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Risk Assessment of Main Control Room Fires for Domestic NPP Based on NUREG-2178

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1. Introduction

A fire of NPP has been recognized as one of the main factors that threaten nuclear power plant (NPP) safety. Previous fire Probabilistic Safety Assessment (PSA) results [1] show that the main control room (MCR) fire is a significant contributor to the fire risk of NPP. The MCR of an NPP is constantly occupied and has the control and instrumentation circuits for all equipment vital to the normal, shutdown, abnormal, and emergency operations of the NPP. The main ignition sources of the MCR for the domestic conventional NPP are the main control bench board (MCB), electric cabinets, and transients.

Unlike the other fire areas of the NPP, the evacuation scenarios of the operators due to the fire as well as typical equipment damage scenarios must be addressed in the process of risk assessment of the MCR. Recently, NUREG-2178 (draft)[2] was published to improve the unrealistic risk assessment results from the previous methodologies especially for the MCB fire scenarios. However, it does not address the electric cabinets and transient fire scenarios. The objective of this study is to introduce the PSA results of the MCR fire for the domestic reference NPP based on NUREG-2178.

2. Methods and Results

In this section fire-induced core damage frequency (CDF) equation is described. The methodology of MCB fire risk is introduced and approaches for performing PSA for electrical cabinet and transient ignition sources in MCR are presented.

2.1 Equation of core damage frequency and abandonment criteria

The CDF from a fire can be represented by Eq. (1) [3].

$$CDF = \sum_{k=1}^{n} \lambda_k SF_k NS_k CCDP_k \qquad (1)$$

λ_k= fire frequency of fire scenario *k*,
SF_k= severity factor of fire scenario *k*,
NS_k= non-suppression probability of fire scenario *k*,
$CCDP_k$ = CCDP (conditional core damage probability) of fire scenario *k*

The forced abandonment conditions for the MCR fire were adopted from NUREG/CR-6850[3]:

- The heat flux at 1.8m (6') above the floor exceeds 1 kW/m2 (relative short exposure). A smoke layer of around 95°C (200°F) can generate such heat flux.
- The smoke layer descends below 1.8m (6') from the floor, and the optical density of the smoke is less than 3 m^{-1}.
- A fire inside the MCB damaging internal targets 2.13m (7') apart.

2.2 Event Tree of MCB, electrical cabinet and transient fires

As shown in Fig.1, the horseshoe type cabinets are the MCB. The MCB of conventional domestic NPP consists of multiple panels. Each MCB houses most of the plant control circuits within the scope of a fire PSA. A fire postulated within the MCB may simultaneously impact multiple trains or multiple systems credited in the fire PSA. USNRC and EPRI [2] developed a new methodology to overcome the limitations in the previous guidance for modeling the MCB fires. The new method is based on MCB operating experience and characterization of an event tree (ET) that captures the scenario progression of fire growth in the MCB. Fig. 2[2] shows the ET for the risk assessment of MCB fire scenarios.

MCR operators may be forced to leave due to electrical cabinets and transient fires as well as MCB fire. In NUREG-2178, there is no guidance on modeling for electrical cabinet and transient fires within the MCR. Thus, we developed the ETs for quantifying fire risk due to electrical cabinet and transient fires as shown in Fig. 3 and Fig.4.

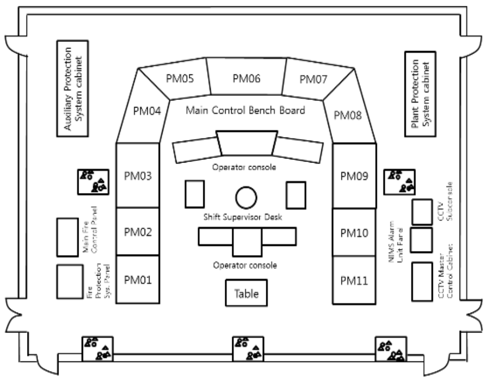

Fig.1. Overview of the MCB for the reference NPP

2.3 Risk Assessment Results

In the previous study [4], CCDP was assumed to be constant without detailed quantification for the fire-induced effects on equipment and operator actions. In this study, core damage frequency (CDF) due to MCB panel, electrical cabinet, and the transient fire scenarios was quantified with a one-top fire event PSA model of domestic reference NPP. For the risk assessment of MCB fires, the same input data [4] of the previous study [4] were used. Table I shows input parameters for the risk assessment of electrical cabinet fires which have not covered by the previous study [4]. Fire Dynamic Simulator(FDS)[5] was used for estimating the time to the MCR abandonment conditions. The FDS simulation results showed that the major factor causing the MCR evacuation was the optical density [6]. As shown in Table I, the evacuation time due to electrical panel fire was estimated at 15.17 min. On the other hand, the transient fire did not induce evacuation conditions.

Table I: Input parameters for the risk assessment of electrical panel fire of domestic NPP

Input Parameter	Input Value	Input Value Source
λ_g	3.37E-05	3.37e-5, electrical panel ignition frequency
δ	9.80E-01	98percentile
t_2	15.16	abandonment time from fire modeling result for single panel
t_3	15.16	abandonment time assumed from fire modeling result for two panels
$P_{ns}(10)$	2.13E-02	$P_{ns}(10)$=2.13E-2
$P_{ns}(t_2)$	2.92E-03	$P_{ns}(t_2)$=2.92E-3
$P_{ns}(t_3)^*$	1.37E-01	$P_{ns}(t_3)^*$ =MIN($P_{ns}(t_3)$/$P_{ns}(10)$,1), $P_{ns}(t_3)$=2.92E-3
μ	1.00E+00	1- habitable condition

The quantification results for the CDF due to MCR fire of each ignition source are presented in Table II. In Table II, CDFs for "IG source sub-total" and "Scenario sub-total" were normalized based on the CDF for all ignition source fires. Compared to the previous study results [1], Table II shows that the CDFs due to abandonment scenarios are relatively lower than those due to non-abandonment scenarios. It is also confirmed that electric cabinet fires and transient fires are to be considered when evaluating the MCR fire.

Table II: Quantification results of MCR fire for the domestic reference NPP

Scenarios	Ignition Sources			Scenario Sub-Total
	MCB	Electrical Cabinets	Transients	
Non-abandonment	8.060E-01	5.479E-01	9.993E-01	7.951E-01
Abandonment	1.940E-01	4.521E-01	7.083E-04	2.049E-01
IG source Sub-Total	9.561E-01	4.300E-02	8.756E-04	1.000E+00

3. Conclusions

This study introduced the PSA results of the MCR fire scenarios for the domestic reference NPP based on NUREG-2178. We developed the event trees for quantifying fire risk due to electrical cabinet and transient fires. The quantification results show that MCB panels are most risk-significant ignition sources among those related to MCR fire. The results also show that, unlike the previous study [1], the CDF due to abandonment scenarios is less than that due to non-abandonment scenarios. As a future study, circuit analysis is required for more realistic quantifications of MCR fire risk.

Acknowledgments

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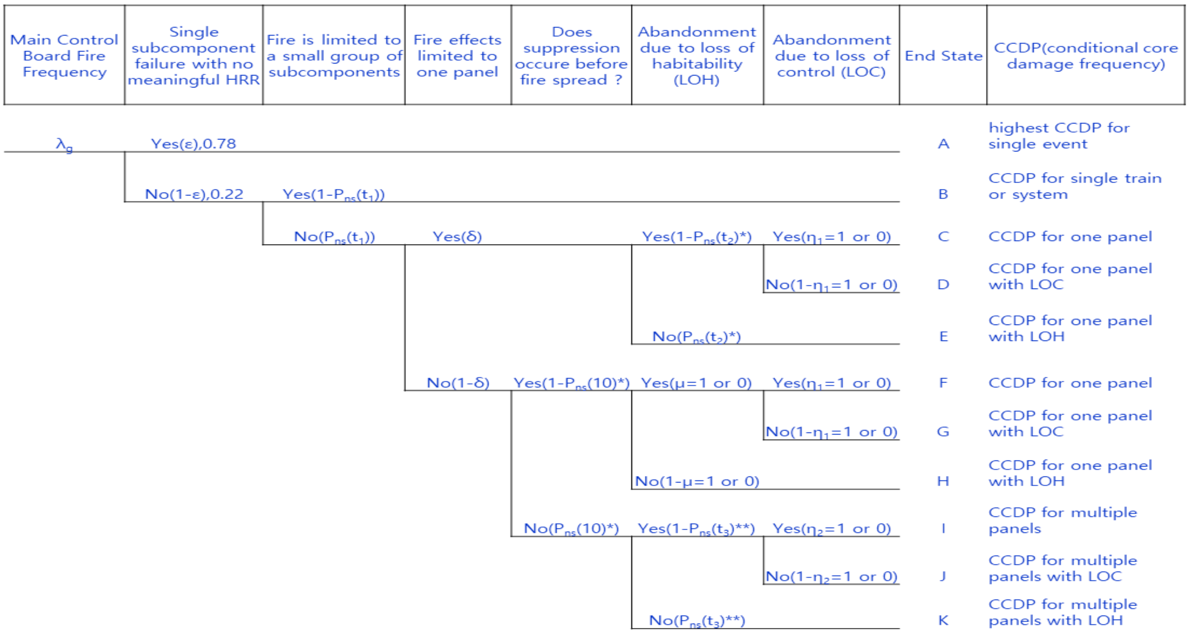

Fig. 2. Event Tree of MCB Fire

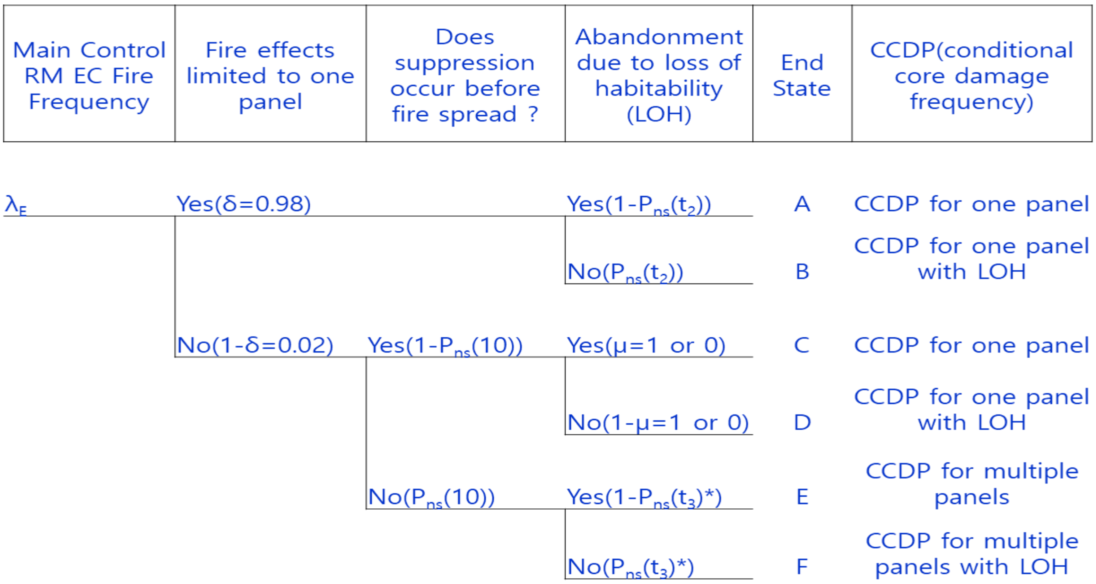

Fig. 3. Event Tree of Electrical Cabinet Fire in MCR

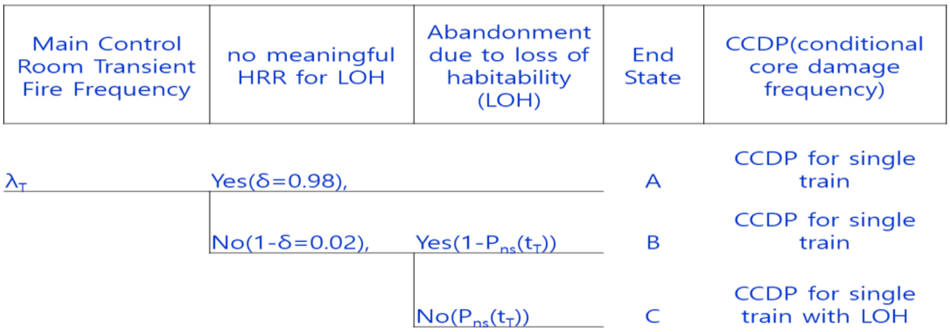

Fig. 4. Event Tree of Transient Fire in MCR