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Study of Severity Factor Calculation for Electrical Enclosures in Nuclear Power Plant for Fire PSA

Soyeon Kim*, Hongki Kim, Sanghyun Kim
KEPCO Engineering & Construction Company, Integrated Safety Assessment Dept., 269 Hyeoksin-ro, Gimcheon-si, Gyeongsangbuk-do, 39660, Republic of Korea
**Corresponding author: ssoyon44@kepco-enc.com*

1. Introduction

The internal fire risk analysis for Nuclear Power Plant is performed to estimate the contribution of internal fires to overall plant's Core Damage Frequency (CDF) and Large Release Frequency (LRF). It provides identification of any plant specific vulnerability to fire-induced accidents, and insights for plant design and construction.

Korea has performed fire Probabilistic Risk Assessment (PRA) for all plants (operating plants and plants under construction) by Fire PRA methodology NUREG/CR-6850 (Ref.2). It consists of 16 key subtasks, and Task 8 (Scoping Fire Modeling) of which is important task because it takes lots of effects to interfacing and following tasks. This task provides how to calculate severity factor values which is used to identify ignition sources that may impact the fire risk of the plant.

Among ignition sources in nuclear power plant, electrical enclosure fire scenarios are more significant than other ignition sources because they account for more than 30% for CDF and LRF respectively. For more realistic estimate of risk associated with electrical enclosure fires, lots of Fire PRA guidance and FAQs after NUREG/CR-6850 have been published. So, the latest data from these are covered for calculation of severity factor in this study.

In particular, NUREG/CR-6850 Supplement 1 (Ref. 3) provides the clarification of fire location depending on the presence or absence of enclosure vents. It is important for severity factors by discussing the potential for fire propagation beyond the enclosure. This study will focus on the approach, result and insight to this clarification by calculating severity factors of Motor Control Center (MCC) for unvented enclosure and Loop Controller for vented enclosure.

2. Fire PSA Severity Factor Calculations and Results

2.1 The Methodical Background

This section provides how to calculate severity factor for ignition sources based on Task 8 (Scoping Fire Modeling) of Fire PRA methodology NUREG/CR-6850 (Ref. 2). This task is for screening some of the ignition sources in the room, along with the application of severity factors to the unscreened ones.

2.1.1. Estimate Heat Release Rate (HRR) for Fixed Ignition Source Screening

The recommended heat release rate value for screening is the 98th percentile of the probability distributions for the different ignition sources listed in NUREG-2178, Vol 1 and Vol 2. The specific HRR distribution is assigned to each ignition source according to its type.

2.1.2. Target and Intervening Combustible Damage and Ignition Criteria

The identification of nearest ignition and damage targets will involve identifying cables as both ignition and damage targets. For cables, the ignition and damage criteria can be assumed to be the same. Heat flux and temperature criteria for damage/ignition are provided in Table I (Ref. 2).

Table I: Damage Criteria for Cables

Cable Type	Radiant Heating Criteria	Temperature Criteria
Thermoplastic	6 kW/m^2	205^{o}C
Thermoset	11 kW/m^2	330^{o}C

2.1.3. Develop Zones of Influence

A set of conservative fire modeling calculations are performed for predicting fire conditions near a target in order to assess if target damage or ignition occurs. Technical details on the determination of the Zone of Influence and calculation of severity factors are based on Appendix F in NUREG-2178, Vol.1.

An ignition source can be screened out if no relevant targets receive damage due to fire, and for ignition sources that are not screened, the severity factor of the fire is used to adjust the fire frequencies for a second round of quantitative screening.

Figure 1 illustrate the concept of Zone of Influence (ZOI). To estimate this fire behavior, the distance to the closest target has to be measured. In this study, hand calculations provided in NUREG-1805 are used.

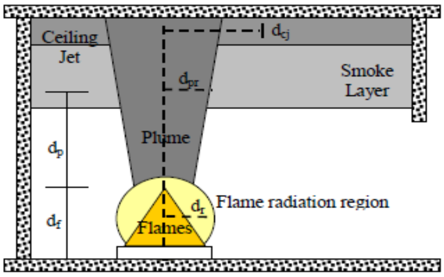

Fig. 1. Zone of Influence (ZOI) (Ref. 2)

2.1.4. Calculation of Revised Compartment Fire Frequency

The compartment fire frequencies are revised given by,

$$\lambda_{J,L} = \sum_{i=1}^{N} \lambda_{IS,J}\, SF_{IS,J} \quad (1)$$

In the formula (1), $\lambda_{IS,J}$ is the compartment frequency calculated in Task 6 (Fire Ignition Frequencies), and $SF_{IS,J}$ is the severity factor for ignition source IS in compartment J.

2.1.5. Calculation of Severity Factors

The severity factor is the area under the gamma probability distribution for the heat release rate to the right of the lowest heat release rate generating damage to the target. As an example, consider the case of a target within the damaging flame radiation illustrated in Figure. 2. Severity factors assigned will range from 0.02 to 1.0 because the screening criteria is based on the 98th percentile of the probability distributions for heat release rate. That is, equipment can be screened if the heat release rate required for generating damage to the nearest intervening combustible is lower than the 98th percentile of the gamma distribution.

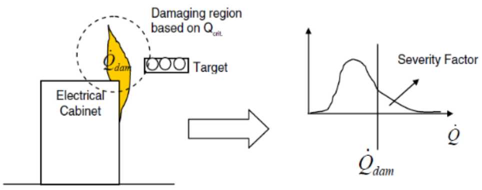

Fig. 2. Conceptual Representation of the Process of Calculating Severity Factors in Task8 (Reference [2])

2.2 Case Study and Results

This section provides applications of severity factor calculation method of electrical enclosures by identifying the positional relationship between the fire location and secondary combustibles. Cable risers are usually directly connected to the top of Motor Control Center and Loop Controller, so these are assumed to be the nearest secondary combustibles in following cases.

Case 1 Motor Control Center (MCC)

In case of MCC where is sealed on the top (without horizontal top vents of openings), assume the fire location to be one foot below the top of the enclosure according to FAQ 08-0043.

Considering plume effect of MCC, the scenario considers obstructed plume effect, suggest the reduction of 38% plume temperature from NUREG-2178, Vol.1. The heat release rate required to damage cable can be obtained using the following plume centerline temperature formula from NUREG-1805 (Ref. 1).

$$T_{p(centerline)} - T_a = \frac{9.1\left(\frac{T_a}{g * c_p{}^2 * p_a{}^2}\right)^{1/3} * \dot{Q}_C{}^{2/3}}{(z - z_0)^{5/3}} \quad (2)$$

Where,

- $T_{p(centerline)}$ = plume centerline temperature (K)
- T_a = ambient air temperature (K)
- $\dot{Q}_C$ = convective HRR (kW)
- g = acceleration of gravity (m/sec^2)
- c_p = specific heat of air (KJ/Kg-K)
- p_a = ambient air density (kg/m^3)
- z = elevation above the fire source (m)
- z_0 = hypothetical virtual origin of the fire (m)

In the formula (2), z_0 is about 0.3m (equal to one foot), and plume centerline temperature is 38% reduced value of the damage temperature criteria from Table I. In case of plume, two different severity factors can be obtained depending on the properties of the cables.

Considering flame effect of MCC, the fire location and nearest target is the same as for plume. The heat release rate required to damage cable can be obtained using the following flame height formula (3) from NUREG-1805.

$$H_f = 0.235\dot{Q}^{\frac{2}{3}} - 1.02D \quad (3)$$

In the formula (3), D is the diameter of the upper area of ignition source, and Q is 130kW which is the 98th percentile of the probability distributions for MCCs listed in NUREG-2178, Vol 1. The lowest heat release rate for needed to be flame height can be obtained from the formula (3).

Case 2 Loop Controller

In case of Loop Controller, it is assumed that the fire location to be the uppermost side vent. It's because when fire damage occurs, the fire would be assumed at the top of the door or opening described in FAQ 08-0042.

In this scenario, fire comes out of the vent located at both sides of enclosure. Zone of Influence is formed adjacent the vents of ignition source. Cable risers directly connected to the top of enclosure are not damaged because all intervening combustibles and targets affected by fire are limited to Zone of Influence surrounding the vents.

The following Table II provides results of severity factor for each case depending on the properties of the cable and Zone of Influence.

Table II: Result of Calculating Severity Factors

Ignition Source	Zone	Cable Type	Severity Factor
MCC	Plume	Thermoplastic	0.403
	Plume	Thermoset	0.308
	Flame	*	0.323
Loop Controller	Plume/ Flame	*	0

Note. * means both thermoplastic and thermoset cable types

3. Conclusions

In this study, calculating severity factor of electrical enclosures has been performed to understand the result of applying data and FAQs by newly published guidance.

According to the results, the vent location of electrical enclosures and the properties of targets are important factors in the determination of severity factor.

Fire location assumed to be one foot below the top for enclosure without horizontal top vents/openings has conservative result compared to vented enclosure. Although it is expected that the presence of vents is considered to have more severe fire impact on the plant where fire erupts from out of the ignition source, the analysis method with newly published guide data indicates that the impact of the ignition source without vents is more severe.

Also, depending on the properties of target, plume effect has conservative result compare to flame effect, even though the critical distance of plume from electrical enclosure is further than the flame as shown in Figure 1.

This result shows these limitations of the newly developed analysis method for calculating unvented electrical enclosures severity factor.

In the future, more accurate design information on the location and size of vents will be needed to assess the fire impact of electrical enclosures, and more research is needed on the fire propagation scenario in the unvented electrical enclosures.

REFERENCES

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