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Evaluation of a Main Control Room Fire Risk

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1. Introduction

This paper introduces the evaluation process and results of MCR fire risk for Hanul Unit 3. KAERI is performing a fire PSA for a reference plant, Hanul Unit 3, as part of developing the Korean site risk profile. Evaluation of a MCR fire risk was performed using fire simulations, a fire human reliability analysis method, and the IPRO-ZONE [1]. The simulations of the MCR fire were conducted by using the FDS (fire dynamic simulator) [2] to estimate the severity factor (SF) and non-suppression probability (NS) for MCR abandonment fire scenarios. The scoping HRA approach of NUREG-1921 [3] was applied to estimate new human actions related to an MCR fire. The IPRO-ZONE was utilized to construct a one-top fire PSA model and generate the fire-induced equipment failure probability. In this study, the scenarios of forced abandonment caused by an ex-MCR fire were not addressed because their contribution to an MCR fire risk is expected to be insignificant [4].

2. Risk Assessment method and MCR features

2.1 Risk assessment method of the MCR fire

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

$$\mathrm{CDF} = \sum_{k=1}^{n} \lambda_k \mathrm{SF}_k \mathrm{NS}_k \mathrm{CCDP}_k \qquad (1)$$

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 fire frequency is calculated using NUREG/CR-6850 supplement 1 [5]. The SFs are given according to the heat release rate and the NSs are estimated using fire simulations. 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. As shown in Fig. 1, the evaluation logic for the risk assessment of an MCB fire was developed based on references [6, 7]. Sequences 1 and 4 in Fig. 1 represent MCR abandonment scenarios. Sequences 2 and 5 represent MCR non-abandonment scenarios. In general, fire propagation scenarios are not addressed for an electrical cabinet fire. For the case of a risk analysis for MCR abandonment, the fire modeling is performed to evaluate the SF and NS. For the MCB non-abandonment scenarios, appendix L of NUREG/CR-6850 [7] is used to estimate the SF and NS. The CCDP is calculated using the plant PSA model with a consideration of the operator performance for the MCR fire.

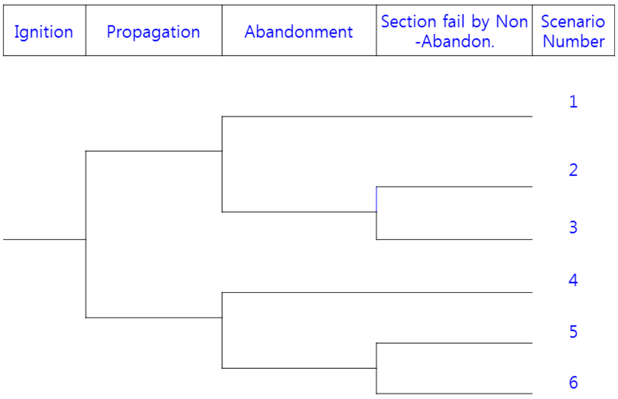


Fig. 1 Evaluation logic for MCB fires

2.2 MCR features of Hanul Unit 3

Descriptions of the bench-board and main electrical cabinets are presented in Table 1. Most equipment of NPP must be controlled and monitored in the MCR. If there is a fire in PM05, the reactor coolant system (RCS) or the subsystem of RCS may be spuriously operated or unavailable. The fire can be further propagated to the adjacent bench-boards.

Table 1. Descriptions of bench-board and cabinets

Pannel or CAB. No.	Description
PM01	Benchboard - HVAC system
PM02	Benchboard - Miscellaneous instrumentation(CCWS, ESWS, IAS etc.)
PM03	Benchboard - Engineered Safety Feature
PM04	Benchboard - CVCS & RCS
PM05	Benchboard - Reactor coolant system
PM06	Benchboard - Reactor control & protection system
PM07	Benchboard - Main steam
PM08	Benchboard - Condensate feedwater
PM09	Benchboard - Turbine auxiliaries
PM10	Benchboard - Site and aux power
PM11	Benchboard - Site and aux power
PM12	Panel - Fire protection system
PM13	Panel - NIMS alarm unit (ALMS, LPMS, IVMS)
PM14	Cabinet - Plant protection system
PM15	Cabinet - Auxiliary protection system

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. The front wall of the

MCR is constructed out of concrete and glass. The other walls are made of concretes. The ceiling is constructed out of gypsum board. The floor is a slab of concrete covered with gypsum board and steel.

During 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. The smoke detector is installed on each MCB and electrical cabinet. Also, air sampling smoke detectors are installed for early detection of a fire in the under-floor area.

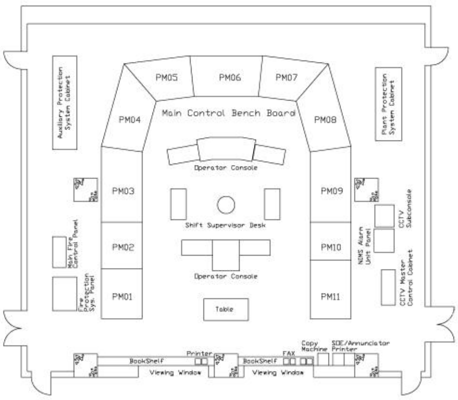


Fig. 2 Overview of the MCR for Hanul Unit 3

3. Risk evaluation

3.1 Abandonment fire scenarios

The simulations of the MCR fire were conducted using the FDS to estimate the SF and NS for MCR abandonment fire scenarios. 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 [7] were applied:

- The heat flux at 1.8m above the floor is above 1000w/m^2.
- The temperature at 1.8m above the floor is above 95℃.
- The smoke layer descends below 1.8m 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. As the smoke purge system is to be manually operated, it is assumed to be unavailable. The heating, ventilation, and air conditioning system (HVACS) is available or unavailable depending on the location of the fire initiation. As presented in Table 1, the HVACS is assumed to be unavailable if there is a fire in PM01, PM02, or PM10. The simulation results for PM02, PM03, and PM06 fires are presented in Table 2. Calculation results of the SV and NS for PM 2 fire are presented in Table 3.

3.2 Non-abandonment fire scenarios

Fig. 3, presented in Fig. L-1 of NUREG/CR-6850, was used to estimate SV and NS for non-abandonment fire scenarios. The distances of target sets in each MCB for Hanlul unit 3 MCR were estimated. As there is a smoke detector in each MCB and electrical cabinet, additional factors were considered to estimate NS according to FAQ 13-001[8].

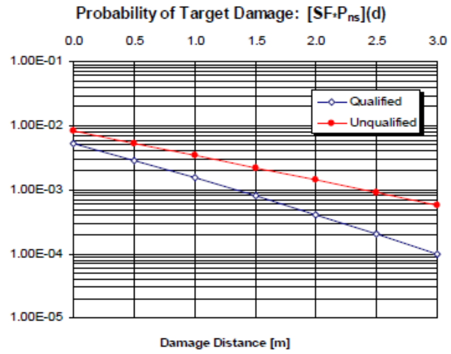


Fig. 3 Likelihood of target damage calculated as the SF times the NS for MCB fires

3.3 Construction of one-top fire PSA model and fire HRA

The IPRO-ZONE [1] was used to construct the one-top fire PSA model of Hanul Unit 3. Fig. 4 shows the relationship between the IPRO-ZONE, the AIMS-PSA, and one-top fire event PSA model. Equipment related to each MCB and cabinet in the MCR was identified to perform the PSA basic event mapping to it. Also, internal PSA fault trees were modified to include the fire-induced effects on the equipment. Additional event trees such as the large secondary side break B event tree were constructed for incorporating the fire-induced accident situations.

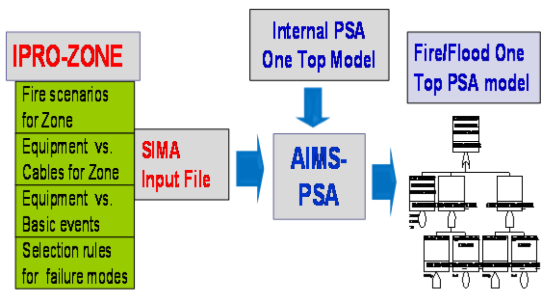
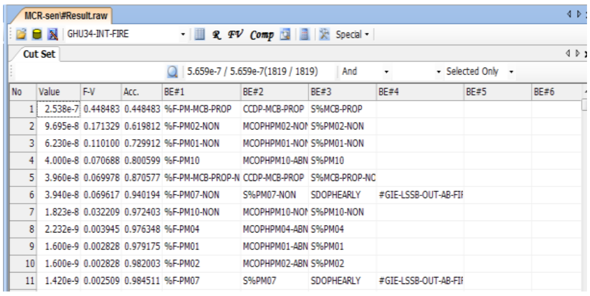


Fig. 4 Relationship between the IPRO-ZONE, the AIMS-PSA, and one-top fire event

Pre-existing internal human actions modeled in the internal PSA were re-quantified to include the fire situations. Based on reference [9], a multiplier of 10 was used to re-estimate the human error probabilities (HEPs) for the pre-existing internal human actions. The HEPs for all ex-MCR actions were assumed to be 1. If the re-quantified pre-existing internal human action were identified to be significant, the scoping HRA method of NUREG-1921 [3] was applied for them. New human actions related to the MCR fire were quantified using the scoping HRA method of NUREG-1921. Abnormal operation procedures were reviewed and operator interviews were conducted to identify critical human actions and to estimate their performance time. Table 4 shows the HRA results for human actions related to MCR abandonment scenarios.

3.4 Risk evaluation of MCR fire scenarios

The quantification results are presented in Fig. 5. The CDF of MCR fire was quantified as 5.659E-7/yr. The CDF for MCR abandonment scenario was estimated as 3.04E-7/yr and that for MCR non-abandonment scenario was 2.62E-7/yr. The first main contributor to an MCR fire risk was identified as propagating the abandonment fire scenario. The second main contributor was identified as a non-abandonment fire scenario in PM02. Compared with the previous industry study results [10], the MCR risk has decreased by approximately 66%.



No	Value	F-V	Acc.	BE#1	BE#2	BE#3	BE#4	BE#5	BE#6
1	2.538e-7	0.448483	0.448483	%F-PM-MCB-PROP	CCDP-MCB-PROP	S%MCB-PROP			
2	9.695e-8	0.171329	0.619812	%F-PM02-NON	MCOPHPM02-NON	S%PM02-NON			
3	6.230e-8	0.110100	0.729912	%F-PM01-NON	MCOPHPM01-NON	S%PM01-NON			
4	4.000e-8	0.070688	0.800599	%F-PM10	MCOPHPM10-ABN	S%PM10			
5	3.960e-8	0.069978	0.870577	%F-PM-MCB-PROP-N	CCDP-MCB-PROP	S%MCB-PROP-NC			
6	3.940e-8	0.069617	0.940194	%F-PM07-NON	S%PM07-NON	SDOPHEARLY	#GIE-LSSB-OUT-AB-FII		
7	1.823e-8	0.032209	0.972403	%F-PM10-NON	MCOPHPM10-NON	S%PM10-NON			
8	2.232e-9	0.003945	0.976348	%F-PM04	MCOPHPM04-ABN	S%PM04			
9	1.600e-9	0.002828	0.979175	%F-PM01	MCOPHPM01-ABN	S%PM01			
10	1.600e-9	0.002828	0.982003	%F-PM02	MCOPHPM02-ABN	S%PM02			
11	1.420e-9	0.002509	0.984511	%F-PM07	S%PM07	SDOPHEARLY	#GIE-LSSB-OUT-AB-FII		

Fig. 5 Evaluation result of MCR fire risk

4. Concluding remarks

This paper presented the risk evaluation results of an MCR fire for Hanul Unit 3 using fire simulations, a fire human reliability analysis method, and the IPRO-ZONE. Fire scenarios were classified into forced abandonment of MCR and non-abandonment of it. They were further classified into propagating and non-propagating fire scenarios. The CDF of an MCR fire was quantified as 5.659E-7/yr.

Compared with the previous industry study results [10], the MCR fire risk has decreased by approximately 66%. In general, the MCR fire scenarios cover all fires that occur within the MCR. Also, they include scenarios involving fires in compartments other than the MCR that may force MCR abandonment. In this study, though forced abandonment scenarios caused by an ex-MCR fire were not addressed, their contribution to MCR fire risk is expected to be insignificant.

Acknowledgements

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REFERENCES

[1] Dae Il Kang et al., “Development of the IPRO-ZONE for internal fire probabilistic safety assessment”, Nuclear Engineering and Design, Vol. 257, page 72–78, 2013.
[2] Kevin McGrattan et al., "Fire Dynamics Simulator (Version 5) User''s Guide", NIST Special Publication 1019-5, National Institute of Standards and Technology, FDS Version 5.5,
[3] S.Lewis et al., “EPRI/NRC-RES Fire Human Reliability Analysis Guidelines”, NUREG1-1921, USNRC, 2012
[4] Private communications with Dr. Jo, 2013
[5] K. Canavan and J.S. Hyslop, "Fire Probabilistic Risk Assessment Methods Enhancements", NUREG/CR-6850 Supplement 1, USNRC, 2010
[6] Francisco Joglar and Guy Ragan, “Modeling main control room fire”, PSA 2013 Topical Meeting, USA, 2013.
[7] Najafi, B., et al, “Fire PRA methodology for nuclear power facilities”, NUREG/CR-6850, USNRC, 2005
[8] NEI, “FAQ 13-001, Clarifications on treatments of VFWDS”, NEI 2013
[9] Don E. Macleod et al., “Simplified HRA process for internal fire analyses”, ANS PSA 2008 Topical Meeting Gaithersburg, MD, 2010.
[10] KOREA HYDRO & NUCLEAR POWER CO., LTD, “Probabilistic Safety Assessment for Ulchin Units 3&4 [Level 1 PSA for External Events : Main Report]”, 2004.9

Table 2. Fire simulation results of the MCR fire using the FDS

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 PM 6 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	732	657
	>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
MCB PM 3 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	1022	850	742
	>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
MCB PM 2 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	870
	>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	1670	1520	1460	1327	1320	1255	1242	1240	1145	1100	970	910	877	800

Table 3. Calculation results of the SV and NS for PM 2 fire

bin	HRR(kW)	SF	Time to Abandonment(sec.)	NS	(SF*NS)
1	34	0.506	N/A	0.00E+00	0
2	130	0.202	1670	1.00E-03	2.02E-04
3	221	0.113	1520	1.00E-03	1.13E-04
4	310	0.067	1460	1.00E-03	6.70E-05
5	400	0.041	1327	1.00E-03	4.10E-05
6	490	0.026	1320	1.00E-03	2.60E-05
7	579	0.016	1255	1.01E-03	1.61E-05
8	669	0.01	1242	1.08E-03	1.08E-05
9	759	0.006	1240	1.09E-03	6.55E-06
10	848	0.004	1145	1.84E-03	7.36E-06
11	938	0.003	1100	2.36E-03	7.07E-06
12	1028	0.002	970	4.82E-03	9.64E-06
13	1118	0.001	910	6.70E-03	6.70E-06
14	1208	0.001	877	8.04E-03	8.04E-06
15	1462	0.001	800	1.23E-02	1.23E-05
Total					5.34E-04

Table 4. HEPs of critical human actions for MCR abandonment scenarios

MCBs	postulated IEs	Systems	Critical human actions	HEPs	Table of NUREG-1921
PM01	TLOCCW	HVAC, ECWS	RSP transfer (EER, RSP)	4.00E-02	ASD15
PM02	TLOCCW	CCWS, ESWS, IAS	RSP transfer (EER, RSP)	4.00E-02	ASD15
PM03	TR	LPSIS, CSS, HPSIS	RSP transfer (EER, RSP)	4.00E-02	ASD15
PM04	SLOCA	CVCS, RCGVS	RSP transfer (EER, RSP), local action for HPSIS	1.00E+00	ASD25
PM05	TR	SDS, RCS, RCP	RSP transfer (EER, RSP)	4.00E-02	ASD15
PM06	TR	PPS, RPS related instrumentation	RSP transfer (EER, RSP)	4.00E-02	ASD15
PM07	LSSBOUT	MSS(ADV, TBV), AFWS	RSP transfer (EER, RSP)	4.00E-02	ASD15
PM08	LOMF	Condenser, MFWS, CWS	RSP transfer (EER, RSP)	4.00E-02	ASD15
PM09	LOMF	TBCCW, FW	RSP transfer (EER, RSP)	4.00E-02	ASD15
PM10	SBO	Class 1E 4.16KV, EDG C/B	RSP transfer (EER, RSP), local actions for 4.16KV bus and EDG C/B	1.00E+00	ASD25
PM11	LOOP	PCB, Non class 1E	RSP transfer (EER, RSP)	4.00E-02	ASD15