FAQ Number 17-0012 **FAQ Revision** 0d

FAQ Title **Incipient Detection for Fire Prevention and Suppression**

Plant:	Harris	Date:	January 2, 2017
Contact:		Phone:	(919) 546-4570
	Harold Stiles	Email:	Harold.Stiles@duke-energy.com
	Gregory Kvamme		Gregory.Kvamme@xenuclear.com
	Kiang Zee		KZee@jensonhughes.com
	Brian Krystek		BJK@epm-inc.com

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Purpose of FAQ:

This FAQ supplements guidance in NUREG-2180 to provide more realistic treatment of a Very Early Warning Fire Detection Systems (VEWFDS), also called incipient detection, for fire prevention and targeted/enhanced suppression. Fire prevention comprises actions taken to preclude the first occurrence of flame, while targeted/enhanced suppression comprises actions taken after the first occurrence of flame and before fire growth to limit fire damage to the initiating component or cabinet.

For Bin 15 (Electrical Cabinets) fires, guidance is provided for both in-cabinet and area-wide applications. For Bin 4 (Main Control Board) fires, guidance is only provided for in-cabinet applications.

In support of this FAQ, an incipient review of the FEDB is enclosed.

Is this Interpretation of guidance? [Yes] / No

Proposed new guidance not in NEI 04-02? [Yes] / No

Details:

NRC document needing interpretation (include document number and title, section, paragraph, and line numbers as applicable):

Section 6.1.1 of NUREG-2180 concerns the modification, as illustrated by Figure 6-6, of the suppression event trees presented in Section 6.4 to support a suppression strategy. Section 10.6.4 is described as providing the human failure event quantification items for a prevention strategy that should be considered when performing the detailed human reliability analysis (Section 10).

Circumstances requiring interpretation of guidance or new guidance:

In modifying the non-suppression event trees shown in Figure 6-4 and Figure 6-5 to incorporate the prevention strategy shown in Figure 6-6, the MCR response for an incipient ALERT and an incipient ALARM are combined, although these are different cues to activate different responders. Consequently, the prevention strategy, which is actually a suppression strategy, likewise combines these different responders.

Detail contentious points if licensee and NRC have not reached consensus on the facts and circumstances:

Properly crediting a fire prevention strategy is difficult because the more aggressively it is pursued the less evidence there is of success. For example, a fire prevented is not counted as a fire event, in the typical sense. Also, the more quickly a fire is prevented during the incipient phase the less is actually known about the real duration of the incipient phase. However, the risk avoidance associated with a successful fire prevention strategy is considered significant. So, while we don't want to over-credit something that is really unknowable, we also don't want to accept assumptions or techniques that discourage a fire prevention strategy.

Potentially relevant existing FAQ numbers:

FAQ 08-0046, "Incipient Fire Detection Systems" (retired 7-1-2016, ML16167A444)

FAQ 08-0050, "Manual Non-Suppression Probability"

Response Section:

Proposed resolution of FAQ and the basis for the proposal:

For fire prevention and suppression crediting incipient detection, a common event tree (Figure 1) for both in-cabinet and area-wide applications is proposed based on the event trees in Figures 6-4, 6-5, and 6-6 of NUREG-2180. The proposed event tree separates the incipient ALERT and incipient ALARM, including the associated responses, and distinguishes the prevention event from the targeted suppression event. Targeted suppression is limited to the initiating component and does not assume, as was done in NUREG-2180, that "…suppression activities regardless of form damage the ability of components within a cabinet to perform their intended design function." For the prevention event, parameter estimates are based on available operating experience.

In describing the proposed event tree, repetition of applicable information already provided in NUREG-2180 is minimized.

Fire Initiating Event (λ): The initiating event is a potentially challenging or greater fire involving a specific component or compartment of the plant. However, because the proposed event tree includes end states other than "Cabinet Damage" or "Fire Damage Outside Cabinet," the Severity Factor should be combined later in the tree with the event associated with damage outside the cabinet. Although focused on Bin 15 ignition sources, NUREG-2180 noted that operating experience has demonstrated that use of VEWFD system is applicable to other types of components.

Detection System Unavailability and Unreliability (β): As described in Section 7.2 of NUREG-2180, this event represents the combined unavailability and unreliability for the VEWFD system and, for the air return application, the ventilation system.

Fraction of Fires Without an Incipient Phase Detectable by System (α): As described in Section 7.1 of NUREG-2180, this event represents the fraction of fires that have an incipient stage less than a nominal minimum threshold. The nominal minimum threshold provides a "sufficient duration" for detector response, which was observed during the test to be half of the test duration, and for maximum operator response time.

NUREG-2180 proposed a nominal minimum threshold of 30 minutes, but that often resulted in insufficient time for feasible operator response, making the detailed HRA more complicated and overly burdensome. Instead, a minimum threshold of at least 1 hour is proposed. This provides 30 minutes for detector response and 30 minutes for operator response. This resulted in the elimination of one event (EPRI FEDB #161) from consideration as an incipient event for the power cabinets. With an assumed incipient duration of 30 minutes, the inclusion of that event was already questionable. Extending the nominal minimum threshold to at least 1 hour did not have a greater impact because demand failures tend to be prompt whereas degradation tends to occur more slowly over time. As noted in Section 7.1 of NUREG-2180, the identification of events with an incipient phase needs to consider the failure mechanism to make an informed decision. As a result, Table 7-1 of NUREG-2180 is changed to:

Category	Incipient Stage Detectable by VEWFD System			Total Number of Events	Fraction (alpha) Mean [lower/upper]
	Yes	No	Undetermined		
Power Cabinets	15.5	17	22.5	55	0.50 [0.40 / 0.60]
Low Voltage Control Cabinets	6	2	5	13	0.28 [0.08 / 0.54]

NOTE: Ideally, the product of **λ** and **α** would represent the likelihood of a potentially challenging or greater fire where incipient detection was credited. However, operating experience shows there has been no fire where incipient detection was credited. Efforts are currently underway to collect more specific operating experience with the intent to modify either **λ** or **α** to be more realistic for incipient applications. Until then, this approach is recognized as an unavoidable conservatism.

System Incipient Detection Ineffectiveness (τ): As described in Section 7.2.3 of NUREG-2180, this parameter represents the ineffectiveness of the incipient system to perform given the anticipated operational scenarios.

Unsuccessful MCR Operator Response to Incipient ALERT (μ_1): The MCR Operator must dispatch both the I&C Technician and the Field Operator to the correct location upon receipt of an incipient ALERT for the VEWFD system. Upon arrival at the correct location, the Field Operator is expected to remain there until either the incipient ALERT clears or, if the event progresses to an actual fire, the fire is suppressed. Unless the incipient ALERT clears, the I&C Technician is expected to pursue the identification of the degraded component and the associated fire prevention strategy. After identifying the degraded component, the I&C Technician may be required to change location while the incipient ALERT is active to obtain more information in support of the fire prevention strategy. Where NUREG-2180 included the dispatch of the Fire Brigade upon receipt of an incipient ALARM, that event is defined separately for the proposed event tree as "μ_2". This separation does not improve the associated HEP for "μ_1" which is at the floor of 1E-4, for all types of VEWFD systems.

Unsuccessful Fire Prevention at Incipient ALERT (δ_1): This event represents fire prevention at the incipient ALERT phase and is a simpler alternative to the "$\xi_{de\text{-}ss}$" event in Section 10.6.4 of NUREG-2180. However, this parameter is estimated from operating experience using a Jeffery's non-informed approach assuming a binomial data set (i.e., the event progresses from the incipient phase to fire, or it does not). The resulting posterior beta distribution has parameters "α" and "β" as:

α = (number of events that progress to fire) + 0.5	= 0 + 0.5	= 0.5
β = (number of events) - (number of events that progress to fire) + 0.5	= 4 - 0 + 0.5	= 4.5
$\delta_1 = \alpha / (\alpha + \beta)$	= 0.5/(0.5 + 4.5)	= 0.1

This approach is not intended to be applied to an event that does not satisfy the nominal minimum threshold for "sufficient duration" of 60 minutes.

While success with the fire prevention strategy requires the same training, procedures, and dedication to finding and fixing the cause of the problem on which the HRA is based, this performance based approach to estimating the effect is not as dependent on some of the variations in HRA inputs. For example, this approach can quantify success even if there is no detailed pre-planned, pre-decided de-energization strategy, that is documented in procedures and involving pre-staged jumpers and only 1 to 3 simple and quick steps that can be completed in 1 to 2 minutes and that are memorized, skill-of-the-craft, or posted at the incipient "ALERT" location. Under these prohibitively restrictive assumptions, NUREG-2180 developed illustrative HRAs for certain situations based on a Cloud Chamber detector.

Although the HEP proposed for "δ_1" does not provide as much credit as most of those developed in NUREG-2180, it would be more widely applicable. Also, the approach used to estimate the HEP proposed for "δ_1" can be used for area-wide applications, except the operating experience includes no event where area-wide incipient detection was credited.

In lieu of events where area-wide incipient detection was credited, the operating experience does include two events where in-cabinet incipient detection performed in a "pseudo area-wide" capacity beyond its intended function to provide useful insights about incipient conditions in nearby cabinets. These events are identified as the "2013 event" and the "2014 event" in Appendix D of NUREG-2180. With regard to factors that could influence this parameter, incipient detectors were installed in multiple cabinets in a large room with more than a dozen other cabinets (see Figure 2). For the 2013 event, the I&C Technician was dispatched 8 minutes after the event started and was able to identify the cause and report to the MCR 13 minutes later. The cause of the 2014 event was similar to the 2013 event and was likewise identified relatively early in the event, in part due to the 2013 operating experience, which was considered during the 2014 event. Properly designed, installed, and maintained area-wide VEWFD systems would be expected to perform at least as well as these "pseudo area-wide" incipient detectors.

Although actions to isolate the degraded equipment were underway at the time of the each event, in neither case was the 1 to 2 hours provided by incipient detection sufficient for success of the prevention strategy. This is attributed to two factors. First, both events involved power panels and progressed more quickly than the events in the control panels. Second, because the incipient detectors were performing beyond their intended function, there was no plan to use them in this fashion. So while the previously developed HEP for "δ_1" is also considered appropriate for a proper area-wide application for control panels, the available operating experience would suggest a more appropriate HEP for an area-wide application for power panels to require the use of a weighting factor (0.5) for whether the actions would have been successful had an appropriate plan existed at that time. The HEP is estimated to be:

α = (number of events that progress to fire) + 0.5 = 2*0.5 + 0.5 = 1.5

β = (number of events) - (number of events that progress to fire) + 0.5 = 2 - 2*0.5 + 0.5 = 1.5

$\delta_1 = \alpha / (\alpha + \beta)$ = 1.5/(1.5 + 0.5) = 0.75

Use of this HEP would require a pre-planned response. But, to avoid unnecessary perturbations to the plant, that response should be based on the receipt of the incipient ALARM which followed 10 minutes and 2 minutes after the incipient ALERT, for the 2013 event and the 2014 event, respectively.

Better estimates of this parameter are expected with more operating experience. Alternately, a plant-specific, detailed HRA may be developed for the "ξ_{de-ss}" event as described in Section 10.6.4 of NUREG-2180.

Unsuccessful MCR Operator Response to Incipient ALARM (μ_2): The MCR Operator must dispatch the I&C Technician (if not previously dispatched for the incipient ALERT) and the Fire Brigade to the correct location upon receipt of an incipient ALARM for the VEWFD system. Upon arrival at the correct location, the Fire Brigade is expected to lead any fire fighting activities, taking over for the Field Operator (if previously dispatched for the incipient ALERT) and to remain there until either the incipient ALARM clears or, if the event progresses to an actual fire, the fire is suppressed. If the incipient ALARM clears but the incipient ALERT remains active, the Field Operator is expected to resume the previous duties. This event was separated from "μ_1" because the cue is different, the timing is different, and some responders are different.

To obtain the lambda for the time available after the incipient ALARM, the operating experience from the only two events actually having an incipient ALARM (i.e., the 2013 event and the 2014 event) was combined with the information in Table D-2 of NUREG-2180. From these two known events, a delta time (between incipient ALERT and incipient ALARM) was apportioned for the other events based on the estimated time available from the incipient ALERT listed in Table D-2. For the 4.75 hours surrogate of the 2015 event (which actually exhibited an incipient phase of 90 hours without an incipient ALARM), a surrogate delta time of 0.75 hours was used. The results are listed in Table 1.

The lambda for incipient ALARM was less than the lambda for incipient ALERT, indicating more time available than previously credited. But for incipient events of relatively short duration, there could be some overlap in the timing with "μ_1". To account for this potential dependency, the recovery credit in "μ_1" was removed to obtain an associated HEP for "μ_2" of 1E-3.

This event is also applicable to fires that do not provide sufficient time for an effective response to an incipient ALERT but where it would be appropriate to credit prompt detection for a successful MCR Operator response to an incipient ALARM. In such cases, the associated HEP for "μ_2" remains 1E-3.

Unsuccessful Fire Prevention at Incipient ALARM (δ_2): This event represents fire prevention at the incipient ALARM phase and, like the previously developed "δ_1" event, is a simpler alternative to the "$\xi_{de\text{-}ss}$" event in Section 10.6.4 of NUREG-2180. This event only applies for sequences where the MCR Operator failed to respond to the incipient ALERT because the I&C Technician would already be engaged in the fire prevention strategy otherwise. Based on the relatively small delta times between incipient ALERT and incipient ALARM as listed in Table 1 when compared to the duration of the incipient phase, the HEP for "δ_2" is the same as previously determined for "δ_1".

Alternately, a plant-specific, detailed HRA may be developed for the "$\xi_{de\text{-}ss}$" event as described in Section 10.6.4 of NUREG-2180.

Targeted Suppression (ξ): This event represents fire suppression at the individual component level based on a statistical model of non-suppression probability for a zero-length fire in a control cabinet. This suppression approach is similar to a special application of the Appendix L treatment of fires on the Main Control Board. To credit targeted suppression, the suppression agent must not impair the ability of other components within the cabinet to perform their intended design function.

Two variations of this parameter were considered: the failure of the Field Operator following success of the MCR Operator Response to Incipient ALERT "μ_1", and the failure of the Fire Brigade following success of the MCR Operator Response to Incipient ALARM "μ_2". With respect to suppressing a small fire at the component level, the Field Operator and the Fire Brigade were considered equally capable. The statistical model was developed for Fire Brigade response times and would be conservative for the Field Operator. It is important to note that both the incipient ALERT and the incipient ALARM would be received in advance of an actual fire, but no targeted suppression would be attempted before the observation of actual fire.

The development of the statistical model did not require the identification of the degraded component, and its use would be conservative with even partial success of the I&C Technician. From Table 10-4 of NUREG-2180, the time required for the I&C Technician to identify the degraded component is estimated to be between 8 and 30 minutes after successful MCR response. Since the fraction of events that would progress from incipient ALERT to fire in less than 30 minutes was already addressed by "α", the pre-fire observation of the specific component would be very likely. In addition, the I&C Technician will have identified the cabinet containing the degraded component much sooner, providing an opportunity to limit the scope of pre-fire observations.

Figure 3 provides the HEP based on a statistical model of non-suppression probability for a zero-length fire in a control cabinet.

For a power cabinet, targeted suppression is not considered feasible (i.e., **ξ** = 1.0).

Enhanced Suppression (π): This event represents fire suppression prior to damage outside the cabinet, where targeted suppression at the component level has failed. Unlike targeted suppression, enhanced suppression does not require the suppression agent to not impair the ability of components within the cabinet to perform their intended design function.

Like targeted suppression, two variations of this parameter were considered: the failure of the Field Operator following success of the MCR Operator Response to Incipient ALERT "μ_1", and the failure of the Fire Brigade following success of the MCR Operator Response to Incipient ALARM "μ_2". Consequently, both variations include arrival at the correct location prior to an actual fire, but neither variation requires the successful identification of the degraded component by the I&C Technician.

With respect to suppressing a growing fire prior to damaging targets outside the cabinet, the Field Operator and the Fire Brigade were not considered equivalent. While the Field Operator is a trained responder, the Fire Brigade arrives with a team of additional resources, equipment, organizational support, and capabilities to address any postulated fire. The performance of the Field Operator is appropriately described for both in-cabinet events "π_1" and area-wide events "π_2" in Section 11.1 of NUREG-2180. However, the performance of the Fire Brigade (π'), regardless of an in-cabinet or area-wide VEWFD system, should use the MCR curve.

Conventional Detection / Suppression (η): This event represents the conventional fire suppression probability, as described in Section 11.2 of NUREG-2180, with two recommended changes.

First, more realistic treatment of the incipient stage is recommended when crediting incipient detection for prompt detection in "η_2", where the issue is whether the fire can be suppressed before damaging targets outside the cabinet. Most fires that have a growth profile are also expected to exhibit a detectable incipient stage, even when the duration of that incipient stage is less than the 1 hour necessary for an effective prevention response. Simply assuming the time to detection at ignition would often be overly conservative and is inconsistent with a general observation from NUREG-2180 that incipient detector response typically occurred half-way through the tests that ended in cable damage conditions.

For fires described by the "α" branch in Figure 1, the general observation from NUREG-2180 suggests that the incipient ALARM can be expected to occur between 0 and 30 minutes prior to reaching cable damage conditions. However, incipient detection is selectively applied and all of the fires described by the "α" branch in Figure 1 would not be considered to be good candidates. For systems installed consistent with the guidance in Section P.1.3 of NUREG/CR-6850, a good candidate would be expected to provide 5 minutes of additional warning between the incipient ALARM and ignition. That time between incipient ALARM and ignition could be credited as additional time to target damage or equivalently as additional time available for suppression. The operating experience from the 87 (and counting) detector-years listed in Table 7-3 of NUREG-2180 for U.S. NPPs supports the use of 5 minutes as reasonably realistic yet conservative. Individual plants could use a different number with additional justification.

Second, inclusion of the Fire Brigade in conventional suppression for "η_3" is recommended when enhanced suppression "π" is provided by the Field Operator. No additional credit is provided for manual suppression when the Fire Brigade is credited for enhanced suppression. The change became necessary when the responses of the Field Operator and the Fire Brigade were separated. In Figure 1, the prime mark (') indicates when the Fire Brigade is credited either for enhanced suppression or conventional suppression.

***If appropriate, provide proposed rewording of guidance for inclusion in the next Revision*:**

Figure 1

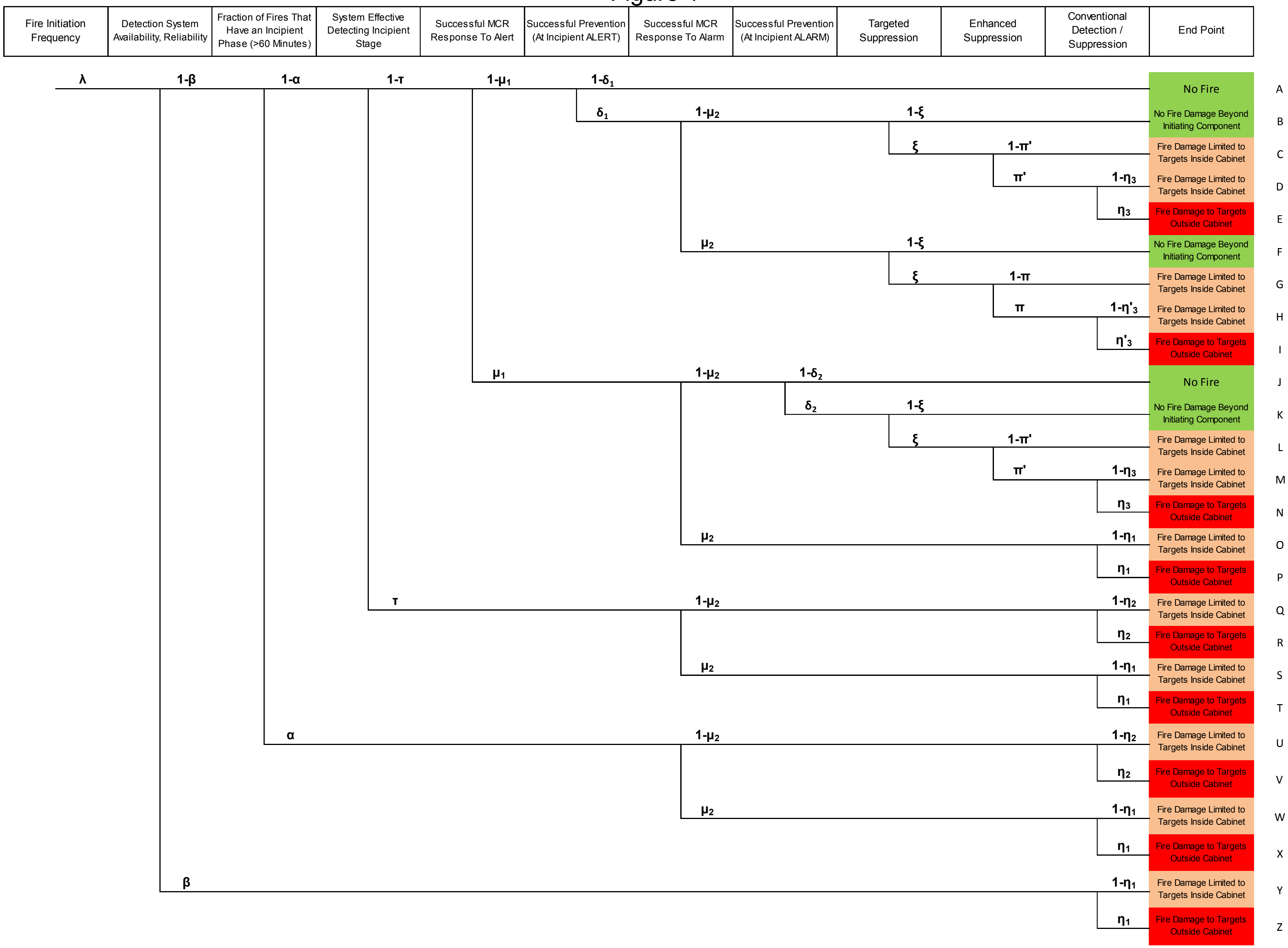

Fire Initiation Frequency
Detection System Availability, Reliability
Fraction of Fires That Have an Incipient Phase (>60 Minutes)
System Effective Detecting Incipient Stage
Successful MCR Response To Alert
Successful Prevention (At Incipient ALERT)
Successful MCR Response To Alarm
Successful Prevention (At Incipient ALARM)
Targeted Suppression
Enhanced Suppression
Conventional Detection / Suppression
End Point
λ
1-β
1-α
1-τ
1-μ1
1-δ1
δ1
1-μ2
1-ξ
ξ
1-π'
π'
1-η3
η3
μ2
1-π
π
1-η'3
η'3
μ1
1-δ2
δ2
1-η1
η1
τ
1-η2
η2
α
β
No Fire
No Fire Damage Beyond Initiating Component
Fire Damage Limited to Targets Inside Cabinet
Fire Damage to Targets Outside Cabinet
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
Y
Z

Figure 2

August 2013 Fire on 6.9kV/480V Transformer for Aux Bus 1E2 in Switchgear Room B

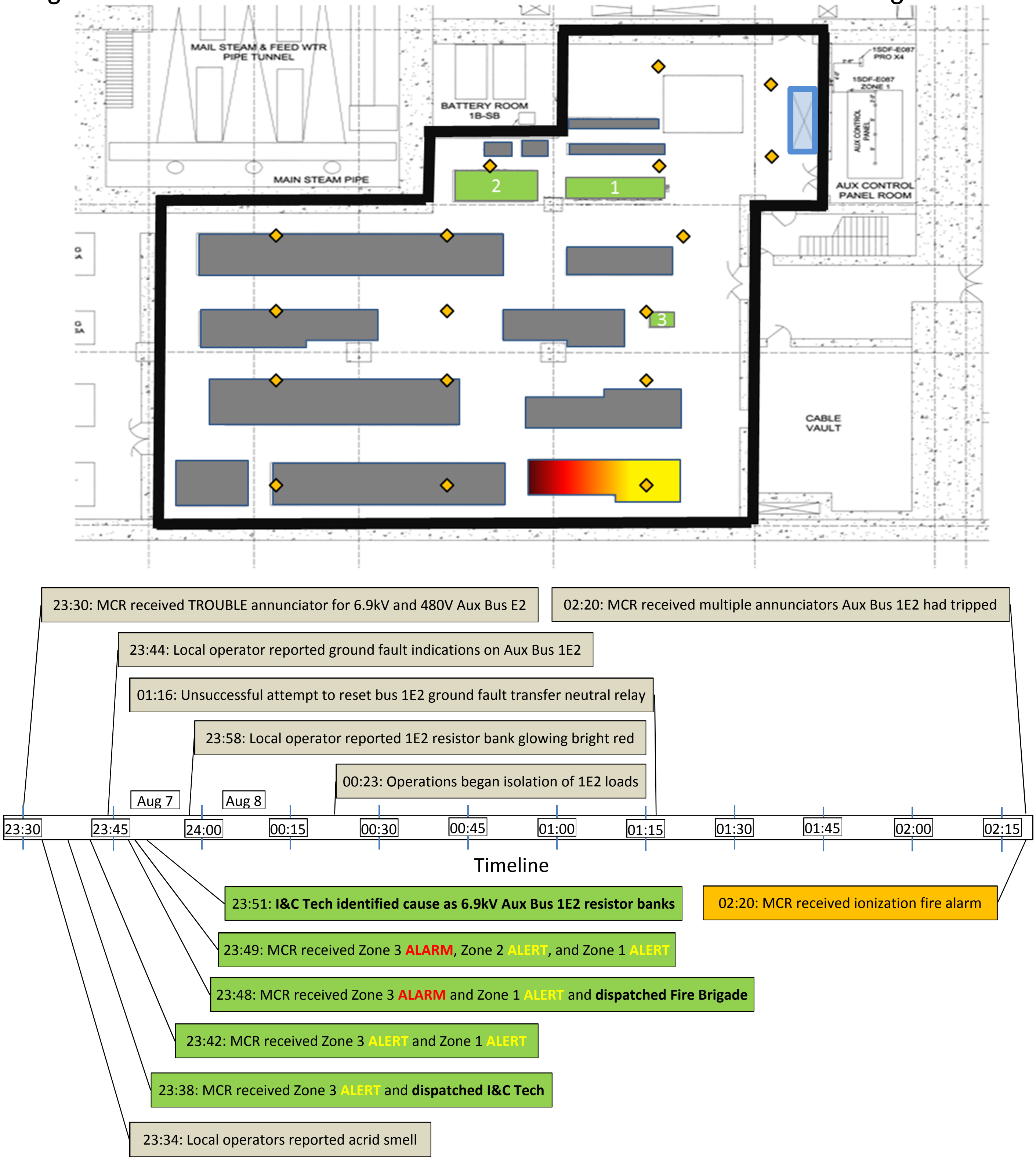
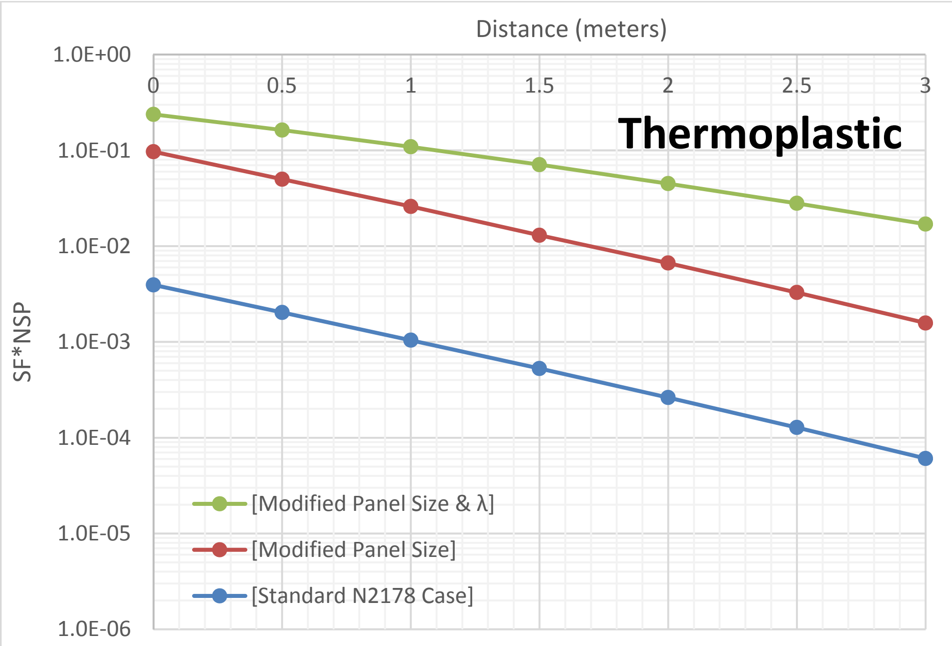
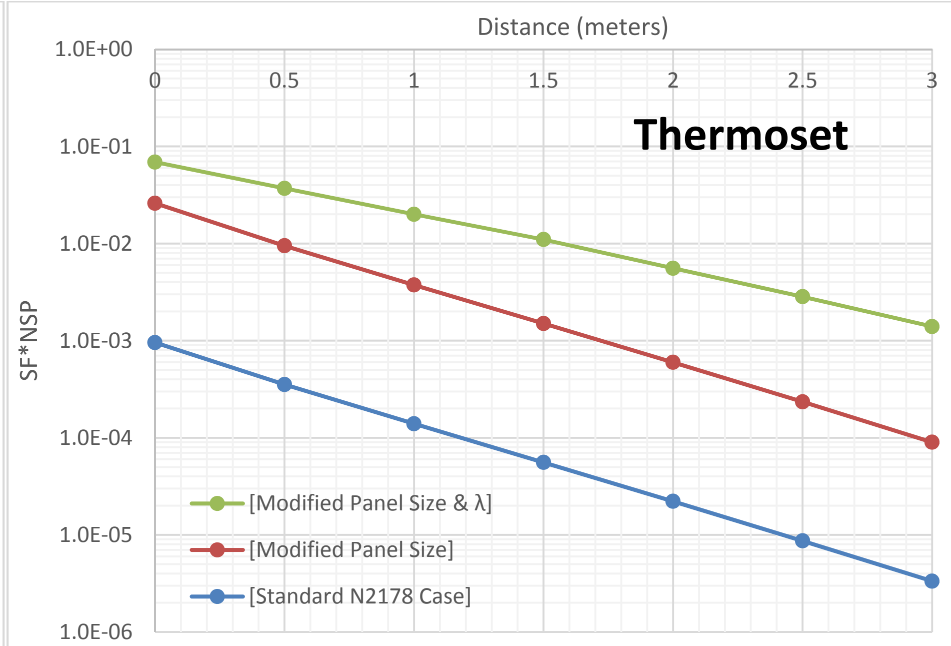


Figure 3
Statistical Zero-Length Non-Suppression Probability





CONFIGURATION						THERMOPLASTIC				THERMOSET			
[Standard N2178 Case]	d (m)	W (ft)	H (ft)	t.det	λ	Tdam (C)	α	β	SF*NSP	Tdam (C)	α	β	SF*NSP
(2178 Class 4a Lg, closed, W=60ft) - 0 m distance	0	60	10	0	0.324	205	0.52	145	3.942E-03	330	0.23	223	9.557E-04
[Modified Panel Size]	d (m)	W (ft)	H (ft)	t.det	λ	Tdam (C)	α	β	SF*NSP	Tdam (C)	α	β	SF*NSP
(2178 Class 4a Lg, closed, W=3ft) - 0 m distance	0	3	7	0	0.324	205	0.52	145	9.700E-02	330	0.23	223	2.600E-02
[Modified Panel Size & λ]	d (m)	W (ft)	H (ft)	t.det	λ	Tdam (C)	α	β	SF*NSP	Tdam (C)	α	β	SF*NSP
(2178 Class 4a Lg, closed, W=3ft) - 0 m distance	0	3	7	0	0.098	205	0.52	145	2.380E-01	330	0.23	223	6.900E-02

Table 1
Lambda For Time Available After Incipient ALARM

Table D-2 Supplement	Incipient Phase (hrs)	Delta Time (hrs)	ASD CC		ASD LS-SS		ION		PHOTO	
			ALERT	ALARM	ALERT	ALARM	ALERT	ALARM	ALERT	ALARM
EPRI FEDB 161	0.5		0.26		0.13		0.17		0.04	
EPRI FEDB 50836	0.9		0.47		0.23		0.31		0.07	
SNZ z-machine	0.98		0.51		0.26		0.33		0.08	
2014 Event		0.03	1.12	1.09	0.56	0.54	0.73	0.71	0.17	0.16
2013 Event		0.17	2.75	2.58	1.38	1.30	1.80	1.69	0.42	0.39
EPRI FEDB 10647	7	0.58	3.64	3.06	1.82	1.53	2.38	2.00	0.56	0.47
2015 Event		0.75	4.75	4.00	2.38	2.00	3.11	2.62	0.73	0.61
Lambda (2180)			*0.518*		*1.036*		*0.793*		*3.382*	
Lambda			*0.326*	*0.373*	*0.651*	*0.745*	*0.499*	*0.570*	*2.128*	*2.432*

* shaded information copied from Table D-2 of NUREG-2180

Enclosure: Incipient Review from FEDB

EPRI's updated fire events database (EPRI 1025284) was published in July 2013. Subsequent to publication, the FEDB was used to update fire ignition frequencies and manual non-suppression probabilities. That effort was published in late 2014 under EPRI 3002002936 and NUREG-2169. While the historical application of the FEDB was to provide data for both fire frequency and manual fire-fighting, it was also recognized that the FEDB could also provide valuable data in fire behavior and other attributes that could be meaningful to develop realistic fire PRA methods and data. This effort is ongoing and the FEDB is currently being used to develop more meaningful methods for electrical cabinet and transient fire sources.

The FEDB was used in NUREG-2180 to identify potentially challenging or greater fires that exhibit incipient behavior. The event tree approach proposed in NUREG-2180 considers the percentage of fires that exhibit an incipient phase lasting at least 30 minutes from the FEDB as an input to quantification. While the relative experience in responding to and mitigating potential fire events with very early warning fire detection is relatively new in nuclear power plant fire protection programs, there is some cursory experience that can be drawn from a review of a.) Fire events with incipient behavior and b.) Fire events in control cabinets. While the experience is not specific to the response of VEWFD systems, the review focused on events that would be most similar. Fire events with noted fire precursors (smoke smell, etc.) were studied to understand the extent of damage and suppression strategy with the notion that incipient experience would also allow for catching the fire in the early stage of development. Fire events in control cabinets were studied as this is the most common industry application and these fires tend to have lower ignition source potential and thus are more likely to be picked up in a smoldering or low energy fire phase.

An insight from the industry pilot of NUREG-2180 noted that the time to damage of secondary targets is the most critical parameter. The time to damage is calculated using a t-squared growth from time zero up to peak heat release rates in twelve minutes. The non-suppression probability is calculated based on the time to target damage from industry data on manual response to actual fire events. The review focused on the most relevant electrical cabinet fire events to determine if secondary targets were impacted and the timing.

Enclosure: Incipient Review from FEDB

Review of fires with incipient behavior

Fire events with incipient behavior (as noted in Appendix D of NUREG-2180) were reviewed to extract insights in the extent of damage and suppression strategy.

Fire ID	Cabinet Type	FEDB Insights	Fire Duration (minutes)	Extent of Damage	Suppression Strategy
69	Control Cabinet	Fire location is in the switchyard. Cause of fire is breakdown of insulation in control cable. Insulation breakdown is believed to be the result of accumulated effects of 25 years of deterioration due to water intrusion, the contact with the resistor and intermittent heat generated by the resistor resulting in fire damage cables in control cabinet.	10 (Estimated)	Unknown, but appears to be confined to control cabinet.	Unknown
83.1	Power	Smoke was discovered in the back boards area of the control room by a security officer (other utility personnel) who was performing an hourly fire watch tour. Smoke was emanating from the Emergency Lighting Uninterruptible Power Supply and the Essential Lighting Distribution Panel. Fire went out by removing power to the cabinets.	2 (Estimated)	Confined to object of origin (localized / single subcomponent)	Power supply removed (simple manual action)
83.2	Power	Following event 83.1, AO was surveying duty area and found smoke and fire in Train B DC equipment room. Fire was contained to essential lighting isolation transformer. Fire extinguished by removing power and applying carbon dioxide by AO and fire brigade.	2 (Estimated)	Confined to object of origin (localized / single subcomponent)	Power supply removed (simple manual action) and 2 portable extinguishers.
89	MCC	Inspection of MCC concluded that damage was isolated to the control transformer and associated circuitry in cubicle of origin.	10 (Known)	Confined to object of origin	Power supply removed (simple manual action)
161	MCC	Strong odor detected in cable vault area. Determined to be from smoldering breaker. At time of discovery operations and fire brigade members were assisting in locating the source of the hot smell. When the source was found the fire was immediately extinguished. Breaker was turned off locally and a CO2 extinguisher was used on the internals of the breaker.	46 (Estimated)	Confined to object of origin	Single portable fire extinguisher
211	MCC	Little information. Noted as transformer failures. Fire extinguished by de-energizing transformer.	2 (Estimated)	Confined to object of origin	Power supply removed (simple manual action)
219	MCC	Little information. Noted as insulation failure of transformer. Fire extinguished by de-energizing breaker.	10 (Estimated)	Confined to object of origin	Power supply removed (simple manual action)
303	Control Cabinet	Fire in plant heating boiler control cabinet, initially reported by off-going shift operations noticing burning smell. Fire due to electrical short resulting in burning electrical insulation and paint on cabinet.	2 (Estimated)	Confined to object of origin (broad/extensive damage)	Multiple portable fire extinguishers

Enclosure: Incipient Review from FEDB

Fire ID	Cabinet Type	FEDB Insights	Fire Duration (minutes)	Extent of Damage	Suppression Strategy
517	**UPS**	**Fire in inverter. Inverter was de-energized to support fire suppression.**	**20 (Known)**	**Confined to object of origin**	**Power supply removed and multiple portable fire extinguishers and water.**
10338	MCC	At the time of the failure, the breaker was closed, the cabinet door was cracked open and one person was observing the motor starter relay to determine the time at which it actuated, so that current and transients could be measured by an inductive pickup installed on the pump motor power cable. When the pump start switch was actuated on the main control board, the breaker failed catastrophically. Electrical flash, fire, smoke, molten metal, metal fumes, metal parts, and plastic parts were produced. Subsequent to extinguishing the fire, the status of the motor control center was thought to be de-energized, but was actually still energized. Live line supply leads had been blown off the breaker terminals and were hanging outside the cubicle doorway. The breaker assembly ('bucket') was pulled outward to disconnect it from the electrical bus while the bus was unknowingly still powered.	Unknown	Confined to object of origin (localized / single subcomponent)	Power supply removed (simple manual action) & single portable extinguisher
20268	MCC	No information other than CPT overheated.	Unknown	Unknown	Unknown
20270	MCC	No additional information.	2 (Estimated)	Unknown	Unknown
20275	MCC	A control transformer burned up causing the diesel generator lube oil heater motor control center to smoke.	Unknown	Confined to object of origin	Unknown
20282	MCC	While on rounds, an operator saw smoke coming from a motor control center	Unknown	Confined to object of origin	Unknown
20287	MCC	Overload on transformer caused failure	2 (Estimated)	Confined to object of origin	Unknown
20295	MCC	Overheated transformer caused fire.	2 (Estimated)	Confined to object of origin	Unknown
20325	Heat Trace Wiring	No additional information.	10 (Estimated)	Confined to object of origin	Single portable extinguisher
20329	Switchgear	No additional information.	2 (Estimated)	Confined to object of origin	Operator blew out flame
20362	MCC	Insulation burned off 1 lead to motor starter contactor & fuse blocks above severely melted. Terminal screws loose on starter input terminals. Extinguished when de-energized.	2 (Estimated)	Confined to object of origin	Power supply removed (simple manual action)

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Fire ID	Cabinet Type	FEDB Insights	Fire Duration (minutes)	Extent of Damage	Suppression Strategy
30338	Control Panel	Fire in electrical cabinet blower. Blower found to be full of dust and dirt. Smoke detector inside of cabinet did not alarm inside the panel which was hazy with smoke.	48 (Known), 3 min suppression time	Confined to object of origin (localized / single subcomponent)	Power supply removed (simple manual action) & single portable extinguisher
30513	Control Panel	Fire/overheating in constant voltage transformer inside rod control cabinet and ignited combustible material inside transformer housing.	2 minutes (Known)	Confined to object of origin	Multiple portable extinguishers (each RO applied 2 quick bursts of Halon)
50473	Electrical Panel	Small flames were observed coming from a relay along with smoke. Water intrusion into the panel from overflow of a ventilation drain line that had become plugged was the cause of the relay failure. Condition became a sparking and smoke event before power was removed to terminate the event. Flames appear to have been self-extinguished before power was removed to the panel.	3 minutes (Known)	Confined to object of origin	Power supply removed

While the detection means for each fire event vary, the fire events reviewed all note that fire was confined to the object of origin. The most severe fire event reviewed was Fire ID 303, which notes the extent of damage as to the confined to object of origin (broad/extensive damage). No secondary targets were damaged in this event.

Fire ID 517 is the only fire in the set of incipient fires that reached a challenging fire severity. The FEDB classifies this fire was challenging due to the fire fighting duration and suppression strategy. Even with the suppression strategy which involved a combination of removing power, portable fire extinguishers, and water, the fire was confined to the object of origin.

Of the 22 fire events with incipient behavior reviewed, none of the fire events damaged secondary targets. Damage to these targets did not occur due to either low energy nature of the fire (smoking, smoldering, overheating), or rapid manual plant response to the fire. It should be noted that both of these areas are identified are topics of ongoing research between EPRI and NRC-RES.

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Review of fires in control cabinets

The primary installation of VEWFDS is in low voltage electrical control cabinets. For this review fire events with MCC, switchgears, load centers, transformers, and other power distribution type equipment was not considered.

Fire ID	Cabinet Type	Description
69	Control Cabinet	Not clear that any fire actually occurred. The failure was the result of conductive heating of a conductor in contact with a resistor. Anticipated 'incipient' time is unknown but given the lack of any reported fire (event involve over-heating) it is expected to have been a very long time period. In addition, it is not clear that any actual application of an extinguishing agent was required. Event duration was reported as 10 minutes.
98	Control Cabinet	Event describes only the presence of smoke. Description includes characterization as 'smoldering', 'overheating' and 'internal to component'. The duration was reported as 46 minutes. The event description did not mention the occurrence of 'fire'.
131	Undetermined	Events description indicates 'flaming combustion' external to component. The event was discovered by plant staff as there was no installed detection. Fire duration reported as 23 minutes.
187	Control Cabinet	Event described as producing thick gray smoke and flaming internal to component. The description also notes 'broad/extensive damage' but confined to object of origin.
303	Control Cabinet	Event described as having flaming external to component, use of multiple extinguishers, and burning of paint on panel. Event duration was 2 minutes and it was detected by personnel.
20272	Electrical Panel	Minimal information available. Duration reported as 2 minutes and damage described as confined to object of origin.
20325	Heat Trace Wiring	Event involved acid spill on heat trace wiring. It is assumed that this event involved the actual heat trace cable – and not internal panel wiring. As such, this event is not considered because the fire was not actually within an electrical cabinet.
30281	Control Panel	Event described as smoldering combustion, confined to object of origin and localized to a single subcomponent. The area had installed detection which did not actuate. The fire was suppressed by removing power and multiple portable extinguishers. The description states that that there was evidence of smoke, opened the panel and saw failed insulation. No flaming was observed.
30338	Control Panel	Ventilation blower for cabinet clogged with dust and dirt. Event described as involving smoke. Detection in area and within cabinet did not actuate. Suppression described as removing power and single portable extinguisher. Damage described as being confined to a single subcomponent. Reported fire duration of 3 minutes.
30478	Control	Event duration was 2 minutes and suppressed by single extinguisher. Detection in area was not actuated and damage was described as extensive insulation within cabinet. The source was described as a 'bunch of relays'.
30513	Control	Fire actuated ionization detector and suppressed by fixed Halon system. Source of fire was described as voltage transformer. Event 'ignited combustible materials inside transformer housing'. Damage described as being limited to object of origin.
30522	Control	Fire actuated detection system and extinguished by single CO_2 extinguisher. Fire was confined to panel but there was damage to internals with 'noticeable charring and smoke damage, external box had some heat and smoke damage'. Flaming combustion was also noted. Fire duration was not provided.
30578	Power Supply	Fire was self-extinguished and damage limited to heat shrink tubing on a connector. The description as includes 'flaming combustion internal to component'.
50473	Electrical Panel	Event described as being extinguished by removing power – small flames from relay with smoke, water intrusion, sparking and smoke before power removed.
50784	Control Cabinet	Event occurred during testing. The relay started to smoke … removed power (pulled fuses) … 'shot' with CO_2 extinguisher. Damage confined to object of origin (localized to single subcomponent).
50811	Control Cabinet	Event described as being detected by a 'failed equipment alarm'. Upon investigation, found 'relay burning'. Extinguished using single portable extinguisher. Damage confined to object of origin (localized to single subcomponent).

Enclosure: Incipient Review from FEDB

There are five events (131, 187, 303, 30478, and 30522) out of the 16 events reviewed which presented evidence that damage to an external target could have occurred had such a target been present. An additional event (30513) was found to be an outlier in that the panel had an interior automatic Halon suppression system, and one event (20325) should not be included. The remaining 9 events all resulted in limited or minimal internal damage. In most of these instances the fire damage was confined to a single sub-component. However, the guidance provided in NUREG-2180 would require that 100% of the postulated electrical cabinet fires be treated with an assumed failure of all internal components and wiring even if a VEWFDS system were installed. This treatment is inconsistent with actual experience where over 64% of the fires were successfully suppressed with damage limited to a single sub-component without any VEWFDS or in-cabinet smoke detection installed.

The industry experience shows that even without any in-cabinet smoke detector installed, over 64% of the fires are successfully suppressed with interior damage being limited to a single sub-component. In all of these instances, the fire was not detected via any smoke detector system and fire damage beyond to originating sub-component was adverted without the required augmented operator procedures or guidance as suggested in FAQ 08-0046 for the δ node.

Given the observed industry experience, it is reasonable and realistic to expect that some fraction of electrical cabinet fires will have limited damage potential to other targets within the same cabinet or panel. This likelihood should be substantially reduced if an in-cabinet detector is installed. The industry experience shows that current industry practices, which do not typically include augmented operator procedures or guidance as suggested in FAQ 08-0046 for the δ node, are sufficient to ‘de-power’ affected equipment and advert a potential fire event before any actual flaming occurs. This activity is clearly a function of the time available to complete that action and the presence of an in-cabinet detector would increase that available time and thereby increase the likelihood of successful fire prevention.

The guidance as currently presented in NUREG-2180, while a notable improvement over the guidance in FAQ 08-0046, does not yet address the δ or ε_1 nodes. The application of the standard time to damage calculation using traditional fire modeling tools, the established HRR distributions, and the 12 minute growth rate does provide two improved variations for the treatment of the ε_2 node (using the two different suppression rate terms). Empirical data is available to develop an interim treatment for the δ and ε_1 nodes of the FAQ 08-0046 event tree. However, excluding the treatment of at least the ε_1 node in a manner that comports to industry experience would lead to gross distortion of the calculated fire risk, which is inherently inconsistent with the requirement to meet the ASME/ANS PRA Standard.