Attachment 8

Guidance for Fire Non-Suppression Probability Analysis

<u>Task 2.7.1 - Fire Detection Analysis</u>

The dominant means of fire detection may vary somewhat depending on the type of fire postulated (e.g. hot work fires with a fire watch present), fire location within the room (e.g., proximity to fire detectors). Hence, the fire detection analysis is nominally conducted on a scenario specific basis. However, in practice, the same analysis result will apply to multiple fire scenarios:

> Example: The fire area under analysis has fixed detection installed. There is no finding against the fire detection system, and the system provides full room coverage. In this case, a fire detection time is calculated using the fire characteristics of a typical fire ignition source in the room, and using a typical fire location. The result is applied to all fire scenarios in the room.

The following general rules will be applied in the fire detection analysis:

- Prompt fire detection is assumed for two cases, and in these cases the time to detection is set to zero. The two cases are:
  - Postulated hot work fires so long as a hot work fire watch is posted and there is no finding of degradation against the licensee's hot work permitting and fire watch programs, or
  - Fires postulated in a fire area with a <u>continuous</u> fire watch posted so long as there are no findings against the fire watch and the point of fire origin (the fire ignition source) can be directly observed by the fire watch.

- For other general fire scenarios, it will be assumed that automatic fire detection systems will be the first line of defense in fire detection. That is, if a fixed fire detection system is in place, the response time of that system will determine the fire detection time for all scenarios. This time is estimated using fire modeling correlations such as those included in the USNRC Fire Dynamics Tools, NUREG-1805.

- For areas covered by fixed fire suppression system, but not an independent fixed detection system, the actuation of the suppression system should universally result in a fire alarm signal. Hence, for these cases the time to fire suppression system actuation will be taken as the fire detection time. This time will be adjusted to reflect findings against the suppression system as appropriate.

- Barring any other means of detection, manual detection (detection by plant personnel) will be considered. Manual detection will apply in fire areas that lack fixed detection, in cases where a detection system is found to be highly degraded, or in cases where the detection signal is tied to actuation of a fixed suppression system and that system is found to be highly degraded. The manual detection time is estimated based on a qualitative evaluation of factors such as room occupancy, frequency of routine entry into a room, fire watch rotation periods when applicable, general room accessibility, and fire severity.

<u>Detection by a Continuous Fire Watch</u>

In fire areas with a continuous fire watch posted, prompt detection of fires will be generally assumed:

- For a continuous fire watch (fire watch is maintained constantly within the physical room) the time to detection by the fire watch would be close to or at the time of ignition. No delay in detection is assumed:

$$t_{detection} = t_{ignition} = 0$$

Discretion is available to assess the effectiveness of a fire watch in the context of specific fire hazards. For example, in some fire areas a continuous fire watch posted in a particular location cannot observe the entire fire area. In this case, the fire area may be treated as continuously occupied for “hidden” fire ignition source scenarios and a nominal delay time may be assigned in fire detection for these scenarios.

<u>Detection by a Fixed Detection System</u>
If a fire area is covered by a fixed fire detection system, but is not covered by a continuous fire watch, then the response time of the fixed system will be assumed to dominate the fire detection time. Fire detection response time is estimated using the following NRR fire analysis worksheets.

<u>Cross-zone Detection</u>
In some circumstances, the analysis of a cross-zone fire detection strategy is needed. In a cross-zone strategy, a minimum of two detectors, one on each of two separate detection circuits, must actuate to generate the desired signal. This is most common when the actuation of an automatic fire suppression system is tied to a fire detection signal. Common applications include: pre-action or dry-pipe fire sprinklers, water deluge systems, water curtains, and gaseous suppression systems.

If a cross-zone detection strategy is encountered, the total detection time will be dominated by the detector located farthest from the fire ignition source. Identify which detectors are assigned to each of the fire detection circuits and locate the nearest detector in each of the circuits. Of these two, the detection time is generally dominated by the detector located further from the fire ignition source (radial horizontal distance from fire center to detector location). Exceptions include:

- Cases where one of the detectors is located in a different beam pocket from the fire ignition source,
- Cases where one detector has a slower time response that another (e.g., a heat detector will generally respond more slowly than a smoke detector).

Identify the detector that is the limiting factor in the time response and base the actuation analysis on the time response of that detector.

<u>Detection by a Roving Fire Watch</u>
Fire watches may be implemented by licensees either as a compensatory measure, or as a part of routine plant operation. All fire watches, at a minimum, provide a fire detection function. Hence, if a fire area is covered by a roving fire watch, and is not covered by an operational fixed fire detection system, then the fire watch recurrence frequency is used to estimate the time to fire detection. When crediting a fire watch with detection, the detection time is assumed to be one-half the recurrence time. The following examples illustrate this approach:

- For a roving fire watch on a 15 minute recurrence schedule (roving patrol) the time to detection by the fire watch is assumed to be ½ the duration of the roving patrol

$$t_{detection} = 7.5 \text{ minutes}$$

- For an hourly fire watch:

$$t_{detection} = 30 \text{ minutes}$$

The detection time by general plant personnel should also be checked consistent with the discussion immediately below. The lowest detection time dominates the process and is taken as the final estimate.

<u>Detection by General Plant Personnel</u>
In the absence of a fixed fire detection system (or a fire detection signal tied to actuation of a fixed fire suppression system), or given a highly degraded fixed detection system, detection of the fire will be assumed to occur by plant personnel. One of two factors will be utilized:

- If the fire area is continuously manned by plant personnel (but not by a fire watch) the fire detection time will be assumed to be 5 minutes.
- In the absence of any other means of detection, a maximum fire detection time of 15 minutes will be assumed.

Again, the dominant manual detection time will be the least of these values and is taken as the final detection time. Hence, in no case should the manual detection time be assumed to be greater than 15 minutes

<u>Task 2.7.2 - Fixed Fire Suppression Systems</u>
General rules to be applied in the fixed suppression system analysis include the following:

- The actuation of a non-degraded, fully functional fixed fire suppression system that is deemed by the inspector to be effective for the fire ignition source scenario (e.g., properly positioned to apply suppressant to the ignition source) will be assumed to disrupt the development of the fire scenario. That is, if such a system actuates, it will be assumed the fire growth will be arrested and no further fire damage will occur.

- Judgments are expected to be made as to whether or not the suppression system, degraded or not, will be effective against the specific fire threat being postulated (i.e., is the system installed and configured such that a fire involving each specific fire ignition source will be controlled given actuation of the suppression system?). If it is judged that the system will not be effective (e.g., the system provides partial coverage, and a specific fire ignition source is outside the coverage zone, or the fire source is such that the fire suppression system would likely be overwhelmed), then the system will not be credited on a scenario-specific basis (e.g., it might be credited in some scenarios and not in others).

- The assessment of any fixed fire suppression system includes application of nominal system reliability factors (generally a random failure probability of 0.02 is applied). Those cases where the fire suppression system fails on demand, fire suppression is totally dependent on manual fire fighting provisions (see Task 2.7.3). Recovery of the failed fire suppression system will not be considered in the SDP Phase 2 analysis.
- If the inspection finding is against a fixed fire suppression system, the finding may result in allowing only partial or no credit to the system. The degradation may be reflected as a reduction in overall reliability or a delay in actuation time.

- If the fixed fire suppression system is automatically actuated, the time to actuation will be calculated based on engineering correlations.

- If the fixed fire suppression system is manually actuated, the time to actuation will be based on the estimated fire brigade response time, plus a nominal period of two minutes to assess the fire situation and actuate the system.

- Fixed gaseous suppression systems have discharge delay timers. The actuation time for such systems will be the estimated time to a valid actuation demand signal (based on engineering correlations) plus the discharge delay time.

- Gaseous fire suppression systems that are degraded due to an inability to maintain adequate concentration will be credited with providing some time delay in the progress of the fire (based on the demonstrated suppressant soak time that is available). However, manual fire response will be needed to complete fire suppression. See discussion on page 9-8.

- Credit will be given to gaseous suppression systems that provide a multiple discharge capacity (this typically requires manual actions to initiate a repeated discharge).

- There are a number of time delays that may apply to gaseous systems, deluge, pre-action sprinklers, or dry-pipe water systems. These delays must be accounted for. In general, the correlation for actuation time is applied. This time reflects the time that a demand signal is generated. The time to actual discharge is the sum of the time to actuation of the demand signal plus any applicable discharge timing delays. Delays to be considered are:

    - For gaseous suppression systems there will be a built-in timer that delays discharge to allow for personnel evacuation. The inspector should determine this time (typically on the order of 30 seconds to 2 minutes).
    - There may be a delay for cross zoned detection system, i.e., the automatic suppression system will not begin actuation sequence until after the second detector is actuated. If cross-zoning is used, the detection time analysis should be reviewed to ensure that the cross-zone detection criteria are met. The time to generation of the actuation signal will be dominated by the slower detector (typically the detector farther from the fire ignition source).
    - Also, there may be a time lag for suppressant to get to the hazard (for example, low pressure CO2 may have to travel an extended distance) or for pipes to fill with water prior to discharge (dry or preaction systems). If the delay is not known, use 1 minute. If it is known, the delay should typically be between 30 and 60 seconds.

Task 2.7.3 - Plant Personnel and the Manual Fire Brigade

Fire suppression by manual fire fighting is assessed based on historical evidence provided by fire event data. In Task 2.7.3, one of the pre-calculated fire duration curves must be selected to be applied to each scenario. The same curve may be used for multiple scenarios, if appropriate, or different curves may be chosen for each scenario.

Additional analyses of the raw fire event data is neither expected nor required as a part of the Phase 2 SDP analysis; rather, one of the pre-calculated curves should be applied to each fire scenarios being analyzed based on the fire type and/or location.

In no case should an attempt be made to generate a new fire duration curve to suit a particular analysis. The various pre-calculated curves for specific conditions should cover the vast majority of fire scenarios. If none of these specific condition curves provide a reasonable match to the conditions of the fire scenario, the "all events" curve should be applied. The "all events" curve represents a composite analysis of all of the events that went into each of the other individual fire duration curves.

Note that some of the curves apply to fires in a particular location (e.g., the main control room or containment). However, most are applicable to particular fire ignition source scenario. The cases that are covered by these pre-calculated curves are:

1. All events
2. Hot work (welding) fires
3. Transient fires
4. Electrical fires
5. Cable fires
6. Transformer/switchyard
7. Main Control Room
8. Turbine Generator
9. Energetic Arcing Faults
10. Containment fires (non-inerted containments)

The mean non-suppression probability curves for each of these fire types are presented at the end of this attachment. The following table presents the same information in a tabulated format. The tabulated values of PNS_{manual} should address most situations. As an alternative, the PNS_{manual} value can be calculated using the following formula:

$$PNS_{manual} = \exp[-\lambda \times t]$$

Where '**8**' is the mean rate constant (1/min) for the given fire type and 't' is the fire duration time (time to damage after detection) in minutes. The values for '**8**' for each of the ten fire type/location categories are provided in the last row of the PNS_{manual} table.

Table A8.1 - Non-suppression Probability Values for Manual Fire Fighting Based on Fire Duration (Time to Damage after Detection) and Fire Type Category

$T_{Damage} - T_{Detection}$ (min)	Mean manual non-suppression probability curve values - PNS_{manual}									
	All Events	Hot Work - Welding	Transients	Electrical Fires	Cable Fires	Switchyard	Main Control Room	Turbine Generator	Energetic Arcing Faults	Containment
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1	0.93	0.93	0.87	0.89	0.84	0.97	0.78	0.98	0.95	0.94
2	0.87	0.86	0.76	0.79	0.70	0.95	0.62	0.96	0.90	0.89
3	0.81	0.80	0.66	0.70	0.59	0.92	0.48	0.94	0.86	0.84
4	0.76	0.74	0.58	0.63	0.49	0.90	0.38	0.92	0.81	0.80
5	0.71	0.69	0.51	0.56	0.41	0.88	0.30	0.90	0.77	0.75
6	0.66	0.64	0.44	0.50	0.35	0.85	0.23	0.88	0.74	0.71
7	0.62	0.59	0.38	0.44	0.29	0.83	0.18	0.86	0.70	0.67
8	0.58	0.55	0.34	0.39	0.24	0.81	0.14	0.84	0.66	0.63
9	0.54	0.51	0.29	0.35	0.20	0.79	0.11	0.83	0.63	0.60
10	0.50	0.47	0.26	0.31	0.17	0.77	0.09	0.81	0.60	0.57
12	0.44	0.41	0.19	0.25	0.12	0.73	0.05	0.78	0.54	0.51
14	0.38	0.35	0.15	0.20	0.08	0.69	0.03	0.74	0.49	0.45
16	0.33	0.30	0.11	0.15	0.06	0.66	0.02	0.71	0.44	0.40
18	0.29	0.26	0.09	0.12	0.042	0.62	0.013	0.68	0.40	0.36
20	0.25	0.22	0.07	0.10	0.029	0.59	0.008	0.65	0.36	0.32
25	0.18	0.15	0.03	0.05	0.012	0.52	0.002	0.59	0.28	0.24
30	0.13	0.11	0.017	0.03	0.005	0.46	0.001	0.53	0.21	0.18
35	0.09	0.07	0.008	0.017	0.002	0.40	*	0.48	0.17	0.14
40	0.06	0.05	0.004	0.009	0.001	0.35	*	0.43	0.13	0.10
45	0.05	0.03	0.002	0.005	*	0.31	*	0.39	0.10	0.08
50	0.03	0.02	0.001	0.003	*	0.27	*	0.35	0.08	0.06
55	0.02	0.02	*	0.002	*	0.24	*	0.31	0.06	0.04
60	0.02	0.01	*	0.001	*	0.21	*	0.28	0.05	0.03
* Value is less than 0.001. Screen using PNS_{manual}=0.001 or use formula to calculate actual value.										
Mean Rate Constant (1/min)	0.069	0.075	0.137	0.117	0.177	0.026	0.242	0.021	0.051	0.057

Task 2.7.4 - Probability of Non-Suppression

The purpose of Task 2.7.4 is to estimate the overall probability of fire suppression failure. Failure in this context means that suppression was not achieved before the FDS of interest is reached. Fire suppression will eventually be achieved for all fires, but if the FDS is reached before suppression, then in the SDP context, fire suppression has failed to prevent fire-induced damage consistent with the postulated FDS scenario.

Fixed fire suppression systems

Both the estimates of fire damage time and the time to fixed suppression system suppressant discharge contain considerable uncertainty. Hence, the probability that the fire suppression system suppresses the fire prior to critical damage is not based on a simple comparison of the time to damage versus time to suppressant discharge. Rather, a probability of non-suppression is assigned based on the "margin" between time to damage and time to suppressant discharge.

The time margin/likelihood relationship is described in the table below. The first column presents the difference in minutes between the time to damage and the time to suppressant discharge. If the two times are close, or damage occurs before suppressant discharge, a high likelihood of damage will be assumed (PNS approaches 1.0). If the time to suppression is shorter than the time to damage, the PNS value decreases reflecting a higher likelihood of suppression success. As the time difference reaches 10 minutes, PNS approaches zero. Note that in quantification, the likelihood that the fire suppression system fails on demand is explicitly treated.

Table A8.2 - Probability of Non-suppression for Fixed Fire Suppression Systems Based on the Absolute Difference Between Damage Time and Suppression Time

Time Delta: (t_{Damage} - $t_{Suppress}$)	PNS_{Fixed}
Negative Time up to 1 Minute	1.0
> 1 Minute to 2 Minutes	.95
> 2 Minutes to 4 Minutes	.80
> 4 Minutes to 6 Minutes	.5
> 6 Minutes to 8 Minutes	.25
> 8 Minutes to 10 Minutes	.1
> 10 Minutes	0.0

PNS treatment for degraded gaseous fire extinguishment systems - inadequate soak time

One specific type of degradation that may be identified for a gaseous fire extinguishment systems involves the inability of the system to maintain the design concentration of fire suppressant for a sufficient time to assure the complete extinguishment of a deep-seated fire. The required suppressant concentration and maintenance time are established by the system design criteria. This degradation is commonly referred to as an "inadequate soak time." This can be an issue for Halon and Carbon Dioxide fire extinguishment systems, as well as for other gaseous suppression systems (e.g., Halon replacements).

For the inadequate soak time degradation case, special consideration is required to estimate the probability on non-suppression (PNS). So long as the system can deliver an initial concentration that meets the design criteria, then some credit is given to the system for disrupting the fire growth and spread process. For this case, the following assumptions are made:

- Fires involving cables or other electrical and electronic components will be deep-seated.
- If a gaseous suppression system cannot maintain adequate concentration for a sufficient time to assure fire extinguishment (per design specifications), manual fire fighting must respond and must achieve final fire suppression.
- The fire will be held in check during the time that the fire suppressant concentration is maintained at design level.
- Assuming that the system actuation is timely (i.e., adequate margin between discharge time and the estimated fire damage time) the systems effectiveness will be reflected as a corresponding delay in the estimated fire damage time. As a result, the manual fire brigade is given an additional time to effectively respond to the fire.
- Upon dissipation of suppressant, the fire will re-flash and the fire growth and damage process will pick up where it left off.

The quantification process for this case is as follows:

- Select the appropriate manual suppression fire duration curve corresponding to the fire ignition source.

- Estimate the time to fire detection in the usual manner. In addition to any other fire detection capability, assume that a valid actuation signal for the gaseous suppression system will trigger a fire alarm.

- Using the fire damage time calculated in Step 2.6 (t_{damage}), and the estimated time to fire detection ($t_{detection}$), calculate the value of PNS_{manual} from the selected fire duration curve in the usual manner (i.e., using t_{damage}-$t_{detection}$ as the time available for manual suppression).

- Estimate discharge/actuation time ($t_{suppress}$) for the gaseous fire extinguishment system in usual manner. Recall that actuation will either be automatic or manual, and that the pre-discharge alarm/warning time must be included.

- Calculate the time margin ("time delta") between the actuation time and fire damage time in the normal manner:
  Time Delta = (t_{damage} - $t_{suppress}$)

- Use the general PNS_{fixed} probability table based on "Time Delta" to assess the likelihood that the suppression system actuation is timely in comparison to the estimated fire damage time.

- If the PNS_{fixed} value assigned is 1.0, then the gaseous system will not be credited. In this case use the value of PNS_{manual} as calculated previously as $PNS_{scenario}$ and the analysis is complete.

- If the PNS_{fixed} value is less than 1.0, then the gaseous system will be credited. Continue this analysis to estimate $PNS_{scenario}$.

- Calculate a modified fire damage time as follows:

$$t_{damage\_new} = t_{damage} + t_{maintain\_gas}$$

  where $t_{maintain\_gas}$ is the length of time that the desired gaseous suppressant design concentration <u>can</u> be maintained.

- Using t_{damage_new} (i.e., in place of t_{damage}) and $t_{detection}$, estimate PNS_{gas_manual} based on the selected manual fire suppression fire duration curve. That is, calculate $[t_{damage\_new} - t_{detection}]$ as the modified time available for manual suppression, and estimate PNS_{gas_manual} in the manner normally applied to PNS_{manual}.

- Estimate $PNS_{scenario}$ by combining PNS_{fixed} , PNS_{manual} , and PNS_{gas_manual} using the following equation:

$$PNS_{scenario} = [0.95 \times (1 - PNS_{fixed}) \times PNS_{gas\_manual}] + [(0.95 \times PNS_{fixed}) \text{ x } PNS_{manual}] + [0.05 \times PNS_{manual}]$$

The calculation of $PNS_{scenario}$ combines three cases. The first case is that the suppression system works (no random failure - 95% general reliability/availability factor), the actuation is timely ($1-PNS_{fixed}$) and the fire brigade responds following dissipation of the fire suppressant concentration (PNS_{gas_manual}). This is reflected in the first term on the right hand side of the equation. In the second case, the fire suppression system does <u>not</u> fail randomly (the 95% reliability/availability factor), but discharge of the fire suppression system is not timely (PNS_{fixed}). In the third case, the gaseous suppression system suffers a random failure on demand (the 5% unreliability/unavailability factor). For the last two cases, the fire brigade must successfully suppress the fire within the originally estimated fire suppression time (PNS_{manual}).

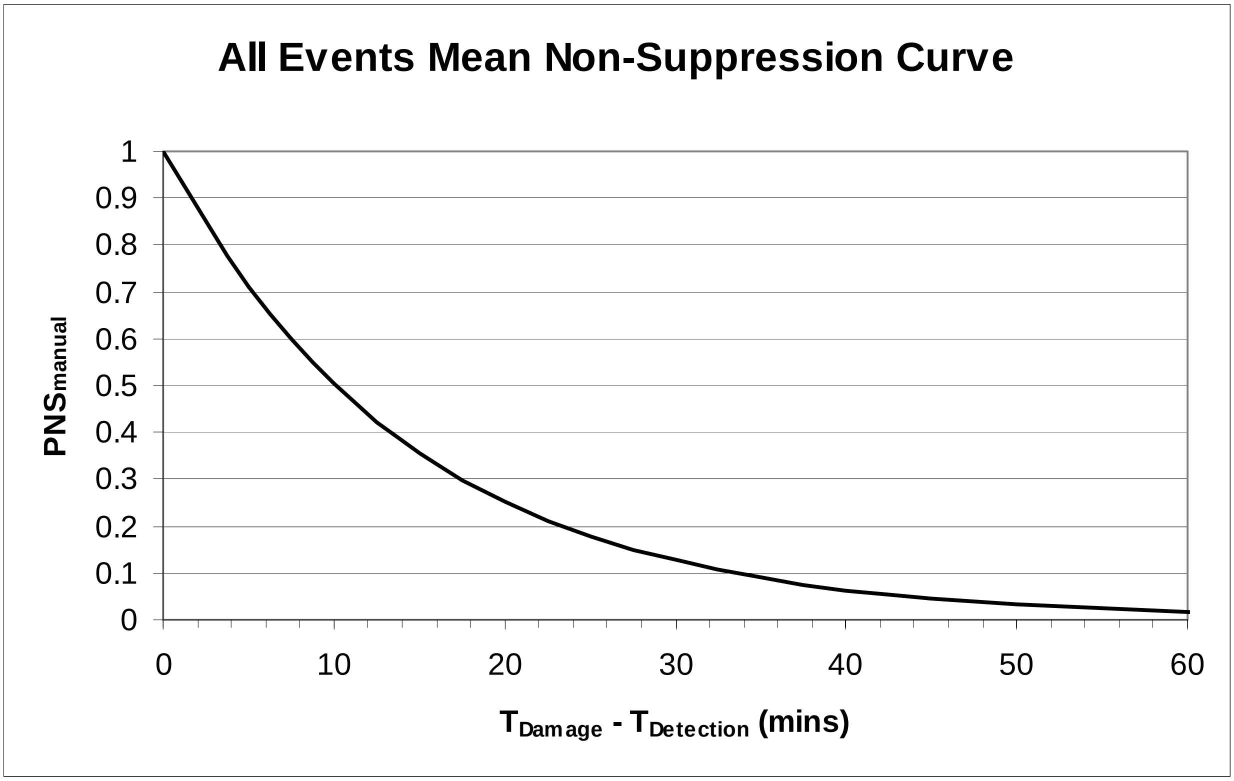
This equation reduces to:

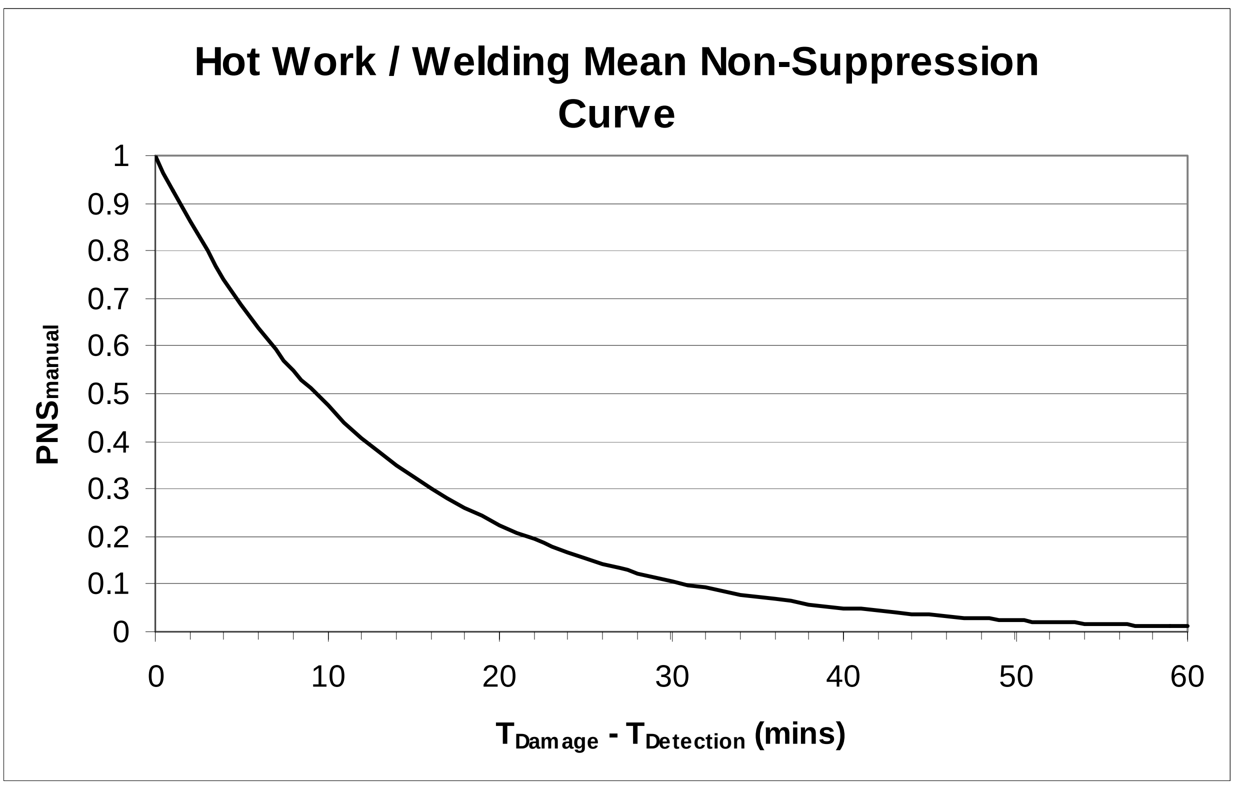
$$PNS_{scenario} = [0.95 \times (1 - PNS_{fixed}) \times PNS_{gas\_manual}] + [(0.95 \times PNS_{fixed}) + 0.05] \times PNS_{manual}$$

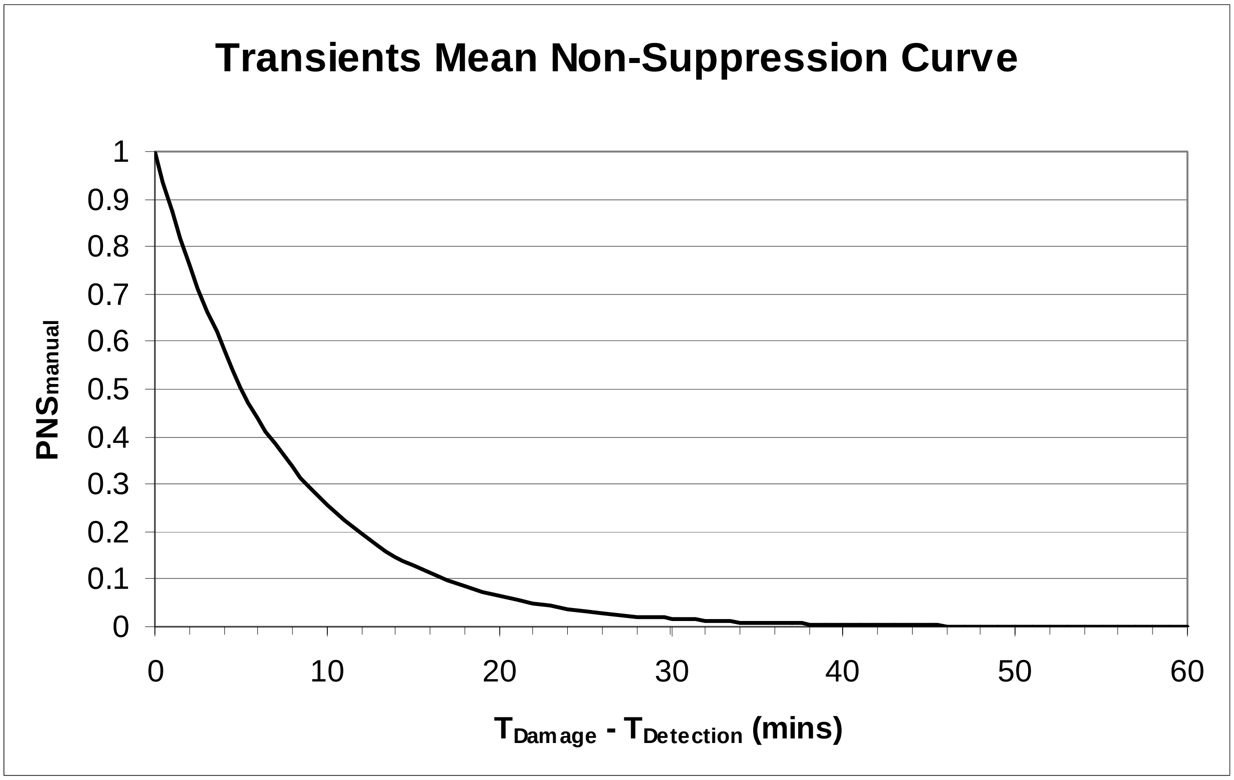
- Verify that ($PNS_{scenario}$ # PNS_{manual}). As in other cases, the manual brigade response given the original fire damage time the minimum credit given to fire suppression for any scenario. If ($PNS_{scenario} > PNS_{manual}$), then reset ($PNS_{scenario} = PNS_{manual}$).

<u>Manual fire suppression:</u>
The following process is repeated for each fire scenario:

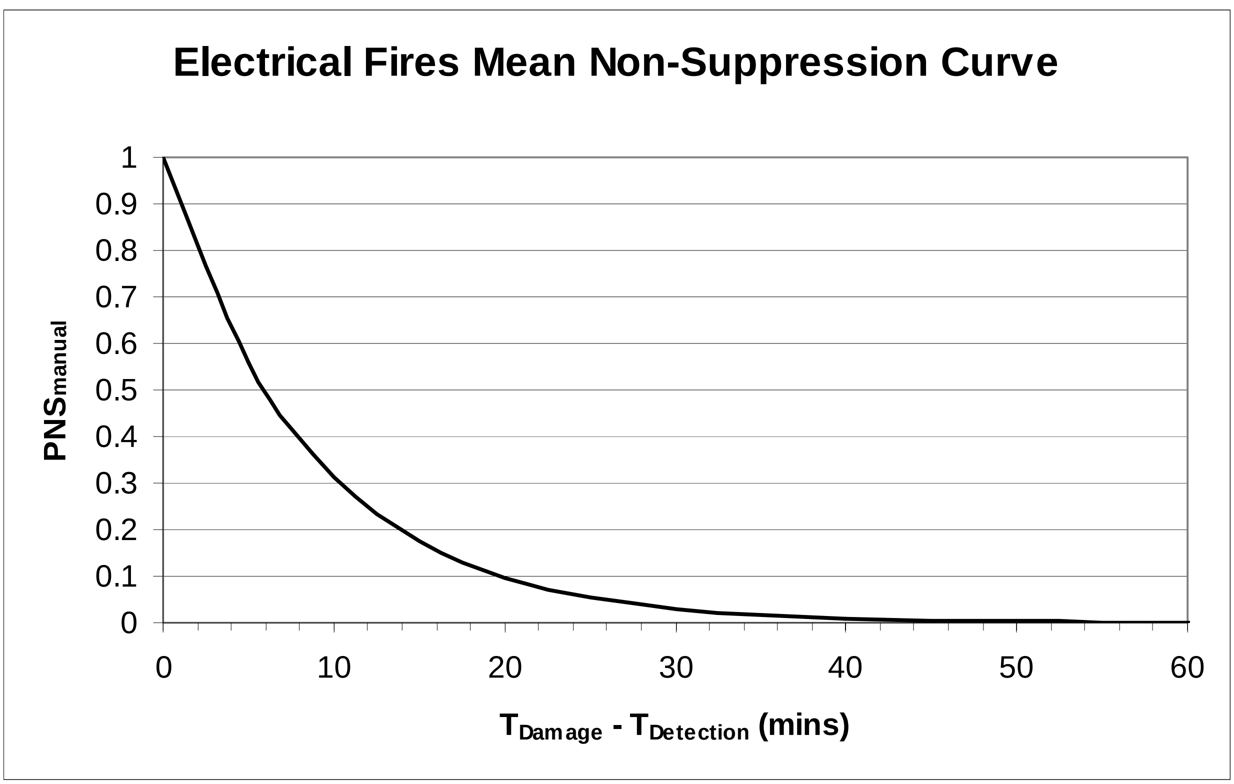
- Subtract the fire detection time from the fire damage time.
- Using the appropriate fire duration curve, read across the x-axis to the time difference from the above step.
- Transfer up to the corresponding point of the fire duration curve, and read across to the left to estimate the PNS_{Manual}.


All Events Mean Non-Suppression Curve
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
PNSmanual
TDamage - TDetection (mins)

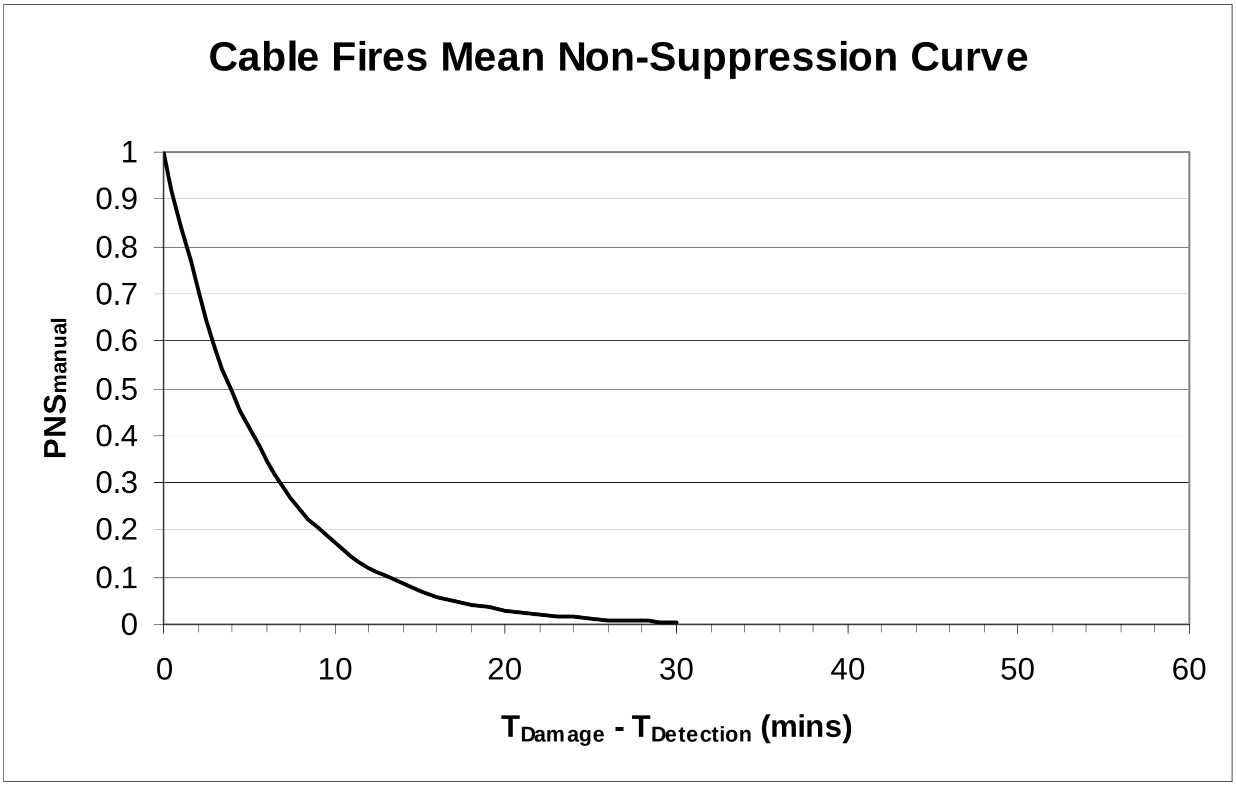

Hot Work / Welding Mean Non-Suppression Curve
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
PNSmanual
TDamage - TDetection (mins)



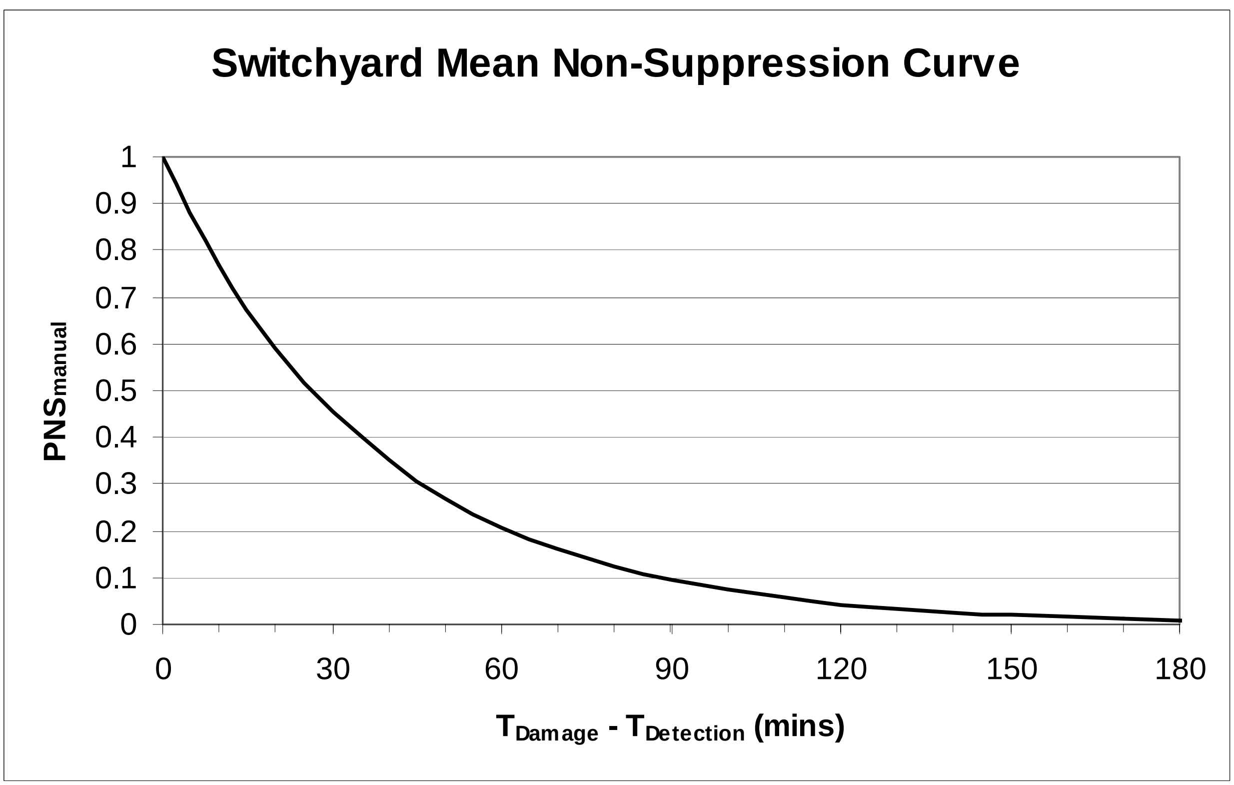
Transients Mean Non-Suppression Curve
PNSmanual
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
TDamage - TDetection (mins)



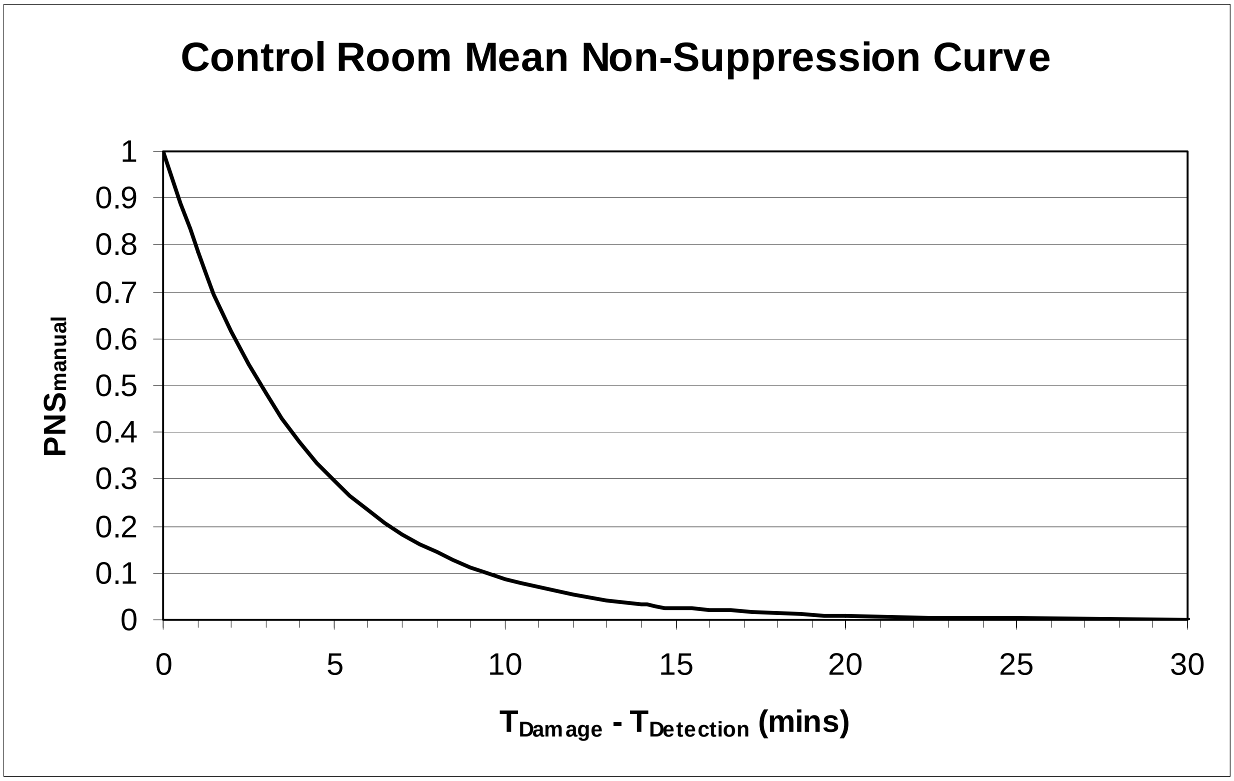
Electrical Fires Mean Non-Suppression Curve
PNSmanual
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
TDamage - TDetection (mins)

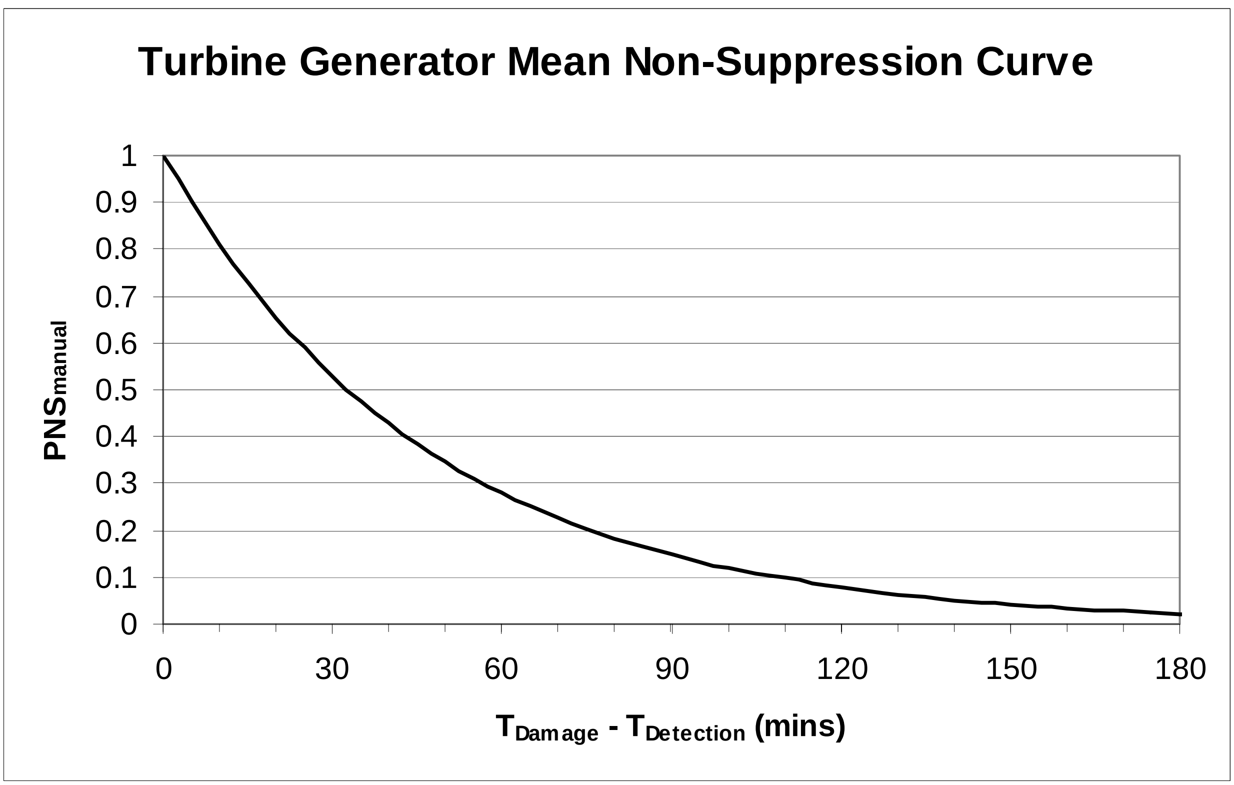


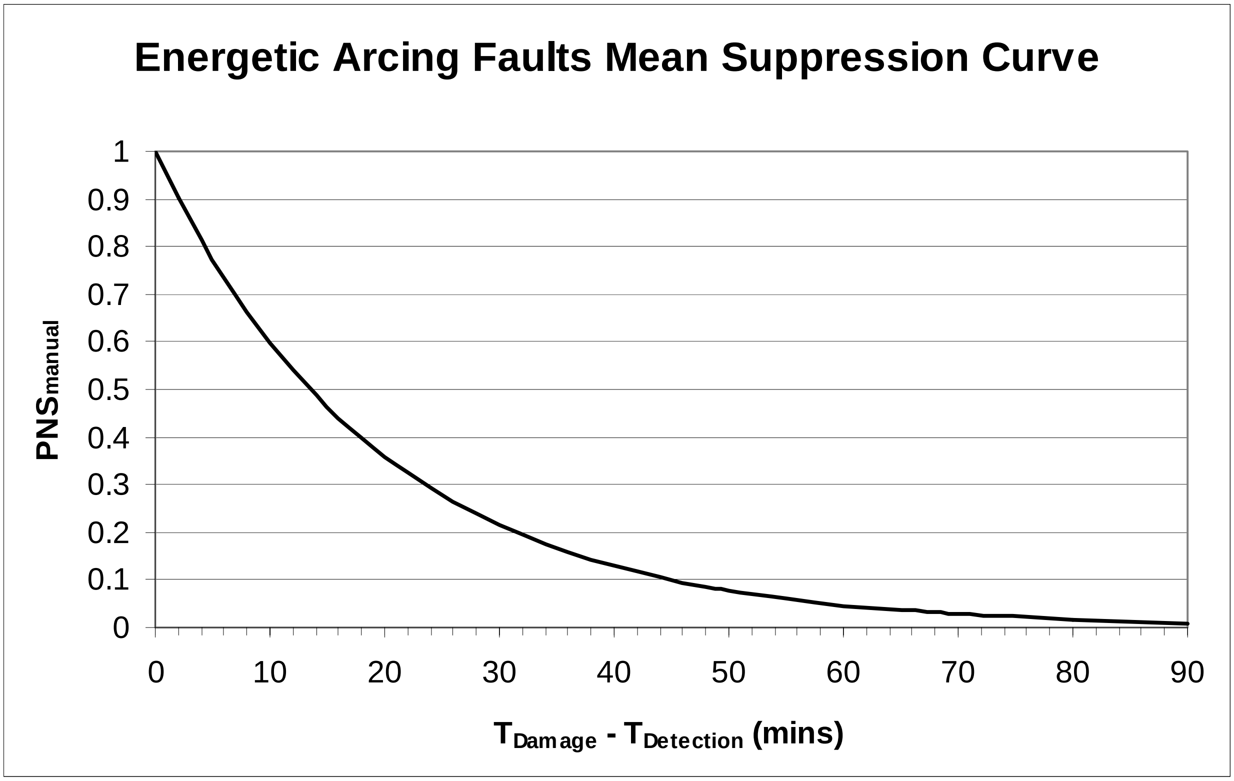
Cable Fires Mean Non-Suppression Curve
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
PNSmanual
0
10
20
30
40
50
60
TDamage - TDetection (mins)



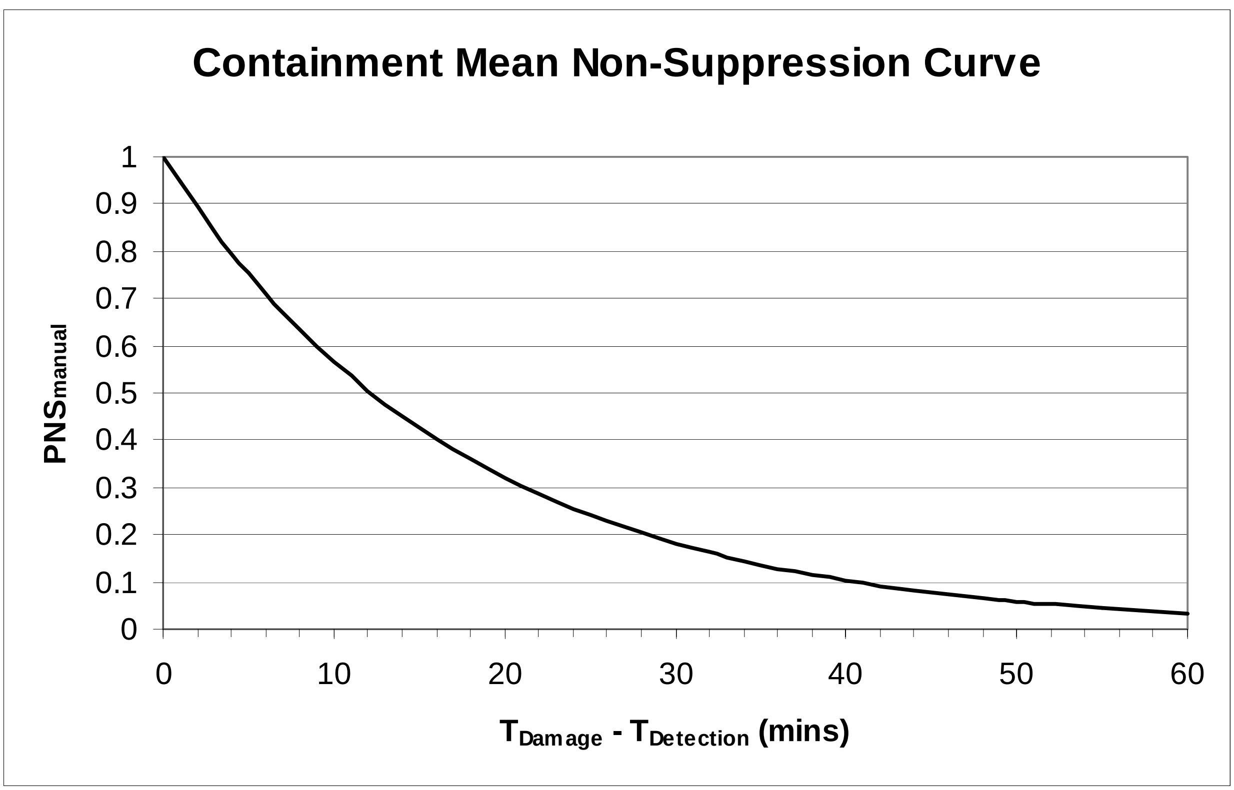
Switchyard Mean Non-Suppression Curve
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
PNSmanual
0
30
60
90
120
150
180
TDamage - TDetection (mins)


Control Room Mean Non-Suppression Curve
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
PNSmanual
0
5
10
15
20
25
30
TDamage - TDetection (mins)


Turbine Generator Mean Non-Suppression Curve
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
PNSmanual
0
30
60
90
120
150
180
TDamage - TDetection (mins)



Energetic Arcing Faults Mean Suppression Curve
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
PNSmanual
0
10
20
30
40
50
60
70
80
90
TDamage - TDetection (mins)



Containment Mean Non-Suppression Curve
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
PNSmanual
0
10
20
30
40
50
60
TDamage - TDetection (mins)