Key operating experience to improve realism in NUREG 2180:

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 draft 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 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.

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) and2 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

Fire ID	Cabinet Type	FEDB Insights	Fire Duration (minutes)	Extent of Damage	Suppression Strategy
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
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

Fire ID	Cabinet Type	FEDB Insights	Fire Duration (minutes)	Extent of Damage	Suppression Strategy
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)
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	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)

Fire ID	Cabinet Type	FEDB Insights	Fire Duration (minutes)	Extent of Damage	Suppression Strategy
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.

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'.

Fire ID	Cabinet Type	Description
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).

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. The remaining 10 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 66% 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 66% 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 ε1 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 ε2 node (using the two different suppression rate terms). Empirical data is available to develop an interim treatment for the δ and ε1 nodes of the FAQ 08-0046 event tree. However, excluding the treatment of at least the ε1 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.