analyzed. For each event, we identified the initiating events, the intermediate system transients and system responses, and the final trip parameters that resulted in the reactor trip. This analysis was based on the event sequences described in the corresponding investigation reports. Because each report provides a detailed narrative for an individual event, the extracted sequences were

standardized and structured into a database with consistent fields and definitions, enabling cross-event comparison and case-based analysis. In addition, the dominant trip parameters that contribute substantially to reactor trips were identified.

2.3 Time margin definition and extraction

Time margin is defined as the elapsed time from the onset of an abnormal condition, as documented in the report, to the reactor trip. Specifically, the start time was identified using the time recorded in the event investigation report as either the occurrence time of the abnormal condition or the time at which the abnormal condition was detected. Because the recorded start time is documented after the event has been treated, it cannot be regarded as the exact onset time of the abnormal condition. Therefore, in this bottom-up analysis, we consistently used the time determined and documented in each report as the initiating time for event classification. Time margins were evaluated in minutes, and margins shorter than 30 seconds were considered as having no time margin.

2.4 Statistical modeling for time margin

The extracted time margins were fitted to probability distributions to characterize their statistical behavior. A total of 86 samples were used for distribution fitting, and the analysis was conducted under three cases to reflect different data conditions. For each case, best-fitted distribution and parameters were selected using the Akaike Information Criterion (AIC). AIC is a model selection metric that balances goodness of fit with model complexity by accounting for the number of parameters, thereby reducing the risk of overfitting [2]. The AIC was also used to compare the best-fitting distributions among the three cases.

Table I: Distribution Parameters

Scenario	Distribution	AIC	Parameters
Entire Data	Exponential	317.31	$\lambda = 0.475$
Data except zero margin	Log normal	164.16	$\mu = 1.590$ $\sigma = 0.848$
Binned Data	Log normal	164.16	$\mu = 1.590$ $\sigma = 0.848$
Two-part Model	Point mass + Log normal	-	$P_0 = 0.698$ $\mu = 1.590$ $\sigma = 0.848$

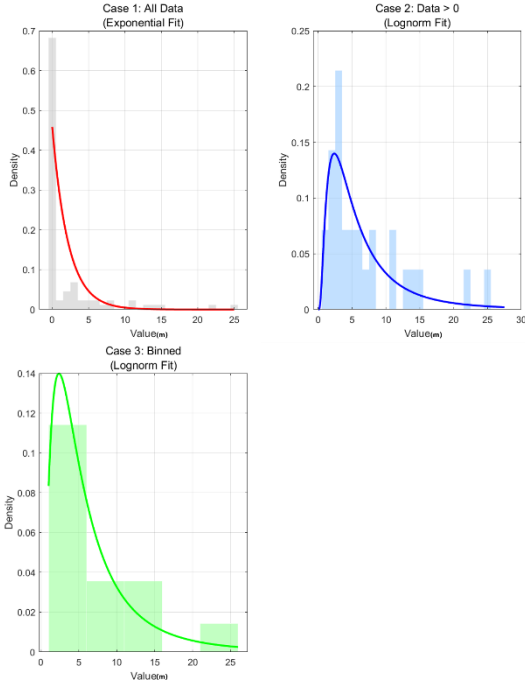


Fig. 1. Distribution fitting of time margin

In Case 1, distribution fitting was performed using all samples. In Case 2, fitting was conducted after excluding data with a zero margin, which were treated as outliers. In Case 3, zero margin cases were also excluded, and the remaining data were grouped into five-minute bins prior to fitting. The fitting results are summarized in Table 1. The same distribution was selected for both Case 2 and 3. Given that Case 2 and 3 yielded approximately half AIC values of Case 1, their distributions were considered more appropriate for representing the time margin.

2.5 Targets for trip event reduction

Table II: Immediate Trip Probabilities

Category	Number	P(T=0)	P(T≠0)
Electrical	25	0.960	0.040
Instrumental	39	0.743	0.257
Mechanical	11	0.273	0.727
Human	11	0.364	0.636
Trip Parameter			
RCP Trip	23	1	0
Turbine Trip	16	0.813	0.187
SG Low Level	11	0.091	0.909
Control Rod	11	0.909	0.091
Improper Insertion			

To derive the targets of the trip event reduction, we integrated the results of pathway reconstruction with the results of time margin analysis. Time margin was analyzed from two perspectives, by trip cause and by dominant trip parameter derived from path reconstruction, and it was analyzed by deriving the rate of stopping immediately and the rate of events that did not.

In the case of an immediate trip event, it is judged that there is no possibility of preventing the reactor condition from trips, so a high ratio of non-immediate trips is judged to be a possibility of reduction. Electrical defects and instrumental defects accounted for 0.744 of the reactor trip events, but the high ratio of immediate trips did not seem appropriate as an analysis target, and in the case of mechanical defects and human errors, the relatively high ratio of non-immediate trips is suitable for the target. In addition, only the steam generator (SG) low-level events, as a trip parameter, had a high ratio of the non-immediate trip event, so there was a possibility of reactor trip reduction through securing time margin in the case of thermal-hydraulic system-related events.

3. Conclusions

Based on 20 years of operational experience recorded in OPIS, we reconstructed the reactor trip pathway and modeled the time margin from the recognition of abnormal condition to the reactor trip. The time margin distribution was expressed as a two-part model that separates immediate trip probability and the non-immediate trip probability distribution. From the integrated results, we identified which type of defect and trip parameter events have the time to intervene to prevent the reactor trip to OSS. This study provides a statistical basis for subsequent studies on reducing improper trips and improving plant performance.

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