Review and Application of Updated Methods for Fire Detection and Suppression Analysis in Fire PSA

Yong Hun Jung [a*], Kyungho Jin [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*

***Keywords : probabilistic safety/risk assessment, fire detection, fire suppression, fire risk**

1. Introduction

Fire detection and suppression are key elements of the fire protection defense-in-depth strategy for nuclear power plants (NPPs). These involve plant features and personnel prepared to rapidly detect, control, and extinguish any fires that are not prevented. A fire probabilistic safety/risk assessment (PSA) incorporates an analysis of fire detection and suppression to determine the Non-Suppression Probability (NSP): the probability that a fire is not detected and suppressed before causing damage to a specific target set in a given fire scenario.

In a fire PSA, a fire scenario is typically modeled as a time-dependent progression of damage states affecting targets (e.g., equipment, cables), initiated by a postulated fire from an ignition source. Fire-induced risk, represented primarily by the core damage frequency (CDF) for Level 1 PSA and the large early release frequency (LERF) for Level 2 PSA, is assessed for each unique fire scenario.

The fire-induced CDF for a fire scenario is generally assessed using the following equation. However, this paper focuses specifically on methods for estimating the NSP:

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

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

This study reviews recently updated methods for the fire detection and suppression analysis in fire PSA, and applies them to example fire scenarios to evaluate their potential risk reduction benefits.

2. Review of Methods

NUREG/CR-6850 (EPRI 1011989) [1] Appendix P provides a method to estimate the NSP using the detection-suppression event tree (DSET). This DSET has seven (7) headings and fourteen (14) sequences based on fire detection and suppression features such as smoke and heat detectors, continuous fire watch, automatic and manual fixed suppression systems (water-based sprinklers, CO_2, Halon, etc.) and fire brigade capabilities (Fig. 1). Event tree (ET) parameters are estimated using available operating experience, human reliability analysis results, and manual NSP curves.

The manual NSP curves were originally developed and provided in NUREG/CR-6850, subsequently updated in NFPA 805 FAQ 08-0050 [2] or NUREG/CR-6850 Supplement 1 (EPRI 1019259) [3], Section 14, and more recently in NUREG-2169 (EPRI 3002002936) [4] (Fig. 2). As described in the revised guidance, the fire brigade response time is incorporated into the estimated suppression rate; therefore, it no longer requires separate consideration in the analysis.

- NUREG/CR-6850 DSET Headings:

(1) Fire (FI)
(2) Prompt Detection (PD)
(3) Prompt Suppression (PS)
(4) Automatic Detection (AD)
(5) Automatic Suppression (AS)
(6) Manual Detection (MD)
(7) Manual Fixed Suppression (MF)
(8) Manual Suppression, i.e., Fire Brigade (FB)

- NUREG/CR-6850 DSET Sequences:

(A) /PD * /PS (OK)
(B) /PD * **PS** * /AS (OK)
(C) /PD * **PS** * **AS** * /MF (OK)
(D) /PD * **PS** * **AS** * **MF** * /FB (OK)
(E) /PD * **PS** * **AS** * **MF** * **FB (NS)**
(F) **PD** * /AD * /AS (OK)
(G) **PD** * /AD * **AS** * /MF (OK)
(H) **PD** * /AD * **AS** * **MF** * /FB (OK)
(I) **PD** * /AD * **AS** * **MF** * **FB (NS)**
(J) **PD** * **AD** * /AS (OK)
(K) **PD** * **AD** * **AS** * /MD * /MF (OK)
(L) **PD** * **AD** * **AS** * /MD * **MF** * /FB (OK)
(M) **PD** * **AD** * **AS** * /MD * **MF** * **FB (NS)**
(N) **PD** * **AD** * **AS** * **MD (NS)**

- ✓ NSP = P(E) + P(I) + P(M) + P(N)

Updated guidance on analyzing detection and suppression capabilities for electrical cabinet fires, NUREG-2230 (EPRI 3002016051) [5], was issued in June 2020 to better represent the operating experience, especially early intervention by plant personnel.

The original DSET in NUREG/CR-6850 was revised and divided into two identical DSETs with split fractions: one for interruptible fire (0.723) and the other for growing fire (0.277). The manual NSP curve for electrical cabinet fires was also updated and divided into two. The interruptible fire is defined as a fire that grows

at a rate that is slow enough to allow for plant personnel to be notified of the event, locate the source, and suppress the fire with minimal effort.

The concepts of 'prompt detection' and 'automatic detection' in NUREG/CR-6850 were revised to 'first detection' (zero time of detection) and 'second detection' (modeled time of detection), respectively. 'Prompt detection', associated with a continuously occupied space or continuous fire watch, is now captured using the guidance on plant personnel presence probabilities. A unique sequence dedicated to 'prompt suppression' was also removed because the development of the interruptible and growing fire suppression rates incorporates zero detection and short suppression times. The branch for failing to manually detect a fire (i.e., sequence N in the original DSET) has been removed, based on the assumption that a fire will eventually be detected.

Both DSETs have six (6) headings and twelve (12) sequences based on fire detection and suppression features (Figs. 3-5). ET parameters are estimated using available operating experience, human reliability analysis results, and manual NSP curves.

- NUREG-2230 DSET Headings:

(1) Fire (FI)
(2) First Detection (FD)
(3) Second Detection (SD)
(4) Automatic Suppression (AS)
(5) Manual Fixed Suppression (MF)
(6) Manual Suppression, i.e., Fire Brigade (FB)

- NUREG-2230 DSET Sequences:

(A) {/FD} * {/AS} (OK)
(B) {/FD} * {**AS** * /MF} (OK)
(C) {/FD} * {**AS** * **MF** * /FB} (OK)
(D) {/FD} * {**AS** * **MF** * **FB**} **(NS)**
(E) {**FD** * /SD} * {/AS} (OK)
(F) {**FD** * /SD} * {**AS** * /MF} (OK)
(G) {**FD** * /SD} * {**AS** * **MF** * /FB} (OK)
(H) {**FD** * /SD} * {**AS** * **MF** * **FB**} **(NS)**
(I) {**FD** * **SD** * (1)} * {/AS} (OK)
(J) {**FD** * **SD** * (1)} * {**AS** * /MF} (OK)
(K) {**FD** * **SD** * (1)} * {**AS** * **MF** * /FB} (OK)
(L) {**FD** * **SD** * (1)} * {**AS** * **MF** * **FB**} **(NS)**
✓ NSP = P(D) + P(H) + P(L)

In the telecommunications industry, incipient fire detection systems, such as very early warning fire detection (VEWFD) systems, have been used extensively and have proven effective in minimizing fire damage and limiting service interruption. Guidance on modeling the use of incipient detection systems in NPP fire PSA applications, NUREG-2180 [6], was initially issued in December 2016 and subsequently updated in May 2024 as NUREG-2180 Supplement 1 (EPRI 3002028821) [7].

Two VEWFD DSETs were developed: one for in-cabinet detection applications and the other for area-wide detection applications. The in-cabinet DEST is used for fire scenarios where smoke detection is located within an electrical cabinet (enclosure). The area-wide DEST is used for fire scenarios where aspirated smoke detection (ASD) VEWFD systems have sampling ports either near the ceiling or across air return grilles. For in-cabinet application, the cabinet characteristics must allow for the application of aspirated VEWFD systems, such that the cabinet is not tightly sealed. For area-wide applications, the cabinet(s) being protected must have openings (vents, grates, etc.) to allow products of combustion to exit the cabinet and migrate to the VEWFD system sampling ports.

Both DSETs have eight (8) headings and thirteen (13) sequences based on fire detection and suppression features (Fig. 6). ET parameters are estimated using available operating experience, test data, human reliability analysis results, manual NSP curves, and the conventional DSET from NUREG/CR-6850 or NUREG-2230.

- NUREG-2180 VEWFD DSET Headings:

(1) Fire (FI)
(2) System Availability and Reliability (1-β)
(3) Fraction of Fires that have an Incipient Stage (1-α_i):
α_1 for power, α_2 for low-voltage control cabinets
(4) System Effectiveness Detecting Incipient Stage (1-τ)
(5) Successful MCR Response (1-μ)
(6) Successful Field Response (Fire Watch Posted) (1-ξ)
(7) Enhanced Manual Suppression (1-π_i):
π_1 for in-cabinet or π_2 for area-wide detection systems
(8) Conventional Detection and Suppression (1-η_i):
η_1 represents the failure probability of
detection and/or suppression systems,
given a failure of the VEWFD system or MCR to respond;
η_2 represents the failure probability of
detection and/or suppression systems,
given a failure of the VEWFD system to provide sufficient
advance warning (note that the VEWFD system would still
provide prompt/first detection functions);
η_3 represents the failure probability of
suppression systems (considering dependency),
given a failure of the enhanced suppression capabilities

- NUREG-2180 VEWFD DSET Sequences:

(A) (1-β) * (1-α) * (1-τ) * (1-μ) * (1-ξ) * (1-π) (OK)
(B) (1-β) * (1-α) * (1-τ) * (1-μ) * (1-ξ) * **(π)** * (1-η_3) (OK)
(C) (1-β) * (1-α) * (1-τ) * (1-μ) * (1-ξ) * **(π)** * **(η_3) (NS)**
(D) (1-β) * (1-α) * (1-τ) * (1-μ) * **(ξ)** * (1-η_2) (OK)
(E) (1-β) * (1-α) * (1-τ) * (1-μ) * **(ξ)** * **(η_2) (NS)**
(F) (1-β) * (1-α) * (1-τ) * **(μ)** * (1-η_1) (OK)
(G) (1-β) * (1-α) * (1-τ) * **(μ)** * **(η_1) (NS)**
(H) (1-β) * (1-α) * **(τ)** * (1-η_2) (OK)
(I) (1-β) * (1-α) * **(τ)** * **(η_2) (NS)**
(J) (1-β) * **(α)** * (1-η_2) (OK)
(K) (1-β) * **(α)** * **(η_2) (NS)**
(L) **(β)** * (1-η_1) (OK)
(M) **(β)** * **(η_1) (NS)**
✓ NSP = P(C) + P(E) + P(G) + P(I) + P(K) + P(M)

In NUREG-2180 Supplement 1 (Fig. 7), the alpha parameter, α (fraction of fires that do not have an

incipient stage), was updated using new fire events data from 2010 through 2014. The pi parameter, π (enhanced suppression rates for incipient detection), was also updated using the 2010-2014 fire events data. Additionally, NUREG-2180 Supplement 1 Section 5 provides guidance on how to use NUREG-2180 with the framework in NUREG-2230. In conclusion, the concepts in NUREG-2230 (interruptible fires) and NUREG-2180 (pre-flaming conditions) are considered independent.

Note that interim guidance on incipient fire detection systems in NFPA 805 FAQ 08-0046 [8] or NUREG/CR-6850 Supplement 1 (EPRI 1019259) [3], Section 13, was retired [9] following the release of NUREG-2180.

3. Application of Methods

The conditions and assumptions for the example fire scenarios analyzed using the updated methods are as follows.

- Fire Detection and Suppression Analysis Methods Used:
  [A] NUREG/CR-6850 Original /
  [B] NUREG/CR-6850 Revised w/ NUREG-2169 /
  [C] NUREG 2230 (Interruptible / Growing / Total) /
  [D] NUREG-2180 Original (& NUREG-2230) /
  [E] NUREG-2180 Revised w/ Sup. 1 (& NUREG-2230)
- Ignition Source (IS): MCC Cabinet (Bin 15)
- Target Set (TG): Cable Trays above IS
- Time to Damage [min.]: 5 / 10 / 15 / 20
- Time to Prompt / First Detection [min.]: 0
- Time to Automatic / Second Detection [min.]: 2
- Time to Delayed Detection (Eventually Detected) [min.]: 15
- Time to Brigade Response (Applicable only to [A]) [min.]: 7
- Incipient Detection System - Type:
  In-Cabinet (IC), Cloud Chamber (CC) and
  Aspirating Smoke Detection (ASD) Type
  VEWFD System w/ Natural Ventilation
- Incipient Detection System -
  Unreliability, Unavailability, and Ineffectiveness:
  1.60E-03, 2.00E-03, 2.70E-03
  (Ineffectiveness for Incipient Stage Detection (τ))
- Fraction of Fires That Do Not Have an Incipient Stage (α):
  2.80E-01 for [D] / 1.00E-01 for [E]
- Human Error Probability for MCR Response
  to Incipient Detection (μ): 1.00E-04
- Human Error Probability for Field Operator Response
  to Incipient Detection (ξ): 4.60E-04
- Enhanced Manual Suppression Rate [1/min.]:
  3.24E-01 for [D] / 3.82E-01 for [E]
- Conventional Detection System - Type:
  Smoke Detector
- Conventional Detection System -
  Unreliability, Unavailability, and Ineffectiveness:
  5.00E-02, 1.00E-02, 7.00E-02
- Failure Probability of Plant Personnel Present: 2.31E-01
- Failure Probability for MCR Indication: 1.00E-02
- Human Error Probability for MCR Response
  to MCR Indication: 1.00E-03
- Automatic Suppression System - Type:
  Halon System
  (scenario analyzed both w/ and w/o crediting this system)
- Automatic Suppression System -
  Unreliability, Unavailability, and Ineffectiveness:
  5.00E-02, 1.00E-02, 0.00E+00
- Human Error Probability for Manual Actuation of
  Fixed Suppression System: 1.00E-01
- Manual Suppression Curve:
  vary depending on the method - [A] / [B] / {[C], [D], [E]}
- Manual Suppression Rate [1/min.]:
  1.20E-01 for [A] / 9.80E-02 for [B] /
  1.49E-01 for Interruptible Fires of [C], [D], [E] /
  1.00E-01 for Growing Fires of [C], [D], [E]
- All the Other Conditions and Assumptions:
  Default or Medium values as provided by each methodology
- Incipient Detection System is Applicable only to [D] & [E]

The results of the detection and suppression analysis for the example fire scenarios are summarized in Table I and Fig. 8. The scenario NSP decreases as the time to damage increases and as more recently updated methods are applied.

For a time to damage of 5 minutes, assuming no credit for suppression systems, the scenario NSP is estimated as 3.57E-01 using Method [C] (NUREG-2230). This represents a reduction of approximately 64% and 54% compared to the scenario NSP estimated using Method [A] (NUREG/CR-6850 Original) and Method [B] (NUREG/CR-6850 Revised), respectively. For a time to damage of 20 minutes, the reduction increases to approximately 84% and 75%, respectively. Using Method [C] instead of [A] or [B] reduces the scenario NSP by approximately two orders of magnitude for a time to damage of 15 minutes when suppression systems are credited. The main reasons for this reduction are as follows: Method [C] provides guidance for using and crediting early detection via non-fire trouble alarms in the MCR and by general plant personnel (either in the vicinity or passerby). This significantly improves the 'first detection' (zero time of detection) capability. Crediting interruptible fires, which represent a split fraction of 0.723 in Method [C], effectively delays the time to damage by 4 minutes. This, in turn, increases the available time for suppression by 4 minutes. The manual suppression rate for NUREG-2230 interruptible fires (1.49E-01 per minute) is higher than the rates for NUREG-2230 growing fires (the 0.277 fraction of Method [C]; 1.00E-01/min) by 49%, NUREG-2169 electrical fires (used for Method [B]; 9.80E-02/min) by 52%, and NUREG/CR-6850 electrical fires (used for Method [A]; 1.20E-01/min) by 24%.

Using Method [D] (NUREG-2180 Original) or Method [E] (NUREG-2180 Revised) to credit the VEWFD system reduces the scenario NSP by approximately 30%-70% or 50%-90%, respectively, compared to using only the conventional DSET framework in Method [C]. Using Method [D] or [E] instead of [A] or [B] reduces the scenario NSP by approximately three orders of magnitude for a time-to-damage of 15 minutes when suppression systems are credited. The main reasons for this reduction are as follows: Crediting incipient stage detection allows

approximately 70% (for Method [D]) to 90% (for Method [E]) of the total scenario frequency to benefit from enhanced manual suppression features. This involves using the increased manual suppression rate (3.24E-01/min for Method [D] and 3.82E-01/min for Method [E]) instead of the standard manual suppression rates. Furthermore, it allows a small fraction (approximately 1% to 3%) of the total scenario frequency to have the 'first detection' (zero time of detection) capability which is assumed to always succeed.

4. Conclusions

This study reviewed recently updated methods for fire detection and suppression analysis in fire PSA and applied them to example fire scenarios to evaluate their potential risk reduction benefits. The use of these improved methods in fire PSA is expected to provide a more realistic representation of fire risk and yield more useful insights regarding fire protection defense-in-depth strategies.

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] Electric Power Research Institute (EPRI) and U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research (RES), EPRI 1011989 and NUREG/CR-6850, Vol. 2, "Fire PRA Methodology for Nuclear Power Facilities: Volume 2: Detailed Methodology," EPRI, Palo Alto, CA, and U.S.NRC-RES, Rockville, MD, September 2005.
https://www.nrc.gov/docs/ML0525/ML052580118.pdf

[2] U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research (RES), NFPA 805 FAQ 08-0050, "CLOSURE OF NATIONAL FIRE PROTECTION ASSOCIATION 805 FREQUENTLY ASKED QUESTION 08-0050 MANUAL NON-SUPPRESSION PROBABILITY," U.S.NRC-RES, Washington, D.C., September 2009.
https://www.nrc.gov/docs/ML0921/ML092190555.pdf

[3] Electric Power Research Institute (EPRI) and U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research (RES), EPRI 1019259 and NUREG/CR-6850 Supplement 1, "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, D.C., September 2010.
https://www.nrc.gov/docs/ML1030/ML103090242.pdf

[4] Electric Power Research Institute (EPRI) and U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research (RES), EPRI 3002002936 and NUREG-2169, "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, D.C., January 2015.
https://www.nrc.gov/docs/ML1501/ML15016A069.pdf

[5] Electric Power Research Institute (EPRI) and U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research (RES), EPRI 3002016051 and NUREG-2230, "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, D.C., May 2020.
https://www.nrc.gov/docs/ML2015/ML20157A148.pdf

[6] U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research (RES), NUREG-2180, "Determining the Effectiveness, Limitations, and Operator Response for Very Early Warning Fire Detection Systems in Nuclear Facilities (DELORES-VEWFIRE)," U.S.NRC-RES, Washington, D.C., December 2016.
https://www.nrc.gov/docs/ML1634/ML16343A058.pdf

[7] Electric Power Research Institute (EPRI) and U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research (RES), EPRI 3002028821 and NUREG-2180 Supplement 1, "Determining the Effectiveness, Limitations, and Operator Response for Very Early Warning Fire Detection Systems in Nuclear Facilities – Update to Event Tree Parameters (Alpha and Pi) and Integration of NUREG-2230 Methods," EPRI, Palo Alto, CA, and U.S.NRC-RES, Washington, D.C., May 2024.
https://www.nrc.gov/docs/ML2414/ML24143A010.pdf

[8] U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research (RES), NFPA 805 FAQ 08-0046, "CLOSURE OF NATIONAL FIRE PROTECTION ASSOCIATION 805 FREQUENTLY ASKED QUESTION 08-0046 INCIPIENT FIRE DETECTION SYSTEMS," U.S.NRC-RES, Washington, D.C., November 2009.
https://www.nrc.gov/docs/ML0932/ML093220426.pdf

[9] U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research (RES), NFPA 805 FAQ 08-0046, "RETIREMENT OF NATIONAL FIRE PROTECTION ASSOCIATION 805 FREQUENTLY ASKED QUESTION 08-0046 INCIPIENT FIRE DETECTION SYSTEMS," U.S.NRC-RES, Washington, D.C., November 2016.
https://www.nrc.gov/docs/ML1616/ML16167A444.pdf

Fire	Prompt		Automatic		Manual			Sequence	End State	Non-Suppression Probability
	Detection	Suppression	Detection	Suppression	Detection	Fixed	Fire Brigade			
FI	PD	PS	AD	AS	MD	MF	FB			
								A	OK	
1.00E+00	0.00E+00	0.00E+00						B	OK	
		1.00E+00		9.40E-01				C	OK	
				6.00E-02		8.40E-01		D	OK	
						1.60E-01	4.51E-01	E	NS	0
							5.49E-01	F	OK	
	1.00E+00		8.70E-01	9.40E-01				G	OK	
				6.00E-02		8.40E-01		H	OK	
						1.60E-01	3.02E-01	I	NS	5.83E-03
							6.98E-01	J	OK	
			1.30E-01	0.00E+00				K	OK	
				1.00E+00	1.00E+00	0.00E+00		L	OK	
						1.00E+00	0.00E+00	M	NS	1.30E-01
							1.00E+00	N	NS	0
					0.00E+00				NS Total	1.36E-01

Fig. 1. Detection-Suppression Event Tree from NUREG/CR-6850 (Original),
for a Time to Damage of 12 minutes, Crediting Suppression Systems.

Fire	Prompt		Automatic		Manual			Sequence	End State	Non-Suppression Probability
	Detection	Suppression	Detection	Suppression	Detection	Fixed	Fire Brigade			
FI	PD	PS	AD	AS	MD	MF	FB			
								A	OK	
1.00E+00	0.00E+00	0.00E+00						B	OK	
		1.00E+00		9.40E-01				C	OK	
				6.00E-02		8.40E-01		D	OK	
						1.60E-01	6.91E-01	E	NS	0
							3.09E-01	F	OK	
	1.00E+00		8.70E-01	9.40E-01				G	OK	
				6.00E-02		8.40E-01		H	OK	
						1.60E-01	6.25E-01	I	NS	3.13E-03
							3.75E-01	J	OK	
			1.30E-01	0.00E+00				K	OK	
				1.00E+00	1.00E+00	0.00E+00		L	OK	
						1.00E+00	0.00E+00	M	NS	1.30E-01
							1.00E+00	N	NS	0
					0.00E+00				NS Total	1.33E-01

Fig. 2. Detection-Suppression Event Tree from NUREG/CR-6850 (Revised with NUREG-2169),
for a Time to Damage of 12 minutes, Crediting Suppression Systems.

Fire	First Detection	Second Detection	Automatic Suppression	Manual Fixed Suppression	Fire Brigade	Sequence	End State	Non-Suppression Probability
FI	FD	SD	AS	MF	FB			
						A	OK	
1.00E+00	9.997E-01		9.40E-01			B	OK	
			6.00E-02	8.40E-01		C	OK	
				1.60E-01	9.08E-01	D	NS	8.85E-04
					9.22E-02	E	OK	
	3.303E-04	0.00E+00	9.40E-01			F	OK	
			6.00E-02	8.40E-01		G	OK	
				1.60E-01	8.76E-01	H	NS	0.00E+00
					1.24E-01	I	OK	
		1.00E+00	9.40E-01			J	OK	
			6.00E-02	8.40E-01		K	OK	
				1.60E-01	1.38E-01	L	NS	2.73E-06
					8.62E-01		NS Total	8.87E-04

Fig. 3. Detection-Suppression Event Tree from NUREG-2230 (Interruptible Fires Path), for a Time to Damage of 12 minutes, Crediting Suppression Systems.

Fire	First Detection	Second Detection	Automatic Suppression	Manual Fixed Suppression	Fire Brigade	Sequence	End State	Non-Suppression Probability
FI	FD	SD	AS	MF	FB			
						A	OK	
1.00E+00	9.97E-01		9.40E-01			B	OK	
			6.00E-02	8.40E-01		C	OK	
				1.60E-01	6.99E-01	D	NS	2.88E-03
					3.01E-01	E	OK	
	2.54E-03	8.70E-01	9.40E-01			F	OK	
			6.00E-02	8.40E-01		G	OK	
				1.60E-01	6.32E-01	H	NS	7.81E-06
					3.68E-01	I	OK	
		1.30E-01	0.00E+00			J	OK	
			1.00E+00	0.00E+00		K	OK	
				1.00E+00	0.00E+00	L	NS	3.30E-04
					1.00E+00		NS Total	3.22E-03

Fig. 4. Detection-Suppression Event Tree from NUREG-2230 (Growing Fires Path), for a Time to Damage of 12 minutes, Crediting Suppression Systems.

Fire	Interruptible Fire	Event Tree	Non-Suppression Probability
FI			
1.00E+00	7.23E-01	8.87E-04	6.42E-04
	2.77E-01	3.22E-03	8.93E-04
			1.53E-03

Fig. 5. Detection-Suppression Event Tree from NUREG-2230 (Total: Combined Interruptible & Growing Fires), for a Time to Damage of 12 minutes, Crediting Suppression Systems.

Fire	Availability & Reliability	Fires that have an Incipient Stage	Effectiveness for Incipient Stage	Successful MCR Response	Successful Field Response	Enhanced Suppression	Conventional DSET	Sequence	End State	Non-Suppression Probability
FI	β	α_i	τ	μ	ξ	π_i	η_i			
								A	OK	
1.00E+00	9.96E-01	7.20E-01	9.97E-01	9.999E-01	9.995E-01	9.80E-01		B	OK	
						2.05E-02	9.90E-01	C	NS	1.41E-04
							9.60E-03	D	OK	
					4.60E-04		9.99E-01	E	NS	4.74E-07
							1.44E-03	F	OK	
				1.00E-04			9.98E-01	G	NS	1.10E-07
							1.53E-03	H	OK	
			2.70E-03				9.99E-01	I	NS	2.79E-06
							1.44E-03	J	OK	
		2.80E-01					9.99E-01	K	NS	4.02E-04
	3.60E-03						1.44E-03	L	OK	
							9.98E-01	M	NS	5.52E-06
							1.53E-03		NS TOTAL	5.51E-04

Fig. 6. Detection-Suppression Event Tree from NUREG-2180 (Original, Integrated with NUREG-2230), for a Time to Damage of 12 minutes, Crediting Suppression Systems.

Fire	Availability & Reliability	Fires that have an Incipient Stage	Effectiveness for Incipient Stage	Successful MCR Response	Successful Field Response	Enhanced Suppression	Conventional DSET	Sequence	End State	Non-Suppression Probability
FI	β	α_i	τ	μ	ξ	π_i	η_i			
								A	OK	
1.00E+00	9.96E-01	9.00E-01	9.97E-01	9.999E-01	9.995E-01	9.90E-01		B	OK	
						9.85E-03	9.90E-01	C	NS	8.45E-05
							9.60E-03	D	OK	
					4.60E-04		9.99E-01	E	NS	5.93E-07
							1.44E-03	F	OK	
				1.00E-04			9.98E-01	G	NS	1.37E-07
							1.53E-03	H	OK	
			2.70E-03				9.99E-01	I	NS	3.49E-06
							1.44E-03	J	OK	
		1.00E-01					9.99E-01	K	NS	1.44E-04
	3.60E-03						1.44E-03	L	OK	
							9.98E-01	M	NS	5.52E-06
							1.53E-03		NS TOTAL	2.38E-04

Fig. 7. Detection-Suppression Event Tree from NUREG-2180 (Revised with Supplement 1, Integrated with NUREG-2230), for a Time to Damage of 12 minutes, Crediting Suppression Systems.

Table I: Results of Detection and Suppression Analysis for Example Fire Scenarios:
Scenario Non-Suppression Probability vs. Time to Damage for each Method.

	w/o Suppression Systems				**w/ Suppression Systems**			
Time to Damage (min)	**5**	**10**	**15**	**20**	**5**	**10**	**15**	**20**
[A] 6850-ORG (■)	1.00E+00	9.02E-01	5.53E-01	3.62E-01	1.38E-01	1.37E-01	1.34E-01	3.48E-03
[B] 6850-REV (◆)	7.78E-01	5.27E-01	3.73E-01	2.29E-01	1.36E-01	1.34E-01	1.32E-01	2.20E-03
[C] 2230-TOT (●)	3.57E-01	1.92E-01	1.05E-01	5.78E-02	3.76E-03	2.17E-03	1.10E-03	5.55E-04
[C1] 2230-IF	2.62E-01	1.24E-01	5.91E-02	2.81E-02	2.84E-03	1.52E-03	5.68E-04	2.69E-04
[C2] 2230-GF	6.07E-01	3.68E-01	2.23E-01	1.36E-01	6.15E-03	3.86E-03	2.47E-03	1.30E-03
[D] 2180-ORG (◆)	2.43E-01	8.26E-02	3.53E-02	1.75E-02	2.34E-03	7.94E-04	3.39E-04	1.68E-04
[E] 2180-REV (■)	1.68E-01	3.94E-02	1.39E-02	6.53E-03	1.62E-03	3.79E-04	1.33E-04	6.27E-05

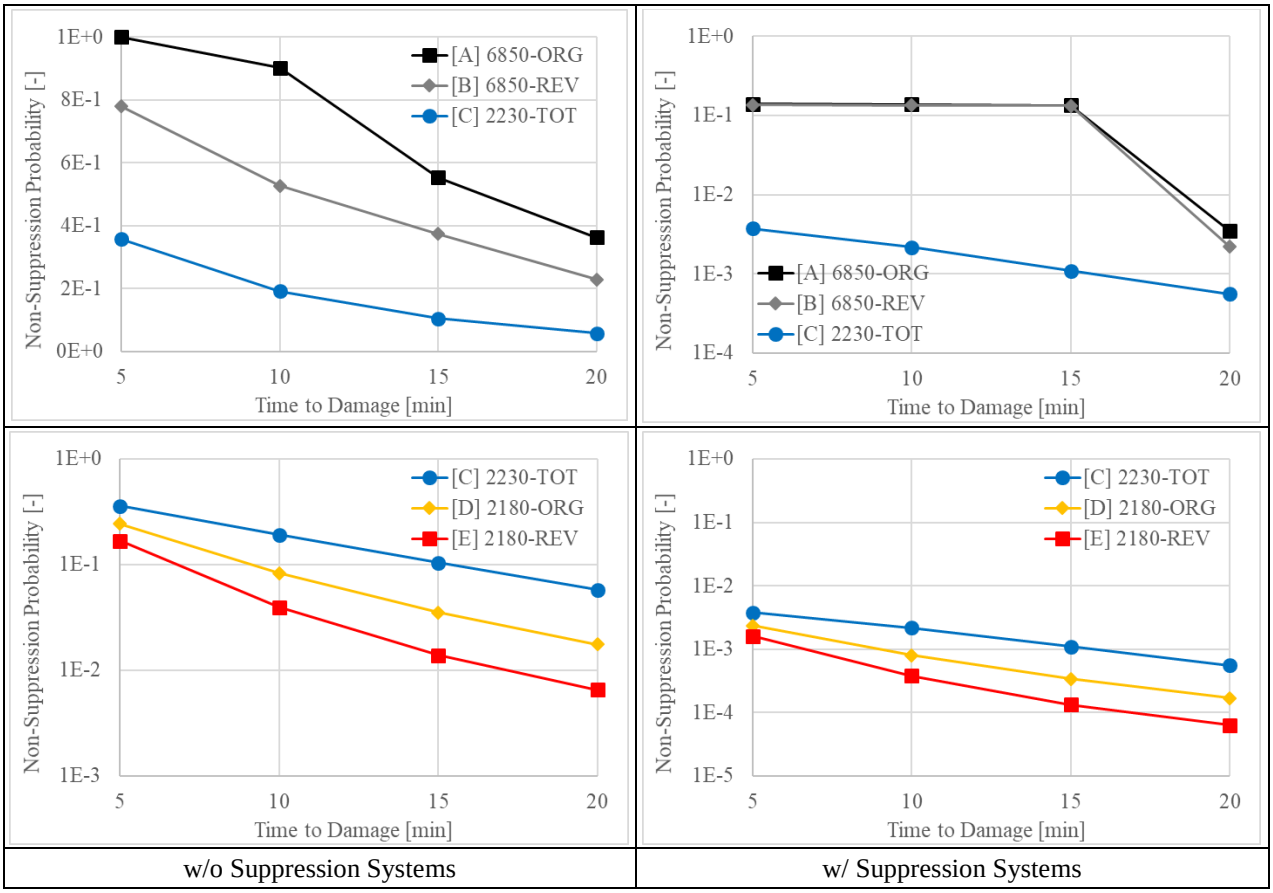

Fig. 8. Results of Detection and Suppression Analysis on Example Fire Scenarios:
Time to Damage versus Scenario Non-Suppression Probability of each Method