A Suggestion of Improved Evaluation Method for Human Error Probability in Fire PSA

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1. Introduction

In the internal event PSA (Probabilistic Safety Assessment) performed in Korea, HEP (Human Error Probability) is evaluated by applying K-HRA developed on the basis of THERP (Technique for Human Error Rate Prediction) and ASEP (Accident Sequence Evaluation Program) HRA in order to reduce the uncertainty of analysis result by minimizing subjectivity of analyst [1,2,3]. In the fire PSA, a conservative multiplier is applied to the HEP evaluated in the internal event instead of the PSFs (Performance Shaping Factors) caused by the fire or the increased operator stress level.

However, applying conservative multipliers in the fire PSA can result in overly conservative results because there are many HFEs (Human Failure Events) that have been evaluated to the maximum for certain PSFs such as maximum stress level "Extremely High" and recovery action failure probability 1.0.

In this paper, we proposed an improved HEP evaluation method which improves an existing HEP evaluation method (multiplier method) to reduce excessive conservatism and to evaluate HEP practically in fire PSA.

2. Methods and Results

In this section, we briefly described the existing HEP evaluation method (multiplier method) applied to the fire PSA and improved multiplier method proposed in this paper. Also, the application results for each method are discussed.

2.1 Existing HEP Evaluation Method (Multiplier Method) in Fire PSA

In the case of PWR (Pressurized Water Reactor) in Korea, multiplier method (a factor of 5 is applied to the Internal Event HEP) based on the evaluation results of Zion unit 1,2 and Byron unit 1,2 performed as part of IPEEE (Individual Plant Examination for External Events) in the United States are applied to calculate HEP in fire PSA [4,5]. In the case of PHWR (Pressurized Heavy Water Reactors) in Korea, the same multiplier method was applied according to generic CANDU probabilistic safety assessment methodology [6].

According to each report, if the fire does not affect the operators in the MCR (Main Control Room), the HEP of the internal event PSA can be applied to fire PSA. However, fire PSA in Korea, a multiplier of 5 was applied to all post-accident HFEs conservatively. The advantage of this method is that the effects of fire on the operator can be easily applied to the PSA model.

However, the importance of human error can be overestimated in the PSA model, and the associated accident scenarios can be the dominant consequences of the fire CDF (Core Damage Frequency), which may lead to other risk contributing factors (e.g., Systems, Structures, Equipments, etc.) are masked. As a result, it may cause difficulty in obtaining risk insight.

2.2 Excessive Conservatism of the Existing Multiplier Method in Fire PSA

There is a virtual post-initiator HFE "A". It assumed four cases that system time window of "A" is 15, 30, 45, and 60 minutes after the reactor trip, and the other factors are evaluated as follows, the operator stress level and HEP evaluation results (Internal HEP: K-HRA method and Fire HEP: existing multiplier method) for each case are shown in Table I.

- Main interest task: Yes
- Number of task: 2 (MCR)
- Task complexity level: Normal
- Cue timing: 1 min after Reactor trip
- Working time: 3 min
- MMI level: High
- Procedures and training level: High
- Task pressure: Low
- Task type: Step-by-Step
- Task severity: No
- Supervisor: Yes

Table I: HEP of Post-Accident Execution Action "A"

Case	System Time Window (T_{sw})	Stress Level	HEP (Internal)	HEP (Fire)
A	15	Extremely High	1.14E-01	5.72E-01
B	30	Very High	9.44E-03	4.72E-02
C	45	Very High	8.29E-03	4.14E-02
D	60	Optimum	1.10E-03	5.50E-03

In the Table I, since "Extremely High" is the maximum stress level in the HRA analysis, an internal event HEP of case A is conservatively evaluated and applying multiplier of 5 to internal event HEP results to evaluate fire event HEP is harsh evaluation.

Assuming that the stress levels of case of B and C evaluated as "Very High" are increased to "Extremely High", applying a multiplier of 5 to the increased HEP is a very conservative estimate.

For case D evaluated "Optimum", according to the NUREG-1921 (Fire human reliability analysis guidelines), since the system time window(T_{sw}) after the reactor trip is 1 hour, it is defined as long-term human action (fire effects no longer dynamic, equipment damage understood, and fire does not significantly affect ability of operators to perform action) and is evaluated as “Similar to internal events HFEs but with some fire effects”. Therefore, applying multiplier of 5 to Case D is a very conservative evaluation [7].

2.3 Improved Multiplier Method in Fire PSA

We proposed an improved multiplier method that differentiates the multiplier according to the system time window (T_{sw}) so that the evaluated HEP value includes a reasonable level of conservatism. Table II shows the multipliers according to system time window (T_{sw}).

If T_{sw} is less than 30 minutes, the stress level of the operator is evaluated as 'Extremely High'. Therefore, the existing multiplier of 5 may be unreasonable, but since the time margin is relatively short, multiplier of 5 was also applied in improved multiplier method.

If T_{sw} is greater than 30 minutes and less than 60 minutes, assuming that the operator's stress level is increased by one step, the greatest increase (2.5 times) in the basic error probability (Table III) occurs when the operator's stress level raised from "Very High" to "Extremely High". From the viewpoint of the time margin, there will be some delay time effect due to the fire so the improved multiplier method proposed Multiplier of 3.

Table II: Comparison of Multiplier Application Factor

System Time Window (T_{sw})	Existing Multiplier	Improved Multiplier
T < 30 min	5	5
30 min ≤ T < 60 min	5	3
60 min ≤ T	5	1

Table III: Basic Error Probability for Task Type(K-HRA)

Task Type	Stress Level	Basic Error Probability (mean)	Error Factor
Step by Step	Optimum	0.005	3
	Moderately High	0.01	3
	Very High	0.02	3
	Extremely High	0.05	3

If T_{sw} is less than 60 minutes, it is classified as long-term human action according to NUREG-1921, so we proposed to apply the same value as internal event HEP. Multiplier application factors for existing and improved methods are compared in Table III [7].

In addition to above multiplier application, we have proposed a method to reduce the time margin and increase the stress level of the operator by one step, assuming the appropriate delay time (5 min) in the following cases.

- Conservatively evaluated HFEs regardless of T_{sw} in internal event PSA
- HFEs with fire effect on the operator (Even if T_{sw} is greater than 60 minutes)

As shown on Fig.1, as the trend that the probability of failure of basic diagnosis error increases rapidly in the interval of time margin less than 30 minutes which is the main factor of diagnosis error. Since the probability of failure of the basic diagnosis error increases rapidly in the margins of less than 30 minutes, the effect on the time margin should be considered.

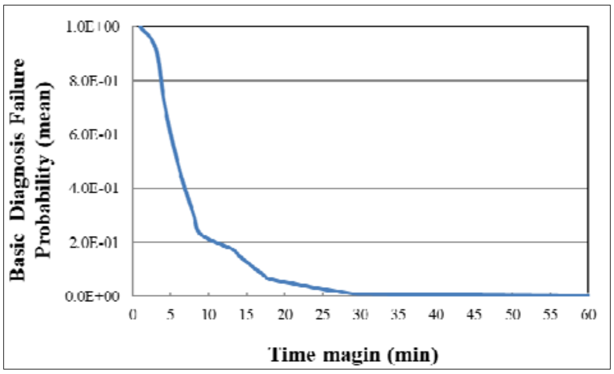

Fig. 1. Trend of Basic Diagnosis Failure Probability by Time Margin

2.4 Application Results of Existing and Improved Multiplier Methods

The HEP evaluation results using existing multiplier method and improved multiplier method are summarized in the Table IV and the HEP increase rate compared with the internal event HEP is described in the Table V.

Table IV: Summary of HEP Evaluation Results using Existing and Improved Multiplier Methods

Case	Internal event HEP	Existing multiplier method	Improved multiplier method (HEP)	
			Multiplier	Additional analysis (Delay time: 5min)
A	1.14E-01	**5.72E-01**	5.72E-01	**1.32E-01**
B	9.44E-03	**4.72E-02**	2.83E-02	**2.28E-02**
C	8.29E-03	**4.14E-02**	2.49E-02	**2.04E-02**
D	1.10E-03	**5.50E-03**	1.10E-03	**2.16E-03**

Table V: Comparison of HEP Increase Rates of Existing and Improved Multiplier Methods

Case	Internal event HEP	Existing multiplier method	Improved multiplier method (HEP)	
			Multiplier	Additional analysis (Delay time: 5min)
A	100.0 %	**500.0 %**	500.0 %	**115.8 %**
B	100.0 %	**500.0 %**	300.0 %	**241.5 %**
C	100.0 %	**500.0 %**	300.0 %	**246.1 %**
D	100.0 %	**500.0 %**	100.0 %	**196.4 %**

In the Case A ($T_{sw} < 30$ min), the same multiplier is applied, and additional analysis showed an increase of 15.8% over the internal event HEP, because most of the factors for the execution error are evaluated as the maximum value in the internal event PSA. Compared with the application of the existing multiplier method, the difference of the increase rate is large.

In the Case of B and C (30 min $\leq T_{sw} <$ 60 min), multiplier of 3 was applied. additional analysis showed an increase of 141.5% (Case B) and 146.1% (Case C) over the internal event HEP. Although the increase rate is less than multiplier of 3 the applied result, it can be concluded that multiplier of 3 is representative of adequate conservatism.

In the Case D (60 min $\leq T_{sw}$), multiplier of 1 was applied. An additional analysis assuming there are an impact for operator due to the fire resulted in an increase of 96.4% over the internal event HEP.

3. Conclusions

The purpose of evaluating HEP in fire PSAs is to appropriately reflect the environmental impacts due to fire and the increased stress levels of the operators. Because of the dynamic behavior of the fire, complex engineering characteristics, and various uncertainties, many experiments and studies are needed to define and evaluate the PSFs due to the fire. Therefore, conservative evaluation like the multiplier method is inevitable at the current technology level.

However, if these conservative assessments fail to adequately address improvements for the vulnerability of the plant, the PSA can only be used as a risk measure.

To solve some of these problems, we proposed an improved multiplier method which may include reasonable conservatism compared to the existing calculation method.

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