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Risk Assessment of the Main Control Room Fire Using Fire Simulations

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1. Introduction

Level 1 PSA (probabilistic safety assessment) results [1] of Ulchin Unit 3 using the EPRI PRA (probabilistic risk assessment) implementation guide [2] showed that the MCR (main control room) fire was the main contributor to the core damage frequency. Recently, USNRC and EPRI developed NUREG/CR-6850 to provide state-of-the-art methods, tools, and data for the conduct of a fire PSA for a commercial NPP [3]. KAERI is performing a fire PSA for a reference plant, Ulchin Unit 3, as part of developing the Korean site risk profile (KSRP). Fire simulations of the MCR fire were conducted using the CFAST (Consolidated Fire Growth and Smoke Transport) model and FDS (fire dynamic simulator) to improve the uncertainty in the MCR fire risk analysis. Using the fire simulation results, the MCR abandonment risk was evaluated.

2. Risk Assessment and MCR features

2.1 Risk assessment of the MCR fire

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

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

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 main fire ignition sources addressed in the MCR fire are the MCB (main control board), electrical cabinets, and transient combustibles. The MCR abandonment and non-abandonment scenarios are in general considered for each ignition source. For the case of the risk analysis owing to the MCR abandonment, the fire modeling is performed to evaluate the severity factor and non-suppression factor. The CCDP is calculated using the plant PSA model with a consideration of the operator performance for the MCR evacuation.

2.2 MCR features of Ulchin Unit 3

The dimensions of the MCR are 21.4 m wide, 18.4 m deep, and 3.6m high. As shown in Fig.1, the MCR has many kinds of cabinets and desks. The front wall of the MCR is constructed out of concrete and glass. The other walls are made of concrete. The ceiling is constructed out of gypsum board. The floor is a slab of concrete covered with gypsum board and steel.

During the normal and emergency operations, the volume flow rate of supply air to the MCR is 15,000 CFM and that of exhaust air from the MCR is 14,800 CFM. Thus, the pressure of the MCR is maintained at an approximately 31.4 Pa overpressure compared with the adjacent compartments. The number and total area of the supply vents are 24 and 3.45m^2, respectively. Those of the return vents are 15 and 10.8m^2, respectively.

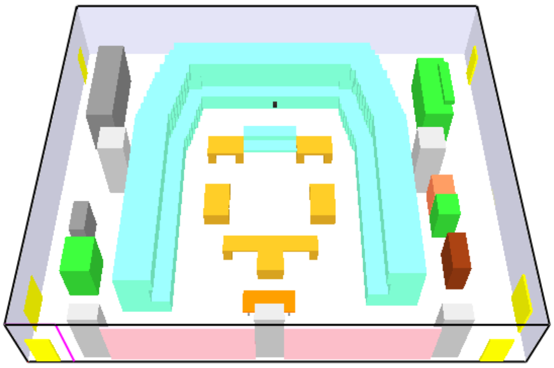

Fig. 1 Smokeview rendering of the MCR

3. Fire simulations

3.1 Fire scenarios and assumptions

The MCB fire, electrical cabinet fire, and transient fire were assumed to occur in the MCR. To evaluate the MCR habitability conditions, one of the following criteria of NUREG/CR 6850 were applied:

- The heat flux at 1.7m above the floor is greater than 1000W/m^2.
- The temperature at 1.7m above the floor is greater than 95℃.
- The smoke layer descends below 1.7m from the floor and the optical density is above 3 m^{-1}.

According to the NUREG/CR-6850 guideline, the peak heat release rate for each fire source was subdivided into fifteen bins. The major assumptions used in the fire simulations were as follows:

- As shown in Fig. 2, the MCB fire propagates to both side sections of the MCB after fifteen minutes of fire initiation.
- One door is assumed to open after fifteen minutes of fire initiation.

- The growth rate of each fire is assumed to be proportional to the square of the burning time.
- The smoke purge system is not available. However, the normal or emergency HVAC system is operable or not depending on the location of the fire initiation.

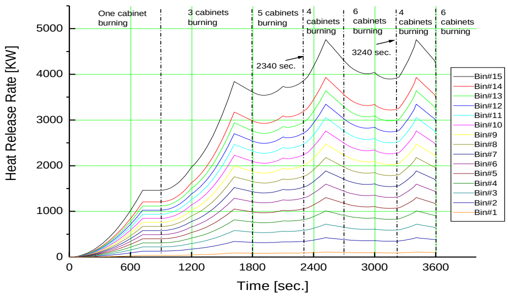

Fig.2 Heat release rate profiles for the MCB fire

3.2 Fire simulation results and risk assessment.

The fire simulations for each fire source in Fig. 1 using the CFAST model were performed to estimate the MCR abandonment time. Table 1 shows the fire simulation results of the peak heat release rate for each fire source. As the main contributor to the CCDP was assumed to be human error probability, the CCDP was estimated using NUREG-1921, Fire PRA HRA guidelines [4]. Table 2 shows risk assessment results of the MCB abandonment fire scenarios. The fire simulations for the MCB fire using the FDS were also performed to compare the FDS and CFAST simulation results. The CCDP calculated using the FDS simulation results is lower than that using the CFAST model.

4. Concluding remarks

Table 1. Fire simulation results of the MCR fire using the CFAST model

Scenarios	Criteria	BIN-1	BIN-2	BIN-3	BIN-4	BIN-5	BIN-6	BIN-7	BIN-8	BIN-9	BIN-10	BIN-11	BIN-12	BIN-13	BIN-14	BIN-15
MCB fire with HVAC	T>95℃ □	N/A	N/A	N/A	N/A	N/A	2450	2040	1605	1515	1445	1385	1310	1250	1195	715
	>1 kW/m^2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2510	2350	2100	1635	1585	1470
	Opt.> 3m^{-1}	N/A	N/A	N/A	N/A	2170	1560	1460	1360	1260	1180	1130	1110	1100	1085	1060
MCB fire w/o HVAC	T>95℃ □	N/A	N/A	N/A	N/A	N/A	1130	965	825	695	655	625	595	575	550	505
	>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	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	N/A	N/A	N/A	N/A	N/A	N/A	3350
ELE Cab. fire with HVAC	T>95℃ □	N/A	N/A	N/A	N/A	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	N/A	N/A	N/A	755
	Opt.> 3m^{-1}	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1000	990	985	970
Transient fire with HVAC	T>95℃ □	N/A	N/A	N/A	N/A	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	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	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Transient fire w/o HVAC	T>95℃ □	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	890
	>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	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	N/A	N/A	N/A	N/A	N/A	N/A	N/A

This paper presents the risk assessment results of the MCR fire using fire simulations. Compared with the previous industry study results [1], the MCR abandonment risk has decreased by approximately 70%.

Table 2. Risk assessment results of the MCB abandonment fire scenarios

Fire source	Fire Frequency	SF*NS*Other factor	CCDP	CDF
MCB	8.24E-04	3.62E-04	1	2.98E-07
Ele. Cabinet	1.86E-05	2.74E-04	0.04	2.04E-10
Transient	9.86E-05	4.24E-06	0.2	8.36E-11

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