NON-CONCURRENCE PROCESS
COVER PAGE

The U.S. Nuclear Regulatory Commission (NRC) strives to establish and maintain an environment that encourages all employees to promptly raise concerns and differing views without fear of reprisal and to promote methods for raising concerns that will enhance a strong safety culture and support the agency's mission.

Employees are expected to discuss their views and concerns with their immediate supervisors on a regular, ongoing basis. If informal discussions do not resolve concerns, employees have various mechanisms for expressing and having their concerns and differing views heard and considered by management.

Management Directive, MD 10.158, "NRC Non-Concurrence Process," describes the Non-Concurrence Process (NCP), http://nrcweb.nrc.gov:8600/policy/directives/catalog/md10.158.pdf.

The NCP allows employees to document their differing views and concerns early in the decision-making process, have them responded to (if requested), and attach them to proposed documents moving through the management approval chain to support the decision-making process.

NRC Form 757, "Non-Concurrence Process" is used to document the process.

Section A of the form includes the personal opinions, views, and concerns of a non-concurring NRC employee.

Section B of the form includes the personal opinions and views of the non-concurring employee's immediate supervisor.

Section C of the form includes the agency's evaluation of the concerns and the agency's final position and outcome.

NOTE: Content in Sections A and B reflects personal opinions and views and does not represent official factual representation of the issues, nor official rationale for the agency decision. Section C includes the agency's official position on the facts, issues, and rationale for the final decision.

At the end of the process, the non-concurring employee(s):

☐ Concurred

☒ Continued to non-concur

☐ Agreed with some of the changes to the subject document, but continued to non-concur

☐ Requested that the process be discontinued

  ☐ The non-concurring employee(s) requested that the record be non-public.

  ☒ The non-concurring employee(s) requested that the record be public.

☐ This record is non-public and for official use only.

☒ This record has been reviewed and approved for public dissemination.

NRC FORM 757 NRC MD 10.158 (02-2016)	U. S. NUCLEAR REGULATORY COMMISSION **NON-CONCURRENCE PROCESS**	NCP TRACKING NUMBER NCP-2016-017 NCP PM 10/21/16

SECTION A - TO BE COMPLETED BY NON-CONCURRING EMPLOYEE

TITLE OF SUBJECT DOCUMENT RESPONSE TO JULY 28, 2016, LETTER REGARDING RETIREMENT OF NATIONAL FIRE PROTE	ADAMS ACCESSION NO. ML16253A111
DOCUMENT SIGNER Joesh G. Giitter	SIGNER TELEPHONE NO. 415-2884
TITLE Director, Division of Risk Assessment	ORGANIZATION NRR
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☐ DOCUMENT AUTHOR ☐ DOCUMENT CONTRIBUTOR ☐ DOCUMENT REVIEWER ☑ ON CONCURRENCE

NON-CONCURRING EMPLOYEE'S SUPERVISOR Stacey Rosenberg	
TITLE Branch Chief	ORGANIZATION NRR/DRA/APLA

☐ I WOULD LIKE MY NON-CONCURRENCE CONSIDERED AND WOULD LIKE A WRITTEN EVALUATION IN SECTION B AND C.

☑ I WOULD LIKE MY NON-CONCURRENCE CONSIDERED, BUT A WRITTEN EVALUATION IN SECTIONS B AND C IS NOT NECESSARY.

WHEN THE PROCESS IS COMPLETE, I WOULD LIKE THE NCP FORM: ☑ PUBLIC ☐ NON-PUBLIC

REASONS FOR THE NON-CONCURRENCE, POTENTIAL IMPACT ON MISSION, AND THE PROPOSED ALTERNATIVES
(use continuation pages or attach Word document)

Originally this non-concurrence was planned solely for endorsing NUREG-2180 as a viable replacement to FAQ 08-0046 on Very Early Warning Fire Detection Systems (VEWFDSs). The crux of that non-concurrence remains and is developed completely in the attached. However, with the endorsement letter having evolved continuously since I first viewed it, I now find another potential concern with the particular statements: (1) "NRC's EXPECTATION is ... in FAQ 08-0046" and (2) "For these licensees ... becomes available." As became evident during the latter phases NUREG-2180, FAQ 08-0046 contained a potentially significant error that likely has allowed plants that have already transitioned successfully to NFPA-805 under 50.48(c), and have the FAQ as an integral part of their new fire protection program licensing basis, to have been approved despite failing to have met the risk metric criteria (total and increase in risk) in RG 1.174, which is the governing document for transition. While the attached non-concurrence discussion addresses the under-estimate in risk attributable to use of the FAQ relative to alternatives to the methodology in NUREG-2180, the following (continuation page) addresses the potential under-estimate in risk (and consequently under-estimate in the risk increase) attributable to use of the FAQ during the transition process, both for plants that have already transitioned as well as for those that may still be in the transition process (it is assumed the FAQ, having been rescinded, will not be used for any future risk-informed submittals). As shown there, the potential for failing to meet the required thresholds for transition under RG 1.174 for plants crediting FAQ 46 is substantial. The letter's uses of EXPECTATION and allowance of "FAQ 08-0046 [to] remain part of the current licensing basis ... becomes available" is inadequate given this potential. It must be enhanced to be a REQUIREMENT that precludes the use of the FAQ for any subsequent risk-informed applications, including exercising self-approval under NFPA-805 itself for those plants with the FAQ as part of their new licensing basis. Ideally, all plants that have credited the FAQ would be required to reanalyze their transition metrics removing that credit to determine whether or not they would still have met the RG-1.174 requirements for transition. If not, some sort of "grace period" might be allowed for these plants to revise their transition, and as a result their licensing basis, by proposing and committing to different modifications to "recover" whatever risk reduction credit has been lost by the rescinding of the FAQ, especially in light of the FAQ's error. As shown in the following (continuation page), the under-estimate could be severe enough to actually warrant backfitting, although this might be avoided by instituting this "grace period" process.

SIGNATURE	DATE
Raymond HV Gallucci	10/20/16

CONTINUATION PAGE, SECTION A

The potential effect from this under-estimate on plants crediting FAQ 46 for transition to their new risk-informed, performance-based fire protection licensing basis under 50.48(c) is shown below to be quite significant, potentially enough to have precluded transition (e.g., unless other modifications were proposed) and rendering any new licensing basis due to approval of the transition erroneous. Consider that, at the time FAQ 08-0046 was issued (November 2009), only one other acceptable method for crediting in-cabinet VEWFDS existed, namely that from NUREG/CR-6850 (remember that the "original" FAQ, later released as Gallucci, et al., "Credit for Very Early Warning Fire Detection [VEWFD] in Fire Probabilistic Risk Assessment," Proceedings of Risk Management - for Tomorrow's Challenges, American Nuclear Society, 2011, LaGrange Park, Illinois, pp. 152-166, never was officially available as an alternative):

> *If a high-sensitivity smoke detection system is credited, the failure probability of the system should be considered. If in-cabinet smoke detection devices are installed in the electrical cabinet postulated as the ignition source, the analyst should assume that the fire will be detected in its incipient stage. This incipient stage is assumed to have a duration of 5 minutes. In order to account for these 5 minutes, the analysts should add them to the time to target damage (or, equivalently, add them to the time available for suppression).*

Given an additional 5 minutes available for suppression, the non-suppression probability for an electrical fire inside a cabinet would be exp(-0.0975[t + 5]), i.e., a decrease by a factor of exp(-0.0975t)/exp(-0.0975[t + 5]) = exp([0.0975][5]) = 1.6, which is 50/1.6 ≈ 30 times lower. In the attached non-concurrence discussion specifically related to NUREG-2180, the potential effect on risk reduction credit for reducing the credit by a factor of 10 was assessed. Reproducing that assessment, but now for a factor of 30, yields the following.

If the risk reduction credit is reduced by 30, the total fire risk would increase by a factor from 2.74 to 18.4, as shown:

For the minimum (6%) case: CDF (w/o credit from FAQ 08-0046) = (30)(0.06) + (1 – 0.06) = 2.74, i.e., 174% higher than CDF (with credit from FAQ 08-0046)

For the maximum (60%) case: CDF (w/o credit from FAQ 08-0046) = (30)(0.6) + (1 – 0.6) = 18.4, i.e., 1,740% higher than CDF (with credit from FAQ 08-0046)

These can easily be scaled by relaxing the assumption that all the electrical cabinet fire scenarios were reduced by FAQ 08-0046. E.g., if only half in each case:

6% case: CDF = (30)(0.06/2) + (1 – 0.06/2) = 1.87 (87% increase)

60% case: CDF = (30)(0.6/2) + (1 – 0.6/2) = 9.70 (870% increase)

The effects on the changes in risk, i.e., the risk increases from NFPA-805 transition/implementation relative to the "idealized, compliant" plant, are the same. These are potentially significant increases in both the "delta-" and "total" risks which could have precluded transitions under NFPA 805 without physical or procedural modifications, or more detailed fire risk analysis employing fire phenomenological modeling, conveniently avoidable due to this potentially significant under-estimation.[1]

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1 For example, if a plant transitioned with a small risk (CDF) increase ("delta-risk"), say 1E-6/y, but a medium total risk (CDF), say 7E-5/y, both of which were acceptable under RG 1.174 as lying in Region II/III in its Figure 4, the change under the full 60% case would result in a delta-risk now at 2E-5/y and total risk at 1E-3/y, pushing it into Region I. Similarly, if a plant transitioned with a medium delta-risk, say 4E-6/y, but a small total risk, say 1E-5/y, both of which were acceptable under RG 1.174 as lying in Region II, the change under the full 60% case would result in a delta-risk now at 7E-5/y and total risk now at 2E-4/y, pushing it into Region I.

The history behind FAQ 08-0046, "Incipient Fire Detection Systems," in Supplement 1 to NUREG/CR-6850 [EPRI 1019259], that ultimately led to NUREG-2180 is relevant and summarized here. As part of the Harris plant pilot transition to NFPA 805, they proposed installation of a Very Early Warning Fire Detection System (VEWFDS) technology to achieve a risk reduction by a factor of 100 in a location contributing significantly to the fire core damage frequency (CDF). An FAQ was proposed and NRR staff with expertise in fire PRA and fire protection were assigned to develop it. Based on manufacturer claims and reported, but not provided, test results, an EPRI report quantified a risk reduction factor as high as 167 for this technology. Independently, the NRR staff, with documented test results acquired by RES from Xtralis®, the vendor of one of the leading VEWFDS technologies (VESDA®), was performing its own evaluation, which suggested that any risk reduction credit would be much more modest, no more than a factor of 10 under the most ideal conditions, and likely less.

During a brief absence by the fire PRA expert, the draft final form of this FAQ was removed from the original team and reassigned to NRR Senior Level Advisors and selected RES staff, with less fire protection expertise and any fire PRA expertise reduced to a consulting role. This team relied heavily on the EPRI report, eschewing use of any of the information assembled and being used by the original team, and ultimately produced FAQ 08-0046, with a maximum risk reduction credit of 50.[1] While not as high as originally desired by Harris, this suited their purpose, enabling them to complete transition without considering other modifications in the critical location. This also suited NRR's purpose to facilitate transition of this pilot plant as expeditiously as possible. The only reason that I did not file a non-concurrence/DPO was that I completed the analysis which I and the fire protection experts had produced in the expunged draft final FAQ and was allowed to publish the results at a conference (see Gallucci, et al., "Credit for Very Early Warning Fire Detection [VEWFD] in Fire Probabilistic Risk Assessment," Proceedings of Risk Management - for Tomorrow's Challenges, American Nuclear Society, 2011, LaGrange Park, Illinois, pp. 152-166 – included as Attachment 1). (Note: This paper, which addressed only VEWFDS installed inside an electrical cabinet, was subsequently updated, but not published, using the Xtralis® data to estimate the risk reduction credit for "area-wide" VEWFDS installation. The result was that the previous credit for in-cabinet installation would be halved. [Included as Attachment 2])

To confirm or replace FAQ 08-0046, the DELORES-VEWFIRE program was started by RES, which ultimately evolved in NUREG-2180. My recommendations that a "clean slate" be used, not tied to the FAQ or prematurely incorporating HRA, [2] were rejected. I have several major concerns with this report, thereby prompting my non-concurrence of the NRR endorsement. Primary is the assumption that "enhanced suppression" drives any benefit to be derived from the use of these systems. To model this "enhanced suppression," the report makes several overly optimistic, and therefore non-conservative, assumptions. First, for an in-cabinet VEWFDS installation, the report assumes that non-suppression probability can be characterized by the curve for MCR fires, as per NUREG-2169, "Nuclear Power Plant Fire Ignition Frequency and Non-Suppression Probability Estimation," October 2014. This itself is based

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1 As discussed in Attachment 4, this factor was the result of an error whose significance in under-estimating risk could have been quite substantial.

2 "[This] … argues for abandoning the FAQ 46 approach and its indefensible event tree entirely for a new mind set, devoid of the industry-driven notions based on speculation and wishful thinking designed to justify unjustifiably large credit for VEWFDS to enable Harris and others to reduce risk … FAQ 46 was guilty of over-modeling. We should avoid a similar mistake with [these] … test results and approach the entire concept more holistically, as I (and others originally assigned to the FAQ) attempted through the ANS paper. Without the long-term tests I've advocated, we cannot quantify any ignition-avoidance effect from VEWFDS. The only quantifiable aspect is the bonus in suppression response time as a result of some earlier warning that a fire is about to occur, well beyond the 'first molecule' phase. And, already, tests such as those by Xtralis® have shown this benefit to be quite limited, 5-10 minutes at most, which translate into no more that factors of 2-3 reduction in non-suppression probability for electrical fires." (e/mail "RE: VEWFD system information on fraction of fires exhibiting an incipient phase," Gallucci to multiple recipients, June 6, 2014)

on the following overly optimistic assumptions. First, as evidenced in the chapters related to HRA, operators are assumed to "drop everything" when a VEWFDS "alert" signal occurs and dispatch responders to the scene immediately. This is based on procedures reported by the Harris plant, which not only had a vested interest in the original FAQ, but also was used as the prime industry consultant during the testing and, having used the FAQ 08-0046 credit to justify, at least in part, its transition to NFPA 805, continues to hold a similar vested interest in the outcome. Given the nature of the fires supposedly detected by VEWFDS, this alert merely indicates that there may be some pre-flaming overheating taking place, not that any actual fire is imminent. To assume operators will "drop everything" is unrealistic and non-conservative, an inappropriate assumption for use in PRA (which strives for realism and, where not achievable, some conservatism). Nonetheless, even after arriving on the scene, the responder is assumed to take no suppression attempt, i.e., the entire value of the early alert is merely to get someone stationed at the location in case a fire actually manifests. Only then would suppression be attempted.

Compounding this non-conservative assumption are two others. First, the suppression activity, if and when it occurs, is assumed to be characterized as if the fire were occurring in the continuously-occupied, multi-manned MCR, where the nature of the electrical fires can be quite different (typically much less severe) than encountered in electrical cabinets outside the MCR. This can be significant, since the mean time to suppress a fire in the MCR is only 3.1 minutes, while that for a non-MCR electrical fire is 10.2 minutes, over three times longer. Second, the responder is assumed to remain in place indefinitely, i.e., regardless of if, or when, the fire actually manifests, a responder will be there poised and ready to suppress the fire. To me, this is akin to assuming that operators will abandon the MCR even if it remains habitable due to unreliable indications from a non-MCR fire. While licensee procedures may require this, we learned during our NFPA-805 audits that this would rarely, if ever, occur. Only loss of habitability, to the extent where even SCBA's would not permit remaining, would drive MCR abandonment. Clearly, if the fire does not manifest until after the responder leaves, any benefit from VEWFDS is no more than that from any other post-flaming fire signal, except perhaps a bit quicker activation.

NUREG-2180 develops a "new" electrical fire curve that assumes a responder is poised and ready when an electrical cabinet fire starts. For this, the mean time to suppress is 5.2 minutes. This somewhat approximates what one might expect when a continuous fire watch, complete with suppression means at hand, is established. In fact, this is comparable to the pre-NUREG-2169 non-suppression curve for welding fires where a continuous fire watch is established, although not with the current NUREG-2169 version, where the mean time to suppress is now 9.3 minutes. Of course, this still suffers from the overly optimistic assumption that the responder remains in place indefinitely but, if one were to accept this non-conservatism, at least seems a reasonable extension as opposed to using the MCR curve.

My objections regarding the non-suppression aspect are mainly philosophical and curiously, do not always impact the results. This in itself is troubling in that the benefit of VEWFDS is touted in NUREG-2180 as enabling "enhanced suppression." Therefore one would expect the choice of non-suppression curve to be highly significant to the results. In Chapter 12, four examples are presented, three dealing with in-cabinet VEWFDS, one with area-wide. As a sensitivity study, I compared the results for selected cases when the NUREG-2169 electrical non-suppression curve was substituted for the MCR curve (Cases 1-3) and "new" electrical fire curve (Case 4). The following are my results using the same number of significant digits as reported:

Case 1. ASD CC with conventional – non-suppression probability using MCR fire curve = 0.11; using new electrical fire curve = 0.16; using NUREG-2169 electrical fire curve = 0.31.
ION without conventional – non-suppression probability using MCR fire curve = 0.17; using new electrical fire curve = 0.22; using NUREG-2169 electrical fire curve = 0.34.

Case 2. ASD CC with conventional – non-suppression probability using MCR fire curve = 0.11; using new electrical fire curve = 0.16; using NUREG-2169 electrical fire curve = 0.31.

ION without conventional – non-suppression probability using MCR fire curve = 0.30; using new electrical fire curve = 0.31; using NUREG-2169 electrical fire curve = 0.34.

Case 3. ASD CC with conventional – non-suppression probability using MCR fire curve = 0.17; using new electrical fire curve = 0.21; using NUREG-2169 electrical fire curve = 0.31. ASD LS1 without conventional – non-suppression probability using MCR fire curve = 0.25; using new electrical fire curve = 0.26; using NUREG-2169 electrical fire curve = 0.31.

Case 4. ASD CC (ceiling) with conventional – non-suppression probability using new electrical fire curve = 0.31; using NUREG-2169 electrical fire curve = 0.31.

The effect of changing non-suppression curves varies. The maximum variation occurs for Cases 1 and 2 (ASD CC), where the non-suppression probability using the inappropriate MCR fire curve rises by about 50% if the better new electrical fire curve is used and by nearly a factor of three if the correct NUREG-2169 electrical fire curve is used. The effects in Cases 1 to 3 of these changes are less pronounced for the ION or ASD LS1 detector. For Case 4 (area-wide), there is effectively no change between non-suppression probabilities using either the new or NUREG-2169 electrical fire curve. Given the substantial difference in the mean times to suppress between these two curves (5.2 vs. 10.2 min), some difference would be expected. Of course, all of these cases crediting the MCR fire or new electrical fire curve are based on the inappropriate, idealized assumption that the responder remains in place indefinitely until the fire manifests (if ever).

Not only is it inappropriate technically to use the MCR fire non-suppression curve in any of these cases, but also it potentially sets an undesired precedent. Sanctioning its use here for non-MCR applications opens the door for misuse by setting a precedent that would be harder to reject in future applications. For the in-cabinet cases, it clearly is non-conservative and overly-optimistic, inappropriate for use in PRA applications where the goal is realism and the default is to err somewhat conservatively. It is troubling that the choice of suppression curve has essentially no effect for the area-wide cases. If the analytical method is highly dependent on the "enhanced suppression" components, should not significant changes in the results ensue when significant changes in the assumptions are made? This seriously questions the validity of the entire approach in addition to my philosophical objections. I feel I must non-concur with any endorsement of NUREG-2180 based on both these concerns. A substantial amount of good work was performed and probably should be preserved as a series of separate volumes, e.g., the test set-up, results and statistical analysis; literature search results, data assembled and analysis; and qualitative aspect of the HRA (I have concerns that the quantitative aspects are too optimistic). However, as much as FAQ 08-0046 is flawed, to replace it with the methodology presented in NUREG-2180 is not the solution.

Another concern, as highlighted in the paper I and some of the authors of NUREG-2180 presented at the ANS PSA Conference in 2015 (see Taylor, G., R. Gallucci, et al. 2015. "Statistical Characterization of the Advanced Notification in Detection Time for Very Early Warning Fire Detection in Nuclear Plant Electrical Enclosures," American Nuclear Society 2015 International Topical Meeting on Probabilistic Safety Assessment and Analysis, April 26-30, 2015, Sun Valley, Idaho, pp. 227-235 – included as Attachment 3), was that only one of the technologies ("cloud chamber," coincidentally that utilized by the Harris plant) showed, on average, some "bonus" time in detecting a fire during the pre-flaming stage, that being on the order of 10 minutes. With a VESDA®-type technology being among the others tested, it is curious that only one technology showed any mean benefit, especially in light of the VESDA® results analyzed by me and the fire protection engineers before we were removed from the original FAQ. One reason for this was difficulty in aligning the calibration for the cloud chamber technology to NFPA 76 standards to enable an equal comparison with the other technologies to be made. While the report offers methods to adjust the cloud chamber results for different calibrations, the base-case reported results still come from the cloud chamber tests with the sensitivity higher than that for the others. These results are nearly always the most optimistic (highest reduction factor) in the Example cases. One would have expected some benefit, on

average, for the other VEWFDS technologies, even if not as much as for the cloud chamber. This is also disconcerting regarding the results as it suggests an uneven "playing field" for the comparisons.

I offer a solution that makes use of some of the results from NUREG-2180, but not the methodological approach. For any detector, define two opportunities for successful detection: (1) during the pre-flaming stage; (2) during the post-flaming stage. Therefore, failure to detect would require failure during BOTH stages, an AND situation, the occurrence of which can be represented as D_t (total detection failure) = D_1 (pre-flaming) x D_2 (post-flaming). For a conventional ceiling-mounted detector, e.g., ionization, $D_1 = 1$ (no opportunity to detect during pre-flaming). This then simplifies to $D_{t,c} = D_{2,c}$, where the "c" subscript represents "conventional." The corresponding non-suppression probability "N" for electrical enclosure fires then becomes $N_{t,c} = D_{2,c} + (1 – D_{2,c})N_{2,c,}$ where $N_{2,c} = \exp(-0.0975T)$, "T" being the "time available for suppression" from start of the post-flaming stage until loss of the supported component cannot be tolerated. Note that this must include a "penalty" (reduction) for the responder to arrive at the fire and begin suppression activities. For illustrative purposes, assume $D_{2,c} = 0.05$, the maximum value from NUREG/CR-6850, and T = 20 min (time from start of fire until loss of supported component cannot be tolerated) – 10 min (time delay before responder can initiate suppression) = 10 min. This yields $N_{t,c} = 0.41$. Note that this applies to ALL electrical enclosure fires regardless of whether or not there is a pre-flaming stage of any significance, since the ceiling-mounted conventional detector never has an opportunity to detect during that stage.

Now, consider VEWFDS, either in-cabinet (designated by subscript "i") or area-wide (designated by subscript "a"). Depending upon the type of electrical enclosure fire, there will be different probabilities of opportunity to detect during the pre-flaming stage, namely a 0.72 chance for low voltage fires, or a 0.50 chance for the rest. Treating the in-cabinet and area-wide equally for now and using the subscript "v' to designate VEWFDS, we can express the non-suppression probability as follows, using "F" as the fraction of fires potentially detectable during the pre-flaming stage (i.e., 0.72 or 0.50):[3]

$$N_{t,v} = F\{(D_{1,v} + [1 – D_{1,v}]N_{1,v})(D_{2,v} + [1 – D_{2,v}]N_{2,v})\} + (1 – F)(D_{2,v} + [1 – D_{2,v}]N_{2,v})$$

The terms inside the { } represent the non-suppression probability for those fires potentially detectable during the pre-flaming stage. Inside the first set of ( ) is the combined probability of non-detection during the pre-flaming stage plus the probability of non-suppression after transition from pre- to post-flaming given detection was successful. Inside the second set of ( ) is the combined probability of non-detection during the post-flaming stage plus the probability of non-suppression during this stage given detection was successful. The final term (multiplied by 1 – F) addresses those fires not detectable during the pre-flaming stage and is analogous to those detectable during the pre-flaming stage that were not detected or, if detected, were not suppressed.

During the pre-flaming stage, failure to detect can occur if the detector is unavailable, unreliable or ineffective. For an ASD CC (aspirating smoke detection – cloud chamber), these three values are 0.0016, 0.0020 and 0.0027, yielding $D_{1,v} = 0.0063$. During the post-flaming stage, it is assumed that any unreliability or ineffectiveness, given there is now a flame, will be negligible compared to the unavailability, such that $D_{2,v} = 0.0016$. Given that the fire has been detected during the pre-flaming stage, there are two failure modes that lead to non-suppression $N_{1,v}$: (1) Failure of the human responder to arrive in time and be poised to suppress the fire before the pre-flaming stage transitions to post-flaming; (2) Failure of the responder to suppress the fire. For (1), we make the simplifying assumption that the pre-flaming stage does not transition to post-flaming before the responder arrives and is poised to suppress, leaving the only failure being that of the responder to respond. This implicitly assumes that the degree of addressability of the VEWFDS does not affect the ability of the responder to arrive and be poised to suppress before the

[3] All fires are detectable during the post-flaming stage.

transition from pre- to post-flaming, a simplifying assumption.[4] For ASD CC, the total HEP (human error probability) representing this failure is 0.00046. For (2), the responder has arrived and is poised to suppress the fire, a probability of essentially 1.0 (1 – 0.00046 = 0.99954). Therefore, non-suppression is represented solely by the non-suppression probability derived from the appropriate non-suppression curve considering the time available for suppression, which, using the above example, could now be as much as the full 20 min if the responder is already poised to suppress when the post-flaming begins (no delay). This will depend upon whether the VEWFDS is in-cabinet or area-wide, as there could be some time delay for the latter to be poised to suppress when the pre-flaming stage transitions to post-flaming.

For in-cabinet VEWFDS, we assume that the responder is in place and poised to suppress the fire when the transition from pre- to post-flaming occurs (in-cabinet VEWFDS, vs. area-wide, should have the higher degree of addressability). Therefore, no delay in initiating suppression activities when the flaming starts is assumed, leaving the full 20 min available for suppression, i.e., T = 20 min. Additionally, the choice of non-suppression curve is that "newly derived" for electrical fires where a responder was present from the start, for which the corresponding non-suppression probability would be exp(-0.194 x 20) = 0.021. Combined with the possibility of no response, the combined non-suppression probability "during the pre-flaming stage"[5] becomes $N_{1,i} = 0.00046 + 0.021 = 0.021$ (recall subscript "i" for in-cabinet, now replacing previous subscript "v"). If the fire is not detected during the pre-flaming stage, then the in-cabinet VEWFDS can be assumed to respond similarly to the conventional ceiling-mounted detector, but presumably more quickly. At the higher calibration setting, the ASD CC indicated a mean "bonus" response time of ~10 min. If we assume that the previous time delay of 10 min assumed for the conventional ceiling-mounted detector included 5 min for the responder to reach the fire (and another 5 min between the start of post-flaming and the detector response), we can now assume that the time available for the responder given the in-cabinet VEWFDS detects the now flaming fire when it starts is reduced only by the time delay for the responder to reach the fire, i.e., 5 min. Therefore, for in-cabinet VEWFDS that does not detect during the pre-flaming stage, the non-suppression probability will use the same non-suppression curve as that for the conventional ceiling-mounted detector, but with T = 20 min – 5 min = 15 min available for suppression instead of only 10 min, i.e., since the responder is not in place at the time the fire starts, the original electrical fire non-suppression curve remains applicable. Therefore $N_{2,i} = \exp(-0.0975 \times 15) = 0.23$. We can now calculate the total non-suppression probability for in-cabinet VEWFDS considering all types of electrical enclosure fires as follows:

$$N_{t,i} = F\{(D_{1,v} + [1 - D_{1,v}]N_{1,i})(D_{2,v} + [1 - D_{2,v}]N_{2,i})\} + (1 - F)(D_{2,v} + [1 - D_{2,v}]N_{2,i})$$

where:

$F = 0.72$ (low voltage) or 0.50 (other)
$D_{1,v} = 0.0063$
$N_{1,i} = 0.021$
$D_{2,v} = 0.0016$
$N_{2,i} = 0.23$

Therefore, $N_{t,i} = 0.070$ (low voltage) or 0.12 (other)

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4 This assumption is somewhat generous when comparing area-wide to in-cabinet VEWFDS, since the former likely has a lower degree of addressability than the latter. This potential difference will be accounted for when considering the non-suppression curves.

5 The phrase "during the pre-flaming stage" does NOT construe any possibility for suppressing the fire during that stage – any fire suppression can occur only during the post-flaming stage. It merely implies that the ability to implement post-flaming suppression was manifested during the pre-flaming stage.

<u>For area-wide VEWFDS</u>, the assumptions are the same as for the in-cabinet case with the following considerations. For the in-cabinet case, the full 20 min was assumed to be available for the responder in place to suppress the fire once it transitioned from pre- to post-flaming. Since the degree of addressability has previously been assumed not to affect the responder's ability to arrive and be poised to suppress the fire before the transition from pre- to post-flaming, the full 20 min remains available.[6] As with the in-cabinet VEWFDS, if the fire is not detected during the pre-flaming stage, then the area-wide VEWFDS can be assumed to respond similarly to the conventional ceiling-mounted detector, but with a speed intermediate between that for the conventional ceiling-mounted detector and that for the in-cabinet VEWFDS. Previously a 10-min time delay was assumed for the conventional detector, but only 5 min for the in-cabinet VEWFDS. The average of these will be assumed for area-wide, i.e., 7.5 min. Therefore, for area-wide VEWFDS that does not detect during the pre-flaming stage, the non-suppression probability will use the same non-suppression curve as that for the conventional ceiling-mounted detector, but with T = 20 min – 7.5 min = 12.5 min available for suppression, i.e., since the responder is not in place at the time the fire starts, the original electrical fire non-suppression curve remains applicable. Therefore $N_{2,a} = \exp(-0.0975 \times 12.5) = 0.30$. We can now calculate the total non-suppression probability for area-wide VEWFDS considering all types of electrical enclosure fires as follows (note use of subscript "a"):

$$N_{t,a} = F\{(D_{1,v} + [1 - D_{1,v}]N_{1,a})(D_{2,v} + [1 - D_{2,v}]N_{2,a})\} + (1 - F)(D_{2,v} + [1 - D_{2,v}]N_{2,a})$$

where:

$F = 0.72$ (low voltage) or 0.50 (other)
$D_{1,v} = 0.0063$
$N_{1,a} = 0.021$ (taken as same as $N_{1,i}$)
$D_{2,v} = 0.0016$
$N_{2,a} = 0.30$

Therefore, $N_{t,a} = 0.089$ (low voltage) or 0.15 (other)

<u>Comparison of technologies.</u>

For conventional ceiling-mounted detection with the assumptions in this analysis, the total non-suppression probability was 0.41. The corresponding values for in-cabinet VEWFDS based on the ASD CC were 0.070 (low voltage) and 0.12 (other), reductions by factors of 5.9 and 3.4. The corresponding values for area-wide VEWFDS based on the ASD CC were 0.089 (low voltage) and 0.15 (other), reductions by factors of 4.6 and 2.7. <u>Roughly speaking, it appears that the difference between in-cabinet and area-wide VEWFDS for the ASD CC when compared to conventional ceiling-mounted detection is small, with overall reductions in non-suppression probability of approximately five (low voltage) and three (other).</u>

<u>Addendum</u>

Since the unavailability of the VEWFDS is the same failure for both the pre- and post-flaming stages, it should be treated as a common-cause failure, modifying the above general equation for the total non-suppression probability for the VEWFDS as follows:

$$N_{t,v} = F\{(D_{1,v} + [1 - D_{1,v}]N_{1,v})(D_{2,v} + [1 - D_{2,v}]N_{2,v})\} + (1 - F)(D_{2,v} + [1 - D_{2,v}]N_{2,v}) + U_v$$

where the terms remain the same as before with the following changes:

$D_{1,v} = 0.0047$
$D_{2,v} \approx 0$

[6] As a sensitivity, this assumption was relaxed and reduced the time available for area-wide VEWFDS from 20 min to 17.5 min. The changes were as follows: $N_{1,a} = 0.034$ and $N_{t,a} = 0.090$ (low voltage) and 0.15 (other). Despite the ~50 increase in $N_{1,a}$, the $N_{t,a}$ values changed little from 0.088 (low voltage) and 0.15 (other).

$U_v = 0.0016$

With this correction, the previous results become as follows (two significant figures):

$N_{t,i} = 0.070$ (low voltage) or 0.12 (other); comparison factors = 5.8 (low voltage) and 3.4 (other)
$N_{t,a} = 0.089$ (low voltage) or 0.15 (other); comparison factors = 4.6 (low voltage) and 2.7 (other)

As expected, given the very low unavailability for the VEWFDS ASD CC, there is essentially no effect.

If one considers the guidance on "in-cabinet smoke detection devices … installed in the electrical cabinet postulated as the ignition source" from NUREG/CR-6850 (Section P.1.3), an addition of five minutes onto the "time available" for suppression results in a reduction factor for non-suppression probability between conventional detection and a VEWFDS, as characterized by the "new" electrical fire curve, of $\exp(-0.194T)/\exp(-0.194[T + 5]) = \exp(0.194[5]) = 2.6$. The results from the paper(s) by the original FAQ team (one published, for in-cabinet VEWFDS; the other un-published, for area-wide VEWFDS), suggested reduction factors from 3 to 10 (in-cabinet VEWFDS), with geometric mean = 5, halved for area-wide VEWFDS. The analysis above, using the NUREG-2180 results, suggests a reduction factor of 5 for low-voltage electrical cabinets and 3 for others. There would appear to now be ample evidence, test results, analyses, etc., to rescind FAQ 08-0046 and replace it with some simple, general guidance that limits the maximum reduction factor for non-suppression probability due to an in-cabinet VEWFDS at 5 with about half, or 3, for area-wide.

ATTACHMENT 1

Credit for Very Early Warning Fire Detection in Fire Probabilistic Risk Assessment

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INTRODUCTION[7]

U.S. commercial nuclear power plants that are planning to upgrade their fire protection programs are considering the installation of very early warning fire detection systems in electrical cabinets that could enable pre-combustion products to be detected well in advance of fire ignition for certain types of combustion sources. The relative newness of this technology to the U.S. commercial nuclear industry poses difficulty when fire probabilistic risk assessments (PRAs) attempt to credit the potential reduction in core damage frequency due to fires when such systems are present. This paper reviews and develops three approaches toward at least narrowing the potential range on the amount of credit in fire PRA until further research can be performed and operational experience can be accumulated.[8]

BACKGROUND

Fires can initiate in a variety of ways. Electrical equipment fires can generally originate from an arc or overheating components. One that evolves from an arc can be highly energetic, causing damage to equipment very rapidly. A fire resulting from overheating, such as wire or cable insulation or circuit boards, often develops more slowly. This paper examines the detection of these overheating events in their incipient (first) or smoldering stage of fire development that provides a window of opportunity to detect and control the spread of fire. A very early warning fire detection system (VEWFDS), such as an aspirating smoke[9] detection (ASD) system, that uses a highly sensitive sensor can detect these very early stages of combustion (overheating). These ASD systems can be configured to generate alarms at increasing sensitivity, and may add to the time available to safely shut down the reactor if the ASD system is sufficiently sensitive. Properly installed and maintained, this type of ASD system can provide the earliest possible warning of a potential fire event by detecting smoke particles at the incipient (first) stage of fire. This paper does not address the detection of fires resulting from arcing or ones whose growth is essentially instantaneous.

An ASD system uses a piping or tubing distribution network that runs from the area(s) to be protected to the detector. NFPA 72, "National Fire Alarm Code®," 2007 Edition, Section 3.3.43.1, defines an "Air Sampling–Type Detector" as one "that consists of a piping or tubing distribution network that runs from

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[7] This paper was prepared (in part) by employees of the United States Nuclear Regulatory Commission. It presents information that does not represent the currently agreed-upon staff position, which is provided in Frequently Asked Question 08-0046, "Incipient Fire Detection Systems," under the NRC's "Process for Communicating Clarifications of Staff Positions Provided in Regulatory Guide 1.205 Concerning Issues Identified During the Pilot Application of National Fire Protection Association Standard 805," RIS 2007-19. *[Ref. 11]* NRC has neither approved nor disapproved its technical content. This paper does not establish an NRC technical position.

[8] The quantitative aspects of this paper focus on available test data, which were not specifically designed for the applications being proposed. More appropriate would be long-term tests where the source is not "aggressively" heated to produce "smoke" on the order of minutes but rather "delicately" heated to produce "smoke" on the order of hours or even days.

[9] The term "smoke" is used fairly loosely throughout this discussion to include any pre-combustion product that may result from overheating of a potential combustible, such as molecules of organic compounds that might be off-gassed from insulation on electric wires as they initially experience overheat.

the detector to the area(s) to be protected. *[Ref. 1]* An aspiration fan in the detector housing draws air from the protected area back to the detector through air sampling ports, piping, or tubing. At the detector, the air is analyzed for fire products."

In addition, NFPA 72, Section 5.7.3.3, "Air Sampling-Type Smoke Detector," contains requirements for very early warning smoke detection systems. The location of the pipe-work and the port holes is generally governed by fire codes and standards. Current standards stipulate the spacing of smoke detectors based upon tests performed by nationally recognized testing laboratories such as Underwriters Laboratories. *[Ref. 2]* In accordance with NFPA 72, 2007 Edition, Section 5.7.3.3.1, each sampling "port" of an air sampling smoke detection system shall be treated as a spot-type detector for the purpose of location and spacing. Section 5.7.3.3.2 states that the maximum air sample transport time from the farthest sampling port to the detector shall not exceed 120 seconds. Typically, the pipes and holes are laid out according to a square grid pattern that places each hole where a conventional detector would otherwise be located. In the case of higher risk areas, the spacing of this grid pattern can be reduced for denser coverage.

Conventional photoelectric or ionization smoke detectors characteristically respond to the presence of smoke at an average of 0.6% obscuration per meter (2%/ft).[10] ASD systems using superior optics and chamber designs are capable of sensing as low as 0.005% to as high as 20% obscuration per meter (0.0015% to 6%/ft) and provide multiple programmable alarm thresholds.

For area-wide (compartment) detection, very early warning ASD (VEWASD) systems have been tested, installed and commissioned, and have proven effective in detecting fires. In the U.S., these systems have been installed for telecommunications equipment, telephone exchanges, controlled environment vaults, wireless base stations, small IT server rooms, and electrical switchgear rooms for detecting low energy fires based on the guidance in NFPA 76, "Standard for the Fire Protection of Telecommunications Facilities." *[Ref. 3]* They are also specifically recommended to protect conventional power generation facilities in NFPA 850, "Recommended Practice for Fire Protection for Electric Generating Plants and High Voltage Direct Current Converter Stations." *[Ref. 6]*

<u>Use in Commercial Nuclear Power Plants</u>

Electrical cabinets (whether fully-enclosed and non-ventilated, or else force-ventilated at the bottom, top and/or side) can pose a major fire risk as the primary cause of a fire incident in nuclear facilities. Typical cabinets will almost always contain plastics, cables, wires, circuit cards, relays, switches, gauges and other components that have been shown by testing to smolder for some time. Detection of fires inside electrical cabinets poses several challenges. For example, the low thermal energy from an in-cabinet fire may be insufficient to activate external detection of smoke during the incipient stage. Cabinets may require a high level of airflow (ventilation) to maintain a suitable operating temperature. Forced air ventilation increases the incidence of smoke dilution, which may impede the detection of smoke by conventional systems (although this effect may be somewhat offset by enhancing the transport of smoke to the detector. Other factors are remote and unmanned locations/sites, diverse temperature ranges, moisture content, particle density, and transport time due to the length of the sampling network (which, therefore, limits the size of the area that can be covered by the detection system).

A VEWASD system has not been installed, tested and approved for application in an electrical cabinet at a nuclear power plant by the authority having jurisdiction in the United States (NRC). In Canada, more

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[10] In testing it has been seen that conventional photoelectric or ionization point ("spot") smoke detectors respond at a smoke concentration that is well above their nominal and factory calibrated levels – typically at an average of 30% obscuration per meter (10%/ft). These observations are based on results for the 80th percentile for unventilated non-flaming fires using Underwriters Laboratory-approved commercial photoelectric spot detectors. *[Ref. 3]* The impedance presented by the external mesh and labyrinth to the chamber, designed to keep insects and light out, is suspected to contribute to these devices providing only 20% certainty of operation. *[Ref. 4]*

than 50 aspirating detection systems have been installed in two commercial nuclear power reactors for detecting fire in the incipient stage. These have been installed as fire protection systems to implement performance-based design approaches as alternatives to prescriptive codes in locations such as control equipment rooms, cable spreading areas, cable tunnels, and other electrical safety environments. *[Ref. 7]*

PRE-EXISITING GUIDANCE FOR CREDITING VEWASD SYSTEMS IN FIRE PRA

Appendix P, "Appendix for Chapter 11, Detection and Suppression Analysis," of NUREG/CR-6850 addresses prompt detection credit for the use in fire PRAs as follows, i.e., Section P.1.3, "Solving the Detection-Suppression Event Tree," states:

> *... Prompt detection should be only credited when a continuous fire watch is assigned to an operation, or a high-sensitivity smoke detection system is installed. If a high-sensitivity smoke detection system is credited, the failure probability of the system should be considered. If in-cabinet smoke detection devices are installed in the electrical cabinet postulated as the ignition source, the analyst should assume that the fire will be detected in its incipient stage. This incipient stage is assumed to have a duration of 5 minutes.[11] In order to account for these 5 minutes, the analysts should add them to the time to target damage (or, equivalently, add them to the time available for suppression). Prompt suppression refers specifically to suppression actions by a fire watch, and can be credited following prompt detection in hot work fire scenarios only ... [Ref. 8]*

Therefore, NUREG/CR-6850 already allows credit for a VEWASD system as a type of prompt detection. That is, if a VEWASD system is installed on a room- or area-wide application, it may receive credit as a means of prompt detection, provided the system's failure probability is factored into the evaluation. If a VEWASD system is installed in-cabinet, detection is assumed to occur as early as possible (incipient fire stage) and credited by adding 5 minutes to the assessed time to target damage when applying the appropriate non-suppression probability.

As will be discussed in this paper, methods are both reviewed and proposed that would provide means of relaxing this current restriction in NUREG/CR-6850 to allow the same 5-minute detection credit for a VEWASD system when installed in a "small" room as for an in-cabinet installation.[12]

EXAMINATION OF THE EPRI-1016735 APPROACH

In Section 3, supported by Appendix C, of EPRI-1016735, "Fire PRA Methods Enhancements – Additions, Clarifications, and Refinements to EPRI-1011989[13] ('EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities')," the Electric Power Research Institute (EPRI) "develops an approach and supporting basis to apply quantitative credit in fire PRAs for the use of incipient fire detection [IFD] for

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[11] The basis for the 5-minute assumption is not explicitly stated in NUREG/CR-6850. It arises from NUREG/CR-4527, "An Experimental Investigation of Internally Ignited Fires in Nuclear Power Plant Control Cabinets, Part II: Room Effects Tests," where it is stated that "[i]n this test, a smoke detector was mounted on the ceiling of the cabinet directly above the electrical ignition source. A second detector was also placed on the ceiling of remote cabinet 'F' ... The purpose of the smoke detector was to determine when a typical in-cabinet detector would detect smoke from an electrical ignition source such as that used here. Smoke was visually observed, in a very small amount, from the electrical ignition source at 9.5 min after the source was turned on or 6 min prior to actual ignition. The detector within the source cabinet signaled smoke detection at approximately 10.5 min after the source was turned on, or approximately 1 min after visual detection of smoke. This was discussion of Test 25 ... involving a full mock-up control panel in the large main control room size control room setup with electrical ignition. This directly supports the 5-minute time credit (i.e., smoke observed 6 minutes before ignition, in-cabinet detector actuation 1 minute later; hence, detector 5 minutes before ignition)." *[Ref. 9]*

[12] Although no physical definition for a "small" room is practical at this time, the following guidance is offered. A "small" room should be one in which any VEWASD system is installed with the ports nearby to the potential ignition sources such that a fire in the equipment could be pinpointed within roughly one minute using a thermographic device. This implies either one limited set of equipment protected by nearby ports of a single VEWASD system or multiple sets of equipment, each protected by nearby ports dedicated separately to each VEWASD system.

[13] This is the same as NUREG/CR-6850 (see Ref. 8).

low voltage electrical components." *[Ref. 10]* These IFD systems (IFDSs) are also referred to as VEWFDSs.

The EPRI approach develops an "IFD Event Tree" that considers four stages to fire ignition: (1) presence of an incipient condition ($\lambda\omega$), (2) effectiveness of an installed VEWFDS (μ), (3) reliability of the VEWFDS (R), and (4) success of pre-emptive actions that are taken (P). The product $\lambda\omega$ represents the fire ignition frequency from NUREG/CR-6850 without any credit for an installed VEWFDS. Once adjusted for the VEWFDS, this ignition frequency becomes $\lambda\omega \cdot (1 - \mu RP)$, based on the event tree.

The parameter μ represents the fraction of ignition sources potentially detectable by the VEWFDS that can actually be detected during the pre-combustion (incipient) stage. It can range from 0 (totally incapable of detection) to 1 (totally capable of detection). A list of components that may effectively be covered by a VEWFDS is provided. In this discussion, we set μ to 1 and address the potential credit for a VEWASD system given it is totally capable of detecting pre-combustion for the potential ignition sources within its range.[14] Therefore, we focus only on the parameters R and P.

In Table 3-1 of EPRI-1016735, some operating history of IFDSs in U.S. commercial nuclear power reactors is provided. The report concludes that these systems have failed once (during preventive maintenance testing) in 54 system-years, or a failure rate per system of ~0.02/yr. This translates into an unreliability of ~0.002 for quarterly testing or ~0.005 for semi-annual testing.[15] The downtime due to this type of failure is estimated as negligible compared to the unreliability. Therefore, EPRI-1016735 assumes a VEWFDS reliability R = 1 – 0.005 = 0.995, using the longer testing interval (semi-annual).

EPRI-1016735 cites several qualitative arguments for assuming that pre-emptive actions will be taken at a significant time before ignition occurs, ultimately quantifying a value for P based on applying the Control Room fire non-suppression curve in NUREG/CR-6850 for 15 minutes or more (Table P-2, with a mean non-suppression rate = 0.33/min), such that the NUREG/CR-6850 minimum allowed non-suppression probability of 0.001 would apply, i.e., P = 1 – 0.001 = 0.999.[16] Taken together, these values for R and P yield a reduction in the fire ignition frequency $\lambda\omega$ by a factor of 167 ($1/[1 - \{1 \cdot 0.995 \cdot 0.999\}]$) for ignition sources considered fully detectable by a VEWASD system (i.e., for $\mu = 1$).

A Different Perspective

The EPRI IFD event tree provides one reasonable approach to quantify the probabilistic credit that may be assigned for a VEWFDS. However, its use could yield overly optimistic values for R and P unless measures are adopted to consider their applicability to plant-specific designs and operational configurations. Review of Table 3-1 in EPRI-1016735 suggests that at least two malfunctions other than the one cited as a failure might be considered as VEWASD system failures as well (one attributed to improper maintenance; one attributed to a power supply failure). Even if each of these was only weighted as one-half of the "actual" failure, at a minimum we consider there to have been at least two VEWASD system failures in the U.S. experience cited, suggesting a failure rate per system of 2/54 yr ≈ 0.04/yr and an unreliability for semi-annual testing of ~0.009, or double that cited in EPRI-1016735. This translates into a reduced value for R = 1 – 0.009 = 0.991.

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[14] The terms IFDS, VEWFDS, and VEWASD system may be used interchangeably throughout this paper, and they should be considered as referring to the same type of system or phenomena.

[15] For periodic testing, failure is assumed to occur at the midpoint of the testing interval, i.e., at (0.25 yr)/2 = 0.125 yr for quarterly testing and (0.5 yr)/2 = 0.25 yr for semi-annual testing, yielding corresponding unreliabilities of (0.125 yr)/(54 yr) ≈ 0.002 and (0.25 yr)/(54 yr) ≈ 0.005, respectively.

[16] For the Control Room Fire non-suppression curve, the value at 15 minutes is actually 0.007, and the minimum value of 0.001 is not reached until 21 minutes.

The use of the Control Room fire non-suppression curve is also considered overly optimistic for a "small" room or in-cabinet installation of a VEWASD system since it is likely less sensitive than the human senses available in a continuously occupied Control Room. More appropriate would be the non-suppression curve for Welding or even Electrical fires (Table P-2 of NUREG/CR-6850 indicates mean non-suppression rates of 0.188 and 0.102/min,[17] respectively), since these latter would be the types against which a VEWASD system would most likely be installed to protect. The non-suppression probabilities at 15 minutes for Welding and Electrical fires are 0.060 and 0.217, respectively. These imply corresponding values for P of 1 – 0.060 = 0.940 and 1 - 0.217 = 0.783, respectively.[18] Using these updated values for R (0.991) and P (0.940 and 0.783), we obtain a reduction in the fire ignition frequency λω by factors ranging from ~15 (based on Welding fires) to ~4 (based on Electrical fires) for ignition sources considered fully detectable by a VEWASD system (i.e., for μ = 1).[19]

A "HOLISTIC" APPROACH

In an effort to independently examine the applicability of the EPRI-1016735 approach, we conducted a literature search for test results of VEWASD systems. Our effort yielded four reports detailing the results of tests for a VEWASD system called VESDA® (manufactured by Xtralis®).[20,21,22,23,24] The first two series of tests were conducted for room-wide installations, from which we postulated that we might extrapolate the results on a limited basis to what might be expected for a "small" room or in-cabinet installation.[25] The third and most recent series provided test results for VEWASD systems specifically tested in-cabinet. These three series are examined further below, after the remaining test series is discussed.

The fourth series of tests compared a VESDA® and another ASD system against four other types of detection systems: (1) beam-projected, (2) video smoke, (3) video flame and (4) conventional spot-type. These tests, conducted in Beijing in 2004, occurred in the beam-pocketed central portion of a large room with an area of 144 m^2 (1550 ft^2) and height of 8.0 m (26.2 ft).[26] However, the fire source, usually timber, was located at floor level with all the detectors mounted far above at the ceiling. Thus, the distance between

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[17] National Fire Protection Association (NFPA) 805 Frequently Asked Question (FAQ) 08-0050, "Manual Non-Suppression Probability," has lowered the mean non-suppression rates for Welding and Electrical fires in NUREG/CR-6850 to 0.188/min and 0.102/min, respectively. *[Refs. 11, 12]*

[18] It should not be inferred that a VEWASD system installed either "in-cabinet" or in a "small" room would be intended for very early detection of potential welding fires, since welding activities are typically performed in the presence of a continuous fire watch to enable prompt suppression of any fire. The Welding fire curve is included solely because it is the next less optimistic non-suppression curve that suggests human-based detection after that for Control Room fires.

[19] $1/(1 - [1 \cdot 0.991 \cdot 0.940]) \approx 15$; $1/(1 - [1 \cdot 0.991 \cdot 0.783]) \approx 4$.

[20] "Final Report – Response Time Comparison of Spot and Aspirated Laser Smoke Detection Technologies in a Telecommunication Facility," Hughes Associates, Inc., Baltimore, Maryland, November 10, 1999 (available at www.haifire.com).

[21] "VESDA® Warehouse Fire Detection Test Results – ASD vs. Point (Spot-type) vs. Beam Detectors," Xtralis®, April 2008 (available at www.xtralis.com).

[22] "IT/Server Room Fire Test Demonstrations – VESDA® and Photoelectric Conventional Point Detectors," Xtralis®, October 2008 (tests were performed in August 2008; available at www.xtralis.com).

[23] "VESDA® Performance in Forbidden City Fire Tests – Engineering Brief Report," Xtralis®, April 2008 (available at www.xtralis.com).

[24] Contact directly with Xtralis® also provided a slide presentation on a 2003 "In-Cabinet Smoke Detection Performance Assessment" by Vision Systems®. An ASD system was tested against point detectors for smoke in a fully-sealed cabinet, with and without airflow. Three design smoke trends were tested: (1) slow growth (2-m 42W and 80W wire burns), (2) medium growth (68-ohm resistor burn), and (3) fast growth (BS6266 2-m wire burn). In all cases, the ASD responded more quickly than the point detector, as follows: (1) faster by 30-39 sec (with airflow) and 43-44 sec (without airflow) for slow growth, (2) faster by 29 sec (with airflow) and 62 sec (without airflow) for medium growth, and (3) faster by 17 sec (with airflow) and at least 89 sec (without airflow – the test was terminated before the point detector responded) for fast growth. These results are consistent with those from the April 2008 tests (discussed below) in which both the VESDA® and the spot detectors responded. Since the test conditions were much better known for the April 2008 tests, they are the ones used for the subsequent quantitative analysis, but recognize that these earlier test results are supportive.

[25] The first test series involved a room with an area of 223 m^2 (2400 ft^2) and height of 4.73 m (15.5 ft). The second test series involved a room with an area of 516 m^2 (5550 ft^2) and height ranging from 8.0 to 8.5 m (26.2 to 27.9 ft). Although no physical definition for a "small" room is practical at this time given these limited test results, the following guidance is offered. A "small" room should be one in which any VEWASD system is installed with the ports nearby to the potential ignition sources such that a fire in the equipment could be pinpointed within roughly one minute using a thermographic device. This implies either one limited set of equipment protected by nearby ports of a single VEWASD system or multiple sets of equipment, each protected by nearby ports dedicated separately to each VEWASD system.

[26] The room itself had an area of 480 m^2 (5170 ft^2) with the same ceiling height.

the source and detectors limits the applicability of the results to what might be expected at nuclear power plants for a "small" room or in-cabinet installation of a VEWASD system. Therefore, the results from this fourth series, which indicated VESDA® response before any other detector type, including the other ASD, in all but one of 11 tests, are not used, other than as qualitative support for the potential rapidity of VESDA® response relative to non-ASD systems.[27]

Analysis of Test Results

In the first series of tests (1999), the locations of the ASD ports relative to the fire source were recorded. We restrict our analysis to those data for which the distance between the source and port is 1.5 meters (5 ft) or less, roughly corresponding to the height of an electrical cabinet (i.e., the fire source and ASD port can be considered "relatively" close to one another, as one might expect "in-cabinet").[28] The second series of tests (April 2008) were conducted with the doors open and closed. Restricting our data to the latter may be considered as roughly approaching what might be a surrogate for a "small" room or in-cabinet installation.

The 1999 test series compared response times between multiple VESDA® and VIEW® systems.[29] Fifty-six tests were conducted, of which 33 employed combustible sources considered representative relative to what might be expected at nuclear power plants as the type of ignition source against which a VEWASD system would most likely be installed to protect, namely insulated wires and printed wire boards.[30] Of these 33 tests, six involved the source and target (a VESDA® port or VIEW® detector) within 1.5 m (5 ft) of each other. In Table 1, the minimum response time for each type of system is recorded, showing that at least one of both sets of VESDA® and VIEW® systems responded in four of the six tests.

The April 2008 test series compared response times between a VESDA® system and optical spot-type and beam ("spot/beam") detectors. Five test sessions were conducted, totaling 21 individual tests, each run for a maximum of 10 min. Combustible sources consisted of timber, smoke pellets, and heptane. Ignoring the heptane results leaves a total of 16 tests where the combustible sources were considered as at least approaching what might be expected at nuclear power plants as the type of ignition source against which a VEWASD system night be installed to protect.[31] These 16 tests were further reduced to nine tests where the room doors were closed, considered to roughly approach what might be a surrogate for a "small" room or in-cabinet installation. In Table 2, the minimum response time for each type is recorded, showing that while the VESDA® system responded in all nine tests, the spot/beam detectors responded in only three (and, in these three cases, only the spot detector responded, i.e., the beam detector did not respond in any of the nine tests).[32]

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[27] Two of the tests employed overheated cable as the source, one of 3-m length, the other of 6-m length. Both indicated VESDA® response prior to the other ASD and no response by any of the other detector types. However, since both tests apparently were terminated when the other ASD responded, the total test durations could not be determined to be longer than 3 min and 18 min, respectively. In the first test, the VESDA® responded 130 sec after the start of the test, but the test could not be determined to have been run for more than an additional 50 sec. In the second test, the VESDA® responded 197 sec after the start of the test, but the test could not be determined to have been run for more than an additional 14.5 min. While the latter suggests a potentially substantial benefit in response time for a VESDA® over other types of detectors, the test conditions (large room with ceiling-mounted detectors quite far from the ignition source) and limited results (just one test) discourage quantitative use of these results.

[28] Also considered roughly applicable for a "small" room.

[29] VIEW® is the Very Intelligent Early Warning laser smoke detector system, manufactured by Notifier® (information available at *www.notifier.com*). Although it operates differently from an ASD system, it also "senses the earliest particles of combustion, providing early warning of a fire condition. It [is] ... up to 100 times more sensitive than a standard photoelectric sensor[, u]sing an exceptionally bright, controlled laser diode ..."

[30] Also included were two "conductive heating tests" of cables.

[31] In addition, these tests results are only employed to estimate the "additional" time available for fire suppression activities when a VEWASD system responds prior to a spot/beam detector, not to estimate the likelihood of very early detection by a VEWASD system.

[32] The rightmost column is the difference between the spot/beam response time and that of VESDA®, where the 10-min test maximum was assumed for spot/beam when there was no response.

The August 2008 test series provided test results for VEWASD systems tested in-cabinet, which would have seemed ideal for our purposes. However, upon reviewing the test results, there was a limitation in that none of the tests was run for more than three minutes. In those where both a VESDA® and point detector were concurrently tested in-cabinet, the VESDA® always responded while the point detector did not.[33] Nevertheless, without a longer time frame over which to give the point detector a chance to respond, comparison of the advantage posed by the in-cabinet VESDA® relative to the point detector would be underestimated. Therefore, results from this third series of tests are used only in the same context as those from the 1999 tests, namely to estimate the likelihood of VEWASD system detection in potentially applicable situations. The limited timing of these tests still provides qualitative support for the potential rapidity of VESDA® response relative to point detectors for in-cabinet installation.

Potential Effect on Non-Suppression Probability

From the 1999 tests, we see that both the VESDA® and VIEW® systems responded in four of the six tests, and neither responded in the other two. This suggests a likelihood of VESDA®/VIEW® detection in 2/3 of the potentially applicable situations. However, from the August 2008 tests, summarized in Table 3, which were specifically performed with the VESDA® systems installed inside electrical cabinets, we see that the VESDA® system responded in all 26 tests, suggesting a likelihood of VESDA® detection approaching unity.[34] We will assume a range from 2/3 to 1 in the estimation that follows.

Now consider the potential difference in detection time for VESDA® vs. spot/beam from the April 2008 tests. When both VESDA® and spot/beam responded (three times), the differences were 14 sec, 18 sec and 25 sec, with VESDA® always being the quicker. These time differences are minimal, suggesting that VESDA® gives limited benefit over spot/beam in cases where both would respond. For more insight, let us consider the remaining six tests where VESDA® responded but neither spot nor beam did, within the 10-min testing time frame (600 sec). For these tests, the time difference ranged from 375 sec to 504 sec, with a mean of 420 sec and standard deviation of 45.8 sec,[35] assuming that the potential time for spot/beam to respond is no more than 600 sec.[36]

How can we interpret the "additional" 420 sec (7 min), on average, which are gained in detection time by VESDA® over spot/beam?[37] If a cabinet, small group of cabinets, or "small" room were equipped with these detectors, it is likely optimistic that personnel responding to a VESDA® alarm (e.g., with a thermographic device) could pinpoint the offending cabinet within 1-2 min.[38] This would leave approximately an "additional" 5 min to engage in fire suppression activities in the ideal case, coincidentally corresponding to the suppression time "bonus" currently allowed in NUREG/CR-6850 for high-sensitivity

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[33] The average VESDA® response times, and their ranges, were as follows: (1) for in-cabinet tests where the smoke source was a one-meter cable, the average response occurred in 53 sec, with a range from 47 to 64 sec; (2) for in-cabinet tests where the smoke source was two resistors, the average response occurred in 26 sec, with a range from 22 to 28 sec; (3) for in-cabinet tests where the smoke source was one resistor, the average response occurred in 26 sec, with a range from 24 to 28 sec.

[34] Three cabinet configurations were modeled. The first, labeled as "Bottom-up," was ventilated with airflow from the bottom to top, with air velocity at the top vents measured at ~0.35 m/s. The second, labeled as "Fully-sealed," was fully-sealed and housed a mixing fan to enhance airflow. The third, labeled as "Front-back," was provided with front-to-back airflow generated by the exhaust fans of servers. Only the second cabinet appeared to be fully-sealed, and this was provided with a mixing fan. The extent to which these configurations approximate those that would be encountered at a nuclear power plant would be a factor when assuming how close to unity the likelihood of VESDA® detection approaches. The range from 2/3 to 1 has been retained to cover potential variations from what would be considered the most pessimistic (little, if any, internal airflow) to most optimistic cases (significant internal airflow).

[35] Statistical analysis of these data suggests that the time difference can be reasonably represented as either a normal or lognormal distribution with the corresponding mean and standard variation. For the normal, the 90%, two-sided confidence bounds are 345 sec and 495 sec. The corresponding values for the lognormal are 350 sec and 499 sec, essentially the same. Based on 10,000 trials, the simulations for each yielded minima and maxima of 253 sec and 606 sec for the normal, and 285 sec and 612 sec for the lognormal, again, essentially the same.

[36] Based on the Appendix, a limit of 10 min (600 sec) to detect is considered reasonable.

[37] This depends on the time required to locate the source. The sampling hole and pipe sampling configuration of a VEWASD system and the detector type determines the level of 'addressability" (source location). Some VEWASD systems provide addressability to only one detector (which has one or many pipes), some to a pipe (which may have one or many holes), and some to an individual hole.

[38] Use of "addressable" VEWASD system could automate this pinpointing of the offending cabinet.

smoke detection. For the incipient stages for the types of fires of interest here, we again assume the non-suppression curve for Welding or even Electrical fires (with mean non-suppression rates of 0.188 and 0.102/min, respectively), may be applied, i.e., non-suppression probability = 1/exp(0.188t) [Welding fire] or 1/exp(0.102t) [Electrical fire], where t is the time available for manual suppression. Therefore, comparing non-suppression probabilities for VESDA® vs. spot/beam, we see that VESDA® will lower the non-suppression probability, on average and under these optimistic assumptions, by a factor of exp(0.188 · 5) = 2.56 [Welding fire] or exp(0.102 · 5) = 1.67 [Electrical fire], or roughly two.[39]

Therefore, a first approximation of the potential benefit of a VEWASD system meeting the same level of qualification and performance as a VESDA® system with respect to reducing core damage frequency (CDF) is as follows (using the range 2/3 < Probability that VESDA® responds < 1):

CDF (with VESDA®) = [CDF (with spot/beam, i.e., without VESDA®)] · [Probability that VESDA® responds] / [Reduction Factor in Non-suppression Probability without VESDA®] = [CDF (with spot/beam, i.e., without VESDA®)] · [range: 2/3 through 1] / 2 = [CDF (with spot/beam, i.e., without VESDA®)] / [3 through 2]

In other words, the potential benefit in reducing CDF (through quicker detection time that translates into more time available for suppression [estimated, on average, to be five minutes]) is a maximum factor of three.

Potential Effect on Fire Ignition Frequency

Is it reasonable to consider the potential for an additional effect of a VEWASD system such as VESDA® for a "small" room or in-cabinet installation on fire ignition frequency with respect to the type of ignition source against which a VEWASD system would most likely be installed to protect? If so, one approach would be to compare the ignition frequency of fires in the Control Room (assumed to be electrical cabinet fires), which are detected mostly by human smell (and thus act as a surrogate for a VEWASD system) against the ignition frequency of a non-human-occupied area where electrical cabinets are also the primary fire source.

While the current ignition frequencies in NUREG/CR-6850 do not provide a zonal frequency for the latter (just the Control Room), earlier data on which NUREG/CR-6850 was based do consider these frequencies on a zonal basis (EPRI-1003111, "Fire Events Database and Generic Ignition Frequency Model for US NPPs"). *[Ref. 13]* There, we find the following mean frequencies at-power:

Auxiliary Bldg (PWR) - electrical cabinets = 0.031/yr
Reactor Bldg (BWR) - electrical cabinets = 0.057/yr
Control Room - electrical cabinets = 0.016/yr

Averaging the first two values yields 0.044/yr, which is 2.75 times greater than the Control Room value, or roughly a factor of 3, which applies solely to frequency reduction.

Potential Combined Effect on CDF

Might the two effects, one on non-suppression probability and one on ignition frequency, compound? If so, a reduction in CDF by a factor as much as ~9 might be possible if the two aspects contribute

[39]If Spot/Beam has a non-suppression probability of 1/exp(αt), then VESDA® would have a value of 1/exp(α[t+5]), such that the ratio of Spot/Beam non-suppression probability to that of VESDA® is {1/exp(αt)}/{1/exp(α[t+5])} = exp(5α).

independently (i.e., $3 \cdot 3 = 9$). If not, then the reduction factor would be somewhere in the range from ~3 to ~9.

A SIMPLIFIED EVENT TREE APPROACH

Neither of the previous two approaches explicitly considered the timing of events involved in successfully detecting a potential fire very early in the growth stage (i.e., while there are only pre-combustion products) or, if this fails, at least detecting the fire just as it is about to start (thereby providing some "bonus" in the time available for suppression, similar to that assumed for successful prompt detection in NUREG/CR-6850). The event tree in Figure 1 presents this third approach. It evolves as follows.

Fire Scenarios (Event Tree Branches)

A potential combustible first experiences overheating that, if allowed to proceed, will eventually ignite the combustible with a frequency = IF. Depending upon the nature of the combustible and its fire pre-growth characteristics (long vs. short incipient fire pre-growth phase), the VEWASD system may or may not be capable of detecting the pre-combustion products (probability of detectability = PD). If the VEWASD system can detect the pre-combustion products, then it must also be effective in doing so to prevent fire during the incipient stage (probability = VE). If the VEWASD system is effective, then there is no effect on non-suppression, since the need for suppression never arises. This is shown as Branch 1.

If the VEWASD system is not effective, then the only benefit will be a reduction in non-suppression probability due to the VEWASD system alarming just as the fire is about to start, providing an additional "bonus" time (TB) to the "normal" damage time if no VEWASD system were present (TD). This constitutes Branch 2. And, if the VEWASD system is unable to detect the pre-combustion products, then it does not even have the opportunity to be "effective," so again the only benefit will be a reduction in non-suppression probability as above (Branch 3).

From the event tree, we can see that the top branch offers a reduction in overall ignition frequency ($0 < VE \leq 1$), while the lower two branches offer a reduction in non-suppression probability. One cannot get BOTH a reduction in ignition frequency AND a reduction in non-suppression probability along any single branch, but both effects can be manifested over the entire tree. Implicit in this event tree are the following simplifying assumptions:

1. The VEWASD system is always available (the industry survey conducted in support of EPRI-1016735 indicates a very high reliability of these systems).
2. Personnel respond at the first indication of potential overheat (otherwise the opportunity to preclude the eventual overheating that results in a fire does not exist).
3. Personnel are always successful in locating the potential ignition source immediately after receiving the first indication (since the pre-growth stage phase is presumably "long" enough such that ignition can be precluded, trained personnel with the proper detection equipment shall be able to pinpoint the source in a relatively brief time).

A more detailed event tree, containing stages for reliability and unavailability of the VEWASD system, as well as probabilities of specific human actions, can be developed. However, given the limited data available and likely high uncertainty on the key elements of this tree, namely the probability of detectability by the VEWASD system and the VEWASD system effectiveness, the additional details are not examined.

Quantification

Determination of the probability of detectability of pre-combustion products by the VEWASD system (PD) is currently subjective. However, the 1999 and 2008 test series from the VESDA® experiments offer some quantitative information that can be used for the VEWASD system effectiveness (VE) and the time bonus (TB). As shown in the 1999 tests, the VESDA® responded in 4 of 6 (0.67) trials, which could be taken as a first approximation of the effectiveness (VE) since the tests were conducted on wires and printed board, the type of combustible for which we would expect slow growth and a long incipient growth stage.

The 2008 series showed that, when the VESDA® responded but neither the spot nor beam detector did, the "time bonus" (TB) was around at least seven minutes (could have been more, but the tests were terminated at 10 minutes before the latter could respond). These tests used timber or smoke pellets, so it is likely that the VESDA® response occurred later in any pre-growth stage rather than early (although likely prior to full smoking or flaming since neither spot nor beam detector responded). This ~7-minute "time bonus" is comparable to the currently assumed 5-minute bonus in NUREG/CR-6850 for a high sensitivity smoke detector inside a cabinet, so there is at least some evidence that the current NUREG/CR-6850 value could represent a reasonable default for TB.

Table 4 shows the results of exercising the event tree for variations in the following three paramenters (with IF set = 1 in all): (1) $0 \leq VE \leq 1$; (2) Welding vs. Electrical fire mean non-suppression rates (α = 0.188 and 0.102/min, respectively); and (3) 5 min ≤ TB ≤ 10 min.[40] For each case, the fire scenario frequencies with and without VEWASD are also calculated, where this scenario frequency with a VEWASD is the sum of the lower two branches (incorporating time bonus in the non-suppression calculation); without a VEWASD it is just the ignition frequency times the non-suppression probability without any time bonus. The ratio of the "without" to "with" frequency then indicates the potential CDF reduction factor, analogous to that estimated for the previous two approaches (EPRI-1016735 and "holistic").

What are considered the potentially more likely combinations of PD and VE are shown as the shaded rows in Table 4 for both the Welding and Electrical fire non-suppression curves (α = 0.188 and 0.102/min, respectively) with TB = 5 minutes. The corresponding reduction factor ranges from infinite (when both PD and VE = 1.00) to ~3 (based on Electrical fires) for ignition sources considered fully detectable by a VEWASD system (i.e., for IF = 1).[41] These results include both ignition frequency and non-suppression probability reduction effects, but never within the same sequence. That is, if the VEWASD system prevents ignition, it cannot reduce non-suppression probability within the same sequence since ignition never occurred. Similarly, if the VEWASD system does not prevent ignition, it can still have some benefit in reducing non-suppression probability by providing a "time bonus" for suppression (defaulted to five minutes, as per NUREG/CR-6850 and at least partially supported by the 2008 series of VESDA® tests).

SUMMARY

Three potential approaches to credit very early warning fire detection in fire PRA have been examined, one proposed in EPRI-1016735 and two by the authors. With the first approach further constrained than in EPRI-1016735, as previously discussed, the potential reduction factors on CDF if a VEWASD system is installed in a "small" room or in-cabinet range from a minimum of ~3 ("Holistic" and Event Tree approaches) to infinite (Event Tree approach). Given the speculative nature of the potential creditable value of this relatively new (to commercial nuclear power) technology to fire PRA and the associated uncertainties in the relevant parameters, it would seem prudent to more tightly constrain the upper limit on the potential effect until operating history for the use of VEWASD system for electrical cabinet fires in

[40] The "normal" damage time if no VEWASD system were present (TD) does not appear in the ratio, since it appears in both the frequency with and without the VEWASD system and, therefore, cancels out when these are ratioed.

[41] To eliminate the unbounded value, we considered PD = VE = 0.9 and 0.99. These results yielded maximum reduction factors of ~13 and ~130, respectively when both values were set at 0.99 for Welding fires. For Electrical fires, the maximum was ~9.

commercial nuclear plants accumulates. For now, only the following guidance might be offered to narrow the range.

Conditions under Which Credit May be Considered

First, it is necessary to identify the conditions under which credit may even be considered for a VEWASD system installed in a "small" room or in-cabinet. The following approach is proposed. For a VEWASD system installed in a "small" room or in-cabinet, all of the following must first be met:

1. The VEWASD system must have been tested, designed and installed in accordance with recognized standards and the manufacturer's instructions.
2. The VEWASD system must be designed to maximize the time available for personnel to locate the hazard and respond accordingly.
3. The VEWASD system must be qualified to detect the anticipated hazard at the locations in question and be capable of providing an adequate level of communication to the fire alarm system and/or plant personnel.

The current NUREG/CR-6850 approach suggests that an in-cabinet or "small" room installation of a VEWASD system may receive an additional 5-minute "bonus" in suppression time. When coupled with the potential reduction in ignition frequency if the VEWASD system successfully detects pre-combustion products in the fire pre-growth stage, the satisfaction of the preceding conditions suggests a total reduction in CDF ranging from a minimum of ~3 to a currently unspecified upper limit.[42] Credit beyond a factor of 10 should be applied very cautiously and only after careful consideration of plant-specific conditions for design, installation, alarms, annunciators, procedures and training of responding staff.

CONCLUSION

Ideally, additional research will be performed, and operating history will be accumulated, specific to the use of VEWASD systems installed in-cabinet or in a "small" room at a nuclear power plant to more precisely quantify the amount of credit that may be assigned in a fire PRA. The qualitative arguments and limited test results currently available suggest that some amount of credit in reducing CDF from fires is justified. Since operating experience to date is mainly based on area-wide installation, rather than in-cabinet or even "small room" installations, the upper portions of the range for the credit factor should be applied very cautiously and only under ideal conditions.

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APPENDIX

A limited literature search for information regarding electrical cabinet fires yielded two documents regarding tests being performed internationally.[43] It should be noted that Europe uses thermoplastic cable, which burns more readily, to a greater extent than thermoset, which is prevalent in the U.S. This means that the European test fires are likely larger than the ones in the U.S. or, equivalently that fires in the U.S. would be smaller than those shown in the two documents. Consider the graphs shown in the studies.

Figure 9 from the Finnish study indicates that some of the fires peak at ~50 kW or less within ~10 minutes (Experiments 5, 7-10).[44] Likely they would not even be considered among the fire events that would contribute to the ignition frequencies in NUREG/CR-6850. Experiments 1, 3, 4 and 6 all reach peaks in excess of 70 kW within 10 minutes. This would support the assumption that a limit of 10 min (600 sec) to detect an in-cabinet or "small" room fire is reasonable. Only Experiment 2C suggests slow fire growth, and even that takes only 30 minutes to reach 70 kW. Test results from the French study are similar. In the open cabinet tests, the fires peak above 1000 kW, reaching at least 100 kW within 10 minutes. In the closed cabinet tests, the fires never reach 50 kW.

Consistent data from two test groups (based on the presumably more limiting fires from thermoplastic cables) support the assumption that a limit of approximately 10 minutes for a VEWASD system to detect a fire is reasonable.

Table 1. Test Results for VESDA® and VIEW®, with Source and Port/Detector within 1.5 m (5 ft) of Each Other

TEST	SOURCE	MINIMUM VIEW (s)	DETECT? (1=Y,0=N)	MINIMUM VESDA (s)	DETECT? (1=Y,0=N)	MINIMUM BOTH (s)	DETECT? (1=Y,0=N)

[43] *On the fire dynamics of vehicles and electrical equipment,* Johan Mangs, VTT Building and Transport, University of Helsinki, Finland, VTT Publications 521, Academic Dissertation, April 28, 2004 (available at *www.vtt.fi/inf/pdf/publications/2004/P521.pdf*); *Phenomenological description of actual electrical cabinet fires in a free atmosphere,* M. Coutin and P. Guillou, EUROSAFE – Towards Convergence of Technical Nuclear Safety Practices in Europe, IRSN (Institut de Radeoprotection et de Surete Nucleaire), France (available at *www.eurosafe-forum.org/files/eurosafe_phenomelogical_zb.pdf*).

[44] Experiment 5 peaks at ~55 kW around 12 minutes.

1	One Bell Canada wire at 22A for 180 s, 24 A for 255 s	9999	0	9999	0	9999	0
2	One Bell Canada wire at 28A for 28 s	82	1	56	1	56	1
3	One Bell Canada wire at 28A for 28 s	75	1	73	1	73	1
4	One Bell Canada wire at 28A for 28 s	9999	0	9999	0	9999	0
5	Printed Wire Board	561	1	662	1	561	1
6	Two BSI 6266 wires at 6 V for 60 s	58	1	47	1	47	1
NOTE: 9999 indicates no response		**SUM =**	**4**	**SUM =**	**4**	**SUM =**	**4**
		COUNT =	**6**	**COUNT =**	**6**	**COUNT =**	**6**

Table 2. Test Results for VESDA® and Spot/Beam, with Doors Closed

TEST	DOORS	MINIMUM VESDA (s)	DETECT? (1=Y,0=N)	SPOT (s)	DETECT? (1=Y,0=N)	BEAM (s)	DETECT? (1=Y,0=N)	SPOT/BEAM minus VESDA (s) (10 min limit)
1-Timber(9)	Closed	225	1	9999	0	9999	0	375
1-Smoke(3g)	Closed (5kW heater)	72	1	90	1	9999	0	18
1-Smoke(9g)	Closed (3kW heater)	90	1	115	1	9999	0	25
1a-Timber(9)	Closed	96	1	9999	0	9999	0	504
2-Timber(9)	Closed	180	1	9999	0	9999	0	420
3-Timber(9)	Closed	210	1	9999	0	9999	0	390
4-Timber(9)	Closed	200	1	9999	0	9999	0	400
5-Smoke(3g)	Closed	73	1	87	1	9999	0	14
5-Timber(9)	Closed	169	1	9999	0	9999	0	431
NOTE: 9999 indicates no response		**SUM =**	**9**	**SUM =**	**3**	**SUM =**	**0**	
		COUNT =	**9**	**COUNT =**	**9**	**COUNT =**	**9**	

Table 3. Results for VESDA® In-Cabinet Tests

TEST	DATE	SOURCE	VENTILATION	RESPONSE TIME (s)	RESPONSE TYPE
4	0821(1)	1m cable	Bottom-to-Top	50	Fire 1
5	0821(1)	2 resistors	Fully Sealed (Mixing Fan)	28	Fire 1
6	0821(1)	1 resistor	Front-to-Back (Exhaust Fans)	26	Fire 1
4	0822(1)	1m cable	Bottom-to-Top	56	Fire 1
5	0822(1)	2 resistors	Fully Sealed (Mixing Fan)	26	Fire 1
6	0822(1)	1 resistor	Front-to-Back (Exhaust Fans)	25	Fire 1
4	0822(2)	1m cable	Bottom-to-Top	47	Fire 1
5	0822(2)	2 resistors	Fully Sealed (Mixing Fan)	25	Fire 1
6	0822(2)	1 resistor	Front-to-Back (Exhaust Fans)	26	Fire 1
4	0823(1)	1m cable	Bottom-to-Top	48	Fire 1
5	0823(1)	2 resistors	Fully Sealed (Mixing Fan)	26	Fire 1
6	0823(1)	1 resistor	Front-to-Back (Exhaust Fans)	26	Fire 1
6B	0823(1)	1m cable	Front-to-Back (Exhaust Fans)	46	Fire 1
4	0823(2)	1m cable	Bottom-to-Top	64	Fire 1

5	0823(2)	2 resistors	Fully Sealed (Mixing Fan)	26	Fire 1
6	0823(2)	1 resistor	Front-to-Back (Exhaust Fans)	28	Fire 1
6B	0823(1)	1m cable	Front-to-Back (Exhaust Fans)	30	Fire 1
4	0824(1)	1m cable	Bottom-to-Top	54	Alert
5	0824(1)	2 resistors	Fully Sealed (Mixing Fan)	28	Action
6	0824(1)	1 resistor	Front-to-Back (Exhaust Fans)	25	Fire 1
4	0825(1)	1m cable	Bottom-to-Top	54	Action
5	0825(1)	2 resistors	Fully Sealed (Mixing Fan)	22	Fire 1
6	0825(1)	1 resistor	Front-to-Back (Exhaust Fans)	25	Fire 1
4	0825(2)	1m cable	Bottom-to-Top	50	Fire 1
5	0825(2)	2 resistors	Fully Sealed (Mixing Fan)	28	Fire 1
6	0825(2)	1 resistor	Front-to-Back (Exhaust Fans)	24	Fire 1

Note: "Alert" alarm precedes "Action," which precedes "Fire 1."

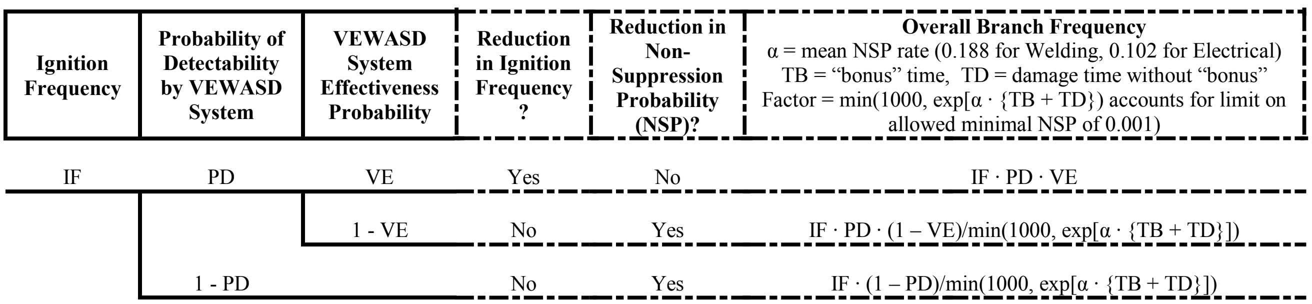

Figure 1. **Simplified Ignition-Detection-Suppression Event Tree with VEWASD System**

Table 4. Ratio of Event Tree Sequence Frequencies without vs. with VEWASD System

PD	VE	α (1/min)	TB (min)	Ratio (Without vs. With VEWASD System)
0-1.00	0	0.188	5	2.56
0	0-1.00	0.188	5	2.56
0.25	0.33	0.188	5	2.79
0.50	0.33	0.188	5	3.07
0.75	0.33	0.188	5	3.40
1.00	0.33	0.188	5	3.82
0.25	0.67	0.188	5	3.08
0.50	0.67	0.188	5	3.82
0.75	0.67	0.188	5	5.15
1.00	0.67	0.188	5	7.76
0.25	1.00	0.188	5	3.41
0.50	1.00	0.188	5	5.12
0.75	1.00	0.188	5	10.2
1.00	1.00	0.188	5	Infinite
0-1.00	0	0.102	5	1.67
0	0-1.00	0.102	5	1.67
0.25	0.33	0.102	5	1.82
0.50	0.33	0.102	5	1.99
0.75	0.33	0.102	5	2.21
1.00	0.33	0.102	5	2.49

PD	VE	α (1/min)	TB (min)	Ratio (Without vs. With VEWASD System)
0.25	0.67	0.102	5	2.00
0.50	0.67	0.102	5	2.50
0.75	0.67	0.102	5	3.35
1.00	0.67	0.102	5	5.05
0.25	1.00	0.102	5	2.22
0.50	1.00	0.102	5	3.33
0.75	1.00	0.102	5	6.66
1.00	1.00	0.102	5	Infinite
0-1.00	0	0.188	10	6.55
0	0-1.00	0.188	10	6.55
0.25	0.33	0.188	10	7.14
0.50	0.33	0.188	10	7.85
0.75	0.33	0.188	10	8.71
1.00	0.33	0.188	10	9.78
0.25	0.67	0.188	10	7.87
0.50	0.67	0.188	10	9.85
0.75	0.67	0.188	10	13.2
1.00	0.67	0.188	10	19.9
0.25	1.00	0.188	10	8.74
0.50	1.00	0.188	10	13.1
0.75	1.00	0.188	10	26.2
1.00	1.00	0.188	10	Infinite
0-1.00	0	0.102	10	2.77
0	0-1.00	0.102	10	2.77
0.25	0.33	0.102	10	3.02
0.50	0.33	0.102	10	3.32
0.75	0.33	0.102	10	3.69
1.00	0.33	0.102	10	4.14
0.25	0.67	0.102	10	3.33
0.50	0.67	0.102	10	4.17
0.75	0.67	0.102	10	5.57
1.00	0.67	0.102	10	8.40
0.25	1.00	0.102	10	3.70
0.50	1.00	0.102	10	5.55
0.75	1.00	0.102	10	11.1
1.00	1.00	0.102	10	Infinite

ATTACHMENT 2

CREDIT FOR VERY EARLY WARNING FIRE DETECTION IN FIRE PROBABILISTIC RISK ASSESSMENT

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I. INTRODUCTION[45]

U.S. commercial nuclear power plants that are planning to upgrade their fire protection programs are considering the installation of very early warning fire detection systems in electrical cabinets that could enable pre-combustion products to be detected well in advance of fire ignition for certain types of combustion sources. The relative newness of this technology to the U.S. commercial nuclear industry poses difficulty when fire probabilistic risk assessments (PRAs) attempt to credit the potential reduction in core damage frequency due to fires when such systems are present. This paper reviews and develops three approaches toward at least narrowing the potential range on the amount of credit in fire PRA until further research can be performed and operational experience can be accumulated.[46]

II. BACKGROUND

Fires can initiate in a variety of ways. Electrical equipment fires can generally originate from an arc or overheating components. One that evolves from an arc can be highly energetic, causing damage to equipment very rapidly. A fire resulting from overheating, such as wire or cable insulation or circuit boards, often develops more slowly. This paper examines the detection of these overheating events in their incipient (first) or smoldering stage of fire development that provides a window of opportunity to detect and control the spread of fire. A very early warning fire detection system (VEWFDS), such as an aspirating smoke[47] detection (ASD) system, that uses a highly sensitive sensor can detect these very early stages of combustion (overheating). These ASD systems can be configured to generate alarms at increasing sensitivity, and may add to the time available to safely shut down the reactor if the ASD system is sufficiently sensitive. Properly installed and maintained, this type of ASD system can provide the earliest possible warning of a potential fire event by detecting smoke particles at the incipient (first) stage of fire. This paper does not address the detection of fires resulting from arcing or ones whose growth is essentially instantaneous.

An ASD system uses a piping or tubing distribution network that runs from the area(s) to be protected to the detector. NFPA 72, "National Fire Alarm Code®," 2007 Edition, Section 3.3.43.1, defines an "Air Sampling–Type Detector" as one "that consists of a piping or

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45 This paper was prepared (in part) by employees of the United States Nuclear Regulatory Commission. It presents information that does not represent the currently agreed-upon staff position, which is provided in Frequently Asked Question 08-0046, "Incipient Fire Detection Systems," under the NRC's "Process for Communicating Clarifications of Staff Positions Provided in Regulatory Guide 1.205 Concerning Issues Identified During the Pilot Application of National Fire Protection Association Standard 805," RIS 2007-19. *[Ref. 11]* NRC has neither approved nor disapproved its technical content. This paper does not establish an NRC technical position.

46 The quantitative aspects of this paper focus on available test data, which were not specifically designed for the applications being proposed. More appropriate would be long-term tests where the source is not "aggressively" heated to produce "smoke" on the order of minutes but rather "delicately" heated to produce "smoke" on the order of hours or even days.

47 The term "smoke" is used fairly loosely throughout this discussion to include any pre-combustion product that may result from overheating of a potential combustible, such as molecules of organic compounds that might be off-gassed from insulation on electric wires as they initially experience overheat.

tubing distribution network that runs from the detector to the area(s) to be protected. *[Ref. 1]* An aspiration fan in the detector housing draws air from the protected area back to the detector through air sampling ports, piping, or tubing. At the detector, the air is analyzed for fire products."

In addition, NFPA 72, Section 5.7.3.3, "Air Sampling-Type Smoke Detector," contains requirements for very early warning smoke detection systems. The location of the pipe-work and the port holes is generally governed by fire codes and standards. Current standards stipulate the spacing of smoke detectors based upon tests performed by nationally recognized testing laboratories such as Underwriters Laboratories. *[Ref. 2]* In accordance with NFPA 72, 2007 Edition, Section 5.7.3.3.1, each sampling "port" of an air sampling smoke detection system shall be treated as a spot-type detector for the purpose of location and spacing. Section 5.7.3.3.2 states that the maximum air sample transport time from the farthest sampling port to the detector shall not exceed 120 seconds. Typically, the pipes and holes are laid out according to a square grid pattern that places each hole where a conventional detector would otherwise be located. In the case of higher risk areas, the spacing of this grid pattern can be reduced for denser coverage.

Conventional photoelectric or ionization smoke detectors characteristically respond to the presence of smoke at an average of 0.6% obscuration per meter (2%/ft).[48] ASD systems using superior optics and chamber designs are capable of sensing as low as 0.005% to as high as 20% obscuration per meter (0.0015% to 6%/ft) and provide multiple programmable alarm thresholds.

For area-wide (compartment) detection, very early warning ASD (VEWASD) systems have been tested, installed and commissioned, and have proven effective in detecting fires. In the U.S., these systems have been installed for telecommunications equipment, telephone exchanges, controlled environment vaults, wireless base stations, small IT server rooms, and electrical switchgear rooms for detecting low energy fires based on the guidance in NFPA 76, "Standard for the Fire Protection of Telecommunications Facilities." *[Ref. 3]* They are also specifically recommended to protect conventional power generation facilities in NFPA 850, "Recommended Practice for Fire Protection for Electric Generating Plants and High Voltage Direct Current Converter Stations." *[Ref. 6]*

II.A. Use in Commercial Nuclear Power Plants

Electrical cabinets (whether fully-enclosed and non-ventilated, or else force-ventilated at the bottom, top and/or side) can pose a major fire risk as the primary cause of a fire incident in nuclear facilities. Typical cabinets will almost always contain plastics, cables, wires, circuit cards, relays, switches, gauges and other components that have been shown by testing to smolder for some time. Detection of fires inside electrical cabinets poses several challenges. For example, the low thermal energy from an in-cabinet fire may be insufficient to activate external detection of smoke during the incipient stage. Cabinets may require a high level of airflow (ventilation) to maintain a suitable operating temperature. Forced air ventilation increases the incidence of smoke dilution, which may impede the detection of smoke by conventional systems (although this effect may be somewhat offset by enhancing the transport of smoke to the detector. Other factors are remote and unmanned locations/sites, diverse temperature ranges, moisture content, particle density, and transport time due to the length of the sampling network (which, therefore, limits the

[48] In testing it has been seen that conventional photoelectric or ionization point ("spot") smoke detectors respond at a smoke concentration that is well above their nominal and factory calibrated levels – typically at an average of 30% obscuration per meter (10%/ft). These observations are based on results for the 80th percentile for unventilated non-flaming fires using Underwriters Laboratory-approved commercial photoelectric spot detectors. *[Ref. 3]* The impedance presented by the external mesh and labyrinth to the chamber, designed to keep insects and light out, is suspected to contribute to these devices providing only 20% certainty of operation. *[Ref. 4]*

size of the area that can be covered by the detection system).

A VEWASD system has not been installed, tested and approved for application in an electrical cabinet at a nuclear power plant by the authority having jurisdiction in the United States (NRC). In Canada, more than 50 aspirating detection systems have been installed in two commercial nuclear power reactors for detecting fire in the incipient stage. These have been installed as fire protection systems to implement performance-based design approaches as alternatives to prescriptive codes in locations such as control equipment rooms, cable spreading areas, cable tunnels, and other electrical safety environments. *[Ref. 7]*

III. PRE-EXISITING GUIDANCE FOR CREDITING VEWASD SYSTEMS IN FIRE PRA

Appendix P, "Appendix for Chapter 11, Detection and Suppression Analysis," of NUREG/CR-6850 addresses prompt detection credit for the use in fire PRAs as follows, i.e., Section P.1.3, "Solving the Detection-Suppression Event Tree," states:

> *... Prompt detection should be only credited when a continuous fire watch is assigned to an operation, or a high-sensitivity smoke detection system is installed. If a high-sensitivity smoke detection system is credited, the failure probability of the system should be considered. If in-cabinet smoke detection devices are installed in the electrical cabinet postulated as the ignition source, the analyst should assume that the fire will be detected in its incipient stage. This incipient stage is assumed to have a duration of 5 minutes.[49] In order to account for these 5 minutes, the analysts should add them to the time to target damage (or, equivalently, add them to the time available for suppression). Prompt suppression refers specifically to suppression actions by a fire watch, and can be credited following prompt detection in hot work fire scenarios only ... [Ref. 8]*

Therefore, NUREG/CR-6850 already allows credit for a VEWASD system as a type of prompt detection. That is, if a VEWASD system is installed on a room- or area-wide application, it may receive credit as a means of prompt detection, provided the system's failure probability is factored into the evaluation. If a VEWASD system is installed in-cabinet, detection is assumed to occur as early as possible (incipient fire stage) and credited by adding 5 minutes to the assessed time to target damage when applying the appropriate non-suppression probability.

As will be discussed in this paper, methods are both reviewed and proposed that would provide means of relaxing this current restriction in NUREG/CR-6850 to allow the same 5-minute detection credit for a VEWASD system when installed in a "small" room as for an in-cabinet installation.[50]

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[49] The basis for the 5-minute assumption is not explicitly stated in NUREG/CR-6850. It arises from NUREG/CR-4527, "An Experimental Investigation of Internally Ignited Fires in Nuclear Power Plant Control Cabinets, Part II: Room Effects Tests," where it is stated that "[i]n this test, a smoke detector was mounted on the ceiling of the cabinet directly above the electrical ignition source. A second detector was also placed on the ceiling of remote cabinet 'F' ... The purpose of the smoke detector was to determine when a typical in-cabinet detector would detect smoke from an electrical ignition source such as that used here. Smoke was visually observed, in a very small amount, from the electrical ignition source at 9.5 min after the source was turned on or 6 min prior to actual ignition. The detector within the source cabinet signaled smoke detection at approximately 10.5 min after the source was turned on, or approximately 1 min after visual detection of smoke. This was discussion of Test 25 ... involving a full mock-up control panel in the large main control room size control room setup with electrical ignition. This directly supports the 5-minute time credit (i.e., smoke observed 6 minutes before ignition, in-cabinet detector actuation 1 minute later; hence, detector 5 minutes before ignition)." *[Ref. 9]*

[50] Although no physical definition for a "small" room is practical at this time, the following guidance is offered. A "small" room should be one in which any VEWASD system is installed with the ports nearby to the potential ignition sources such that a fire in the equipment could be pinpointed within roughly one minute using a thermographic device. This implies either one limited set

IV. EXAMINATION OF THE EPRI-1016735 APPROACH

In Section 3, supported by Appendix C, of EPRI-1016735, "Fire PRA Methods Enhancements – Additions, Clarifications, and Refinements to EPRI-1011989[51] ('EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities')," the Electric Power Research Institute (EPRI) "develops an approach and supporting basis to apply quantitative credit in fire PRAs for the use of incipient fire detection [IFD] for low voltage electrical components." *[Ref. 10]* These IFD systems (IFDSs) are also referred to as VEWFDSs.

The EPRI approach develops an "IFD Event Tree" that considers four stages to fire ignition: (1) presence of an incipient condition ($\lambda\omega$), (2) effectiveness of an installed VEWFDS (μ), (3) reliability of the VEWFDS (R), and (4) success of pre-emptive actions that are taken (P). The product $\lambda\omega$ represents the fire ignition frequency from NUREG/CR-6850 without any credit for an installed VEWFDS. Once adjusted for the VEWFDS, this ignition frequency becomes $\lambda\omega \cdot (1 - \mu RP)$, based on the event tree.

The parameter μ represents the fraction of ignition sources potentially detectable by the VEWFDS that can actually be detected during the pre-combustion (incipient) stage. It can range from 0 (totally incapable of detection) to 1 (totally capable of detection). A list of components that may effectively be covered by a VEWFDS is provided. In this discussion, we set μ to 1 and address the potential credit for a VEWASD system given it is totally capable of detecting pre-combustion for the potential ignition sources within its range.[52] Therefore, we focus only on the parameters R and P.

In Table 3-1 of EPRI-1016735, some operating history of IFDSs in U.S. commercial nuclear power reactors is provided. The report concludes that these systems have failed once (during preventive maintenance testing) in 54 system-years, or a failure rate per system of ~0.02/yr. This translates into an unreliability of ~0.002 for quarterly testing or ~0.005 for semi-annual testing.[53] The downtime due to this type of failure is estimated as negligible compared to the unreliability. Therefore, EPRI-1016735 assumes a VEWFDS reliability $R = 1 - 0.005 = 0.995$, using the longer testing interval (semi-annual).

EPRI-1016735 cites several qualitative arguments for assuming that pre-emptive actions will be taken at a significant time before ignition occurs, ultimately quantifying a value for P based on applying the Control Room fire non-suppression curve in NUREG/CR-6850 for 15 minutes or more (Table P-2, with a mean non-suppression rate = 0.33/min), such that the NUREG/CR-6850 minimum allowed non-suppression probability of 0.001 would apply, i.e., $P = 1 - 0.001 = 0.999$.[54] Taken together, these values for R and P yield a reduction in the fire ignition frequency $\lambda\omega$ by a factor of 167 ($1/[1 - \{1 \cdot 0.995 \cdot 0.999\}]$) for ignition sources considered fully detectable by a VEWASD system (i.e., for $\mu = 1$).

IV.A. A Different Perspective

The EPRI IFD event tree provides one reasonable approach to quantify the probabilistic credit that may be assigned for a VEWFDS. However, its use could yield overly optimistic values for R and P unless measures are adopted to consider their applicability to plant-specific designs and operational configurations. Review

of equipment protected by nearby ports of a single VEWASD system or multiple sets of equipment, each protected by nearby ports dedicated separately to each VEWASD system.

[51] This is the same as NUREG/CR-6850 (see Ref. 8).

[52] The terms IFDS, VEWFDS, and VEWASD system may be used interchangeably throughout this paper, and they should be considered as referring to the same type of system or phenomena.

[53] For periodic testing, failure is assumed to occur at the midpoint of the testing interval, i.e., at (0.25 yr)/2 = 0.125 yr for quarterly testing and (0.5 yr)/2 = 0.25 yr for semi-annual testing, yielding corresponding unreliabilities of (0.125 yr)/(54 yr) ≈ 0.002 and (0.25 yr)/(54 yr) ≈ 0.005, respectively.

[54] For the Control Room Fire non-suppression curve, the value at 15 minutes is actually 0.007, and the minimum value of 0.001 is not reached until 21 minutes.

of Table 3-1 in EPRI-1016735 suggests that at least two malfunctions other than the one cited as a failure might be considered as VEWASD system failures as well (one attributed to improper maintenance; one attributed to a power supply failure). Even if each of these was only weighted as one-half of the "actual" failure, at a minimum we consider there to have been at least two VEWASD system failures in the U.S. experience cited, suggesting a failure rate per system of 2/54 yr ≈ 0.04/yr and an unreliability for semi-annual testing of ~0.009, or double that cited in EPRI-1016735. This translates into a reduced value for R = 1 – 0.009 = 0.991.

The use of the Control Room fire non-suppression curve is also considered overly optimistic for a "small" room or in-cabinet installation of a VEWASD system since it is likely less sensitive than the human senses available in a continuously occupied Control Room. More appropriate would be the non-suppression curve for Welding or even Electrical fires (Table P-2 of NUREG/CR-6850 indicates mean non-suppression rates of 0.188 and 0.102/min,[55] respectively), since these latter would be the types against which a VEWASD system would most likely be installed to protect. The non-suppression probabilities at 15 minutes for Welding and Electrical fires are 0.060 and 0.217, respectively. These imply corresponding values for P of 1 – 0.060 = 0.940 and 1 - 0.217 = 0.783, respectively.[56] Using these updated values for R (0.991) and P (0.940 and 0.783), we obtain a reduction in the fire ignition frequency $\lambda\omega$ by factors ranging from ~15 (based on Welding fires) to ~4 (based on Electrical fires) for ignition sources considered fully detectable by a VEWASD system (i.e., for $\mu = 1$).[57]

V. A "HOLISTIC" APPROACH

In an effort to independently examine the applicability of the EPRI-1016735 approach, we conducted a literature search for test results of VEWASD systems. Our effort yielded four reports detailing the results of tests for a VEWASD system called VESDA® (manufactured by Xtralis®).[58,59,60,61,62] The first two series of tests were conducted for room-wide installations, from which we postulated that we might extrapolate the results on a limited basis to what might be expected for a "small" room or in-cabinet installation.[63] The third and most recent

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[55] National Fire Protection Association (NFPA) 805 Frequently Asked Question (FAQ) 08-0050, "Manual Non-Suppression Probability," has lowered the mean non-suppression rates for Welding and Electrical fires in NUREG/CR-6850 to 0.188/min and 0.102/min, respectively. *[Refs. 11, 12]*

[56] It should not be inferred that a VEWASD system installed either "in-cabinet" or in a "small" room would be intended for very early detection of potential welding fires, since welding activities are typically performed in the presence of a continuous fire watch to enable prompt suppression of any fire. The Welding fire curve is included solely because it is the next less optimistic non-suppression curve that suggests human-based detection after that for Control Room fires.

[57] $1/(1 - [1 \cdot 0.991 \cdot 0.940]) \approx 15$; $1/(1 - [1 \cdot 0.991 \cdot 0.783]) \approx 4$.

[58] "Final Report – Response Time Comparison of Spot and Aspirated Laser Smoke Detection Technologies in a Telecommunication Facility," Hughes Associates, Inc., Baltimore, Maryland, November 10, 1999 (available at www.haifire.com).

[59] "VESDA® Warehouse Fire Detection Test Results – ASD vs. Point (Spot-type) vs. Beam Detectors," Xtralis®, April 2008 (available at www.xtralis.com).

[60] "IT/Server Room Fire Test Demonstrations – VESDA® and Photoelectric Conventional Point Detectors," Xtralis®, October 2008 (tests were performed in August 2008; available at www.xtralis.com).

[61] "VESDA® Performance in Forbidden City Fire Tests – Engineering Brief Report," Xtralis®, April 2008 (available at www.xtralis.com).

[62] Contact directly with Xtralis® also provided a slide presentation on a 2003 "In-Cabinet Smoke Detection Performance Assessment" by Vision Systems®. An ASD system was tested against point detectors for smoke in a fully-sealed cabinet, with and without airflow. Three design smoke trends were tested: (1) slow growth (2-m 42W and 80W wire burns), (2) medium growth (68-ohm resistor burn), and (3) fast growth (BS6266 2-m wire burn). In all cases, the ASD responded more quickly than the point detector, as follows: (1) faster by 30-39 sec (with airflow) and 43-44 sec (without airflow) for slow growth, (2) faster by 29 sec (with airflow) and 62 sec (without airflow) for medium growth, and (3) faster by 17 sec (with airflow) and at least 89 sec (without airflow – the test was terminated before the point detector responded) for fast growth. These results are consistent with those from the April 2008 tests (discussed below) in which both the VESDA® and the spot detectors responded. Since the test conditions were much better known for the April 2008 tests, they are the ones used for the subsequent quantitative analysis, but recognize that these earlier test results are supportive.

[63] The first test series involved a room with an area of 223 m^2 (2400 ft^2) and height of 4.73 m (15.5 ft). The second test series involved a room with an area of 516 m^2 (5550 ft^2) and height ranging from 8.0 to 8.5 m (26.2 to 27.9 ft). Although no physical definition for a "small" room is practical at this time given these limited test results, the following guidance is offered. A "small" room should be one in which any VEWASD system is installed with the ports nearby to the potential ignition sources such that a fire in the equipment could be pinpointed within roughly one minute using a thermographic device. This implies either one limited set of equipment protected by nearby ports of a single VEWASD

series provided test results for VEWASD systems specifically tested in-cabinet. These three series are examined further below, after the remaining test series is discussed.

The fourth series of tests compared a VESDA® and another ASD system against four other types of detection systems: (1) beam-projected, (2) video smoke, (3) video flame and (4) conventional spot-type. These tests, conducted in Beijing in 2004, occurred in the beam-pocketed central portion of a large room with an area of 144 m^2 (1550 ft^2) and height of 8.0 m (26.2 ft).[64] However, the fire source, usually timber, was located at floor level with all the detectors mounted far above at the ceiling. Thus, the distance between the source and detectors limits the applicability of the results to what might be expected at nuclear power plants for a "small" room or in-cabinet installation of a VEWASD system. Therefore, the results from this fourth series, which indicated VESDA® response before any other detector type, including the other ASD, in all but one of 11 tests, are not used, other than as qualitative support for the potential rapidity of VESDA® response relative to non-ASD systems.[65]

V.A. Analysis of Test Results

In the first series of tests (1999), the locations of the ASD ports relative to the fire source were recorded. We restrict our analysis to those data for which the distance between the source and port is 1.5 meters (5 ft) or more, roughly corresponding to the height sufficiently distant from an electrical cabinet (i.e., the fire source and ASD port can be considered "relatively" far from one another, as one might expect "room-wide"). The second series of tests (April 2008) were conducted with the doors open and closed. Restricting our data to the latter may be considered as roughly approaching what might be a surrogate for a "small" room or in-cabinet installation.

The 1999 test series compared response times between multiple VESDA® and VIEW® systems.[66] Fifty-six tests were conducted, of which 33 employed combustible sources considered representative relative to what might be expected at nuclear power plants as the type of ignition source against which a VEWASD system would most likely be installed to protect, namely insulated wires and printed wire boards.[67] Of these 33 tests, 18 involved the source and target (a VESDA® port or VIEW® detector) beyond 1.5 m (5 ft) from each other. In Table 1, the minimum response time for each type of system is recorded, showing that at least one of both sets of VESDA® and VIEW® systems responded in 10 of the 18 tests.

The April 2008 test series compared response times between a VESDA® system and optical spot-type and beam ("spot/beam") detectors. Five test sessions were conducted, totaling 21 individual tests, each run for a maximum of 10 min. Combustible sources consisted of timber, smoke pellets, and heptane. Ignoring the heptane results leaves a total of 16 tests where the combustible sources were considered as at least approaching what might be expected at nuclear power plants as the type of ignition source against

system or multiple sets of equipment, each protected by nearby ports dedicated separately to each VEWASD system.

64 The room itself had an area of 480 m^2 (5170 ft^2) with the same ceiling height.

65 Two of the tests employed overheated cable as the source, one of 3-m length, the other of 6-m length. Both indicated VESDA® response prior to the other ASD and no response by any of the other detector types. However, since both tests apparently were terminated when the other ASD responded, the total test durations could not be determined to be longer than 3 min and 18 min, respectively. In the first test, the VESDA® responded 130 sec after the start of the test, but the test could not be determined to have been run for more than an additional 50 sec. In the second test, the VESDA® responded 197 sec after the start of the test, but the test could not be determined to have been run for more than an additional 14.5 min. While the latter suggests a potentially substantial benefit in response time for a VESDA® over other types of detectors, the test conditions (large room with ceiling-mounted detectors quite far from the ignition source) and limited results (just one test) discourage quantitative use of these results.

66 VIEW® is the Very Intelligent Early Warning laser smoke detector system, manufactured by Notifier® (information available at *www.notifier.com*). Although it operates differently from an ASD system, it also "senses the earliest particles of combustion, providing early warning of a fire condition. It [is] ... up to 100 times more sensitive than a standard photoelectric sensor[, u]sing an exceptionally bright, controlled laser diode ..."

67 Also included were two "conductive heating tests" of cables.

which a VEWASD system night be installed to protect.[68] These 16 tests were further reduced to SEVEN tests where the room doors were open, considered to roughly approach what might be a surrogate for a "room-wide" installation. In Table 2, the minimum response time for each type is recorded, showing that while the VESDA® system responded in all seven tests, the spot/beam detectors responded in only one.[69]

V.B. Potential Effect on Non-Suppression Probability

From the 1999 tests, we see that both the VESDA® and VIEW® systems responded in 10 of the 18 tests, and neither responded in the other eight. This suggests a likelihood of VESDA®/VIEW® detection in 5/9 of the potentially applicable situations. Next, consider the potential difference in detection time for VESDA® vs. spot/beam from the April 2008 tests. When both VESDA® and spot/beam responded (once), the difference was 109 sec. This time difference is much less than the other six tests where only the VESDA® responded, suggesting that VESDA® gives limited benefit over spot/beam in cases where both would respond. For more insight, let us consider the remaining six tests where VESDA® responded but neither spot nor beam did, within the 10-min testing time frame (600 sec). For these tests, the time difference ranged from 410 sec to 534 sec, with a mean of 488 sec and standard deviation of 44.5 sec, assuming that the potential time for spot/beam to respond is no more than 600 sec.[70]

How can we interpret the "additional" 488 sec (~8 min), on average, which are gained in detection time by VESDA® over spot/beam?[71] If a room were equipped with these detectors, it is likely optimistic that personnel responding to a VESDA® alarm (e.g., with a thermographic device) could pinpoint the offending source within 2-3 min.[72] This would leave approximately an "additional" 5 min to engage in fire suppression activities in the ideal case, coincidentally corresponding to the suppression time "bonus" currently allowed in NUREG/CR-6850 for high-sensitivity smoke detection. For the incipient stages for the types of fires of interest here, we again assume the non-suppression curve for Welding or even Electrical fires (with mean non-suppression rates of 0.188 and 0.102/min, respectively), may be applied, i.e., non-suppression probability = 1/exp(0.188t) [Welding fire] or 1/exp(0.102t) [Electrical fire], where t is the time available for manual suppression. Therefore, comparing non-suppression probabilities for VESDA® vs. spot/beam, we see that VESDA® will lower the non-suppression probability, on average and under these optimistic assumptions, by a factor of $\exp(0.188 \cdot 5) = 2.56$ [Welding fire] or $\exp(0.102 \cdot 5) = 1.67$ [Electrical fire], or roughly two.[73]

Therefore, a first approximation of the potential benefit of a VEWASD system meeting the same level of qualification and performance as a VESDA® system with respect to reducing core damage frequency (CDF) is as follows (assuming a 5/9 Probability that VESDA® responds):

CDF (with VESDA®) = [CDF (with spot/beam, i.e., without VESDA®)] · [Probability that VESDA® responds] / [Reduction Factor in Non-suppression Probability without VESDA®] = [CDF

[68] In addition, these tests results are only employed to estimate the "additional" time available for fire suppression activities when a VEWASD system responds prior to a spot/beam detector, not to estimate the likelihood of very early detection by a VEWASD system.

[69] The rightmost column is the difference between the spot/beam response time and that of VESDA®, where the 10-min test maximum was assumed for spot/beam when there was no response.

[70] Based on the Appendix, a limit of 10 min (600 sec) to detect is considered reasonable.

[71] This depends on the time required to locate the source. The sampling hole and pipe sampling configuration of a VEWASD system and the detector type determines the level of 'addressability' (source location). Some VEWASD systems provide addressability to only one detector (which has one or many pipes), some to a pipe (which may have one or many holes), and some to an individual hole.

[72] Use of "addressable" VEWASD system could automate this pinpointing of the offending source.

[73] If Spot/Beam has a non-suppression probability of $1/\exp(\alpha t)$, then VESDA® would have a value of $1/\exp(\alpha[t+5])$, such that the ratio of Spot/Beam non-suppression probability to that of VESDA® is $\{1/\exp(\alpha t)\}/\{1/\exp(\alpha[t+5])\} = \exp(5\alpha)$.

(with spot/beam, i.e., without VESDA®)] · [5/9] / 2 = [CDF (with spot/beam, i.e., without VESDA®)] / [~3]

In other words, the potential benefit in reducing CDF (through quicker detection time that translates into more time available for suppression [estimated, on average, to be five minutes]) is a maximum factor of three.

V.C. Potential Effect on Fire Ignition Frequency

Is it reasonable to consider the potential for an additional effect of a VEWASD system such as VESDA® for a "room-wide" installation on fire ignition frequency with respect to the type of ignition source against which a VEWASD system would most likely be installed to protect? If so, one approach would be to compare the ignition frequency of fires in the Control Room (assumed to be electrical cabinet fires), which are detected mostly by human smell (and thus act as a surrogate for a VEWASD system) against the ignition frequency of a non-human-occupied area with a variety of fire sources.

While the current ignition frequencies in NUREG/CR-6850 do not provide a zonal frequency for the latter (just the Control Room), earlier data on which NUREG/CR-6850 was based do consider these frequencies on a "plant-wide" basis (EPRI-1003111, "Fire Events Database and Generic Ignition Frequency Model for US NPPs"). *[Ref. 13]* There, we find the following mean frequencies (1/yr) at-power for a variety of fire sources (excluding cables, hydrogen and transients):

Fire Protection Panels = 0.0013
RPS MG Sets = 0.0034
Transformers = 0.014
Battery Chargers = 0.0055
Gas Turbines = 0.0017
Air Compressors = 0.0059
HVAC Subsystems = 0.016
Electric Motors = 0.0072
Dryers = 0.0055
Electrical Cabinets (excluding Containment and Intake Structure):
Auxiliary Bldg (PWR) = 0.031
Reactor Bldg (BWR) = 0.057
Diesel Generator Room = 0.0072
Switchgear Room = 0.017
Cable Spreading Room = 0.0025
Turbine Bldg = 0.025
Control Room - electrical cabinets = 0.016

Averaging non-Control Room values yields 0.013/yr, which is slightly less (~1.2 times) than the Control Room value. Thus, little benefit toward frequency reduction would be expected.

V.D. Potential Combined Effect on CDF

Even if the two effects, one on non-suppression probability (a factor approaching 3) and one on ignition frequency (roughly no effect), were to compound, a reduction in CDF by a factor no more than ~3 would seem creditable.

Neither of the previous two approaches explicitly considered the timing of events involved in successfully detecting a potential fire very early in the growth stage (i.e., while there are only pre-combustion products) or, if this fails, at least detecting the fire just as it is about to start (thereby providing some "bonus" in the time available for suppression, similar to that assumed for successful prompt detection in NUREG/CR-6850). The event tree in Figure 1 presents this third approach. It evolves as follows.

V.E. Fire Scenarios (Event Tree Branches)

A potential combustible first experiences overheating that, if allowed to proceed, will eventually ignite the combustible with a frequency = IF. Depending upon the nature of the combustible and its fire pre-growth characteristics (long vs. short incipient fire pre-growth phase), the VEWASD system may or may not be capable of detecting the pre-combustion products (probability of detectability = PD). If the VEWASD system can detect the pre-combustion products, then it must also be

effective in doing so to prevent fire during the incipient stage (probability = VE). If the VEWASD system is effective, then there is no effect on non-suppression, since the need for suppression never arises. This is shown as Branch 1.

If the VEWASD system is not effective, then the only benefit will be a reduction in non-suppression probability due to the VEWASD system alarming just as the fire is about to start, providing an additional "bonus" time (TB) to the "normal" damage time if no VEWASD system were present (TD). This constitutes Branch 2. And, if the VEWASD system is unable to detect the pre-combustion products, then it does not even have the opportunity to be "effective," so again the only benefit will be a reduction in non-suppression probability as above (Branch 3).

From the event tree, we can see that the top branch offers a reduction in overall ignition frequency ($0 < VE \leq 1$), while the lower two branches offer a reduction in non-suppression probability. One cannot get BOTH a reduction in ignition frequency AND a reduction in non-suppression probability along any single branch, but both effects can be manifested over the entire tree.

VI. A SIMPLIFIED EVENT TREE APPROACH

Implicit in this event tree are the following simplifying assumptions:

4. The VEWASD system is always available (the industry survey conducted in support of EPRI-1016735 indicates a very high reliability of these systems).
5. Personnel respond at the first indication of potential overheat (otherwise the opportunity to preclude the eventual overheating that results in a fire does not exist).
6. Personnel are always successful in locating the potential ignition source immediately after receiving the first indication (since the pre-growth stage phase is presumably "long" enough such that ignition can be precluded, trained personnel with the proper detection equipment shall be able to pinpoint the source in a relatively brief time).

A more detailed event tree, containing stages for reliability and unavailability of the VEWASD system, as well as probabilities of specific human actions, can be developed. However, given the limited data available and likely high uncertainty on the key elements of this tree, namely the probability of detectability by the VEWASD system and the VEWASD system effectiveness, the additional details are not examined.

VI.A. Quantification

Determination of the probability of detectability of pre-combustion products by the VEWASD system (PD) is currently subjective. However, the 1999 and 2008 test series from the VESDA® experiments offer some quantitative information that can be used for the VEWASD system effectiveness (VE) and the time bonus (TB). As shown in the 1999 tests, the VESDA® responded in 10 of 18 (0.56) trials, which could be taken as a first approximation of the effectiveness (VE) since the tests were conducted on wires and printed board, the type of combustible for which we would expect slow growth and a long incipient growth stage.

The 2008 series showed that, when the VESDA® responded but neither the spot nor beam detector did, the "time bonus" (TB) was around at least seven minutes (could have been more, but the tests were terminated at 10 minutes before the latter could respond). These tests used timber or smoke pellets, so it is likely that the VESDA® response occurred later in any pre-growth stage rather than early (although likely prior to full smoking or flaming since neither spot nor beam detector responded). This ~8-minute "time bonus" is comparable to the currently assumed 5-minute bonus in NUREG/CR-6850 for a high sensitivity smoke detector inside a cabinet, so there is at least some evidence that the current NUREG/CR-6850 value could represent a reasonable default for TB.

Table 4 shows the results of exercising the event tree for variations in the following two paramenters (with IF set = 1 and VE = 0.56 in all): (1) Welding vs. Electrical fire mean non-suppression rates (α = 0.188 and 0.102/min, respectively); and (2) 5 min ≤ TB ≤ 10 min.[74] For each case, the fire scenario frequencies with and without VEWASD are also calculated, where this scenario frequency with a VEWASD is the sum of the lower two branches (incorporating time bonus in the non-suppression calculation); without a VEWASD it is just the ignition frequency times the non-suppression probability without any time bonus. The ratio of the "without" to "with" frequency then indicates the potential CDF reduction factor, analogous to that estimated for the previous two approaches (EPRI-1016735 and "holistic").

What are considered the potentially more likely combinations of PD and VE are shown as the shaded rows in Table 4 for both the Welding and Electrical fire non-suppression curves (α = 0.188 and 0.102/min, respectively) with TB = 5 minutes. The corresponding reduction factor ranges from ~6 (when PD = 1.00) to ~2 (based on Electrical fires) for ignition sources considered fully detectable by a VEWASD system (i.e., for IF = 1). These results include both ignition frequency and non-suppression probability reduction effects, but never within the same sequence. That is, if the VEWASD system prevents ignition, it cannot reduce non-suppression probability within the same sequence since ignition never occurred. Similarly, if the VEWASD system does not prevent ignition, it can still have some benefit in reducing non-suppression probability by providing a "time bonus" for suppression (defaulted to five minutes, as per NUREG/CR-6850 and at least partially supported by the 2008 series of VESDA® tests).

VII. SUMMARY

Two potential approaches to credit very early warning fire detection in fire PRA have been examined. The potential reduction factors on CDF if a VEWASD system is installed "room-wide" ranges from a minimum of ~2-3 ("Holistic" and Event Tree approaches) to ~6 (Event Tree approach). Given the speculative nature of the potential creditable value of this relatively new (to commercial nuclear power) technology to fire PRA and the associated uncertainties in the relevant parameters, it would seem prudent to more tightly constrain the upper limit on the potential effect until operating history for the use of VEWASD system for electrical cabinet fires in commercial nuclear plants accumulates. For now, only the following guidance might be offered to narrow the range.

VII.A. Conditions under Which Credit May be Considered

First, it is necessary to identify the conditions under which credit may even be considered for a VEWASD system installed in a "small" room or in-cabinet. The following approach is proposed. For a VEWASD system installed in a "small" room or in-cabinet, all of the following must first be met:

1. The VEWASD system must have been tested, designed and installed in accordance with recognized standards and the manufacturer's instructions.
2. The VEWASD system must be designed to maximize the time available for personnel to locate the hazard and respond accordingly.
3. The VEWASD system must be qualified to detect the anticipated hazard at the locations in question and be capable of providing an adequate level of communication to the fire alarm system and/or plant personnel.

The current NUREG/CR-6850 approach suggests that an in-cabinet or "small" room installation of a VEWASD system may receive an additional 5-minute "bonus" in suppression time. When coupled with the potential reduction in ignition frequency if the VEWASD system successfully detects pre-combustion products in

[74] The "normal" damage time if no VEWASD system were present (TD) does not appear in the ratio, since it appears in both the frequency with and without the VEWASD system and, therefore, cancels out when these are ratioed.

the fire pre-growth stage, the satisfaction of the preceding conditions suggests a total reduction in CDF ranging from a minimum of ~3 to a currently unspecified upper limit.[75] Credit beyond a factor of 10 should be applied very cautiously and only after careful consideration of plant-specific conditions for design, installation, alarms, annunciators, procedures and training of responding staff.

VIII. CONCLUSION

Ideally, additional research will be performed, and operating history will be accumulated, specific to the use of VEWASD systems installed in-cabinet or in a "small" room at a nuclear power plant to more precisely quantify the amount of credit that may be assigned in a fire PRA. The qualitative arguments and limited test results currently available suggest that some amount of credit in reducing CDF from fires is justified. Since operating experience to date is mainly based on area-wide installation, rather than in-cabinet or even "small room" installations, the upper portions of the range for the credit factor should be applied very cautiously and only under ideal conditions.

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X. APPENDIX

A limited literature search for information regarding electrical cabinet fires yielded two documents regarding tests being performed internationally.[76] It should be noted that Europe

[75] The authors' experience suggests an upper limit of a factor of ~10, although one cannot *a priori* eliminate even higher factors.

[76] *On the fire dynamics of vehicles and electrical equipment,* Johan Mangs, VTT Building and Transport, University of Helsinki,

uses thermoplastic cable, which burns more readily, to a greater extent than thermoset, which is prevalent in the U.S. This means that the European test fires are likely larger than the ones in the U.S. or, equivalently that fires in the U.S. would be smaller than those shown in the two documents. Consider the graphs shown in the studies.

Figure 9 from the Finnish study indicates that some of the fires peak at ~50 kW or less within ~10 minutes (Experiments 5, 7-10).[77] Likely they would not even be considered among the fire events that would contribute to the ignition frequencies in NUREG/CR-6850. Experiments 1, 3, 4 and 6 all reach peaks in excess of 70 kW within 10 minutes. This would support the assumption that a limit of 10 min (600 sec) to detect an in-cabinet or "small" room fire is reasonable. Only Experiment 2C suggests slow fire growth, and even that takes only 30 minutes to reach 70 kW. Test results from the French study are similar. In the open cabinet tests, the fires peak above 1000 kW, reaching at least 100 kW within 10 minutes. In the closed cabinet tests, the fires never reach 50 kW.

Consistent data from two test groups (based on the presumably more limiting fires from thermoplastic cables) support the assumption that a limit of approximately 10 minutes for a VEWASD system to detect a fire is reasonable.

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[77] Experiment 5 peaks at ~55 kW around 12 minutes.

TABLE 1. Test Results for VESDA® and VIEW®, with Source and Port/Detector Beyond 1.5 m (5 ft) from Each Other

TEST	SOURCE	MINIMUM VIEW	DETECT? (1=Y,0=N)	MINIMUM VESDA	DETECT? (1=Y,0=N)	MINIMUM BOTH	DETECT? (1=Y,0=N)
1	Conductive Heating Test	4833	1	3899	1	3899	1
2	Conductive Heating Test	4935	1	4915	1	4915	1
3	One Bell Canada wire at 20A for 300 s	9999	0	9999	0	9999	0
4	One Bell Canada wire at 22A for 120 s	9999	0	9999	0	9999	0
5	One Bell Canada wire at 22A for 75 s	9999	0	9999	0	9999	0
6	One Bell Canada wire at 28A for 28 s	182	1	203	1	182	1
7	One Bell Canada wire at 6 V for 40 s	8	1	6	1	6	1
8	Printed Wire Board	323	1	369	1	323	1
9	One BSI 6266 wire at 5.5 V for 60 s	9999	0	9999	0	9999	0
10	Two BSI 6266 wires at 5.5 V for 60 s	9999	0	9999	0	9999	0
11	Two BSI 6266 wires at 5.5 V for 60 s	9999	0	9999	0	9999	0
12	Two BSI 6266 wires at 5.5 V for 60 s	9999	0	9999	0	9999	0
13	Two BSI 6266 wires at 6 V for 60 s	9999	0	9999	0	9999	0
14	Two BSI 6266 wires at 6 V for 60 s	105	1	87	1	87	1
15	Two BSI 6266 wires at 6 V for 60 s	129	1	160	1	129	1
16	Two BSI 6266 wires at 6 V for 60 s	45	1	53	1	45	1
17	Two BSI 6266 wires at 6 V for 60 s	64	1	83	1	64	1
18	Three BSI 6266 wire at 5.5 V for 60 s	166	1	185	1	166	1
NOTE: 9999 indicates no response		**SUM =**	**10**	**SUM =**	**10**	**SUM =**	**10**
		COUNT =	**18**	**COUNT =**	**18**	**COUNT =**	**18**

TABLE 2. Test Results for VESDA® and Spot/Beam, with Doors Open

TEST	DOORS	MINIMUM VESDA	DETECT? (1=Y,0=N)	SPOT	DETECT? (1=Y,0=N)	BEAM	DETECT? (1=Y,0=N)	SPOT/BEAM minus VESDA (10 min limit)
2-Smoke(3g)	Open	97	1	9999	0	9999	0	503
2a-Timber(9)	Open	135	1	9999	0	9999	0	465
3-Smoke(3g)	Open	86	1	9999	0	9999	0	514
4-Smoke(3g)	Open	66	1	9999	0	9999	0	534
4-Smoke(30g)	Open	56	1	165	1	190	1	109
5-Smoke(9g)	Open	96	1	9999	0	9999	0	504
5-Timber(18)	Open	190	1	9999	0	9999	0	410
NOTE: 9999 indicates no response		**SUM =**	**7**	**SUM =**	**1**	**SUM =**	**1**	
		COUNT =	**7**	**COUNT =**	**7**	**COUNT =**	**7**	

TABLE 3. Results for VESDA® In-Cabinet Tests

TEST	DATE	SOURCE	VENTILATION	RESPONSE TIME (s)	RESPONSE TYPE
4	0821(1)	1m cable	Bottom-to-Top	50	Fire 1
5	0821(1)	2 resistors	Fully Sealed (Mixing Fan)	28	Fire 1
6	0821(1)	1 resistor	Front-to-Back (Exhaust Fans)	26	Fire 1
4	0822(1)	1m cable	Bottom-to-Top	56	Fire 1
5	0822(1)	2 resistors	Fully Sealed (Mixing Fan)	26	Fire 1
6	0822(1)	1 resistor	Front-to-Back (Exhaust Fans)	25	Fire 1
4	0822(2)	1m cable	Bottom-to-Top	47	Fire 1

5	0822(2)	2 resistors	Fully Sealed (Mixing Fan)	25	Fire 1
6	0822(2)	1 resistor	Front-to-Back (Exhaust Fans)	26	Fire 1
4	0823(1)	1m cable	Bottom-to-Top	48	Fire 1
5	0823(1)	2 resistors	Fully Sealed (Mixing Fan)	26	Fire 1
6	0823(1)	1 resistor	Front-to-Back (Exhaust Fans)	26	Fire 1
6B	0823(1)	1m cable	Front-to-Back (Exhaust Fans)	46	Fire 1
4	0823(2)	1m cable	Bottom-to-Top	64	Fire 1
5	0823(2)	2 resistors	Fully Sealed (Mixing Fan)	26	Fire 1
6	0823(2)	1 resistor	Front-to-Back (Exhaust Fans)	28	Fire 1
6B	0823(1)	1m cable	Front-to-Back (Exhaust Fans)	30	Fire 1
4	0824(1)	1m cable	Bottom-to-Top	54	Alert
5	0824(1)	2 resistors	Fully Sealed (Mixing Fan)	28	Action
6	0824(1)	1 resistor	Front-to-Back (Exhaust Fans)	25	Fire 1
4	0825(1)	1m cable	Bottom-to-Top	54	Action
5	0825(1)	2 resistors	Fully Sealed (Mixing Fan)	22	Fire 1
6	0825(1)	1 resistor	Front-to-Back (Exhaust Fans)	25	Fire 1
4	0825(2)	1m cable	Bottom-to-Top	50	Fire 1
5	0825(2)	2 resistors	Fully Sealed (Mixing Fan)	28	Fire 1
6	0825(2)	1 resistor	Front-to-Back (Exhaust Fans)	24	Fire 1

Note: "Alert" alarm precedes "Action," which precedes "Fire 1."

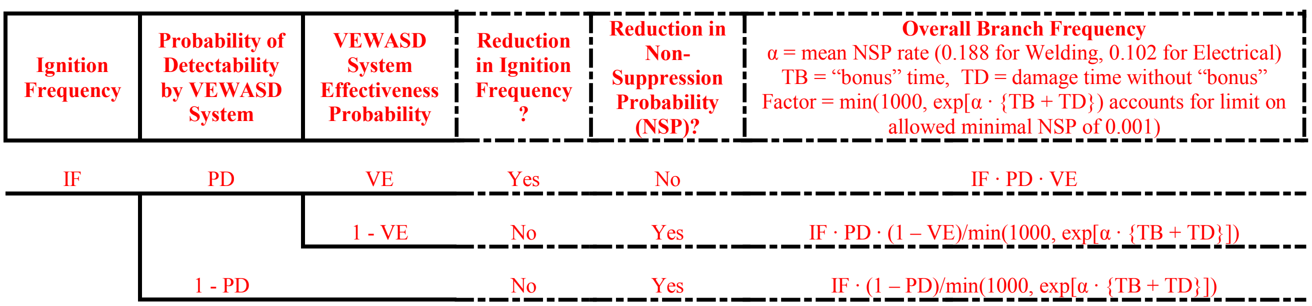

FIGURE 1. Simplified Ignition-Detection-Suppression Event Tree with VEWASD System

TABLE 4. Ratio of Event Tree Sequence Frequencies without vs. with VEWASD System

PD	α (1/min)	TB (min)	Ratio (Without vs. With VEWASD System)
0	0.102	5	1.67
0.25	0.102	5	1.93
0.50	0.102	5	2.31
0.75	0.102	5	2.85
1.00	0.102	5	3.75
0	0.188	5	2.56
0.25	0.188	5	2.97
0.50	0.188	5	3.54
0.75	0.188	5	4.39
1.00	0.188	5	5.76
0	0.102	10	2.77
0.25	0.102	10	3.22

PD	α (1/min)	TB (min)	Ratio (Without vs. With VEWASD System)
0.50	0.102	10	3.84
0.75	0.102	10	4.75
1.00	0.102	10	6.24
0	0.188	10	6.55
0.25	0.188	10	7.61
0.50	0.188	10	9.07
0.75	0.188	10	11.2
1.00	0.188	10	14.7

ATTACHMENT 3

STATISTICAL CHARACTERIZATION OF THE ADVANCED NOTIFICATION IN DETECTION TIME FOR VERY EARLY WARNING FIRE DETECTION IN NUCLEAR PLANT ELECTRICAL ENCLOSURES

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This paper[zzz] uses recent test data to evaluate the differences in time to detection of low energy fire sources between very early warning fire detection systems and ION spot-type detection systems as a basis to evaluate the non-suppression probability assuming detection of pre-flaming fire conditions. As indicated by the stochastic simulation results, there is fairly wide variability in the actual reduction factor due to the variability in the test results. If used in probabilistic risk applications, the distributional aspects should be applied with appropriate consideration of uncertainty and sensitivity.

I. OVERVIEW

Very early warning fire detection (VEWFD) has been used in numerous performance-based applications outside of the nuclear industry as a tool to provide advanced notification of potential fire hazards.[1,2,3] With the pursuit of performance-based fire protection programs in commercial nuclear power plants (NPPs) via the National Fire Protection Association (NFPA) Standard 805, "Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants," there is an interest in using VEWFD systems as a tool to support these approaches. A key point of interest is characterizing these systems' performance via non-suppression probability estimates used in fire probabilistic risk assessments (PRAs).

Due to the lack of available data to support the types of VEWFD applications expected to be used in NPPs, the NRC issued an interim staff guidance document in 2009 to support licensees transitioning to NFPA 805.[4] Subsequently, the NRC initiated a confirmatory research program to collect detection system performance data and evaluate any potential risk benefits. The results of the research program are nearing publication. However, to provide an alternative evaluation: this paper uses the test data, recent updates to the manual suppression curves and the exponential suppression model presented in EPRI 1011989 (NUREG/CR-6850)[aaaa] "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities," including Supplement 1, to evaluate the performance differences between ION spot-type smoke detection and VEWFD systems when used for in-cabinet smoke detection applications.[5]

I.A. The Incipient Stage

Fire development profiles are typically discussed in terms of "fire stages," commonly referred to as *incipient*, *growth*, *steady-state*, and *decay*. The intended use of VEWFD is to detect low energy fires

[zzz] This paper was prepared (in part) by employees of the United States Nuclear Regulatory Commission (USNRC). The USNRC has neither approved nor disapproved its technical content. This paper does not establish a USNRC technical position.

[aaaa] This joint report will be referred to as "EPRI 1011989" exclusively throughout this paper.

in their incipient stage.[4,6,7] However, Appendix G of EPRI 1011989 states that

> *the duration of this [incipient] stage may vary from seconds to hours*

and with regard to development of HRR profiles

> *The incipient stage is not usually included due to its uncertainty in duration and that it is not expected to generate thermal conditions that threaten the integrity of other targets in the room.*

Arguments have been made that for specific types of electrical enclosures and components, the incipient phase is of sufficient duration to allow for VEWFD systems to provide at least one-hour of warning prior to ignition.[4] This paper doesn't explicitly explore the validity of these arguments, but can be modified to reflect any changes in the current state of knowledge related to the effect or duration of the incipient stage for "risk-relevant" fires on the estimation of the non-suppression probability as used in fire PRA.

I.B. Experimental Approach

I.B.1. Smoke Source

Electrical fires are often preceded by some form of arcing or joule heating of electrical components. A pre-flaming smoke source was developed that mimics these slow overheat conditions to degrade polymeric electrical and electronic materials. The source consists of a copper bus bar block with an axial cylindrical hole where a 500W cartridge heater is mounted. Polymeric materials such as insulated electrical conductors, phenolic terminal block, and printed circuit boards representative of those found in NPP electrical enclosures are attached to the external surface of the bus bar along with a single thermocouple to allow for temperature feedback control. The cartridge heater raises the surface temperature of the copper bus bar block from ambient to a maximum temperature of 485 °C using one of three linear heating rate periods (HRPs), namely; 15 minutes, 1 hour and 4 hours. Heat from the copper block travels down the stranded conductors via conduction and elevates the temperature of the conductor insulation. Based on thermal imaging camera data, elevating the copper block temperature to 485 °C results in surface conductor temperatures at or above the piloted ignition temperatures for the materials tested.[8] Although the experimental approach was not intended to ignite the source materials, literature and ad hoc ignition tests demonstrate that the materials were elevated to temperatures where piloted ignition and sustained combustion could be supported. Since electrical enclosures contain components that are energized, potential ignition sources are typically present. Figure 1 shows the smoke source with five insulated conductors attached.

I.B.2. Scales of Testing

Three scales of testing were performed using cabinets of dimensions shown in Table I. Laboratory scale testing consisted of small and large cabinets located within slightly larger enclosures used to contain and evacuate the gases from the test space. The small room facility consisted of a 2.5 m high ceiling and a 38 m^2 floor area, while a large room facility had a ceiling height of 3 m and a 100 m^2 floor area. All cabinets were ventilated at or near the top of the enclosures with front, rear, and bottom vents to allow air into the electrical enclosure.

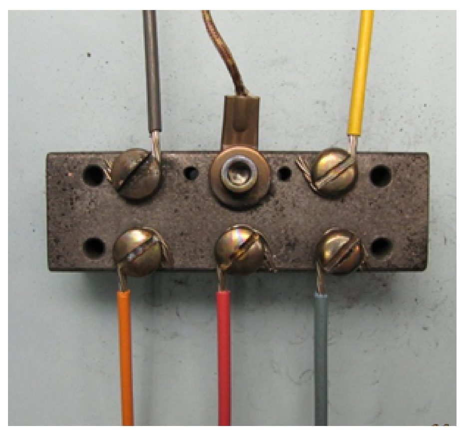


Figure 1. Photograph of pre-flaming smoke source with insulated conductors attached (thermocouple connection shown top center).

TABLE I. Cabinet Dimensions

Test Series	Cabinet Dimensions
Laboratory Scale – small	0.56 m by 0.61 m by 1.32 m tall
Laboratory Scale – large	0.61 m by 0.61 m by 2.13 m tall
Small Room	0.61 m by 0.61 m by 1.78 m tall

	Single, 4- and 5-cabinet banks
Large Room	0.74 m by 0.91 m by 2.11 m tall Single and 3-cabinet banks

I.B.3 Smoke Detectors Evaluated

Two types of VEWFD detectors were tested, aspirated and spot-type. Aspirated smoke detection (ASD) systems from three different manufacturers were tested using two different detection technologies, namely; light-scattering and cloud chamber. A spot-type light-scattering detector capable of achieving VEWFD sensitivities was also included. Conventional ionization (ION) spot-type smoke detectors were also tested. NFPA 76, "Standard for the Fire Protection of Telecommunications Facilities," provides sampling port sensitivity in %/ft obsc(uration) to meet VEWFD requirements. The tested light-scattering-based VEWFD systems were configured to meet the 0.2%/ft obsc. (the "alert" setpoint) and those data will be used in this paper as the first response of VEWFD systems. The cloud chamber ASD is not configurable to %/ft obsc.; therefore, the vendor recommended settings for the specific application were used (1.0E+06 particles per cm^3 at the sampling port). The conventional ION spot-type "alarm" setpoint was set to 1.0%/ft obsc.[bbbb] and used for comparative purposes.[9]

I.B.4 Test Procedure

In all tests, the smoke source was located within the electrical enclosure. Typical placement was on or near the floor of the electrical enclosure, with a few tests placing the source at approximately 2/3 height of the electrical enclosure. All smoke detectors were included in the laboratory scale-small and small room tests. In the laboratory scale-large and the large room tests, only one of the two light-scattering type ASDs was included.

An electrical low pressure impactor (ELPI) was used to monitor the aerosol concentration and size distribution at the electrical enclosure ceiling near the in-cabinet smoke detectors and ASD sampling ports. The ELPI provided measurements of mass concentration, mass mean diameter (MMD) and arithmetic mean diameter (AMD). The laboratory scale – small tests were used to evaluate the aerosol characteristics generated by numerous materials. The AMD and MMD both varied by a factor of three from polytetrafluoroethylene (PFTE) to chlorosulfonated polyethylene (CSPE) insulated conductors. Based on these results the later tests reduced the number of materials to Polyvinyl chloride (PVC), cross-linked polyethylene (XLPE) and CSPE which represented the smallest, medium and largest particle sizes tested, respectively.

I.C. Pre-Existing Guidance for In-Cabinet Smoke Detection

Appendix P, "Appendix for Chapter 11, Detection and Suppression Analysis," of EPRI 1011989 provides guidance for evaluating the performance of in-cabinet smoke detection, which states:

> *...If in-cabinet smoke detection devices are installed in the electrical cabinet postulated as the ignition source, the analyst should assume that the fire will be detected in its incipient stage. This incipient stage is assumed to have a duration of 5 minutes. In order to account for these 5 minutes the analysts should add them to the time to target damage (or, equivalently, add them to the time available for suppression).*

Appendix P (updated by Supplement 1, with enhancements not addressed in this paper) presents non-suppression probability curves based on suppression times from actual "risk-relevant" events documented in the fire events database, which represent the probability of failing to suppress a fire. The curves are modeled as exponential distributions with T a random variable describing when (time duration) the fire is suppressed and λ the mean rate (per unit time) at which the fire is suppressed. The non-suppression probability (NSP) is estimated as

$$NSP = Pr(T>t)= 1/\exp(\lambda t)$$

"t" represents the time available for suppression prior to target damage and is calculated as

[bbbb] The ION spot-type detectors tested meet the sensitivity settings of NFPA 76 for early warning fire detection (i.e., ≤ 1.5 %/ft. obscuration).

t = <time to damage> - <time to detection>.[5]

II. AN EMPIRICALLY-BASED STATISTICAL APPROACH

The Appendix P guidance provides a simple approach that has been used to characterize the risk reduction associated with having smoke detection within electrical enclosures as an early detection measure for a postulated electrical enclosure ignition source. Although this approach can be easily applied, it does not distinguish between the performance differences among detection technologies currently available on the commercial market. To provide a more detection technology specific characterization, the performance of the ION spot-type detector is assumed to represent the "5-minute" guidance provided in Appendix P. Empirical data from the performance of ION spot-type detection is compared to other more sensitive smoke detectors and characterized for any potential time "bonus" or "penalty." This differential characterization is then used along with the manual non-suppression model to characterize through stochastic simulation the differences in detection system performance in terms of reduction factors on the non-suppression probability.

II.A. Characterization of Test Data

The "Alarm" response for the ION spot-type detector (1%/ft obsc.) and the "Alert" response for VEWFD detectors[cccc] (0.2%/ft obsc. or 1E+06 particles per cm^3 at sampling port) are used. The data were normalized to the HRP to allow for comparison of individual detector response as a function of total test duration. This allowed for the comparison of detector performance among all three HRPs. The results indicated that the 15-minute HRP data were not consistently poolable by material with either the 1- or 4-hour HRP data using Kolmogorov-Smirnov (k-s) poolability tests. Review of the aerosol data provides confirmation that the mass and number concentration profiles are dependent on the rate of component degradation consistent with the literature.[2,10] For the 15-minute HRP, the number and mass concentrations increase at similar rates concurrently, while there is an increasing difference between the profiles when the HRP is increased with the mass lagging number concentration for both the 1- and 4-hour HRP tests showing similar results.

Comparisons of the normalized time to detection between the 1- and 4-hour data show similar results. However, the limited number of data in the 4-hour HRP test excludes conducting statistical poolability tests for several of the materials. Since the 1-hour HRP data represent the largest pool of in-cabinet data and with the limitations described above, they will be used to support the statistical evaluation presented here.

II.B. Statistical Analysis of Data

As discussed above, the materials tested generate different aerosol characteristics with regard to the mass and number concentration, and varied by a factor of three. Because of the aerosol difference among materials, the smoke detectors tested have their own individual response characteristics to the materials tested. For instance, the cloud chamber and ION detectors respond better to small particles while the light-scattering detectors respond better to particles with larger cross section. Although the statistical evaluation could address each material separately, the material aerosol characteristics are considered to be representative of the varieties of materials found in electrical enclosures (insulation from conductors, phenolic terminal blocks, printed circuit cards, etc.). Additionally, the detectors were evaluated concurrently in each test to the same smoke source and located symmetrically within the enclosure to promote comparisons and limit variability. Because of these aspects, no evaluation of detector response to specific materials will be provided.

The time between VEWFD "alert" and ION spot-type "alarm" responses is calculated for each individual test and VEWFD system (i.e., light-scattering ASD – LS, cloud chamber ASD – CC and light-scattering sensitive spot – SS). Data from the two light-scattering ASDs were combined based on

[cccc] The cloud chamber ASD was not directly configurable to %/ft. obsc. Instead, vendor recommended settings were used. These settings are believed to be more sensitive than the light-scattering ASDs, but this could not be confirmed. It is important to keep this in mind when considering the better results in terms of earlier detection shown by cloud chamber over light-scattering ASDs later in this paper, as it may be somewhat overly optimistic depending upon calibration.

similar technologies and identical sensitivity settings. Poolability k-s tests were used to evaluate the three data bins (LS, CC, SS). It was determined that the LS and SS datasets were poolable (based on α=0.05). However, to provide insights to variation in ASD response (CC vs LS) as well as comparisons between SS and ASD VEWFD detector response, it was decided to keep these data bins separated.

Statistics of these three datasets are presented in Table II. The data were plotted in a histogram using a 5-minute bin width, as shown in Figure 2. The light-scattering type detectors (LS and SS) displayed bi-modal characteristics, while a single mode was observed for the CC detector. These system responses are likely due to the aerosol characteristics generated from the test materials along with differences/similarities between the detection mechanisms of the ION spot-type and VEWFD detectors. It is also worth noting that the ION spot-type detector is responding earlier than the LS and SS detectors on average (i.e., mean $\Delta t>0$ minutes).

TABLE II. Dataset statistical characteristics

Statistic	*Time between VEWFD and ION response (VEWFD - ION), in minutes*		
	LS	*CC*	*SS*
Mean	*2.1*	*-10.9*	*3.1*
Std. Dev.	*9.9*	*7.0*	*9.7*
Maximum	*-31.8*	*-29.3*	*-16.4*
95^{th} %ile	*-12.8*	*-24.4*	*-12.4*
Median	*3.7*	*-9.7*	*6.0*
5^{th} %ile	*16.8*	*-1.8*	*16.4*
Minimum	*21.5*	*4.6*	*20.1*
Count	*114*	*89*	*73*

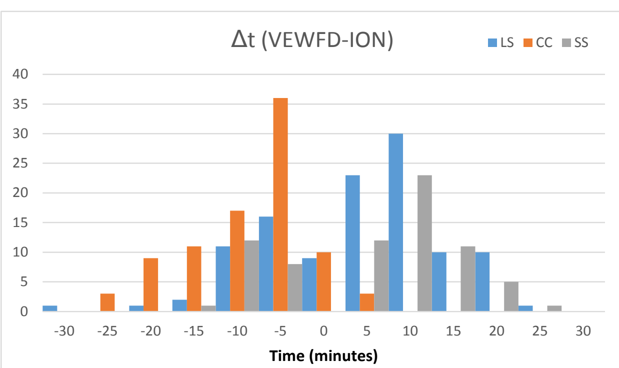


Figure 2. Histogram of Datasets

To support the statistical simulation, the CC detector response was modeled as a normal distribution with a mean of -11 minutes and a standard deviation of 7 minutes. The two light-scattering datasets were both modeled as two normal distributions. The $\Delta t=0$ minute was assumed as the dissemination point between the data to develop each normal distribution. Table III presents the parameters used for each of the bi-modal distribution, along with a weighting factor based on the fraction of data used to develop each distribution.

TABLE III. Bi-modal normal distribution parameters

Distribution	Parameter	LS	SS
$\Delta t<0$	Mean	-9.0	-10.5
	Std. Dev.	6.2	2.5
	Weight	0.351	0.288
$\Delta t>0$	Mean	8.2	8.6
	Std. Dev.	5.2	4.8
	Weight	0.649	0.712

II.C Fire Development Timeline for Simulation

The time line assumed for the simulation is presented in Figure 3. The electrical component fire source is assumed to start degrading at t_0, develop into a fire and, if unsuppressed continues until the component which the circuit supports fails due to circuit damage at t_f. The difference between t_f and t_0 represents the theoretical maximum time that would be available for suppression if the fire source was detected instantaneously at its start. For ION "detection," the time available for suppression is $t_f - t_i$.[dddd] For VEWFD "detection" occurring, the time available for suppression is presumably lengthened (although not necessarily, since the ION "detection" sometimes precedes that by the VEWFD detector) to $t_f - t_v$, an increase in the "available" time by an additional $t_f - t_v - (t_f - t_i) = t_i - t_v = \Delta t$.

II.D Defining the Simulation Parameters of Interest

[dddd] The assumed 5-minute warning time for the ION detector from Appendix P of ERPI 1011989 is not explicitly included here. If it was, that would imply $T_f - T_i \geq 5$ min. Given the time line can span as much as 70.5 minutes; this 5-min

Based on current models for estimating the non-suppression probability, ION "detection" can be modeled as:

$NSP_i = 1/\exp(\lambda_e[t_f - t_i])$

and VEWFD detection as,

$NSP_v = 1/\exp(\lambda_e[t_f - t_v])$.

The decrease in NSP for VEWFD versus ION "detection" is:

$$NSP_v/NSP_i = \exp(\lambda_e[t_f - t_i])/\exp(\lambda_e[t_f - t_v]]) = \exp(\lambda_e[t_f - t_i - t_f + t_v]) = \exp(\lambda_e[t_v - t_i]) = 1/\exp(\lambda_e \Delta t).$$

The factor by which the non-suppression probability decreases is the inverse, or $\exp(\lambda_e \Delta t)$. It is this non-suppression probability reduction factor which is simulated.

The simulation assumes there is a theoretical maximum time available for suppression, i.e., $\max(t_f - t_0)$. Since the non-suppression probability for electrical fires has a minimum (floor) value of 0.001 and λ_e = 0.098/minute[11], $\max(t_f - t_0) = (\ln[1/0.001])/0.098$ = 70.5 minutes. Therefore, this imposes an upper limit on the time interval assumed for simulation, since any additional time available as a result of VEWFD preceding ION detection (or vice-versa) could not exceed this. However, as indicated by the distributional analyses, the maximum mean additional time that would be available is ~11 minutes for CC preceding ION detection. With a standard deviation of ~7 minutes, any time interval more than roughly three standard deviations above the mean would rarely be covered by this additional time. This suggests limiting the maximum time interval for simulation to approximately 11 + 3(7) = 32 minutes. Therefore, the maximum time interval simulated is 30 minutes, as longer intervals (up to the theoretical maximum of 70.5 minutes) should yield very similar results.

Three simulations are performed for each VEWFD vs. ION detection case, with limiting time intervals of 5, 15 and 30 minutes. As per the distributional analyses, these additional times (Δt) are assumed to be normally distributed. For LS and SS, which are characterized by a weighted summation of two normal distributions, the simulation selects randomly and independently from each distribution, then performs the weighted summation to yield the net Δt, and from this the reduction factor in NSP. The weights are those given previously with the distributions, 0.351 and 0.649 for LS; 0.288 and 0.712 for SS. The simulation for CC is simply that for the one distribution characterizing its corresponding Δt.

For λ_e, statistical results indicate a nearly symmetric distribution, with a mean of 0.098/minute, median of 0.097/minute, and two-sided 90% confidence limits of 0.086/minute and 0.110/minute. Thus, it seems reasonable to assume this is also normally distributed with a mean of 0.098/minute and standard deviation of 0.012/1.645 = 0.0073/minute.

The simulations are performed using the CrystalBall® software that interfaces with Microsoft Excel®.[12] Each simulation employs 1,000 trials. The results for the reduction factors for the nine simulations are shown in the Table IV. The accompanying composite Figure 3 shows the simulation results for the reduction factors for the three 15-minute time interval cases.

II.E Evaluation of the Results

For both LS and SS for all three time limits the results are comparable, with reduction factors < 1 (indicating that they provide less rather than more time for suppression) up through their mean values, which are ~ 0.8-0.9. Only at the upper percentiles do these indicate that additional suppression time would become available vs. ION. This is consistent with the results from Section II.B. These trends are evident from Figure 4 as well.

For CC, the reduction factor ranges, on average from ~1.6 to 3.7 as one proceeds from the 5- to 30-minute time limit. This increase makes sense since the longer time limits produce less truncation of the available time in the simulations. Clearly, there is an advantage for CC vs. LS/SS (see Figure 4), with this advantage increasing as the time limit increases. CC with a 30-minute time interval shows a reduction factor that averages around 3.7 with two-sided, 90% confidence limits of 1.0 and 9.0. At 15 minutes, these are reduced to 2.9, 0.9 and 4.8, respectively.[eeee]

increment would negligibly affect the results of the simulation.

[eeee] Recall the caution in the footnote to Section II.A regarding calibration for cloud chamber vs. light-scattering ASDs when interpreting these results.

II.F Considerations for Application of These Results

The evaluation of smoke detection performance presented in this paper focuses exclusively on the in-cabinet application where the detection system is sampling from or located in the electrical enclosure (hazard) that is being protected. It also assumed “full addressability,” in that the precise enclosure where the detector has alerted is readily known to the staff responding to the alarm (i.e., there is no “time penalty” involved with either the ION or VEWFD detectors in locating the enclosure). The evaluation does not characterize the reliability, availability, and effectiveness of the smoke detection systems evaluated. This paper does not characterize the nature of the incipient stage. That is, fires caused by failures on demand or failures during change of state of electrical components are not evaluated. For these types of rapid failures, VEWFD provides essentially no advanced warning compared to ION spot-type detection.

The use and quantification of any smoke detection system in fire PRA assumes that the systems are tested, designed, installed, and maintained in accordance with recognized standards and the manufacturers’ instructions or recommendations. With the exception of the CC, the VEWFD systems evaluated in this paper were configured to meet the NFPA 76 sensitivity and transport time requirements. The CC was not directly configurable to the units of percent per foot obscuration and as such vendor recommendations were followed which resulted in a nominal port sensitivity of 1.0E+06 particles per cm^3.

III. CONCLUSIONS

These test results indicate a wide variance of system performance for the materials and the modes of degradation tested to evaluate smoke detection system response to the “incipient stage” of potentially threatening fire conditions. Smoke detection systems configured as VEWFD responded both sooner and later than ION spot-type smoke detectors used for in-cabinet applications. The amount of advanced warning is dependent on the materials involved, mode of degradation or combustion, environmental conditions within the protected enclosure and the detection technology used.

Stochastic simulations based on empirical data, an exponential model for the non-suppression probability, and operating experience suppression rate estimates have shown that light-scattering based VEWFD configured at a 0.2% obsc./ft. at the sampling port may provide, on average, a 0.8-0.9 reduction factor in the non-suppression probability, which is actually an increase in probability. The cloud chamber VEWFD system configured at 1.0E+06 particles per cm^3 at the sampling port may provide, on average, as much as a 3.7 reduction factor in non-suppression probability.

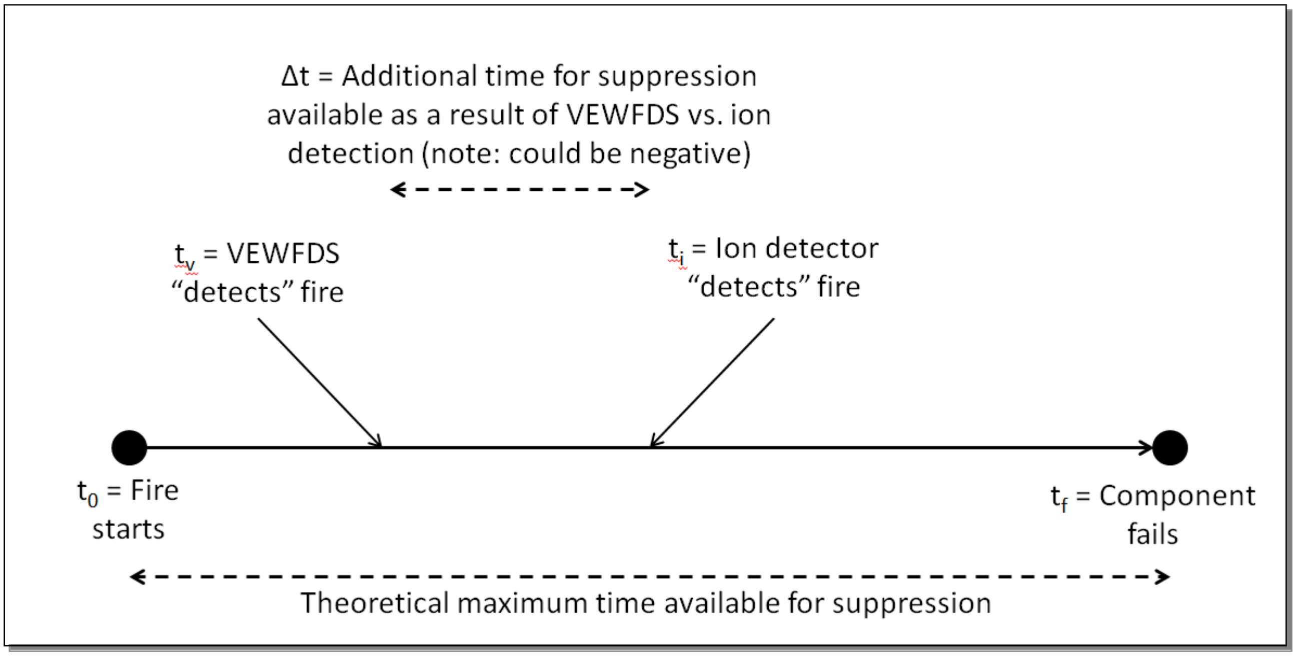
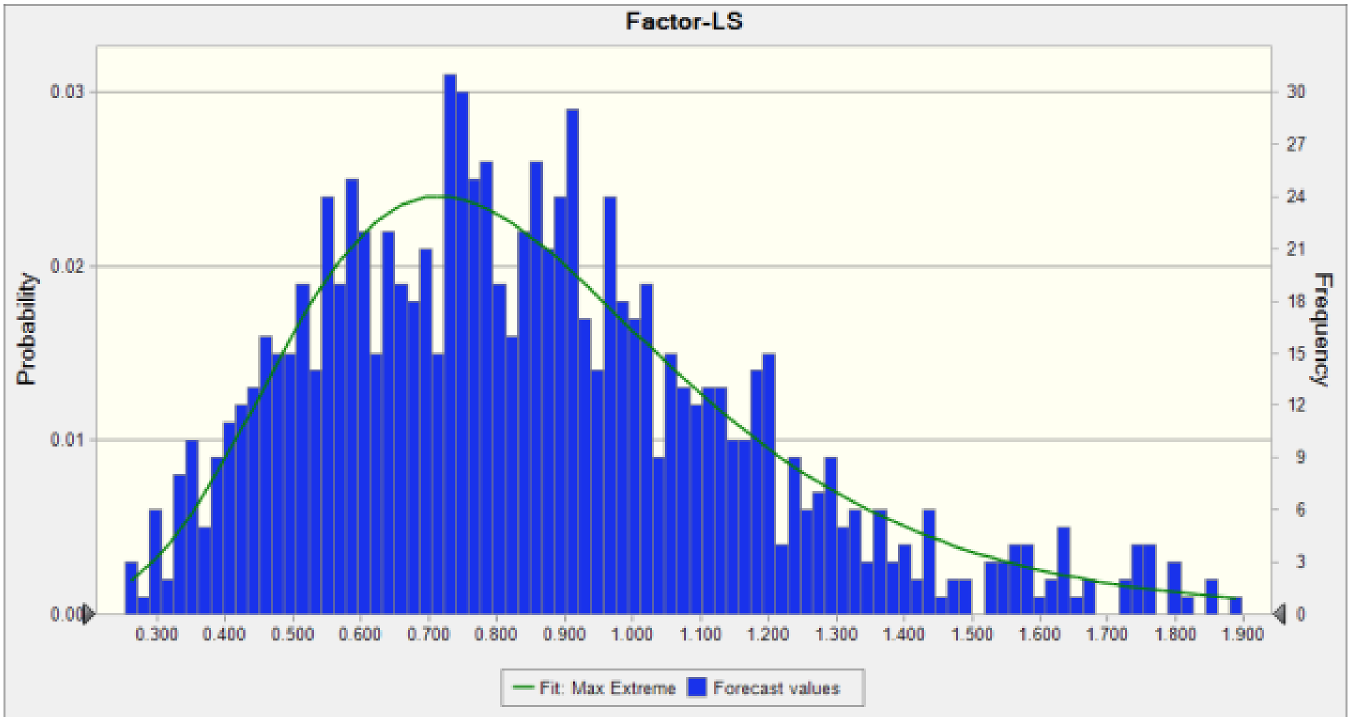


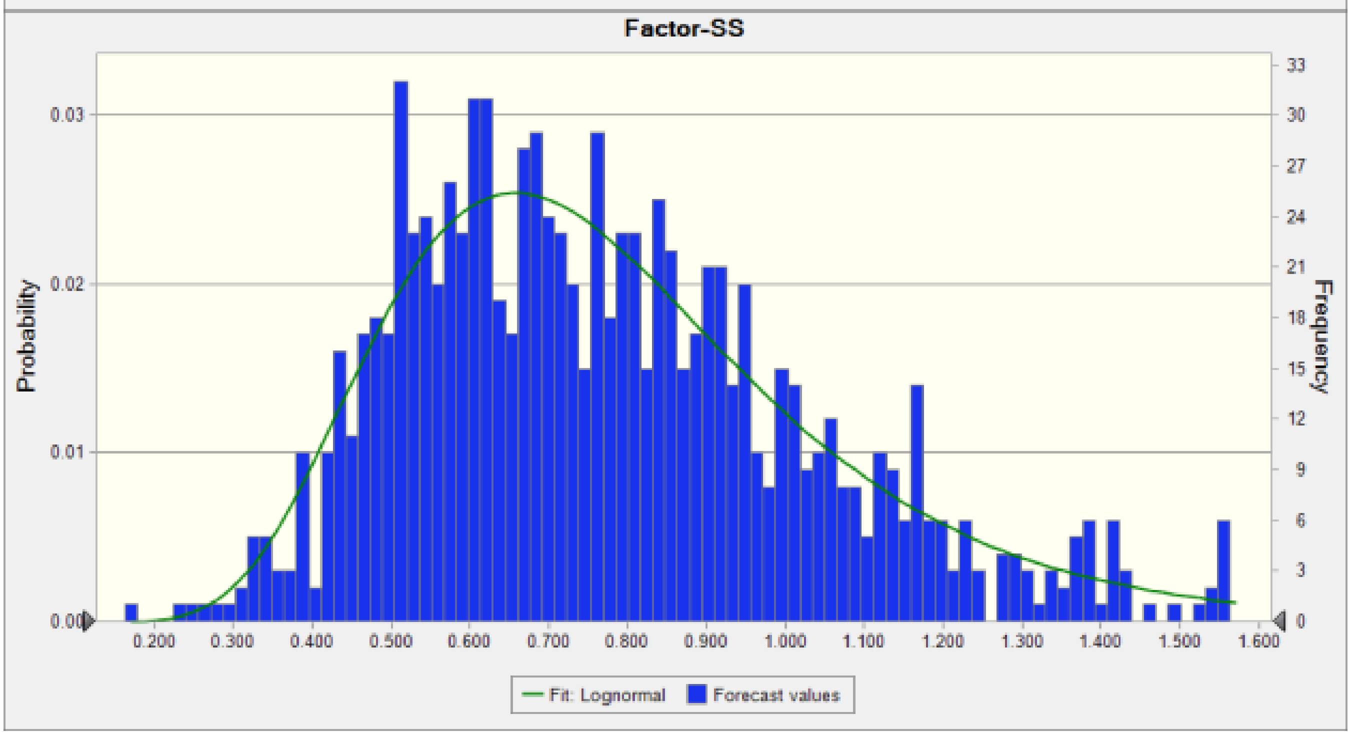
Figure 3. Timeline for simulation

TABLE IV. Simulation Results for reduction factors in non-suppression probability

Time Limit	*VEWFDS*	*Statistics*[84]						
		Minimum	*5th %ile*	*Median*	*Mean*	*95th %ile*	*Maximum*	*Std Dev*
5 min	*LS*	*0.229*	*0.421*	*0.829*	*0.871*	*1.528*	*1.759*	*0.323*
	SS	*0.252*	*0.412*	*0.724*	*0.771*	*1.265*	*1.770*	*0.273*
	CC	*0.260*	*1.056*	*1.613*	*1.553*	*1.722*	*1.816*	*0.213*
15 min	*LS*	*0.252*	*0.405*	*0.825*	*0.877*	*1.590*	*2.391*	*0.364*
	SS	*0.163*	*0.433*	*0.744*	*0.789*	*1.340*	*2.253*	*0.282*
	CC	*0.301*	*0.899*	*2.852*	*2.899*	*4.824*	*5.548*	*1.285*
30 min	*LS*	*0.157*	*0.407*	*0.816*	*0.880*	*1.588*	*2.815*	*0.376*
	SS	*0.233*	*0.423*	*0.732*	*0.779*	*1.290*	*2.403*	*0.283*
	CC	*0.292*	*0.977*	*2.841*	*3.654*	*9.031*	*32.521*	*3.199*

84 Reduction factors <1 (excluding the standard deviation) indicate that VEWFDS detection occurs after that for ion detection, and there is no reduction, but rather an increase in non-suppression probability. Such are evident only up through the mean statistics for LS and SS.


Factor-LS
Probability
Frequency
0.03
0.02
0.01
0.00
30
27
24
21
18
15
12
9
6
3
0
0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000 1.100 1.200 1.300 1.400 1.500 1.600 1.700 1.800 1.900
Fit: Max Extreme
Forecast values


Factor-SS
Probability
Frequency
0.03
0.02
0.01
0.00
33
30
27
24
21
18
15
12
9
6
3
0
0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000 1.100 1.200 1.300 1.400 1.500 1.600
Fit: Lognormal
Forecast values

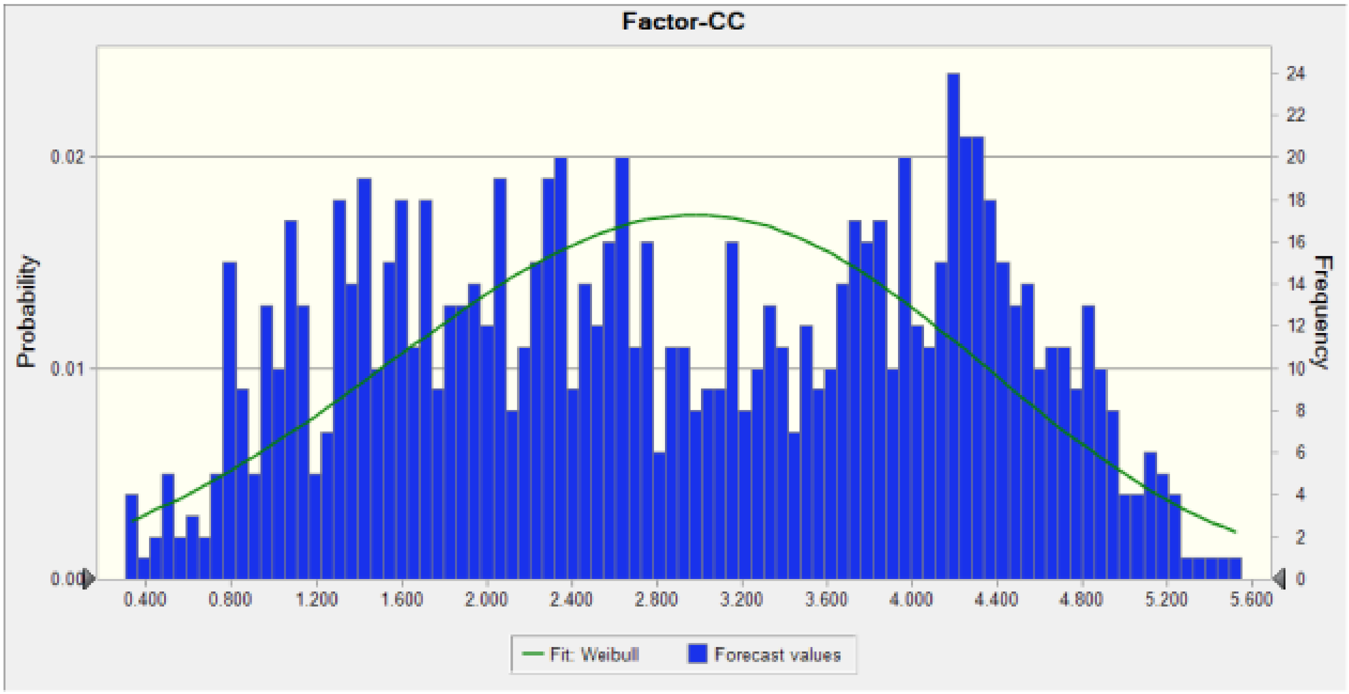


Figure 4. Simulation Results for reduction factors for 15 minute interval
(First = Light-Scattering based ASD, Second = Light-Scattering Sensitive Spot, Third = Cloud Chamber ASD)

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ATTACHMENT 4

In the process of developing FAQ 08-0046, an error (whether typographical or technical is unknown) was made when converting the detailed event tree on page 4 to the simplified version on page 8. The simplification was made by assuming that $\delta = 1$, i.e., the technician was always successful in preventing the fire during the incipient stage. This should have effectively eliminated the topmost branch of the detailed event tree, the only one resulting in no fire, leaving the remaining six where there was always fire damage, at least within the cabinet. However, when this branch was discarded, the label for "no fire" was erroneously retained for the new topmost branch, which now actually was one of the three where fire damage occurred only within the cabinet (not to targets outside). Compounding this was the mislabeling of the next branch as one where fire damage was limited within the cabinet instead of fire damage within and beyond the cabinet. The net result was that, when the default values were assigned to the various branch probabilities, one would estimate a probability of no fire damage = 0.979, that for fire damage only to the cabinet as 0.021 and fire damage to the cabinet and beyond as 2.0E-5. In reality, there was always fire damage within the cabinet (probability = 1), with the probability of that damage extending beyond the cabinet as 0.001. Therefore, there would be an under-estimate by a factor of 1/0.021 ≈ 50 that fire damage at least within the cabinet occurred would result if the simplified event tree was used. Likewise, there would be a similar under-estimate by a factor of 0.001/2.0E-5 ≈ 50 that fire damage occurred both within the cabinet and beyond.

This potential for under-estimate is shown in the event trees below and further demonstrated on the fourth and sixth slides of the attached RES presentation (CDF = 1.77E-5/y without VEWFDS in cabinet vs. CDF = 3.54E-7/y with VEWFDS in cabinet, but incorrectly credited as reducing an auxiliary analysis sown in Attachment 5 is reproduced here, but now with the under-estimate by a factor of 50 instead of 10.

> *Appendix I to Attachment 5 demonstrates that the contribution from electrical cabinet fires to fire risk (measured in terms of core damage frequency) typically ranges from six to 60 percent. Since these VEWFDSs are credited to protect against fires in electrical cabinets, the risk reduction credit applies directly to the risk arising from these fires. If the risk reduction credit is reduced by 50, the total fire risk would increase by a factor from 3.94 to 30.4, as shown:*
>
> > *For the minimum (6%) case: CDF (w/o credit from FAQ 08-0046) = (50)(0.06) + (1 – 0.06) = 3.94, i.e., 294% higher than CDF (with credit from FAQ 08-0046)*
> >
> > *For the maximum (60%) case: CDF (w/o credit from FAQ 08-0046) = (50)(0.6) + (1 – 0.6) = 30.4, i.e., 2,940% higher than CDF (with credit from FAQ 08-0046)*
>
> *These can easily be scaled by relaxing the assumption that all the electrical cabinet fire scenarios were reduced by FAQ 08-0046. E.g., if only half in each case:*
>
> > *6% case: CDF = (50)(0.06/2) + (1 – 0.06/2) = 2.47 (147% increase)*
> >
> > *60% case: CDF = (50)(0.6/2) + (1 – 0.6/2) = 15.7 (1,470% increase)*
>
> *The effects on the changes in risk, i.e., the risk increases from NFPA-805 transition/implementation relative to the "idealized, compliant" plant, are the same. These are potentially significant increases in both the "delta-" and "total" risks which could have precluded transitions under NFPA 805 without physical or procedural modifications, or more detailed fire risk analysis*

employing fire phenomenological modeling, conveniently avoidable due to this potentially significant under-estimation.[85]

85 *For example, if a plant transitioned with a small risk (CDF) increase ("delta-risk"), say 1E-6/y, but a medium total risk (CDF), say 7E-5/y, both of which were acceptable under RG 1.174 as lying in Region II/III in its Figure 4, the change under the full 60% case would result in a delta-risk now at 3E-5/y and total risk at 2E-3/y, pushing it into Region I. Similarly, if a plant transitioned with a medium delta-risk, say 4E-6/y, but a small total risk, say 1E-5/y, both of which were acceptable under RG 1.174 as lying in Region II, the change under the full 60% case would result in a delta-risk now at 1E-4/y and total risk now at 3E-4/y, pushing it into Region I.*

FAQ Applied Erroneously

λ	β	γ	ε	end
1	0.99	0.99	0.999	9.79E-01
			0.001	9.80E-04
		0.01	0.999	9.89E-03
			0.001	9.90E-06
	0.01		0.999	9.99E-03
			0.001	1.00E-05
			SUMS	2.09E-02
				1.99E-05
				1.00E+00

The green branch corresponds to no fire damage (0.979). The three orange branches represent the fire damage being limited only to the cabinet (0.021). The two red branches represent the fire damaging not only the cabinet, but spreading outside to potentially damage other targets (2.0E-5).

FAQ Applied Correctly

λ	β	γ	ε	end
1	0.99	0.99	0.999	9.79E-01
			0.001	9.80E-04
		0.01	0.999	9.89E-03
			0.001	9.90E-06
	0.01		0.999	9.99E-03
			0.001	1.00E-05
			SUMS	9.99E-01
				1.00E-03
				1.00E+00

The three orange branches represent the fire damage being limited only to the cabinet (0.999). The three red branches represent the fire damaging not only the cabinet, but spreading outside to potentially damage other targets (0.001).

VEWFD PRA Quantification

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Fire Risk Quantification

- Fire Scenario Risk Equation

$$\mathbf{CDF_i} = \lambda_{SF} \times P_{ns} \times CCDP$$

  - λ_{SF} : Scenario frequency of fire event
  - P_{ns} : Probability of non-suppression
  - CCDP : Conditional Core Damage Probability

- Installing VEWFD systems increases the probability the fire is extinguished by lowering the term P_{ns} (i.e., reduced risk)

Parameter Value Selection

- The following parameter values show the impact VEWFD systems have on plant risk, CDF
  - λ_{SF} of 3.00E-05
    - A fire ignition scenario frequency (λ_{SF}) of 3.00E-05 is selected which represents a sample plant with 1000 electrical enclosures, which is typical. The base frequency of 3.00E-2 is provided in NUREG-2169/EPRI 3002002936; Updated Fire Events Database
  - CCDP of 5.90E-01
    - The conditional core damage probability (CCDP) was selected based on the average top 20 electrical enclosure scenarios which employ VEWFD systems in a real plant

Base Risk

No In Cabinet VEWFD system

λ_{SF} x $\mathbf{P_{ns}}$ x CCDP= CDF

- 3.00E-05 x 1.0 x 5.90E-01

CDF= 1.77E-05

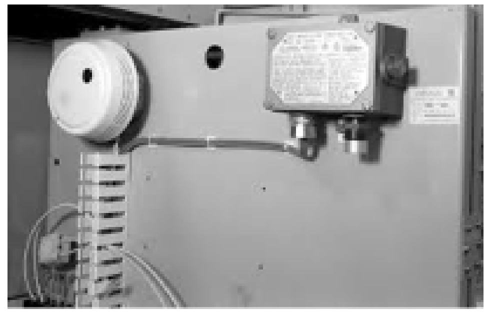
NUREG/CR-6850

In-Cabinet Detection

5 Minutes of additional time for detection prior to ignition

λ_{SF} x $\mathbf{P_{ns}}$ x CCDP= CDF

- 3.00E-05 x 0.27 x 5.90E-01



CDF= 4.75E-06

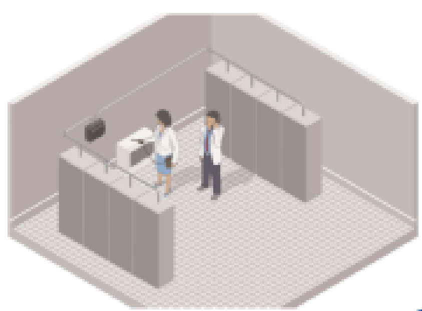
Using FAQ 08-0046

Factor of 50 for in cabinet VEWFD System

λ_{SF} x $\mathbf{P_{ns}}$ x CCDP= CDF

- 3.00E-05 x 0.02 x 5.90E-01

CDF= 3.54E-07



U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Using NUREG-2180 Information

Factor dependent on fire modeling and fire damage determination

Assumed

10 min damage time

In-cabinet VEWFD system

λ_{SF} x P_{ns} x CCDP= CDF

- 3.00E-05 x 0.14 x 5.90E-01

CDF= 2.48E-06

CDF VEWFD Credit Impact

METHODOLOGY	CDF	Delta CDF (Factor of credit)
Baseline Risk No VEWFD System	1.77E-05	1
NUREG/CR-6850 Methodology 5 Minutes of additional time	4.75E-06	3.7
Supplement 1 NUREG/CR-6850 FAQ 08-0046 In Cabinet VEWFD System	3.54E-07	50
NUREG-2180 In Cabinet VEWFD System	2.48E-06	7

November 23, 2009

MEMORANDUM TO: AFPB File

FROM: Alexander R. Klein, Chief */RA/*
Fire Protection Branch
Division of Risk Assessment
Office of Nuclear Reactor Regulation

SUBJECT: CLOSURE OF NATIONAL FIRE PROTECTION ASSOCIATION 805 FREQUENTLY ASKED QUESTION 08-0046 INCIPIENT FIRE DETECTION SYSTEMS

The purpose of this memorandum is to close National Fire Protection Association (NFPA) Standard 805 Frequently Asked Question (FAQ) 08-0046. The enclosed position was previously sent for comment under the joint U. S. Nuclear Regulatory Commission's (NRC) Office of Nuclear Regulatory Research (RES) / Electric Power Research Institute Memorandum of Understanding process. It was later sent to the Nuclear Energy Institute's NFPA 805 Task Force for industry and other stakeholder comment. The comments that were received are available in Agencywide Documents Access and Management System (ADAMS) at accession numbers ML091970034 and ML092120077. The NRC's Office of Nuclear Reactor Regulation's (NRR) resolution of the comments is documented in ADAMS at accession number ML093220197. The enclosed position represents a joint resolution of this FAQ between RES and NRR.

Enclosure:
As Stated

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Charles Moulton, NRR/DRA
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ADAMS Accession No.: ML093220426 *via email

OFFICE	NRR/DRA/AFPB	NRR/DRA/AFPB	RES/DRA/FRB	NRR/DRA/APLA
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DATE	11/ 19 /09	11/ 19 /09	11/23 /09	11/ 18 /09

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FAQ 08-0046: Incipient Fire Detection Systems

Guidance for Modeling Non-Suppression Probability When an Incipient Fire Detection System is Installed to Monitor Electrical Cabinets

Purpose:

The purpose of this interim position is to provide the current staff position for determining the probability of non-suppression in fire areas that have installed incipient fire detection systems.

Background:

FAQ 08-0046 was proposed by the Nuclear Energy Institute (NEI), through its National Fire Protection Association (NFPA) 805 Task Force, to seek additional guidance on modeling the use of incipient fire detection systems in Fire probabilistic risk assessment (PRA) applications. The authors believed that insufficient guidance existed on modeling these systems in NUREG/CR-6850 (EPRI 1011989), "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities." Initial development of the additional guidance was performed under the Memorandum of Understanding (MOU) between the Electric Power Research Institute (EPRI) and Office of Nuclear Regulatory Research (RES). These efforts were not concluded prior to EPRI publication of EPRI 1016735, "Fire PRA Methods Enhancements: Additions, Clarifications, and Refinements to EPRI 1011989," in December 2008.

Incipient Fire Detection Systems have been used extensively in the telecommunications industry to minimize fire damage and limit interruption of service. A national consensus standard has been developed, NFPA 76, "Fire Protection of Telecommunications Facilities" to address fire events in these high value facilities. NFPA 76 classifies incipient fire detection systems as Very Early Warning Fire Detection Systems (VEWFDS): Systems that detect low-energy fires before the fire conditions threaten telecommunications service.

In telecommunications service, VEWFDS have proven to be very effective in detecting fires in the incipient stage that originated in electrical and electronic cabinets and low voltage electrical circuits (cable runs, junction boxes, termination cabinets, etc). In fact, NFPA 76 essentially requires VEWFDS use in high value areas such as Main Distribution Frame Equipment and other signal processing areas.

In order to achieve closure of this FAQ in a timely manner, the NRC has developed an interim position, as discussed below. This position was developed based on the staff's understanding of the VEWFDS detection equipment as well as how electrical and electronic equipment in nuclear power plants fail and should not be seen as prejudicing the NRC's view of future developments in this area. Final endorsement of this position will be addressed through the next revision of either Regulatory Guide 1.205 or NUREG/CR-6850.

Applicability

This interim position applies to Aspirating Smoke Detectors (ASD) installed as Very Early Warning Fire Detectors as defined by NFPA 76, (2009 version) installed to monitor incipient degradation in electrical cabinets as discussed below. The position is based on the information on ASD VEWFDS available to the NRC staff. NFPA 76 requires that in order for a fire detection system to be considered a VEWFDS, it must meet two sensitivity criteria: It must be set up to provide Alert thresholds of at least 0.2 percent per foot obscuration (effective sensitivity at each

port) and Alarm thresholds of at least 1 percent per foot of obscuration (effective sensitivity at each port). Licensees are free to propose the use of other technologies that meet these sensitivity requirements, but additional information/justification will be required.

Spot type detectors installed to meet the requirements of NFPA 72 may have been described as being capable of detecting fires in the incipient stage. In many cases the description of fire detection systems in licensee's design and licensing basis documentation claims that the detection system can detect fires in the incipient stage. While this my be true to some extent, in order to obtain the credit described in this interim position, the detection system must be capable of meeting the more stringent requirements described in NFPA 76.

Discussion:

The current state of the art with respect to fire detection systems includes very highly sensitive detection systems designed to sense very slowly progressing degradation of electrical components before the flaming stage of fire occurs (incipient stage). There are numerous types of electrical components that exhibit this type of failure mode, many of which are used extensively in commercial nuclear power plants. Most low voltage (~250 volts or less) electric and electronic components will degrade over a long period of time, with observable telltales that can be sensed by these sensitive detection systems.

Examples of these include terminal strips, cables, inter-panel wiring, electro-mechanical relays, transformers, switches, power supplies, amplifiers, bistables, controllers, manual-automatic control stations, indicators, gauges, and computers. In fact, a very high percentage of the electrical and electronic components inside cabinets in nuclear plants would be expected to exhibit this type of degradation.

Industry Proposal:

EPRI has developed a methodology to credit VEWFDS in Fire PRA quantification. EPRI Technical Report 1016735, "Fire PRA Methods Enhancements, Additions, Clarifications and Refinements to 1011989" includes a discussion on crediting VEWFDS in Chapter 3, "Crediting Incipient Fire Detection Systems in FPRA Quantification." There is also information on incipient fire detection systems in Appendix C, "Supplement for Crediting Incipient fire Detection in FPRA Quantification."

The EPRI report provides a good general overview of the concept of VEWFDS fire detection, as well as a good description of the types of fires that exhibit gradual degradation that is detectable using VEWFDS.

The EPRI report proposes to apply this methodology to all electrical/electronic components with a voltage of equal to or less than 250VDC or 480VAC.

The EPRI report also proposes to apply this methodology to various rotating equipment categories. Due to the variety of failure mechanisms related to mechanical/rotating equipment, the staff does not feel that application of the full risk reduction factors being considered for VEWFDS are appropriate for these components. Licensees that wish to credit risk reduction (beyond defense-in-depth) for VEWFDS that monitor rotating equipment must provide justification in the NFPA 805 License Amendment Request. The staff will consider each on a case-by-case basis.

The EPRI approach utilizes an event tree to model the factors that could impact the effectiveness of the VEWFDS in preventing/mitigating a postulated event. The event tree provided by EPRI includes split fractions for: 1) the percentage of components that would be covered by VEWFDS, 2) the reliability/availability of the VEWFDS and 3) the percentage of time the pre-emptive actions of the first responders are successful.

The NRC staff has reviewed the EPRI approach and the NRC interim staff position represents changes to that approach.

NRC Interim Staff Position:

While the approach proposed by EPRI in 1016735 provides a high level approach to modeling a VEWFDS, there are several other issues that should be addressed and conditions applied to improve accuracy/realism.

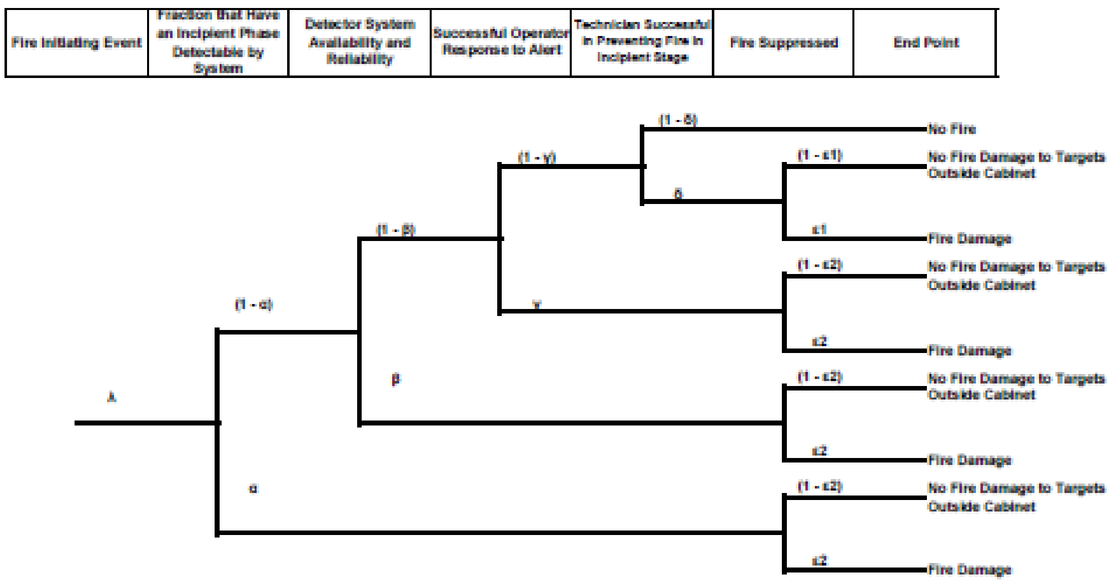
The first relates to the population of components that would exhibit incipient degradation. An additional factor should be added to the event tree to address the fact that a given electrical cabinet may have some percentage of components that may fail quickly and therefore not allow credit for incipient detection. Examples include electrical/electronic circuit boards that contain electrolytic capacitors, chart recorder drives, cooling fan motors, mechanical timers driven by electric motors, etc.

The second relates to the rate of component degradation. The failure mechanisms that provide indication in the incipient phase may occur over extended time periods. This time period has a direct correlation to the effectiveness of the process since a longer degradation time would imply that the time period between detection of the degrading condition and a transition to a flaming fire would be longer, resulting in a higher probability of success that a fire will be prevented or, if not prevented, mitigated. However, although there is significant operating experience with VEWFDS, there is limited useful data documenting the duration of the incipient degradation time. As a result of the limited data, there is uncertainty related to the incipient degradation time. This uncertainty should be factored into the assessment of VEWFDS effectiveness.

The third relates to the response to a VEWFDS alert/alarm. Since the proposed approach uses human intervention as the primary means of mitigating an impending fire, a factor should be inserted that allows this important part of the process to be accurately modeled.
In order to prevent a fire, the response activity must also include actions to remove power from the failing component/subcomponent. As the event tree is currently constructed in the EPRI report, the actions to respond to the location and find the component/subcomponent have been addressed (essentially the "Operator Response"). The skill set needed to accomplish this is similar to that for responding to any other fire: the skill set corresponding to that of an operator or trained fire brigade member. However, once the component/subcomponent has been located and identified, another skill set will be required. This task (call it the "Technician Response") requires someone knowledgeable in electrical/electronic circuits that can locate and read the appropriate drawings to determine how to remove power from the degrading device. In many cases, this activity is not a trivial exercise. It may involve researching numerous drawings (elementary, connection, interconnection, etc.) to properly locate the appropriate fuse, circuit breaker or switch. In some cases, the required isolation device may not be in the same cabinet, row, or possibly even in the same room.

If the actions to locate the device and remove power are not taken at an early stage, the effectiveness of the incipient process to prevent a fire is reduced. Note that this factor can be influenced by the rate of component degradation. If the degradation process occurs over a long time period, and is detected early in the process, the available time to prevent/mitigate a potential fire is much greater, allowing a higher probability of success.

Based on these considerations the following event tree is proposed for more accurately assessing the risk of fire assuming that a VEWFDS is installed. There is limited data from which the various factors can be derived. The EPRI report has cited a small number of tests that demonstrate the sensitivity of VEWFDS. The tests, however, do not address the duration or probability of the incipient degradation process that is a key factor in the true benefit of these systems. The NRC approach to dealing with this lack of data is addressed in the following.



Discussion of Branches of NRC Event Tree:

At this time, this interim staff position, and the corresponding event tree, only applies to the installation of VEWFDS installed to monitor incipient fire conditions inside low voltage (less than or equal to 250V) electrical cabinets. The branch points of the event tree are discussed in turn below. Each branch includes conditions that should be in place to obtain the credit listed.

Fraction that Has an Incipient Phase Detectable by System: For VEWFDS monitoring equipment inside electrical cabinets with a voltage of 250V or less, α, the factor for that percentage of components that do not exhibit incipient degradation may be set to 0.

- To take credit for this value, only low voltage (less than or equal to 250V) electrical cabinets may be included. In order to set this number to 0, the analyst must verify that the cabinet does not contain fast acting components (such as electrical/electronic circuit boards that contain electrolytic capacitors, chart recorder drives, cooling fan motors, mechanical timers driven by electric motors, etc.) This

assumption should be confirmed by inspection of the cabinet and adjusted if necessary based on the results of the inspection if there are components that would be fast acting. If fast acting components are present, the event tree should include the branches addressing the Fraction that Has an Incipient Phase Detectable by System (α). For instance, if a cabinet contains 25 relays that would not be fast acting, along with a cooling fan and a motor-operated timer relay, the licensee could ratio the number of fast acting components (2) to the total number in the cabinet (27) and come up with a value for α ($\alpha = 2/27 = 0.074$).

- Where aspirated VEWFDS systems are used, the characteristics of the cabinet to be monitored must allow the use of an aspirated VEWFDS (aspirated systems would not function properly in a tightly sealed cabinet).

- In addition, in contrast to the EPRI position, 480 V AC cabinets and rotating equipment are also excluded. If licensees desire to credit VEWFDS on components with fast acting, higher voltage systems or components, or rotating equipment, additional factors should be included to address their higher probability of not exhibiting incipient behavior.

Detection System Availability and Reliability: Success for this branch in the event tree means that the VEWFDS has issued an alert. β, the failure probability for this branch can be determined using the process provided by EPRI in 1016735 or set equal to 1E-02.

- The licensee should justify that their system is sufficiently similar to the systems evaluated in EPRI 101673 when using this value for reliability. For example, EPRI 101673 primarily has information on cloud chamber and laser aspirating detector systems. The use of other technologies should be justified to use the proposed value above.

- The system should be designed and installed by trained and qualified technicians to NFPA 76 following appropriate vendor guidance, tested in accordance with an appropriate standard including appropriate vendor requirements, and maintained in accordance with manufacturers and code requirements.

- The system should pass the full vendor's acceptance test, associated sensitivity testing, including any extended period of commissioning prior to being placed in service.

- In addition to the regular functional testing required by NFPA 76 and any required preventive maintenance required by the vendor, the system should be tested and maintained in accordance with NFPA 72 and all vendor requirements (calibrated as required by the manufacturer).

- Most VEWFDS have the capability to provide two or more alarm levels. Alarms that are set to occur prior to the flaming stage are typically referred to as "Alerts" and alarms that are set to occur when the device has entered the flaming or true fire stage are called "Alarms." VEWFDS alert and alarm levels should be controlled through the licensee's setpoint control program. Calibrations, such as re-baselining the alert and alarm levels that reduce the sensitivity of the system should be evaluated to assure that the early detection function of the system is not compromised. Reductions in sensitivity should be considered in the fire PRA as a reduction in the system's effectiveness.

- Testing and calibrations should be documented; Documentation should be maintained for the life of the plant.

Successful Operator Responses to Alert: Success of this event implies that plant personnel have identified the cabinet which contains the source of the alert and have staged appropriately trained personnel (qualified fire watch as is used for hot work or a "Flash Watch") at that location who are prepared to initiate fire suppression if an actual fire (e.g., open flaming) were to break out. γ reflects the likelihood that plant personnel fail to respond to an alert signal in a timely manner (i.e., prior to outbreak of open flaming within the source). γ, the probability of failure of the operator/fire brigade to respond to the alert and find the component can be determined based on a Human Reliability Analysis (HRA) or conservatively set to 1E-02 if the VEWFDS is addressable to multiple cabinets or 5E-03 if the VEWFDS is addressable to an individual cabinet. The lower value recognizes that the cabinet affected is known and does not require additional investigation by the responders to identify the affected cabinet.

- The recommended value assumes that the VEWFDS provides at least one hour of warning prior to the actual outbreak of an open flaming fire. This value is considered conservative for an annunciator response when there is nothing else going on – since the alert occurs prior to any damage, it can be assumed there is no fire and no transient at this time.

- This number assumes that the operator response procedure directs the area and/or cabinet (if the VEWFDS is addressable to individual cabinets) to be investigated upon an alert from the VEWFDS.

- This number assumes that procedures would be in place to require establishment upon the annunciation of an alert of a qualified continuous "Flash Watch" (similar to that used to monitor hot work) until the potential for fire has been removed or until there has been a formal, documented evaluation of the event. (Note: One acceptable means of meeting this qualification requirement is to provide training in accordance with the requirements in NFPA 1081, "Standard for Industrial Fire Brigade Member Professional Qualifications," Section 5.2.1 "Manual Fire Suppression")

- Effective methods must be established for locating the source of the incipient detection (portable VEWFDS, thermography, etc.) and the associated equipment must be dedicated for use, maintained in an operable condition, available on site at all times and appropriately staged to be rapidly accessed by first responders when needed.

- First responders are properly trained to respond to the incipient condition, identify the faulted cabinet, and suppress potential fires. Personnel using portable equipment to locate incipient degradation must be trained in its use, including on-the-job training such that they are familiar with the equipment, procedures for its use and any limitations and/or precautions required. Also, adequate procedures exist, and the response process has been included within the scope of the fire brigade training and periodic drill process.

Technician Successful in Preventing Fire in Incipient Stage: To simplify the analysis, δ, the factor for the probability of failure to remove power from the device once it has been located, is set to 1. This is done because of the difficulty in assessing the likelihood of successful prevention.

This approach is taking credit for the fire watch only, as a surrogate for prevention. To be

effective, the licensee must commit to procedures that require an appropriately trained fire watch in place until the problem has been resolved. Success in this approach is ultimately judged based on the ability to control the fire rather than suppress it. So long as the fire is prevented from growing significantly, the adverse consequences related to a large cabinet fire, and the associated fire growth due to secondary combustibles are prevented. This is conservative, since in reality there would not be a fire contribution at all if the fire was prevented. In the case of fire prevention, the only impact on plant operation would be the unavailability of the component(s) in the cabinet for the duration of the repair.

If a licensee desires to obtain more credit in this process, the more detailed NRC event tree may be used, including the branches with δ (with adequate and appropriate justification in the form of a detailed Human Reliability Analysis). One way a licensee could achieve significant fire prevention credit would be to "pre-locate" the isolation devices for all ignition sources within each cabinet in an effort to speed up the process. If such an effort was taken, additional credit for preventing fires could be allowed. This would need to include predetermining the isolation devices, conveniently displaying that information for use in response to VEWFDS alert, training responders so that they could rapidly locate and operate the isolation device(s), and drills to periodically demonstrate this ability.

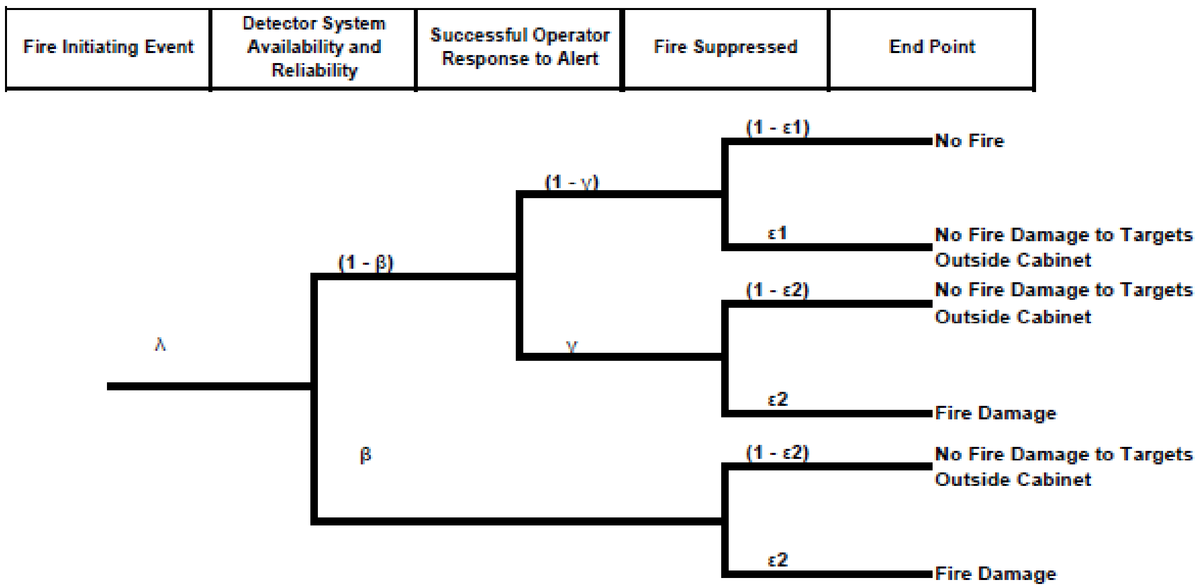
Fire Suppressed: There are two cases for this branch point.

Success in the event following success in successful operator response to alert or alarm is that the "Flash Watch" stationed at the cabinet has successfully controlled the fire before it affects the target. ε_1 represents the probability that, given success of event γ, the personnel staged at the cabinet responsible for the VEWFDS alert fails to promptly suppress the fire (i.e., quickly enough to prevent damage to PRA targets outside the cabinet) once open flaming does break out. $\varepsilon 1$, the probability of "enhanced" non-suppression may be set to 1E-03. This is considered to be reasonable given the nature of the response required by a trained responder who is stationed at the location with the correct equipment.

Success for the branches following failure in the successful operator response or detector unavailability is prevention of damage to the targets by the fire brigade. $\varepsilon 2$, the probability of "normal" non-suppression should be taken from the Detection Suppression Event Tree in NUREG/CR-6850, Appendix P using the electrical fire suppression curve for manual suppression as appropriate. Credit should be given as described in Appendix P for automatic detection and suppression (normal spot detectors and automatic suppression in the area) as well as delayed manual detection, manual actuation of fixed suppression and manual suppression via the fire brigade.

With the above simplifications, the event tree simplifies to the following:

The top branch below should read "No fire damage to targets outside cabinet." The second branch should read "Fire damage." Therefore, there is ABSOLUTELY NO BRANCH where fire damage to the cabinet does NOT occur, i.e., the probability of fire damage to the cabinet is the same as the fire initiating event.



Other General Considerations

Note that the staff plans to document the licensee commitments associated with the VEWFDS design, installation, testing, compensatory measures and procedures for responding to the VEWFDS alert/alarms in each licensee's license amendment request and reviewed and approved in the associated NRC Safety Evaluation, as applicable.

Licensees that employ VEWFDS and model them in their Fire PRA models that do not use the proposed values provided in this position should justify the various split fractions used in the plant-specific application and provide a characterization of the uncertainty on each of the split fractions and perform a sensitivity analysis to demonstrate robustness of the proposed position on acceptability of the plant change. The licensee should describe the operator response in sufficient detail for the NRC staff to understand how the Human Error Probability (HEP) was determined. Regardless of how VEWFDS are modeled, licensees should provide a description of alarm response procedures, troubleshooting methods, and training of operators, maintenance personnel, fire watch standers, and fire brigade members.

Based on the possible significant risk reduction being credited for VEWFDS installation, licensees should include in their fire protection program appropriate compensatory measures to address the unavailability/inoperability of the VEWFDS. These compensatory measures should be controlled through the use of a licensee-controlled process such as a Technical Requirements Manual or other defined process used to address fire protection program impairments that will ensure that the compensatory measures will be carried out. For licensees that plan to install VEWFDS as part of the NFPA 805 transition, the process for defining and controlling the compensatory measures should be described in the NFPA 805 License

Amendment Request. Unless compensatory measures are evaluated to be equivalent to VEWFDS, such as continuous hot work type fire watch or use of a portable VEWFDS, an extended period of unavailability/inoperability may have a significant impact on overall plant fire risk. For example, an out of service period of four days would decrease the effectiveness of the system by an order of magnitude, based on the assumed availability factor. Even a day of unavailability would reduce effectiveness by a factor of about 3.

Two additional factors in a performance-based approach are the implementation of the NFPA 805 monitoring program and the fire PRA maintenance and update process. The staff expects licensees that implement VEWFDS to monitor the availability, reliability and effectiveness of the VEWFDS so that, over time, more accurate and representative data may be used in the risk model. As required by NFPA 805, licensees are expected to set availability, reliability and effectiveness targets and to take appropriate corrective actions when system performance does not meet the targets. Licensees are also expected to maintain their risk analysis current with the latest information. This includes consideration of new information from nuclear industry operating experience and external sources such as industry testing, research, data from other industries (such as the telecommunications industry), etc. While implementing the fire PRA maintenance and update process, if operating experience indicates that VEWFDS availability, reliability and effectiveness are not as high as currently modeled in the fire PRA, actions must be taken to update the analysis to reflect the new information.

Licensees are cautioned that while the installation of VEWFDS to monitor critical control cabinets may significantly decrease fire risk and positively impact several of the fire protection defense-in-depth attributes (preventing fires from occurring and rapidly detecting and suppressing those fires that do occur), consideration of defense-in-depth is a requirement of NFPA 805. Licensees are still required to demonstrate the ability to achieve the nuclear safety performance criteria assuming that a challenging fire impacts safe shutdown equipment. Depending upon the other defense-in-depth attributes for a given fire area, recovery actions and/or physical plant modifications may still be required to demonstrate the ability to meet the nuclear safety performance criteria.

Deviations from the information provided in this position should be justified and, prior to credit in NRC regulatory activities, should be submitted to the NRC for review and approval.

References:

1. Revision 0 to FAQ 08-0046, March 31, 2008, Accession No. ML081200120

2. NRC Draft Interim Position on FAQ 08-0046, Accession No. ML091750338

3. Resolution of stakeholder comments on the NRC Draft Interim Position, Accession No. ML093220197

4. EPRI 1016735, Fire PRA Methods Enhancements, December 2008, Accession No. ML090290195

5. NEI 04-02, Guidance for Implementing a Risk-Informed, Performance-Based Fire Protection Program Under 10 CFR 50.48(c), Revision 1, Accession No. ML052590476

6. NFPA 805, Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants, 2001 Edition (available through the Public Document Room or NFPA)

ATTACHMENT 5

Appendix I to this Attachment demonstrates that the contribution from electrical cabinet fires to fire risk (measured in terms of core damage frequency) typically ranges from six to 60 percent. Since these VEWFDSs are credited to protect against fires in electrical cabinets, the risk reduction credit applies directly to the risk arising from these fires. If the risk reduction credit is reduced by an order of magnitude, the total fire risk would increase by a factor from 1.27 to 6.40, as shown:

For the minimum (6%) case: CDF (w/o credit from FAQ 08-0046) = (10)(0.06) + (1 – 0.06) = 1.54, i.e., 54% higher than CDF (with credit from FAQ 08-0046)

For the maximum (60%) case: CDF (w/o credit from FAQ 08-0046) = (10)(0.6) + (1 – 0.6) = 6.40, i.e., 540% higher than CDF (with credit from FAQ 08-0046)

These can easily be scaled by relaxing the assumption that all the electrical cabinet fire scenarios were reduced by FAQ 08-0046. E.g., if only half in each case:

6% case: CDF = (10)(0.06/2) + (1 – 0.06/2) = 1.27 (27% increase)

60% case: CDF = (10)(0.6/2) + (1 – 0.6/2) = 3.70 (270% increase)

The effects on the changes in risk, i.e., the risk increases from NFPA-805 transition/implementation relative to the "idealized, compliant" plant, are the same. These are potentially significant increases in both the "delta-" and "total" risks which could have precluded transitions under NFPA 805 without physical or procedural modifications, or more detailed fire risk analysis employing fire phenomenological modeling, conveniently avoidable due to this potentially significant under-estimation.[86] Wherever FAQ 08-0046 was employed, any licensing actions dependent to some extent on the results of a fire PRA remain subject to this potentially gross distortion of the fire risk.

APPENDIX I – Contribution of Electrical Cabinet Fires to Risk

In December 2010, NEI presented a "Roadmap for Attaining Realism in Fire PRAs" to the ACRS as part of a session reviewing Fire PRA and transitions to NFPA-805. This presentation stirred much controversy among the NRC staff as it used early, in some cases screening-level, results from the first wave of NFPA-805 applicants to emphasize what the industry considered an undue emphasis on electrical cabinet fires (allegedly due to over-conservatisms from NUREG/CR-6850). Counter-points were presented by the staff, emphasizing the preliminary nature of these results and the fact that applicants were choosing NOT to perform more detailed fire phenomenological modeling to attain their desired "realism," but defaulting to screening/scoping values offered in NUREG/CR-6850 as a starting point. Realism was attainable with more detailed fire phenomenological modeling, but industry preferred to propose new methods to adjust risk estimates based on fire events data and yet unreviewed analyses.

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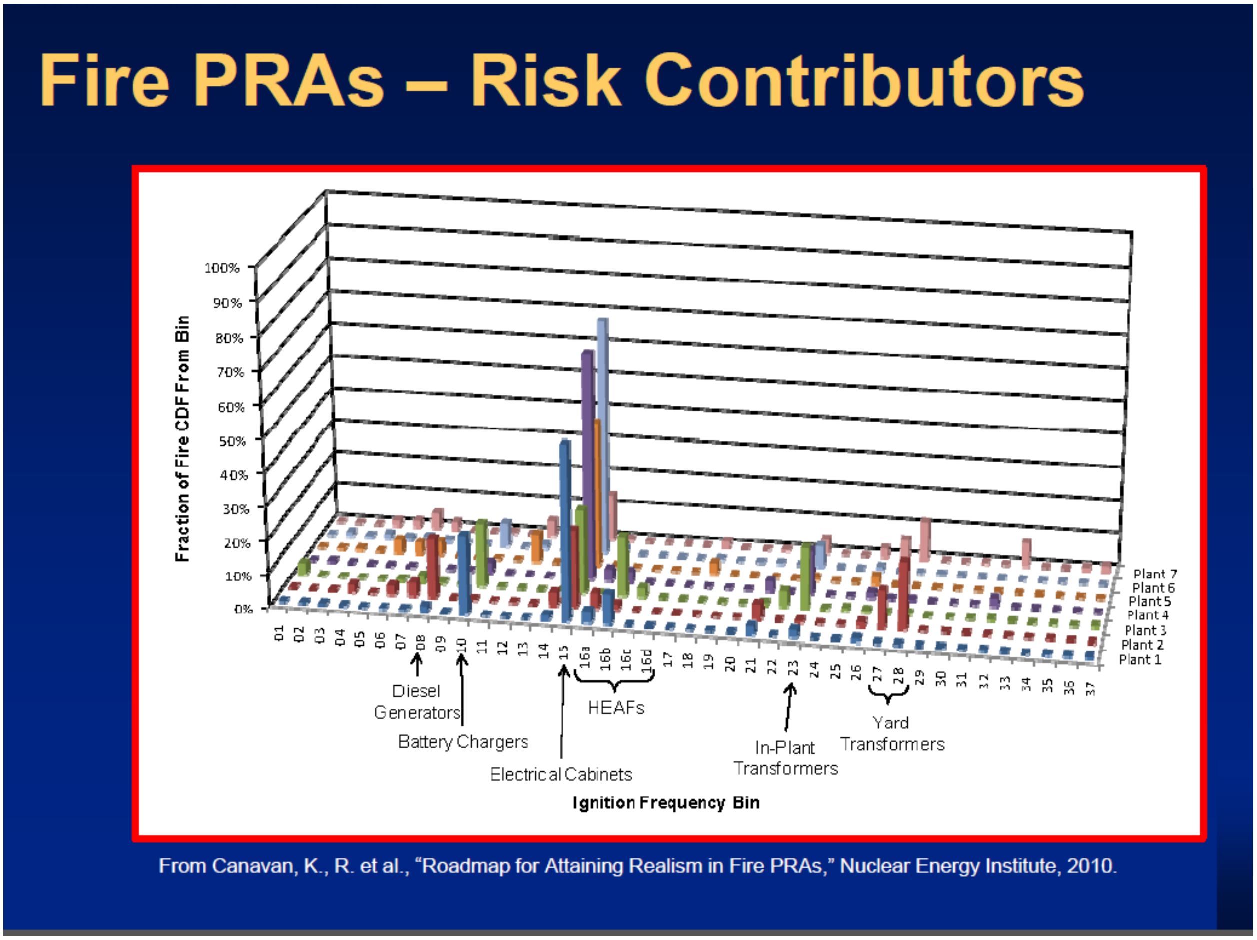
[86] For example, if a plant transitioned with a small risk (CDF) increase ("delta-risk"), say 1E-6/y, but a medium total risk (CDF), say 7E-5/y, both of which were acceptable under RG 1.174 as lying in Region II/III in its Figure 4, the change under the full 60% case would result in a delta-risk now at 7E-6/y and total risk at 5E-4/y, pushing it into Region I. Similarly, if a plant transitioned with a medium delta-risk, say 4E-6/y, but a small total risk, say 1E-5/y, both of which were acceptable under RG 1.174 as lying in Region II, the change under the full 60% case would result in a delta-risk now at 3E-5/y and total risk now at 7E-5/y, pushing it into Region I.

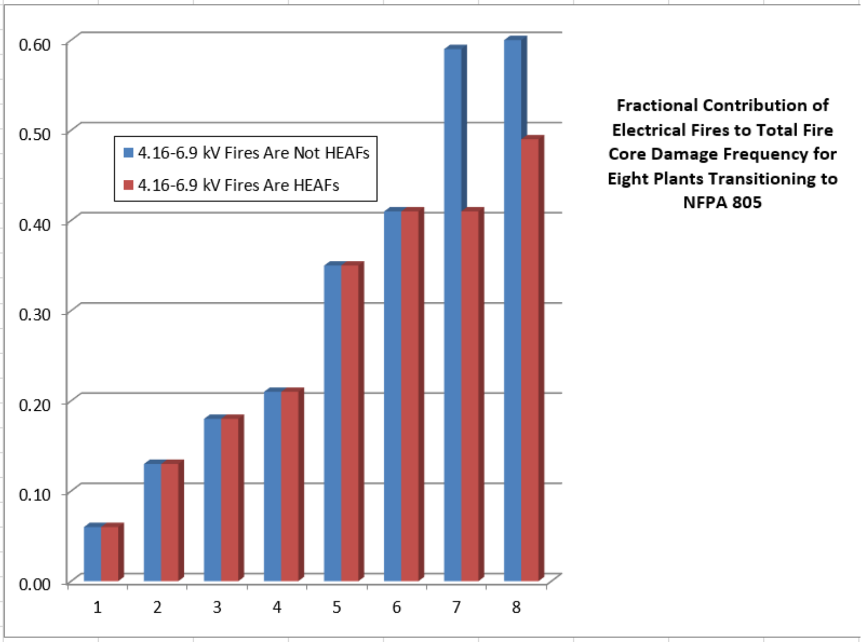
The figure below was especially controversial as it emphasized this alleged undue dominance of electrical cabinet fires due to fire PRA over-conservatism. This figure has been used in presentations, including by NRC staff, to emphasize that electrical cabinet fires can be dominant contributors to fire risk. While there is no argument that this is true, use of the figure gives the impression that such fires are nearly always the dominant risk contributors, which is not true. Subsequent review of eight NFPA-805 applications completed or well along in the review process indicated that the contributions from such fires spanned a range, from ~6 to 60% to the total fire core damage frequency.[87]



The following figure plots these results, still conveying the message that electrical cabinet fires CAN be important, but not creating the impression that they are nearly always so. This is especially true now in light of the revised fire ignition frequencies where Main Control Board fires are six times more likely than shown by the EPRI "Roadmap" as presented in 2010. Use of this updated figure should be preferred to that for the outdated EPRI figure when conveying this message.

87 These estimates were based on the descriptions of the dominant fire scenarios in Attachment W of the NFPA-805 LARs. These scenarios were reviewed and, based on the descriptions, the contribution to the core damage frequency of all the dominant scenarios from those attributable to fire damage from electrical cabinets was calculated. This fractional contribution to core damage frequency was assumed to be representative for the total.

4.16-6.9 kV Fires Are <u>Not</u> HEAFs	4.16-6.9 kV Fires Are HEAFs
0.06	0.06
0.13	0.13
0.18	0.18
0.21	0.21
0.35	0.35
0.41	0.41
0.59	0.41
0.60	0.49
Mean	Mean
0.32	0.28
Std Dev	Std Dev
0.21	0.16



(There are two sets of data because, for two plants it was unclear whether or not they treated 4.16-6.9 kV fires as HEAFs, so the contributions could vary for those two.)

NRC FORM 757 NRC MD 10.158 (02-2016)	U. S. NUCLEAR REGULATORY COMMISSION	NCP TRACKING NUMBER
	NON-CONCURRENCE PROCESS	NCP 2016-017

SECTION B - TO BE COMPLETED BY NON-CONCURRING EMPLOYEE'S SUPERVISOR

TITLE OF SUBJECT DOCUMENT	ADAMS ACCESSION NO.
Response to July 28, 2016 Letter Regarding Retirement of NFPA-805 FAQ 08-0046	

NAME
Stacey Rosenberg

TITLE	TELEPHONE NUMBER
Chief, PRA Licensing	(301) 415-2357

ORGANIZATION
DRA/NRR

COMMENTS FOR THE NCP REVIEWER TO CONSIDER (use continuation pages or attach Word document)

Branch staff assigned to assist with review and response to non-concurrence. No additional comments for reviewer(s).

SIGNATURE	DATE
Stacey Rosenberg	11/10/2016

NRC FORM 757
NRC MD 10.158
(02-2016)

U. S. NUCLEAR REGULATORY COMMISSION

NON-CONCURRENCE PROCESS

NCP TRACKING NUMBER: NCP-2016-017

SECTION C - TO BE COMPLETED BY NCP COORDINATOR

TITLE OF SUBJECT DOCUMENT	ADAMS ACCESSION NO.
Response to July 28, 2016 Letter Regarding Retirement of NFPA-805 FAQ 08-0046	

NAME
Greg Casto

TITLE	TELEPHONE NUMBER
Chief, Fire Protection Branch,	(301) 415-0565

ORGANIZATION
AFPB/DRA/NRR

AGREED UPON SUMMARY OF ISSUES (use continuation pages or attach Word document)

Summary of issues were provided to staff member issuing non-concurrence, with his reply on those issues provided on November 8, 2016, by email. Upon review, the NCP Coordinator determined that issues were understood and discussed in the attached reply to non-concurrence.

EVALUATION OF NON-CONCURRENCE AND RATIONALE FOR DECISION (use continuation pages or attach Word document)

The evaluation response is attached.

TYPED NAME OF NCP COORDINATOR	TITLE
Greg Casto	Chief, Fire Protection

ORGANIZATION
DRA/NRR

SIGNATURE--NCP COORDINATOR	DATE
[signature]	NOV 9 16

TYPED NAME OF NCP APPROVER	TITLE
Joseph Giitter	Director, Division of Risk Assessment

ORGANIZATION
NRR

SIGNATURE--NCP APPROVER	DATE
[signature]	11/16/16

SUMMARY OF ISSUES
Non-concurrence NCP 2016-017

The issues raised in the non-concurrence NCP 2016-017 were reviewed, and the following was identified by the NCP Coordinator items to be addressed in the non-concurrence:

1) NUREG-2180 endorsement by NRR as a viable replacement to FAQ 08-0046:

   "Originally this non-concurrence was planned solely for endorsing N U REG-21 80 as a viable replacement to FAQ 08-0046 on Very Early Warning Fi re Detection Systems (VEWFDSs). The crux of that non-concurrence remains and is developed completely in the attached..." NUREG-2180 develops a "new" electrical fire curve that assumes a responder is poised and ready when an electrical cabinet fire starts. For this, the mean time to suppress is 5.2 minutes. This somewhat approximates what one might expect when a continuous fire watch, complete with suppression means at hand, is established. In fact, this is comparable to the pre-NUREG-2169 non-suppression curve for welding fires where a continuous fire watch is established, although not with the current NUREG-2169 version, where the mean time to suppress is now 9.3 minutes. Of course, this still suffers from the overly optimistic assumption that the responder remains in place indefinitely but, if one were to accept this non-conservatism, at least seems a reasonable extension as opposed to using the MCR curve. My objections regarding the non-suppression aspect are mainly philosophical and curiously, do not always impact the results. This in itself is troubling in that the benefit of VEWFDS is touted in NUREG-2180 as enabling "enhanced suppression." Therefore one would expect the choice of non-suppression curve to be highly significant to the results.

2) The staff's expectation for FAQ 08-0046 to remain part of a licensee's current licensing basis:

   "N RC's EXPECTATION i n FAQ 08-0046" and "For these licensees ... becomes available" as became evident during the latter phases in a current draft letter to NEI regarding FAQ 08-0046 contained a potentially significant error that likely has allowed plants that have already transitioned successfully to N FPA-805 under 50.48(c), and have the FAQ as an integral part of their new fire protection program licensing basis, to have been approved despite failing to have met the risk metric criteria in RG 1 .174, which is the governing document for transition..." The letter's use of EXPECTAT I ON and allowance of "FAQ 08-0046 [to] remain part of the current licensing basis ... becomes available" is inadequate given this potential. It must be enhanced to be a REQU I R EM ENT that precludes the use of the FAQ for any subsequent risk-i nformed applications, including exercising self-approval under N FPA-805 itself for those plants with the FAQ as part of their new licensing basis.

In reviewing the non-concurrence items with the NCP initiator, the following was received:

NUREG-2180 has TWO major flaws – the use of the MCR non-suppression curve AND the overly-optimistic crediting of human response, both of which contribute to maximizing the credit attributable to VEWFDS in an effort to recover as much as possible of the lost credit from FAQ 08-0046. Via multiple, independent analyses I have shown that the credit for these systems is no more than a factor of 5, and that includes the pre-emption of the fire, which the NUREG does

not. With its current factor of 9 reduction for non-suppression alone, the NUREG will easily allow the nuclear industry to recover most, if not all, of the lost credit from the FAQ once pre-emption is added to the mix. The FAQ, flawed from the start compared to the "stolen" version based on actual experimental results (my Attachment 1) rather than the subjectivity used to generate it (ignoring the experimental results from my original), was further flawed by the error described in Attachment 4. Note that the original FAQ (Att. 1) was "stolen" and given to the SLS's, etc., so as to allow Harris to receive the ridiculous factor of 50 credit to enable their NFPA-805 transition, a technically-flawed but politically-expedient maneuver to expedite NFPA-805. If the NUREG is endorsed as is, we will essentially have replaced the flawed FAQ with an equivalent version that, on the surface, appears to have much more technical "meat" behind it, but in reality still remains flawed due to its non-conservative carry-overs from the rescinded FAQ.

This response was considered and addressed in Section C.

Non-Concurrence Process Documentation

NCP-2016-017; Section C (Document Sponsor)

Background

In 2008, FAQ 08-0046, "Incipient Fire Detection Systems," was proposed by the Nuclear Energy Institute (NEI) National Fire Protection Association (NFPA) 805 Task Force to describe the treatment of very early warning fire detection systems (VEWFDSs) in a fire probabilistic risk assessment (PRA), because NUREG/CR-6850, Appendix P "Appendix for Chapter 11, Detection and Suppression Analysis," provides limited guidance for the evaluation of fire detection performance during the incipient stage of a fire.

In 2009, the NRC issued the FAQ 08-0046 closure memorandum (ADAMS Accession No. ML093220426) which provides interim guidance to licensees on how to credit VEWFDSs, applying only to use of VEWFDS configured for very early warning fire detection to protect electrical enclosures containing low-voltage control components found in nuclear power plants. The interim guidance was based on vendor expectation and consensus standard performance objectives. A lack of applicable data was apparent.

In 2010, a user need request was transmitted from the Office of Nuclear Reactor Regulation (NRR) requesting confirmatory research in order to advance the state of knowledge regarding the performance and assessment of VEWFDS in nuclear power plants. To improve accuracy and realism, and in an effort to better understand and quantify the effect of incipient-fire detection systems in fire PRA, the NRC Office of Nuclear Regulatory Research (RES) conducted a confirmatory research program to obtain a better understanding of VEWFDS performance and operating experience. RES pursued the development of draft NUREG-2180, "Determining the Effectiveness, Limitations, and Operator Response for Very Early Warning Fire Detection Systems in Nuclear Facilities (DELORES-VEWFIRE). NUREG-2180 provides the advance knowledge and approaches for evaluating VEWFD systems, human response, and operating experience related to detecting fires during the incipient stage in nuclear power plant installations.

RES has completed technical guidance on VEWFDS in NUREG-2180. NRR has reviewed the document and determined that it contains information that may be used by licensees to develop the effect that the installation of certain types of VEWFDS have on reducing the risk associated with fire in nuclear power plant electrical enclosures. Further, the methodology presented in NUREG-2180, along with applicable test data and operating experience will allow for better quantification of risk benefits from the use of VEWFDS.

The research has shown that the treatment of VEWFDS as described in FAQ 08-0046 could not be confirmed, based on research, industry operating experience, and information provided by industry as part of technical analysis developed for NUREG-2180. On July 1, 2016, the NRC issued a letter to the Nuclear Energy Institute informing them of the retirement of FAQ 08-0046 effective July 29, 2016, (ADAMS Accession No. ML16167A444) stating that in light of the improved state of knowledge gained from the development of NUREG-2180, the NRC retired FAQ 08-0046. The staff decision to retire FAQ 08-0046 was because the staff recognized during the development of NUREG-2180 that some assumptions used in the FAQ were not able to be confirmed. Accordingly, its continued use could cause licensees that are considering future application of FAQ 08-0046 undue difficulty in defending some of the assumptions used in the FAQ's methodology. During a September 20, 2016, public meeting (summary available at

ADAMS Accession No. ML16270A592) the staff discussed industry concerns related to the decision to retire FAQ 08-0046, including regulatory implications for licensees that have incorporated the methodology provided in FAQ 08-0046.

The issues raised in the non-concurrence NCP 2016-017 relate to the following issues:

1) NUREG-2180 endorsement by NRR as a viable replacement to FAQ 08-0046, and
2) The staff's expectation for FAQ 08-0046 to remain part of a licensee's current licensing basis

Issue #1: Specific Issue Summaries and Actions Taken

> *"Originally this non-concurrence was planned solely for endorsing N U REG-21 80 as a viable replacement to FAQ 08-0046 on Very Early Warning Fi re Detection Systems (VEWFDSs). The crux of that non-concurrence remains and is developed completely in the attached..."* NUREG-2180 develops a "new" electrical fire curve that assumes a responder is poised and ready when an electrical cabinet fire starts. For this, the mean time to suppress is 5.2 minutes. This somewhat approximates what one might expect when a continuous fire watch, complete with suppression means at hand, is established. In fact, this is comparable to the pre-NUREG-2169 non-suppression curve for welding fires where a continuous fire watch is established, although not with the current NUREG-2169 version, where the mean time to suppress is now 9.3 minutes. Of course, this still suffers from the overly optimistic assumption that the responder remains in place indefinitely but, if one were to accept this non-conservatism, at least seems a reasonable extension as opposed to using the MCR curve. My objections regarding the non-suppression aspect are mainly philosophical and curiously, do not always impact the results. This in itself is troubling in that the benefit of VEWFDS is touted in NUREG-2180 as enabling "enhanced suppression." Therefore one would expect the choice of non-suppression curve to be highly significant to the results.

Summary/Discussion

The non-concurrence argues that NUREG-2180 is not a suitable document to replace FAQ 08-0046; the non-concurrence author feels the need to disagree with NUREG-2180 for the two reasons. The first reason that the author disagrees with NUREG-2180 is because it uses the main control room (MCR) suppression curve for enhanced suppression in modeling in-cabinet detection. The non-concurrence indicates that foundation behind MCR curve is flawed for two reasons. The first position from NUREG-2180 that the non-concurrence disputes is that operators will make responding to the incipient condition a high priority, i.e. the non-concurrence indicates this is akin to dropping everything to respond to an incipient condition. The second position in the NUREG-2180 that the non-concurrence disputes is that the field engineer or operator will remain present after notification of an incipient condition until the fire initiates, and thus will be poised to fight fire upon its initiation. In essence, the non-concurrence concludes that operators will not necessarily be in the room or in the vicinity of the fire upon its initiation as they will not remain in the room after the incipient condition is indicated until the fire is identified.

In regard to this position in the NUREG-2180, the staff found during its Shearon Harris Nuclear Power Plant site visit that the licensee would treat an incipient condition with very high priority and have personnel respond immediately and remain in the location of the incipient detection until the fire is identified and suppressed. In fact, during an actual incipient event at Shearon Harris, upon receipt of an indication from their VEWFDS an operator was stationed at the site of the indication until the fire was identified and extinguished. It is the staff's understanding that licensees are implementing their procedures in the same way. Also, the staff believes that there is a high likelihood of successful suppression of a cabinet fire before damage occurs outside the cabinet if the operator has located the fire upon its initiation and is poised to fight the fire. As a result, the staff concludes that the use of the MCR suppression curve is acceptable. However, the takeaway from the non-concurrence argument is that these procedures and their implementation should be inspected during triennial fire protection inspections and staff review/audit of licensees' fire protection programs.

The second reason that the non-concurrence author disagrees with NUREG-2180 is that there is a lack of distinction in results for the area wide installation when applying the NUREG-2180 specially developed electrical curve for enhanced suppression vs. use of 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," electrical curve. To draw this conclusion, the non-concurrence author performs several sensitivity studies of the aspirating smoke detection (ASD) cloud chamber detector with respect to the suppression curves used in NUREG-2180 and various other alternate suppression curves (e.g., for electrical cabinets) for both the in-cabinet and area wide installation of VEWFDS. The in-cabinet results show a distinction due to suppression curves, contrary to the area wide sensitivity study. The non-concurrence author claims that the lack of difference in results from the sensitivity study for suppression curves for area wide detection is "troubling."

The staff did not specifically validate the calculations provided by the author, but notes that credit for suppression is a decreasing exponential curve with the exponent defined by the product of the suppression rate, defined separately for the different types of suppression bins, and the time available before fire damage. The suppression curve representing enhanced detection for area wide VEWFDS is not nearly as aggressive as for in-cabinet VEWFDS (rate = 0.194/minute for enhanced suppression in area wide vs. 0.324/minute for enhanced suppression in in-cabinet). Also the area wide system requires more time to locate the incipient condition than an in cabinet system since the in-cabinet system provides a more definitive location of the fire since it is designed to sample a smaller area. Thus, the staff expects much less sensitivity with respect to different suppression assumptions for an area wide VEWFDS installation than for an in-cabinet installation. Furthermore, the staff notes in Section A of the non-concurrence under the comparison of VEWFDS technologies that small differences in suppression occurs between in in-cabinet and area wide VEWFDS for the cloud chamber relative to conventional ceiling mounted detection. This result from the non-concurrence documentation is surprising, as an in-cabinet system is generally expected to provide more time to react to an incipient condition than an area wide VEWFDS, and suggests that the non-concurrence author's analysis requires more detailed examination. In conclusion, with respect

to this relative lack of sensitivity of area wide systems to different assumptions, the staff is not surprised at this relative lack of sensitivity.

Another concern raised by the non-concurrence is that only the cloud chamber VEWFDS system provided a bonus time in detecting the incipient condition, and the inability to calibrate the cloud chamber system to NFPA 76,"Standard for Fire Protection of Telecommunication Facilities," to enable an equal comparison to other technologies could be the reason that some other VEWFDS technologies didn't provide a benefit. The staff agrees with the non-concurrence regarding the calibration of the cloud chamber system to NFPA 76 standards during testing. In fact, NUREG-2180 on page 2-18 states that vendor recommendations should be followed regarding calibration requirements. Further, NUREG-2180 provides the corresponding parameter estimates that were used to quantify the risk from the calibration associated with the tests. Thus, the risk model is consistent with the tests. Should different VEWFDS sensitivities other than recommended in the NUREG-2180 be used, then the PRA model would need to be adjusted. The staff agrees that that any reductions in sensitivity will affect system performance, and the fire PRA quantification should be modified as a reduction in the system's effectiveness, as stated in NUREG-2180. The staff will verify during license amendment review that the VEWFDS sensitivity settings are consistent with code requirements per NFPA 76 standard, and the system sensitivity calculations are adequate and correct. Further, the regional inspection staff will verify that the installed VEWFDS testing has been completed per code or regulatory requirements.

Conclusion for Issue #1

This review finds that a number of the issues raised by the non-concurrence, as discussed in included Attachments, appear to be considered in the development of NUREG-2180. Additionally, potential inconsistencies with VEWFDS modeling are substantially decreased by a combination of established PRA modeling standards, guidance, technical reviews and inspections.

Issue #2: Specific Issue Summaries and Actions Taken

> *"NRC's EXPECTATION in FAQ 08-0046" and "For these licensees ... becomes available" as became evident during the latter phases in a current draft letter to NEI regarding FAQ 08-0046 contained a potentially significant error that likely has allowed plants that have already transitioned successfully to NFPA-805 under 50.48(c), and have the FAQ as an integral part of their new fire protection program licensing basis, to have been approved despite failing to have met the risk metric criteria in RG 1.174, which is the governing document for transition..."* The letter's use of EXPECTATION and allowance of "FAQ 08-0046 [to] remain part of the current licensing basis ... becomes available" is inadequate given this potential. It must be enhanced to be a REQUIREMENT that precludes the use of the FAQ for any subsequent risk-informed applications, including exercising self-approval under NFPA-805 itself for those plants with the FAQ as part of their new licensing basis.

Summary/Discussion

Another point made in the non-concurrence is that FAQ 08-0046 should not be established as the licensing basis for plants transitioning to NFPA 805. The non-concurrence makes the point that FAQ 08-0046 overestimates the credit for VEWFDS installed in electrical cabinets. It states that FAQ 08-0046 includes an error in labeling a few event tree end states which underestimates fire damage and thus the core damage frequency (CDF) for those sequences. An estimate of the extent of the non-conservatism is made, and concludes that the decision to allow certain plants to transition to NFPA 805 would be reversed if the FAQ was not used. The staff agrees that FAQ 08-0046 is non-conservative. In fact, the pre-publication final version of NUREG-2180 corrects these end state errors, and applies a more sophisticated PRA approach to yield less credit than the FAQ 08-0046. The staff notes that the postulated increases in risk cited in the non-concurrence Footnote #1 assume that the risk from all electrical cabinets are reduced by the FAQ 08-0046 approach, which is excessive as the FAQ 08-0046 only applies to electrical cabinets less than 250 V and each of those cabinets don't have VEWFDS. The staff has not done a separate analysis for those plants which are crediting FAQ 08-0046 in their NFPA 805 license amendment requests (LARs), but acknowledges that FAQ 08-0046 credit may be important to plants for their transition to NFPA 805 licensing basis. Since July 29, licensees with license applications in review or with future license submittals cannot use FAQ 08-0046. The staff is currently interfacing with those plants that credit FAQ 08-0046 whose NFPA 805 LAR is under review to assess the importance of the FAQ 08-0046 to their risk metrics. Plants with NFPA 805 LARs with applications crediting VEWFDS and currently undergoing the staff review will be assessed on a plant-by-plant basis, and have had to demonstrate that they have appropriate levels of credit using other AHJ approved guidance other than FAQ 08-0046. The staff has engaged with all applicable NFPA 805 licensees to discuss site specific options that allow for completion of the NFPA 805 safety evaluation. The staff is in the process of requesting additional information to assess their risk relative to the guidelines in RG 1.174, Revision 2 (ADAMS Accession No. ML100910006).

Despite this non-conservatism present in FAQ 08-0046, the staff feels that the FAQ is acceptable as the licensing basis. Licensees that had NFPA 805 amendment requests approved, with VEWFDS credit applied per FAQ 08-0046, were approved by the staff in their respective safety evaluations with the credit in the FAQ representing the current Authority Having Jurisdiction (AHJ) approved credit at that time. Such credit, per risk-informed related regulatory criteria and guidance, is recognized as subject to change and as such, is subject to reevaluation and modification in that licensee's PRA model. Licensees who credited the installation of VEWFDS using the methods in FAQ 08-0046 in their NFPA 805 LARs and staff approved in safety evaluation are expected to evaluate the impact on their fire PRA in accordance with their licensing bases, e.g., license conditions and Section 1.4 of Regulatory Guide 1.200, Revision 2, and to meet the risk guidelines in Regulatory Guide 1.174, Revision 2. NFPA 805, Section 2.4.3.3, states, in part, that the fire risk evaluation approach, methods, and data shall be based on the as-built and as-operated and maintained plant.

For NFPA 805 plants with an approved safety evaluation, FAQ 08-0046 (if used) remains part of their current licensing basis until a final replacement methodology (i.e., NUREG-2180) becomes available. Once NUREG-2180 is published and is endorsed by the AHJ, licensees will consider

and incorporate the NUREG-2180 methodology consistent with their licensing bases and the PRA maintenance and upgrade process based on Regulatory Guide 1.200, Revision 2. Further, NFPA 805 plants are expected to update their risk analyses periodically with nuclear industry operating experience and new information consistent with their current licensing bases and PRA maintenance and upgrade processes outlined in the ASME/ANS PRA standard (ASME/ANS RA-Sa-2009) as endorsed in RG 1.200 Revision 2. The plant license condition provides structure and detailed criteria to allow post-transition self-approval for fire protection program changes that meet the requirements of NFPA 805 with regard to fire risk evaluations, engineering analyses, and plant change evaluations.

For licensees with approved safety evaluation credit from FAQ 08-0046, this becomes part of their NFPA-805 licensing basis until required PRA updates, (per 10 CFR 50.69 (e)). For a licensing basis to be required to be modified, the licensee's condition would need to meet backfitting criteria per 10 CFR 50.109. The non-concurrence did not specifically describe how a backfit would be justified, though it did discuss that some licensees (that credited FAQ 08-0046) may find that their PRA underestimates fire damage and thus the CDF for those sequences. Regarding backfit consideration, which would be necessary to un-approve the FAQ credit for safety evaluation approved licensees, this condition would apply to 10 CFR 50.109(a)(1)(iii) (after NRC approval). The backfit would have to represent a substantial increase in protection to public health and safety or common defense and security whose costs are justified in light of this increased protection, as related to compliance (10 CFR 50.109(a)(4)(i)), necessary for adequate protection, (50.109(a)(4)(ii)) , or by defining or redefining what is needed for adequate protection (10 CFR 50.109(a)(4)(iii)). Further, a positive backfit justification would have to provide a substantial increase in protection to public health and safety or common defense and security, as well as have the cost of the backfit justified in light of the increase in protection. Because licensees were approved by safety evaluation to use the credit in FAQ 08-0046, which represented the currently accepted VEWFDS guidance at the time of the approval, and because regulatory requirements are in place for these licensees to appropriately consider changes to PRA modeling via their maintenance and upgrade process, including changes that would impact risk informed decisions, safety is maintained and the non-concurrence position to require licensees to promptly remove credit in retired FAQ 08-0046 is not warranted.

Conclusion for Issue #2:

As discussed previously, licensees are no longer able to use FAQ 08-0046 interim guidance to VEWFDS credit. This includes licensees with submitted license amendments in review by the staff. For licensee with safety evaluation approved amendments that credited VEWFDS using the FAQ, updates will occur in accordance with required PRA update processes as described in RG 1.174 and/or RG 1.200, as applicable. Based on review for requiring safety evaluation approved licensees to modify FAQ 08-0046 credit prior to their required PRA update review, the staff does not find that regulatory position supports actions to update their PRA on a more prompt schedule, nor that the staff would find a safety basis to require that action.

Overall Results:

The staff will note the non-concurrence to the letter to NEI regarding retirement of FAQ 08-0046. Additionally, the non-concurrence package will be included publically in ADAMS with the letter.

November 17, 2016

Mr. Michael D. Tschiltz
Director, Risk Assessment
Nuclear Energy Institute
1201 F St., NW, Suite 1100
Washington, DC 20004-1218

SUBJECT: RESPONSE TO JULY 28, 2016, LETTER REGARDING RETIREMENT OF NATIONAL FIRE PROTECTION ASSOCIATION 805 FREQUENTLY ASKED QUESTION 08-0046 "INCIPIENT FIRE DETECTION SYSTEMS"

Dear Mr. Tschiltz:

The U.S. Nuclear Regulatory Commission's (NRC) Office of Nuclear Reactor Regulation (NRR) has reviewed Nuclear Energy Institute (NEI) letters dated July 28, 2016, (available in the NRC's Agencywide Documents Access and Management System (ADAMS) Accession No. ML16211A327) and October 27, 2016, (ADAMS Accession No. ML16302A293), regarding the NRC's letter dated July 1, 2016 (ADAMS Accession No. ML16167A444), stating that in light of the improved state of knowledge gained from the development of NUREG-2180, "Determining the Effectiveness, Limitations, and Operator Response for Very Early Warning Fire Detection Systems in Nuclear Facilities (DELORES-VEWFIRE)," the NRC is retiring National Fire Protection Association (NFPA) Standard 805 Frequently Asked Question (FAQ) 08-0046 "Incipient Fire Detection Systems" (closure memorandum available at ADAMS Accession No. ML093220426). The purpose of the interim position in the FAQ 08-0046 closure memorandum was to provide the current staff position for developing the probability of non-suppression in fire areas that have very early warning fire detection systems (VEWFDS) installed in certain types of electrical cabinets. The NRC Interim Staff Position was that, while the approach proposed by the Electric Power Research Institute (EPRI) in EPRI 1016735, "Fire PRA Methods Enhancements: Additions, Clarifications, and Refinements to EPRI 1011989" (December 2008) provides a high level approach to modeling VEWFDS, there are several other issues that should be addressed and conditions applied to improve accuracy/realism.

Your July 28th letter stated that the basis for FAQ 08-0046 retirement was the anticipated availability of replacement guidance, i.e., NUREG-2180, "Determining the Effectiveness, Limitations, and Operator Response for Very Early Warning Fire Detection Systems in Nuclear Facilities (DELORES-VEWFIRE)." Your letter also stated that you had identified numerous and necessary changes to NUREG-2180, and it would be premature to retire FAQ 08-0046 at this time. To clarify our actions regarding FAQ 08-0046, the staff recognized during the development of NUREG-2180 that some assumptions used in the FAQ were not able to be confirmed. Accordingly, its continued use could cause licensees that are considering future application of FAQ 08-0046 undue difficulty in defending some of the assumptions used in the FAQ's methodology.

During a September 20, 2016, public meeting (summary available at ADAMS Accession No. ML16270A592) we discussed concerns raised in your July 28, 2016, letter and our decision to retire FAQ 08-0046. We also discussed the regulatory implications for licensees that have incorporated the methodology provided in FAQ 08-0046 and what we believe represents a mutual understanding of the path forward on this issue. NRR's expectation is that future license amendment requests, fire risk evaluations supporting self-approval evaluations, or probabilistic risk assessment (PRA) maintenance and upgrades will not specifically credit the methodology provided in FAQ 08-0046.

Licensees with NFPA 805 applications crediting VEWFDS and currently undergoing NRC review will be assessed on a plant-by-plant basis. The staff has engaged with all applicable licensees to discuss site-specific options that allow for completion of the NFPA 805 safety evaluations. The NRC may request additional information in the form of a sensitivity study regarding VEWFDS credit (e.g., in-cabinet and area-wide applications). Insight from similar reviews involving changes to operating experience and licensee-specific pilot efforts or audits may also be considered in completing these reviews.

Licensees that have already received a safety evaluation (for applications crediting VEWFDS using the methodology provided in FAQ 08-0046) are expected to update their risk analyses periodically with nuclear industry operating experience and new information consistent with their current licensing bases and PRA maintenance and upgrade processes outlined in the ASME/ANS RA-Sa-2009 standard. For these licensees, the methodology provided in FAQ 08-0046 remains part of their current licensing basis until a replacement methodology becomes available. Once available, it is expected that licensees will consider and incorporate the replacement methodology consistent with their licensing bases and the PRA maintenance and upgrade process.

At this time NUREG-2180 (ADAMS Package Accession No. ML16286A001) is in the final publication process and will serve as an accepted method that supersedes the interim guidance provided in the FAQ 08-0046 closure memorandum. As discussed in a letter to you from the Office of Nuclear Regulatory Research on October 6, 2016, (ADAMS Accession No. ML16271A158), the staff concluded that based on interactions and feedback from NEI and licensees, no new information had been provided that changed the results discussed in the report and the NRC intends to issue NUREG-2180 as a final report. In addition, the FAQ 08-0046 closure memorandum included the following: "While implementing the fire Probabilistic Risk Analysis (PRA) maintenance and update process, if operating experience indicates that VEWFDS availability, reliability and effectiveness are not as high as currently modeled in the fire [probabilistic risk assessment], actions must be taken to update the analysis to reflect the new information." If a licensee is performing a periodic or interim PRA update, performing a fire risk evaluation in support of self-approval, or submitting a future risk informed license amendment request, the staff's expectation is that they will assess the impact of new operating experience and information on their PRA analyses and incorporate the change as appropriate per Regulatory Guide 1.200, Revision 2, "An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities," March 2009 (ADAMS Accession No. ML090410014).

The NRC remains committed to ensuring that plant fire PRAs reflect a high level of realism and believes that retiring FAQ 08-0046 as of July 29, 2016 serves that purpose. With regard to your comments on the current draft of NUREG-2180, including insights obtained by a tabletop pilot exercise conducted by industry members, please refer to the NRC's Office of Nuclear Regulatory Research letter dated October 6, 2016 (ADAMS Accession No. ML16271A158). If you have any questions regarding our activities in this area, please do not hesitate to contact me.

Sincerely,

/RA/

Joseph G. Giitter, Director
Division of Risk Assessment
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission

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