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Application of Fire Modeling Uncertainty Analysis to the Determination of Cable Failure

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1. Introduction

Recently USNRC published NUREG-1934[1] which presents a model uncertainty analysis method for a fire simulation. In NUREG-1934, the need for addressing input parameter uncertainty in a fire simulation is mentioned, but only a sensitivity analysis is suggested as a way of assessing input parameter uncertainty. In this paper, an input parameter uncertainty was performed using the Monte Carlo simulation and the Latin Hypercube sampling (LHS) technique, and the results were compared with those of the model uncertainty analysis and sensitivity analysis approaches of NUREG-1934. The simulated sample problem was the cabinet fire in a motor control center in a switchgear room, presented in Appendix D of NUREG-1934, and Fire Dynamics Simulator (FDS) 5.5 was used for the fire simulation. The purpose of the fire simulation is to determine whether cables within cable trays can be damaged in the simulated fire scenario.

2. Fire scenario and modeling

The motor control center in switchgear room considered in this study is a rectangular type compartment with different heights. The dimensions of the room are 17.1 m wide, 8.5 m deep, and 3.0m/9.1m high. There are two cabinets (A, B) and three cable trays (A, B, C) in the room. NUREG-1934 assumed that a fire starts within a motor control center cabinet A. The cables are assumed to be damaged when their exposure heat flux reaches 11kW/m^2.

The FDS program provided in Fire PRA workshop [2] was used for the fire simulation with some modifications of its input parameters. The FDS input parameters were mainly adopted from NUREG-1934 and the SFPE (Society of Fire Protection Engineers) Handbook. Table 1 shows the nominal values of the FDS input parameters and their uncertainty distributions. 100 sample calculations, which are greater than the 93 samples determined by Wilks' two-sided tolerance limit [3], were performed to increase the assurance of the Monte Carlo simulation. The 93 samples by Wilks' two-sided tolerance limit represent a 95% confidence interval within which 95% of the resulting distribution for the output lies. MOSAIQUE (Module for SAmpling Input and QUantifying Estimator) [4] was used to generate the random samples of the input parameters with the LHS and to perform a network-based computer run of the FDS input files.

3. Fire simulation results

3.1 Basic analysis results

Using the nominal values of Table 1, a basic simulation was performed to estimate the cable heat flux of each cable tray. The maximum cable heat fluxes of cable tray A, B, and C were predicted to be 46.3kW/m2, 5.67kW/m2, 1.8kW/m^2, respectively. Thus, based on the deterministic uncertainty analysis method of NUREG-1934, the damage probability of each cable was calculated as 0.99986, 1.59x10^{-3}, and 0, respectively. With information on the predicted heat fluxes and the estimated damage probabilities, we can determine with certainty that the cables in cable tray A will be damaged and the cables in cable tray C will not. However, the failure of the cables in cable tray B cannot be determined because its predicted maximum heat flux is 5.67kW/m^2. A sensitivity analysis for the cables in cable tray B showed that the peak heat release rate (HRR) to cause the cables in cable tray B to be damaged was 1196.9kW. Using the data for the HRR in Table 2, the value of the cumulative distribution function for Gamma function (x=1196.9, α=0.7, ß=216) was estimated to be 0.99827. With the damage probability of the cables in cable tray B and the sensitivity analysis result, we can determine that the cables in cable tray B will not fail due to a fire in cabinet A.

3.2 Uncertainty analysis results

As the effects of the fire in cabinet A on cable trays A and C could be definitely identified, an input parameter uncertainty analysis was performed for only the cables in cable tray B. The maximum heat fluxes of the cables in cable tray B for 100 sample simulations are presented in Fig. 1. There were two simulation results that exceed the damage criterion, 11kW/m^2. Thus, the damage probability of the cables in cable tray B was estimated as 0.02. If the best estimate safety analysis approach [5] of a nuclear power plant is applied to this study, the cables in cable tray B were determined to be damaged due to the fire in cabinet A. From this study, we can conclude that the input parameter uncertainty analysis approach may lead to more conservative results than the uncertainty analysis and sensitivity analysis method of NUREG-1934.

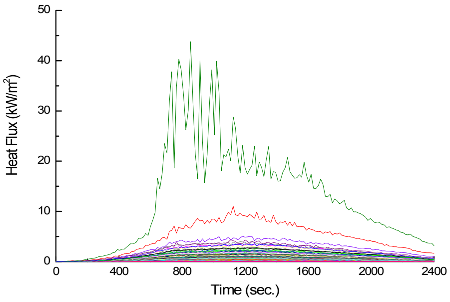

Fig. 1 Monte Carlo Simulation Results for Cable B

4. Concluding Remarks

This paper presents the uncertainty analysis results of fire modeling input parameters for motor control center in switchgear room of nuclear power plants. The study results showed that applications of the uncertainty analysis and sensitivity analysis methods of NUREG-1934 to the cables in cable tray B lead to a determination that they will not fail due to a fire in cabinet A. However, if the best estimate safety analysis approach of a nuclear power plant is applied to uncertainty analysis results of fire modeling input parameters, the cables in cable tray B were determined to be damaged. More efforts are needed to study on the incorporation of the fire modeling uncertainty analysis into the decision-making for the target failures.

Acknowledgements

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References

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[4] HO-GON LIM, ETC., "MOSAIQUE: A network based software for probabilistic uncertainty analysis of computerized simulation models", Nuclear Engineering and Design, Volume 241, pp1776-1784 2011

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Table 1. Nominal Value and Uncertainty Distribution of Input Parameters

Parameter description	Nominal Value	Parameter uncertainty	Uncertainty distribution
Concrete Wall			
Specific Heat	0.75 kJ/kg/K	$\sigma=0.15$, $\sigma/\mu=20\%$	Normal
Conductivity	1.6W/m^2/K	$\sigma=0.32$, $\sigma/\mu=20\%$	Normal
Density	2,400Kg/m^3	$\sigma=480$, $\sigma/\mu=20\%$	Normal
Emissivity	0.9	$\sigma=0.18$, $\sigma/\mu=20\%$, max=1	Normal
Cabinet-Steel			
Specific Heat	0.465 kJ/kg/K	ramp input Cp=0.425+7.73*10-4*T -1.69*10-6*T2+2.22*10-9*T3 (20~600℃ range) Cp=0.666+13.002/(738-T) (600~750℃ range)	Not Applicable
Conductivity	54W/m^2/K	ramp input, Conductivity=54-0.0333*T (20-800℃range)	Not Applicable
Density	7,850Kg/m^3	$\sigma=1{,}570$, $\sigma/\mu=20\%$	Normal
Emissivity	0.9	$\sigma=0.18$, $\sigma/\mu=20\%$, max=1	Normal
Cable-XPE/XLPE mixture			
Specific Heat	1.39kJ/kg/K	$\sigma=0.278$, $\sigma/\mu=20\%$	Normal
Conductivity	0.235W/m^2/K	$\sigma=0.47$, $\sigma/\mu=20\%$	Normal
Density	1,375Kg/m^3	$\sigma=275$, $\sigma/\mu=20\%$	Normal
Emissivity	0.9	$\sigma=0.18$, $\sigma/\mu=20\%$, max=1	Normal
Fuel			
HRR	702kW	$\alpha=0.7$, $\beta=216$	Gamma
Combustion Heat	28,300 kJ/kg	$\alpha=39.3$, $\beta=720$,	Gamma
Soot Yield	0.1	$\sigma=0.02$, $\sigma/\mu=20\%$	Normal
Radiative fraction	0.35	$\sigma=0.07$, $\sigma/\mu=20\%$	Normal
CO yield	$Y_{co}=0.00088+0.37*Y_s$, dependent on soot yield (Y_s)		
Ventilation			
Supply fan	-0.472m^3/s	Not Applicable	Not Applicable
Return Fan	0.472m^3/s	Not Applicable	Not Applicable