Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 29-30, 2015

Sensitivity Analysis on Fire Modeling of Main Control Board Fire Using Fire Dynamics Simulator

Dae Il Kang and Ho Gon Lim
KAERI, P.O.Box 105 Yusong, Daejeon, Korea, 305-353, dikang@kaeri.re.kr

1. Introduction

A main control board (MCB) fire can cause a forced main control room (MCR) abandonment of the operators as well as the function failures or spurious operations of the control and instrumentation-related components. If the MCR cannot be habitable, a safe shutdown from outside the MCR can be achieved and maintained at an alternate shutdown panel independent from the MCR.

When the fire modeling for an electrical cabinet such as an MCB was performed, its many input parameters can affect the fire simulation results. In this study, sensitivity analyses for an MCB fire were performed to identify the effects on the MCR forced abandonment time according to the changes of height and number for fire initiation places. Hanul Unit 3 NPP was selected as a reference plant for this study.

2. MCR features and fire modeling method

2.1 MCR features of Hanul Unit 3

The dimensions of the MCR for the reference NPP are 21.4 m wide, 18.4 m deep, and 3.6 m high. As shown in Fig. 1, the MCR has many kinds of cabinets. The horse shoe type cabinet in Fig. 1 is the MCB. During normal and emergency operations, the volume flow rate of supply air to the MCR is 7.08 m^3 /s (15,000 cubic feet per minutes (CFM)), and that of exhaust air from the MCR is 6.98 m^3 /s (14,800 CFM). The height of the MCB is 2.9 m. Any fire of the PM01 ~ PM11 control panels may lead to spurious operations or failures of the systems related to each MCB panel. A fire within each MCB panel may spread to a whole panel or be propagated to an adjacent panel.

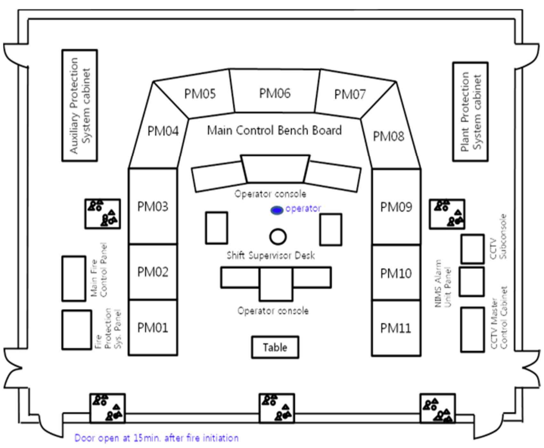

Fig. 1 Overview of the MCR for Hanul Unit 3

2.2 Fire modeling method

The forced abandonment conditions for the MCR fire used in this study were adopted from NUREG/CR-6850 [1]. It is assumed that the MCR abandonment initiates if one of the following criteria is satisfied:

- The heat flux at 1.8m (6') above the floor exceeds 1 kW/m^2. 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 from each other.

Among the above three conditions, the conditions directly related to the fire modeling for all fire scenarios are the heat flux, temperature, and optical density.

Table 1. Example of the discretized distributions and severity factors of HRR

Bin	Heat Release Rate - kW (Btu/s)			Severity Factor
	Lower	Upper	Point Value	(SFi)
1	0 (0)	90 (85)	34 (32.7)	0.506
2	90 (85)	179 (170)	130 (123)	0.202
3	179 (170)	269 (255)	221 (209)	0.113
4	269 (255)	359 (340)	310 (294)	0.067
5	359 (340)	448 (425)	400 (397)	0.041
6	448 (425)	538 (510)	490 (464)	0.026
7	538 (510)	628 (595)	579 (549)	0.016
8	628 (595)	717 (680)	669 (634)	0.01
9	717 (680)	807 (765)	759 (719)	0.006
10	807 (765)	897 (850)	848 (804)	0.004
11	897 (850)	986 (935)	938 (889)	0.003
12	986 (935)	1076 (1020)	1028 (974)	0.002
13	1076 (1020)	1166 (1105)	1118 (1060)	0.001
14	1166 (1105)	1255 (1190)	1208 (1145)	0.001
15	1255 (1190)	Infinity	1462 (1386)	0.001

The heat release rate (HRR), measured in kW or BTU/s, is the rate at which the combustion reaction produces heat and is the critical input parameter affecting the fire simulation results [1]. The discretized probability distributions of the HRR for the different ignition sources are presented in Appendix E of NUREG/CR-6850. Table 1 shows one example of the discretized distributions and severity factors of HRRs for vertical cabinets with a qualified cable, with a fire in more than one cable bundle. Fire simulations using the HRR point values from Bin 15 to Bin 1 in Table 1 are carried out to estimate the time to the MCR abandonment conditions. If the HRR of a specific Bin does not induce abandonment conditions, the fire simulations are stopped. In this study, FDS 5(5.5.5, SVN 7031) [2] was used for conducting fire simulations for an abandonment risk assessment of an MCB fire.

3. Fire scenarios and simulation results

The major assumptions used in the fire simulations were as follows:

- A postulated fire is assumed to be occurred at PM06. As shown in Fig. 1, the PM06 fire propagates to its side sections PM05 and PM07 at fifteen minutes after fire initiation.
- The growth rate of each fire is assumed to be proportional to the square of the burning time. The fire grows to a maximum value in 12 min, remains steady for 8 additional minutes, and decays linearly to 0 in 19 min.
- In base fire modeling, the height of the fire initiation places was assumed to be 2 m. And the fire initiation places were assumed to be constant even though PM06 fire spread to adjacent MCBs.
- In case of sensitivity analysis, the height of the fire initiation place was assumed to be 1 m. It was assumed that both PM05 and PM07 fires were initiated at fifteen minutes after the start of PM06 fire.

The fire simulations using FDS were performed to estimate the MCR abandonment time. Fire simulation results of the non-propagating fire are presented in Table 2 and those of the propagating fire are presented in Table 3. The numbers in Tables 2 and 3 shows the time to the MCR abandonment conditions, and N/A indicates no abandonment conditions. The fire simulation results of Table 2 and 3 showed that the major factor causing the MCR evacuation was the optical density. As shown in Table 2 and 3, the decrease in the height of fire ignition place shortens MCR abandonment time. Also, the use of single fire ignition place in fire modeling for the propagating fire does.

4. Concluding remarks

In this study, sensitivity analyses for an MCB fire were performed to identify the effects on the MCR forced abandonment time according to the changes of height and number of fire initiation places. This study results showed that the decrease in the height of fire ignition place and the use of single fire ignition place in fire modeling for the propagating fire shortened MCR abandonment time.

Acknowledgements

This work was supported by Nuclear Research & Development Program of the National Research Foundation of Korea (NRF) grant, funded by the Korean government, Ministry of Science, ICT & Future Planning.

REFERENCES

[1] Najafi, B., Nowlen, S. P., Joglar, F., Funk, D., Anoba. R. C., Kazarians, M., Wyant, F., Kolaczkowski, A., Hannaman, G., Forester, J., 2005, "Fire PRA methodology for nuclear power facilities", NUREG/CR-6850, USNRC.

[2] McGrattan, K., Klein, B., Hostikka, S., Floyd, J., 2010. Fire Dynamics Simulator (Version 5) User's Guide, NIST Special Publication 1019-5, FDS Version 5.5. National Institute of Standards and Technology, Gaithersburg, MD.

Table 2. Fire simulation results of the non-propagating fire

Scenarios	Criteria	Bin 5	Bin 6	Bin 7	Bin 8	Bin 9	Bin 10	Bin 11	Bin 12	Bin 13	Bin 14	Bin 15
		400	490	579	669	759	848	938	1028	1118	1208	1462
height−2m	T>95℃	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>1 kW/m^2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Opt.> 3m^{-1}	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	935	852	775
height−1m	T>95℃	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	>1 kW/m^2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Opt.> 3m^{-1}	N/A	N/A	N/A	N/A	N/A	N/A	N/A	937	857	807	762

Table 3. Fire simulation results of the propagating fire

Scenarios	Criteria	Bin 5	Bin 6	Bin 7	Bin 8	Bin 9	Bin 10	Bin 11	Bin 12	Bin 13	Bin 14	Bin 15
		1051.2	1287.7	1521.6	1758.1	1994.6	2228.5	2465.0	2701.5	2938.0	3174.5	3842.0
Fire ignition places−single	T>95℃	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1608	1562	1512	1412
	>1 kW/m^2	N/A	N/A	N/A	N/A	N/A	N/A	1652	1597	1557	1442	1377
	Opt.>3m^{-1}	N/A	1682	1570	1492	1382	1320	1232	1152	957	837	772
Fire ignition places−multiple	T>95℃	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1756	1602	1565	1452
	>1 kW/m^2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1755	1665	1545	1447
	Opt.>3m^{-1}	N/A	N/A	1630	1520	1457	1331	1247	1175	910	840	782
Fire ignition paces −multiple, height−1m	T>95℃	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1756	1602	1532	1427
	>1 kW/m^2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1755	1665	1567	1452
	Opt.>3m^{-1}	N/A	1662	1572	1487	1392	1257	1172	942	867	802	757