A Quantitative Study on Conservatism of the Currently Used Approach for Applying Non-Suppression Probabilities in a Fire Risk Assessment

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

1. Introduction

A fire event probabilistic safety assessment (PSA) is performed on a fire scenario basis. In other words, fire-induced risk, primarily represented as core damage frequency (CDF) for the level-1 PSA and large early release frequency (LERF) for the level-2 PSA, is assessed for each unique fire scenario. A fire scenario in a fire PSA is generally modeled as a progression of damage states of targets such as equipment and cables over time that is initiated by a postulated fire involving an ignition source.

The fire-induced CDF is assessed on a fire scenario as follows, and this paper only covers approaches for applying the non-suppression probability (NSP) of manual firefighting by a fire brigade to each fire damage state:

$$CDF_F = \sum(FIF_i \times SF_i \times NSP_i \times CCDP_{F,i})$$

Where
CDF_F : Fire-induced Conditional Core Damage Frequency
FIF_i : Fire Ignition Frequency
SF_i : Fire Severity Factor
NSP_i : Fire Non-Suppression Probability
$CCDP_{F,i}$: Fire-induced Conditional Core Damage Probability
i : Fire Scenario

The fire damage states (FDSs) are generally classified and defined as follows, and this paper only covers the cases where fires initiated by ignition sources may lead to the FDS0, 2, 3 and each FDS constitutes a single scenario:

- [FDS0]: Only ignition sources are damaged by the fire. The ignition source can also be a target by itself, such as an electrical enclosure, damage of which results in a CCDP greater than zero.
- [FDS1]: Components or cables near the fire ignition source (within the zone of influence) are damaged by the fire due to the vertical convective and/or radial radiative heat transferred from the fire.
- [FDS2]: All components or cables within the compartment of fire origin are extensively damaged by the fire due the development of a damaging hot gas layer.
- [FDS3]: All components or cables within the compartment of fire origin and an adjacent compartment are extensively damaged by the fire due to the development of a damaging hot gas layer and postulated fire spread through a failed fire barrier element between two compartments.

The objective of this paper is to analyze whether or not and in what condition the simple approach widely used at present in Korea for applying the NSP to each FDS scenario provides a conservative fire risk results.

2. Methods and Results

Fig. 1 show a conceptual Venn Diagram visualizing NSPs for FDS2 and FDS3 scenarios.

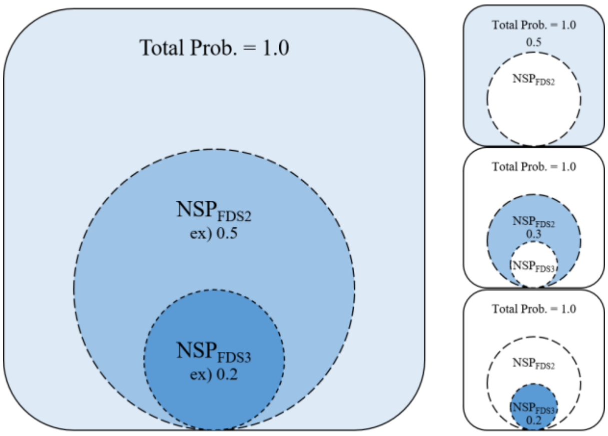

Fig. 1. A Conceptual Venn Diagram Visualizing Non-Suppression Probabilities for FDS2 and FDS3 scenarios.

As depicted in Fig. 1, an exact approach for applying the NSP to each FDS scenario is as follows:

A. Exact Approach:
[FDS0]: $(1\text{-}NSP_{FDS2}) \times (CCDP_{FDS0})$
[FDS2]: $(NSP_{FDS2}\text{-}NSP_{FDS3}) \times (CCDP_{FDS2})$
[FDS3]: $(NSP_{FDS3}) \times (CCDP_{FDS3})$

Meanwhile, instead of using the exact approach shown above, a relatively simple approach has been widely used until now in Korea like below:

B.I. Currently Used Approach for Case-I:
FDS0 Target Sets Do Involve PSA Equipment:
[FDS0]: $(1) \times (CCDP_{FDS0})$
[FDS2]: $(NSP_{FDS2}) \times (CCDP_{FDS2})$
[FDS3]: $(NSP_{FDS3}) \times (CCDP_{FDS3})$

The following clearly show that, under certain conditions (Case-I), the use of the simple approach provides some degree of conservatism (i.e., larger risk results) for FDS0 and FDS2 scenarios when compared with the exact approach:

➢ Comparison of the Approaches for Case-I:
[FDS0]: A<**B.I** by (NSP_{FDS2}) × ($CCDP_{FDS0}$)
[FDS2]: A<**B-I** by (NSP_{FDS3}) × ($CCDP_{FDS2}$)
[FDS3]: A=B.I

As mention, the comparison result shown above are only valid for conditions where target sets of the FDS0 scenarios (i.e., ignition source(s)) do involve equipment credited in the PSA models (Case-I). Under the conditions where target sets of the FDS0 scenarios do not involve PSA equipment (Case-II), the use of the simple approach expresses the risk result of each FDS scenario as follows:

B.II. Currently Used Approach for Case-II:
FDS0 Target Sets Do Not Involve PSA Equipment:
[FDS0]: N/A
[FDS2]: (NSP_{FDS2}) × ($CCDP_{FDS2}$)
[FDS3]: (NSP_{FDS3}) × ($CCDP_{FDS3}$)

The comparison result between two approaches under such conditions (Case-II) indicate that there is a tradeoff between risk results of FDS0 and FDS2 scenarios like below:

➢ Comparison of the Approaches for Case-II:
[FDS0]: **A**>B.II by (1-NSP_{FDS2}) × ($CCDP_{FDS0}$)
[FDS2]: A<**B.II** by (NSP_{FDS3}) × ($CCDP_{FDS2}$)
[FDS3]: A=B.II

If the following inequality is satisfied, one can conclude that the simple approach still provides conservative results in terms of total risk of all FDS scenarios when compared with the exact approach:

$$(NSP_{FDS3}) \times (CCDP_{FDS2}) > (1-NSP_{FDS2}) \times (CCDP_{FDS0})$$

For a more efficient analysis, the inequality can be simplified as follows:

$$R_{CCDP} > R_{NSP}$$

where

$$R_{CCDP} = (CCDP_{FDS2}) / (CCDP_{GTRN})$$

$$R_{NSP} = (1-NSP_{FDS2}) / (NSP_{FDS3})$$

This simplification is based on the fact that, under such conditions (Case-II), the FDS0 scenario only induces a plant trip without affecting any mitigating safety functions (i.e., general transient initiating event) like below:

$$(CCDP_{FDS0}) = (CCDP_{GTRN})$$

R_{CCDP} and R_{NSP} are only dependent on CCDP and NSP for each FDS scenario, respectively. NSP of the fire brigade response is generally calculated based on the method and data provided through NUREG/CR-6850[1-2], Sup. 1[3], NUREG-2169[4], NUREG-2178 Vol. 2[5], and NUREG-2230[6]. Fig. 2 show NSP curves for each suppression category with probability on y-axis and available time to suppression on x-axis.

R_{NSP} values calculated for "ALL: All Fires" category at various available times to suppression for FDS2/3 scenarios are summarized in Table I. For instance, the R_{NSP} value is calculated as 2.9 for "ALL: All Fires" category at available times to suppression of 20/20 minutes for FDS2/3 scenarios, respectively. This implies that the simple approach can provide conservative fire risk results if $CCDP_{FDS2}$ is 2.9 times greater than $CCDP_{GTRN}$. Note that $CCDP_{FDS2}$ is not only always greater than $CCDP_{GTRN}$, but also a few orders of magnitude greater than $CCDP_{GTRN}$ in most practical cases.

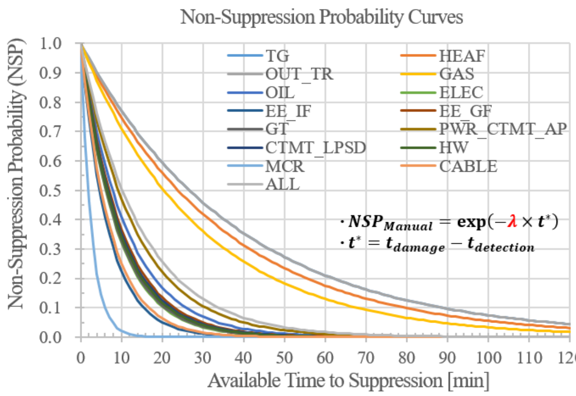

Fig. 2. Non-Suppression Probability Curves: Probability vs. Available Time to Suppression for each Suppression Category

Table I: *R* Values Calculated for "ALL: All Fires" Category at Various Available Times to Suppression for FDS2 and FDS3 Scenarios

Available Time [min] FDS2 / FDS3	$R_{NSP} = (1-NSP_{FDS2}) / (NSP_{FDS3})$ for "ALL: All Fires" Category
05 / 05	4.05E-01
05 / 10	5.69E-01
05 / 15	7.99E-01
10 / 10	9.74E-01
10 / 15	1.37E+00
10 / 20	1.92E+00
15 / 15	1.77E+00
15 / 20	2.49E+00
20 / 20	2.90E+00

3. Conclusions

The results of this study verified that, in most practical cases, the simple approach widely used at present in Korea for applying the NSP to each FDS scenario provides a conservative fire risk results.

Acknowledgements

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(Ministry of Science and ICT)(RS-2022-00144204).

REFERENCES

[1] EPRI and U.S.NRC-RES, "Fire PRA Methodology for Nuclear Power Facilities: Volume 1: Summary & Overview," Electric Power Research Institute (EPRI), Palo Alto, CA, and U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research (RES), Rockville, MD, Tech. Report. EPRI 1011989 and NUREG/CR-6850, Vol. 1, Sep. 2005.

[2] EPRI and U.S.NRC-RES, "Fire PRA Methodology for Nuclear Power Facilities: Volume 2: Detailed Methodology," EPRI, Palo Alto, CA, and U.S. NRC, RES, Rockville, MD, Tech. Report. EPRI 1011989 and NUREG/CR-6850, Vol. 2, Sep. 2005.

[3] EPRI and U.S.NRC-RES, "Fire Probabilistic Risk Assessment Methods Enhancements: Supplement 1 to NUREG/CR-6850 and EPRI 1011989," EPRI, Palo Alto, CA, and U.S. NRC, RES, Washington, DC, Tech. Report. EPRI 1019259 and NUREG/CR-6850, Sup. 1, Sep. 2010.

[4] EPRI and U.S.NRC-RES, "Nuclear Power Plant Fire Ignition Frequency and Non-Suppression Probability Estimation Using the Updated Fire Events Database: United States Fire Event Experience Through 2009," EPRI, Palo Alto, CA, and U.S. NRC, RES, Washington, DC, Tech. Report. EPRI 3002002936 and NUREG-2169, Sep. 2010.

[5] U.S.NRC-RES and EPRI, "Refining and Characterizing Heat Release Rates from Electrical Enclosures During Fire, Volume 2: Fire Modeling Guidance for Electrical Cabinets, Electric Motors, Indoor Dry Transformers, and the Main Control Board," EPRI, U.S. NRC, RES, Rockville, MD, and Palo Alto, CA, Tech. Report. NUREG-2178, Vol. 2 and EPRI 3002016052, Jun. 2020.

[6] EPRI and U.S.NRC-RES, "Methodology for Modeling Fire Growth and Suppression Response for Electrical Cabinet Fires in Nuclear Power Plants," EPRI, Palo Alto, CA, and U.S. NRC, RES, Washington, DC, Tech. Report. EPRI 3002016051 and NUREG-2130, Jun. 2020.