Risk Assessment of Oil Fire Scenarios for Domestic Nuclear Power Plant

Dae Il Kang* and Yong Hun Jung
KAERI, 111 Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, 34057, Republic of Korea
**Corresponding author: dikang@kaeri.re.kr*

1. Introduction

A fire of nuclear power plants (NPPs) has been recognized as one of the main factors that threaten NPP safety. A fire event probabilistic safety assessment (PSA)[1] is one of the main methods to analyze the fire safety of NPP. Fire risk, generally represented as core damage frequency (CDF), is assessed through the estimation of fire ignition frequency, the calculations of severity factor and non-suppression probability, and the quantification of conditional core damage probability. Oil fires at NPPs can occur in fire areas with pumps, hydraulic valves, or diesel generators. In general, deterministic fire safety analysis is performed based on the assumption that an oil spill of 100% of the oil capacity occurs. However, a fire event PSA for oil fire is conducted according to the several scenarios based on review results of oil fire event data. The purpose of this paper is to introduce oil fire risk assessment methods in a fire event PSA and to evaluate oil fire risk for domestic reference NPP[2].

2. Methods and Results

2.1. Estimation of Oil Fire Frequency and Assigning the Severities According to Fire Scenarios

Table I [1,3] shows Bin IDs representing oil fires in ignition sources considered in the full-power fire PSA. For example, in the case of a pump fire with Bin ID 21, the pump fire frequency is 2.72E-2/yr, the electric fraction is 0.54 and the oil fraction is 0.46. The oil fire frequency of the pump is then 1.25E-2/yr (2.72E-2/yr * 0.46).

A typical oil fire risk assessment determines the amount of oil that can be spilled in the room. Next, it assigns severities according to fire scenarios as Table II [1,4,5]. The generic pump oil fire of Table II is applicable to the pumps of smaller oil capacity than main feed water pumps. In NUREG/CR-6850[1], there was only one approach for assigning likelihoods to postulated sizes of oil spills; the likelihood of 0.98 to a scenario consisting of 10% of the amount of oil spilled and ignited, and the likelihood of 0.02 to a scenario consisting of 98% or more of the amount of oil spilled and ignited.

2.2 Strategy for Addressing Oil Fire Risk Assessment

In the event of an oil fire, the fire modeling tool is used to identify whether the secondary combustible is affected or not. If an oil fire is found to affect secondary combustibles, the fire model should be taken into account not only oil fire ignition sources but also secondary combustibles to identify the damaged targets and whether the fire is spread to neighboring fire areas. Based on the oil fire severity assessment guidelines mentioned above, the oil fire risk assessment is generally performed in the considerations of the following three scenarios:

- Damage of the oil spill equipment only: In this case, it is not necessary to perform the fire modeling. The oil fire risk assessment considers only oil spill equipment to evaluate the risk.
- 10% oil spill: Fire modeling is performed to identify potential secondary combustibles and targets. The fire risk is assessed by considering oil spill equipment and affected targets.
- 100% oil spill: Fire modeling is performed to determine whether a fire is spread to neighboring fire areas or not, and to identify the targets. If a fire spreads to neighboring fire areas, the risk will be assessed by considering equipment located at not only oil fire-causing areas but also neighboring fire areas.

Table II: Severities of fire scenarios according to oil fire types

Oil fire types	100% oil spill (severity)	10% oil spill (severity)	Equipment only(severity)
Typical oil fire [4]	0.02	0.98	Not Applicable
Generic pump oil fire[4]	0.05	0.07	0.88
Main feed water pump oil fire[5]	0.00034	0.0306	0.966
Turbine Generator Oil fire [1]	Severity 0.95: damage is assumed to be limited to the T/G systems and any components in the vicinity of the T/G. Severity 0.05: 20ft^2 oil spill (3-4 MW Fire), Possible oil run down to lower elevations, Possible structural failures above oil fire, Potential migration of heavy smoke into the control room or other areas where operators may need to be present to achieve safe shutdown		

2.3 *Design of the ESWS Building for Domestic NPP*

We selected the essential service water system(ESWS) building of domestic reference NPP for the risk assessment of oil fire scenarios[2]. The ESWS building consists of two fire areas (000-K02/K01) and is adjacent to the component cooling water system (CCWS) heat exchanger building (000-D01/D02). Details of each fire area are as follows:

- 000-K02: ESWS building A. It consists of two fire rooms 069-K02 and 090-K02. It is adjacent to the fire areas 000-K01 and 000-D01 (fire rooms 078-D01/100-D01)
- 000-K01: ESWS building B. It consists of two fire rooms 069-K01 and 090-K01. It is adjacent to the fire areas 000-K02 and 000-D02 (fire rooms 078-D02/100-D02)

The ESWS pump room A/B (069-K02/K01) of the reference domestic NPP is located in the lower part of the ESWS building. The heating, ventilation, and air conditioning(HVAC) room (090-K02/K01) is placed in the upper part of the ESWS building. As shown in Fig.1, the ESWS Pump Room A is located on the right side of the ESWS Pump Room B. There is a grating between the ESWS pump room and the ESWS HVAC room, allowing the ESWS pump room to be overlooked from the ESWS HVAC room, leaving the two rooms virtually open. There is no penetration between ESWS pump rooms A and B. The ESWS HVAC rooms A and B are accessible between them through the fire doors. The long tunnel, located at the base of the ESWS pump room, is connected to the Piping area (078-D01, D02) of the Component Cooling Water System (CCWS) heat exchanger building.

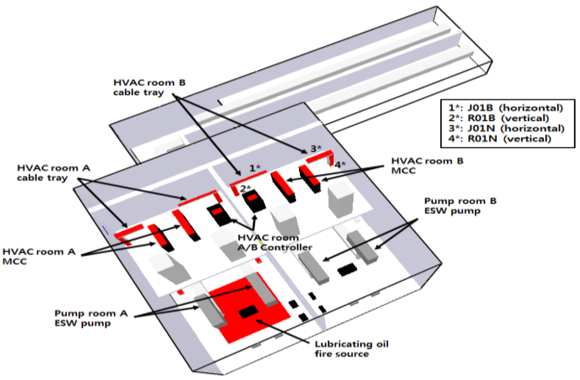

Fig. 1. The pump room and HVAC room of the ESWS building.

2.4 Fire Scenarios of ESWS Building

The ignition sources of each fire room for the ESWS building are as follows:

- ESWS pump room (069-K02/K01): Junction boxes, pumps, cables, transients
- ESWS HVAC room (090-K01/K02): Junction boxes, electrical cabinets, ventilation subsystems, cables, transients

The oil fire under consideration can occur in the pump room. Each pump room has two ESWS pumps, two ESWS screen wash pumps, and one ESWS sump pump. Of the oil fires from ESWS pumps, those from two ESWS pumps were considered. Other pumps were not considered due to their small pump size and their small amount of oil capacity. Since the ignition frequency for the five pumps in each pump room was evaluated at 7.08E-04/yr, that of each pump is 1.4E-3/yr. Thus, the oil fire frequency for the two ESWS pumps was evaluated at 1.3E-4/yr considering the oil fire fraction of 0.46 in the pump fire.

The oil fire may spread to the HVAC room of the same train as well as to neighboring fire areas (from A to B or from B to A). References [6,7] show that the fire modeling results for oil fire in one ESWS pump are as follows:

- 10% oil spill: No other equipment in the ESWS pump room except pumps is affected.
- 100% oil spill: Equipment placed at not only the HVAC room of the same train but also the neighboring fire area are damaged. Equipment of CCWS Heat Exchanger fire area is not affected.

2.5 Risk Assessment Results

For the comparison of oil fire risk with other ignition source risks in the ESWS building, all the fire scenarios of the ESWS building was quantified[2]. Table III shows the risk assessment results, along with the fire scenario ignition frequency, target equipment, severity, non-suppression probability, and conditional core damage probability. As shown in Table III, suppression features were not credited for all the fire scenarios. The risk quantification was conducted using a one-top fire event PSA model for the reference NPP. The cut-off value used for the risk assessment was 1.0E-13/yr. In Table III, 069-K01/K02 fire scenarios represent the quantification results of entire pump room fires except for the oil fire scenarios. 090-K01/K02 fire scenarios indicate the quantification results of the entire HVAC room fires except for the oil fire scenarios. The oil fire scenarios are 069-K01/K02_F0/F1/F2, indicating that the pump itself is damaged (F0), 10% spill (F1), and 100 %o spill (F2). The 069-K01/K02_F2 scenarios damage all the equipment in the ESWS building. Of the total risk assessment results of the ESWS building, oil fire risk assessment results accounted for about 2%. This is expected to be due to the low severity of the 100% oil spill fire, which can be spread even if the oil fire is likely to spread to adjacent fire areas.

The conservative way to assess the risk of pump oil fire without fire modeling is to assume that fire spreads to neighboring fire areas when there is 100% or 10% oil spill. In this case, the 069-K01/K02_F1 fire scenario was assumed to be the 100% oil spill scenario. Then, the oil fire risk of each pump room was quantified to 1.26E-09/yr. The oil fire risk assessment result of the ESWS building increases by 68% compared with base oil fire risk results of Table III. However, the total fire risk of the ESWS building increase by only about 1%, and oil fire risk still accounts for 3.3% of the total fire risk of ESWS building. A lot of time and many efforts are required for the fire modeling in a fire event PSA. A simple way to reduce the burden for this is to conduct the risk assessment of oil fire scenarios without fie modeling. Detailed fire modeling for oil fire scenarios is performed if the quantification results of oil fire scenarios are risk-significant.

3. Conclusions

This study is to introduce oil fire risk assessment methods in a fire event PSA and to quantify oil fire risk for domestic reference nuclear power plant. We introduced the revised guidelines for assigning the severities for oil fire scenarios after the publication of NUREG/CR-6850. The essential service water system(ESWS) building of domestic reference NPP was selected for the risk assessment of oil fire scenarios. The quantification results of oil fire scenarios show that oil fire risk account for about 2% of the total fire risk for the ESWS building. The overall risk increase for the ESWS building was small even if the oil fire risk was assessed without fire modeling. More efforts are required for the study on the risk assessment of other oil fire scenarios.

Acknowledgments

This work was supported by Nuclear Research & Development Program of the National Research Foundation of Korea grant, funded by the Korean government, Ministry of Science and ICT (Grant number 2017M2A8A4016659).

REFERENCES

[1] Najafi, B. et al. Fire PRA methodology for nuclear power facilities, NUREG/CR-6850, USNRC, 2005.
[2] Dae Il Kang and Yong Hun Jung, Risk Assessment of Domestic Nuclear Power Plant Using the Recent Fire PSA Techniques, KAERI/TR-8119/2020. KAERI, 2020.
[3] A. Lindeman et al.,Nuclear Power Plant Fire Ignition Frequency and Non- Suppression Probability Estimation Using the Updated Fire Events Database, NUREG-2169, USNRC, 2015.
[4] USNRC, RECENT FIRE PRA METHODS REVIEW PANEL DECISIONS AND EPRI 1022993,“EVALUATION OF PEAK HEAT RELEASE RATES IN ELECTRICAL CABINET FIRES, Refined Treatment of Oil Pump Fires from NUREG/CR-6850, ML12171A583, 2012.
[5] FAQ 08-0044, Large oil fire size, ML092110516, 2009.
[6] Yong Hun Jung and Dae Il Kang, Review and Application of the Recent Modeling Approach for Liquid Fuel Fire Scenarios in Nuclear Power Plants, Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea, July 9-10, 2020
[7] Yong Hun Jung, Dae Il Kang, Sam Won Chung, and Seungjun Oh, Analysis of Liquid Fuel Spill Fire Scenarios in Domestic Reference Nuclear Power Plant Using the Recent Modeling Approach, Transactions of the Korean Institute of Fire Science and Engineering Spring Meeting, Jeju, Korea, July 2-09, 2020.

Table I: Oil-related ignition source bins and oil-fire fractions.

Bin ID	Location	Ignition Source	Generic Frequency(/yr) (NUREG-2169)	Electrical fraction (NUREG/CR-6850)	Oil fraction (NUREG/CR-6850)
2	Containment (PWR)	RCP	1.37E-3	0.14	0.86
8	DG room	DG	7.81E-3	0.16	0.84
9	Plant Wide Components	Air Compressors	4.69E-3	0.83	0.17
21	Plant Wide Components	Pumps	2.72E-2	0.54	0.46
23a	Plant Wide Components	Transformer (oil filled)	9.56E-3	0	1
26	Plant Wide Components	Ventilation subsystem	1.64E-2	0.95	0.05
30	Turbine Building	Boiler	1.09E-3	0	1
32	Turbine Building	MFW Pump	4.38E-3	0.11	0.89
35	Turbine Building	TG oil	5.49E-3	0	1

Table III. Fire risk assessment result of ESWS building

Scenarios	Scenario Description	Frequency (/yr)	Barrier Probability	Targets	Severity Factor	Non-Suppression Probability	Conditional Core damage probability	Risk results (/yr)
069-K01*	PUMP ROOM FIRE	9.31E-04	N/A	069-K01	1	1	1.67E-05	1.55E-08
069-K02*	PUMP ROOM FIRE	9.39E-04	N/A	069-K02	1	1	2.40E-05	2.25E-08
090-K01*	HVAC ROOM FIRE	1.11E-03	N/A	090-K01	1	1	1.67E-05	1.85E-08
090-K02*	HVAC ROOM FIRE	1.02E-03	N/A	090-K02	1	1	2.40E-05	2.44E-08
069-K01_F0	PUMP ROOM FIRE - PP ONLY	1.30E-04	N/A	ESW pump only	0.88	1	1.15E-06	1.32E-10
069-K01_F1	PUMP ROOM FIRE- 10% LEAK	1.30E-04	N/A	All pumps in 069-K01	0.07	1	1.53E-05	1.39E-10
069-K01_F2	PUMP ROOM FIRE- 100% LEAK	1.30E-04	7.40E-03	000-K01/K02	0.05	1	1.09E-02	5.26E-10
069-K02_F0	PUMP ROOM FIRE - PP ONLY	1.30E-04	N/A	ESW pump only	0.88	1	1.15E-06	1.31E-10
069-K02_F1	PUMP ROOM FIRE- 10% LEAK	1.30E-04	N/A	All pumps in 069-K02	0.07	1	2.24E-05	2.04E-10
069-K02_F2	PUMP ROOM FIRE- 100% LEAK	1.30E-04	7.40E-03	000-K02/K01	0.05	1	1.09E-02	5.26E-10

*: except oil fire scenarios