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Preliminary Analysis of New Fire PSA Methodology for Main Control Room

H. S. Lee [a*]
[a]*KHNP Central Research Institute., 70, 1312-gil Yuseong-daero, Daejeon, 34101, Korea*
[*]*Corresponding author: hansul.lee@khnp.co.kr*

1. Introduction

A fire in the MCR (Main Control Room) of a NPP (Nuclear Power Plant) can cause evacuation of the operators in case of failure of the initial suppression and lead to the loss of control of the NPP during the evacuation of the operators. Loss of NPP control can lead to core damage. In most domestic NPPs, the MCR fire scenario is the most dominant fire scenario. This paper deals with the results of a Preliminary analysis of a new fire PSA (Probabilistic Safety Assessment) methodology (NUREG/CR-6850) jointly developed by NRC (Nuclear Regulatory Committee) and EPRI (Electric Power Research Institute) for the fire CDF (Core Damage Frequency) of MCR to reduce the total fire risk of NPPs [1]. Existing MCR fire risks were analyzed based on EPRI TR-105928 methodology [2]. The new fire PSA was applied for an equivalent comparison with MCR fire risk from existing PSA methodology.

2. Methods and Results

In this section, we have discussed the selection background of the reference NPP for preliminary analysis, the preliminary analysis method and application results of the new fire PSA methodology.

2.1 Selection Background of Reference Plant

A NPP with the largest fraction of MCR fire CDF in total fire CDF was selected as a preliminary analysis reference NPP. The table I shows the percentage of total fire CDF and MCR fire CDF by type of domestic operating NPPs. OPR-2 NPP was selected as the reference NPP.

Table I: Fraction of MCR fire CDF by reactor type

Type	Fraction of MCR Fire CDF (%)
WH-1	14.85
WH-2	25.00
WH-3	19.08
WH-4	21.67
OPR-1	46.99
OPR-2 (Reference)	**71.49**
OPR-3	62.88
OPR-4	59.36
FRA-1	9.81
FRA-2	10.87
CANDU-1	0.49
CANDU-2	1.30

2.2 Latest Fire Ignition Frequency

The MCR ignition frequency of the existing fire PSA methodology was evaluated based on NSAC-178L (1965 ~ 1988), the fire experience data of US nuclear power plant Published by EPRI [3]. The MCR ignition frequency of OPR-2 was classified as Group 1 and Group 2 according to the ignition sources in the MCR. The classification criteria for Group 1 and Group 2 are as follows.

- Group 1: Cabinets that directly affect the normal operation of the NPP in the MCR (e.g., Bench board)
- Group 2: Cabinets that do not directly affect the normal operation of the NPP in the MCR (e.g., Fire protection panel, Operator console etc.)

A fire in Group 2 ignition sources is expected to affect operator evacuation. However, they were screened out for equivalent comparison with existing fire PSA methodology and the ignition frequency of MCR was calculated to be 4.59E-03/yr. The ignition frequency of the MCR applying the latest ignition frequency was calculated as 4.91E-03/yr without considering the group 2 ignition source. The ignition frequency of the MCR was calculated to be 9.00E-03/yr considering the Group 2 ignition source [4].

2.3 Detailed Fire Modeling

The detailed fire modeling is related to fire severity (SF, Severity Factor) and failure probability of fire suppression (P_{ns}, Probability of Non-Suppression). Existing fire modeling applied a single value (Fixed value: 0.25) for the fire severity value. In the new fire PSA methodology, the fire severity evaluates the probability of fire propagation considering both the HRR (Heat Release Rate) distribution and the failure probability of fire suppression. Assuming the bench board in the MCR is a cabinet with multiple bundles of certified cables, the HRR presented in NUREG/CR-6850 Appendix E is 702 kW [1]. Applying the results of

CFAST (Consolidated Model of Fire Growth and Smoke Transport) analysis of NPP of the same reactor type, equipment within 1.74m around the ignition source is damaged before evacuation of the operator, and the probability of failure of the target is calculated to be 1.22E-04. Figure 1 shows the target damage probability according to distance in MCR

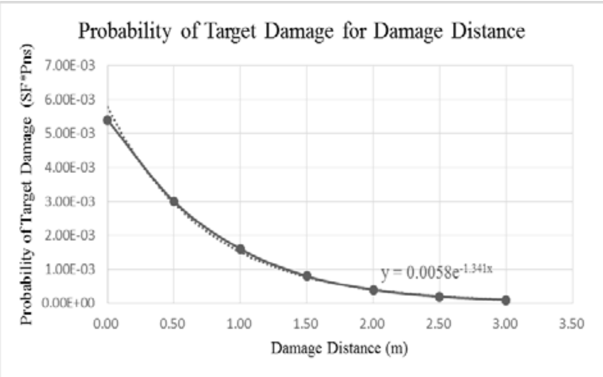

Fig. 1. Probability of Target Damage for Damage Distance

2.4 Review of Fire Scenario in MCR

In the existing fire PSA methodology, a fire scenario was defined based on the SNL (Sandia National Laboratory) cabinet test results. The growth of the fire is divided into three stages: initial, growth, and diffusion. The initial stage is defined as 5 minutes after the fire occurs. In the initial stage, the function of the bench board with fire is failed. The growth phase is defined as 5 to 15 minutes after the fire occurs. During the growth phase, the operator attempts to extinguish the fire. It is defined as the diffusion stage after 15 minutes of fire occurrence. In the diffusion phase, the fire spreads throughout the MCR, causing all equipment in the MCR to be damaged and the operator to evacuate. In the new fire PSA methodology, if the operator resides in the MCR, it is possible to immediately detect and suppress the fire in the MCR. Therefore, evacuation of the operators is evaluated as a dominant fire scenario rather than the damage caused by the fire spread.

2.5 Results of Preliminary Analysis

For comparison with the existing fire PSA results, only the bench board installed in the MCR was considered as an ignition source and the latest ignition frequency was applied. Based on the results of the CFAST analysis of the NPP of the same reactor type, the evacuation time of operators was changed from 15 minutes to 11.8 minutes. The fire severity and the failure probability of fire suppression were recalculated considering the HRR distribution. The operator recovery failure probability and malfunction probability are same as existing values. The CDF for each bench board in the MCR was calculated, and the CCDP (Conditional Core Damage Probability) due to the fire in the bench board was used the existing value. Table II shows the CDF for each bench board in MCR.

Table II: CDF change rate per bench board in MCR

Main Control Board	CDF change rate (%)
PM01	99.12% (▼)
PM02	99.12% (▼)
PM03	98.90% (▼)
PM04	96.99% (▼)
PM05	99.88% (▼)
PM06	(Screened out)
PM07	99.75% (▼)
PM08	99.31% (▼)
PM09	(Screened out)
PM10	99.87% (▼)
PM11	95.88% (▼)
Total	**98.81% (▼)**

A fire on the PM06 and PM09 bench boards can affect operator evacuation and damage adjacent bench boards during fire spread. However, they were excluded from the analysis for an equivalent comparison with the existing results. They also do not contribute to accident mitigation. As a result of applying the new fire PSA methodology, the fire CDF of MCR decreased by 98.91% compared to the previous result and the total fire CDF decreased by 29.36%. The results of the existing fire PSA methodology and the results of applying the new fire PSA methodology are compared in Table III.

Table III: Change rate of MCR and total fire CDF

Fire CDF (/yr)	CDF change rate (%)
MCR	98.81 (▼)
Total	29.36 (▼)

The reasons for the difference from the existing fire PSA results are as follows.

- In the existing fire PSA method, the fire severity value (SF, Severity Factor) was 0.25 (fixed value).
- In the existing fire PSA method, the failure probability of fire suppression (P_{ns}, Probability of Non-Suppression) is applied to the fixed value (1.20E-01 ~ 3.40E-3) according to the elapsed time of fire without considering the distance between the ignition source and the target and the evacuation start time of the operator.
- In the new fire PSA method, the fire severity and failure probability of fire suppression were calculated by using the fire detail modeling considering the evacuation start time of the operator, the distance between the ignition

source and the target, and the heat release rate of the ignition source (Existing fire PSA $SF \cdot P_{ns}$: 3.00E-02 ~ 8.50E-04 / New fire PSA $SF \cdot P_{ns}$: 1.22E-04).

The preliminary analysis results were derived using the same calculation formula (e.g., $CDF_{scenario} = \lambda \cdot SF \cdot P_{ns} \cdot CCDP$) as the existing fire PSA methodology and some factors in the calculation formula were recalculated by applying the new fire PSA methodology.

The operator evacuation scenarios are the most dominant scenarios in the existing fire analysis and the calculation formula of the existing fire analysis is as follows.

- $CDF_{evacuation} = \lambda \cdot SF \cdot P_{ns} \cdot$(failure rate of change-over switch + failure probability of Train B electrical equipment room cooling + failure probability of on-site manual action)

In the calculation of the operator evacuation scenarios, $SF \cdot P_{ns}$ was recalculated using the new fire PSA methodology (Existing fire PSA $SF \cdot P_{ns}$: 8.50E-04 / New fire PSA $SF \cdot P_{ns}$: 1.22E-04). As a result, the CDF of the operator evacuation scenarios were significantly reduced. As the CDF of the most dominant fire scenarios decreased, the total fire CDF was reduced.

From the point of view of applying the latest ignition frequency, ignition frequency of the new fire PSA methodology was increased by 6.52% than the existing ignition frequency, but the effect on the MCR fire CDF was insignificant.

3. Conclusions

In this paper, fire CDF of MCR is calculated by applying new fire PSA methodology without altering framework of existing fire PSA methodology. The results of applying the new fire PSA methodology are compared with the existing results and described in Section 2.5.

For comparison with the existing fire PSA results, only the bench board in the MCR was considered as an ignition source. Considering the ignition frequency of electrical cabinets such as fire protection boards and operator consoles in the MCR and the cables installed in the MCR floor, the fire CDF in the MCR can increase with the new fire PSA methodology. However, if the fire severity and the failure probability of fire suppression were calculated realistically, the increment of CDF due to the application of the latest ignition frequency can be reduced.

Through the preliminary analysis of the new fire PSA methodology, we confirmed the reduction effect of MCR fire CDF of domestic NPPs. The stepwise application of the new fire PSA methodology is expected to contribute to the management of the overall fire risk of domestic NPPs.

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