RISK-DEFORMED REGULATION: WHAT WENT WRONG WITH NFPA 805

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Before proceeding, and lest opponents of nuclear power think this paper lends support to their efforts to shut down the nuclear industry, I must state the following. NFPA 805 will have been successful in that plants transitioning to it will be as safe as or safer than prior to transition. Plants that made no changes will have at least assessed their fire risks and be more knowledgeable of potential weaknesses that could compromise safety. Having found none, they will not have the need for changes. Plants that made effective changes will be safer than before.[2] *If you are one who believes the end justifies the means, then this "bottom line" is all that matters and you need read no further. However, if you are one who believes the means are also important, then you are the audience that I address.*

I am in no way contending that adoption of NFPA 805 compromised safety – I, too, believe that plants will be as safe or safer as a result of the transition. Why I wrote this paper is to express frustration over the "compromises" allowed by the NRC, and the "short-cuts" and "deviations" taken by the nuclear industry, to fulfill the promise of a "sea change" in fire protection at nuclear power plants through risk-informed, performance-based regulation. And, while no diminution of safety will have occurred, it is possible there were missed opportunities to improve safety if changes might have been made, or different changes substituted for those that were made, if not for these "compromises," "short-cuts" and "deviations."

I must confess to being guilty of false optimism in December 2006 when I wrote "perhaps the single achievement most responsible for the improved regulatory environment for fire protection at commercial nuclear power plants has been the modification to 10CFR50.48 that allows licensees to 'maintain a fire protection program that complies with NFPA 805 as an alternative to complying with [past, purely deterministic regulations]'" (Gallucci, "Thirty-Three Years of Regulating Fire Protection at Commercial U.S. Nuclear Power Plants: Dousing the Flames of Controversy," Fire Technology, Vol. 45, pp. 355-380, 2009).

Introduction

I contend that National Fire Protection Association (NFPA) 805 (*Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants [2001 Edition]*) was written as a risk-informed, performance-based standard intended for use after a risk-informed, performance-based fire protection program had been established.[3] It was not specifically intended to be the mechanism by which this transition took place, although it clearly offered guidance that could be used in this regard. Adopting

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1 This paper was prepared by a former employee of the U.S. NRC. The views presented do not nor ever did represent an official NRC position, only those of the author. The author was the first to receive a PhD in nuclear engineering based on a thesis specifically related to fire PRA in power plants (Gallucci, 1980, "A Methodology for Evaluating the Probability for Fire Loss of Nuclear Power Plant Safety Functions" [Doctoral Thesis], Rensselaer Polytechnic Institute, Troy, NY; Gallucci and Hockenbury, 1981, "Fire-Induced Loss of Nuclear Power Plant Safety Functions," Nuclear Engineering and Design 64:135-147) and worked for over 35 years in nuclear risk, reliability and safety analysis under both governmental and commercial auspices. I was hired at the NRC in 2003 as the expert in fire PRA for the Office of Nuclear Reactor Regulation (NRR) and participated in the NFPA-805 program from the start of the pilot process in 2005 until, by mutual agreement with NRC management, I was "phased out" in mid-2014. The perspectives here cover that approximately nine-year time period, with some extended time specific to issues discussed in Appendices II and III that stemmed from this earlier time period.

2 The term "effective" conveys that some changes only may have "seemingly" reduced risk. If such changes were prompted by questionable risk-reduction credits such as those cited later in this paper related to two of the Frequently Asked Questions, then perhaps actual risk-reduction changes that could have been made were not. Nonetheless, the plant did not become "less safe," but just missed an opportunity to become "safer," a consequence of the problems with "risk-deformed regulation" presented in this paper.

3 There was more than just semantics to the commonly used phrase "transition to NFPA 805." The choice of preposition ("to") was significant by implying that NFPA 805 was the endpoint of the transition, not the means by which it was accomplished. If NFPA 805 had been intended as the vehicle for transition, a preposition such as "through," "via" or "under" would have been appropriate. This subtlety was never appreciated.

it as the standard for the actual transition was a choice made by the NRC through 10CFR50.48(c) and interpreted via Regulatory Guide (RG) 1.205 (*Risk-Informed, Performance-Based Fire Protection for Existing Light-Water Nuclear Power Plants [Dec. 2009, Rev. 1]*). As evidenced by the statements below, "change evaluations" for NFPA 805 were intended to apply to a plant after the risk-informed, performance based fire protection program had been established (see underlines). (Other citations are also provided for clarification and subsequent reference.)

NFPA 805. Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants (2001 Edition)

2.2(h). *Perform the plant change evaluation that demonstrates that changes in risk, defense-in-depth, and safety margins are acceptable (see 2.4.4).*

2.2.9 Plant Change Evaluation. *In the event of a change to a previously approved fire protection program element, a risk informed plant change evaluation shall be performed and the results used as described in 2.4.4 to ensure that the public risk associated with fire-induced nuclear fuel damage accidents is low and that adequate defense-in-depth and safety margins are maintained.*

2.4.3 Fire Risk Evaluations. *The PSA methods, tools, and data used to provide risk information for the performance-based evaluation of fire protection features (see 4.2.4.2) or provide risk information to the change analysis described in 2.4.4 shall conform with the requirements in 2.4.3.1 through 2.4.3.3.*

2.4.4 Plant Change Evaluation. *A plant change evaluation shall be performed to ensure that a change to a previously approved fire protection program element is acceptable. The evaluation process shall consist of an integrated assessment of the acceptability of risk, defense-in-depth, and safety margins ...*

4.2.4 Performance-Based Approach. *... When the use of recovery actions has resulted in the use of this approach, the additional risk presented by their use shall be evaluated ...*

4.2.4.2 Use of Fire Risk Evaluation. *... The evaluation process shall compare the risk associated with implementation of the deterministic requirements with the proposed alternative. The difference in risk between the two approaches shall meet the risk acceptance criteria described in 2.4.4.1 ...*

A.2.4.3. *Regarding the needs of the change analysis, this standard requires the assessment of the risk implications of any proposed change and the acceptability of these implications.*

A.2.4.4.1. *An example approach for acceptance criteria for changes in risk from a plant change can be found in Regulatory Guide 1.174, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant Specific Changes to the Licensing Basis." ...*

A.4.2.4 *... The risk for the fire area and the risk presented by the implementation of recovery actions to recover the nuclear safety function should be compared to the risk associated with maintaining the function free of fire damage in accordance with the deterministic requirements specified in Chapter 4 ...*

As interpreted by RG 1.205, the NRC created a "transitional plant change evaluation" which it termed a "fire risk evaluation" to represent this same type of post-establishment change analysis to be performed for the transition itself (see underlines). (As above, other citations are also provided for clarification and subsequent reference.)

RG 1.205. Risk-Informed, Performance-Based Fire Protection for Existing Light-Water Nuclear Power Plants (Dec. 2009, Rev. 1)

1.2 Exceptions and Clarifications (f) *...NFPA 805 states that the additional risk of recovery actions that are relied on to demonstrate the availability of a success path, as set forth in NFPA 805, Section 4.2.3.1, must be addressed using performance-based methods, as required by NFPA 805, Section 4.2.4 (see Regulatory Position 2.4).*

2.2.4 Risk Evaluations *...One type of risk assessment, the plant change evaluation, provides risk information as described in NFPA 805, Sections 2.2.9 and 2.4.4. Regulatory Position 3.2 discusses plant change evaluations, which apply to a plant that has made the transition to NFPA 805. Another type of risk assessment provides risk information on the performance-based alternatives to the deterministic approach in the fire risk evaluation, which includes, as necessary, the evaluation of the additional risk of certain recovery actions in accordance with NFPA 805, Section 4.2.4 (refer to Regulatory Position 2.4). Fire risk evaluations are used to make the transition to NFPA 805.*

2.2.4.2 Total Plant Delta Risk of Implementing NFPA 805 *... The total increase or decrease in risk associated with the implementation of NFPA 805 for the overall plant should be calculated by summing the risk increases and decreases for each fire area (including any risk increases resulting from previously approved recovery actions). The total risk increase should be consistent with the acceptance guidelines in Regulatory Guide 1.174 ...*

2.2.4.3 Baseline Risk for Plant Change Evaluations. *Upon completing the transition to an NFPA 805 licensing basis, the post transition baseline risk for use in evaluating the effect of subsequent plant changes on cumulative risk will be the risk of the plant at the point of full implementation of NFPA 805 (i.e., after completing all plant modifications and changes that the licensee has committed to make during the transition).*

3.2 NFPA 805 Plant Change Evaluation Process: 3.2.1 Definition of a Change. *NFPA 805 includes provisions for licensees to make changes to their approved FPPs [Fire Protection Programs], once the transition to a 10CFR50.48(c) license is complete. Sections 2.2.9 and 2.4.4 of NFPA 805 require a "plant change evaluation" for any change to a previously approved FPP element ...*

The Fundamental Flaw

As presented in NFPA 805, the "Fire Risk Evaluation" in Section 2.4.3 is specifically aligned with the "Plant Change Evaluation" cited in Section 2.4.4 which "shall be performed to ensure that a change to a previously approved fire protection program element is acceptable." RG 1.205 interpreted this to apply the Plant Change Evaluation process during transition, calling it a "Fire Risk Evaluation," which was "used to make the transition to NFPA 805." Ignored in this interpretation was just what would a Plant Change/Fire Risk Evaluation during transition be measured against? And why, when the Plant Change Evaluation process was clearly intended to apply after establishing a risk-informed, performance-based fire protection program, was there even a need to perform some sort of "risk comparison" to judge the "propriety" of the final configuration? One argument was that NFPA 805 called for evaluating the "additional risk presented by … [the use of recovery actions]." But NFPA 805 never required this "during transition." Yet RG 1.205 chose to sanction this as such. In addition, RG 1.205 interpreted the need to calculate the "total increase or decrease in risk associated with the implementation of NFPA 805 for the overall plant …," again implying a "during transition" action.

Although only mentioned as an "example approach for acceptance criteria for changes in risk from a "plant change" in the appendix section of NFPA 805 (not endorsed in 10CFR50.48[c]), RG 1.174 (*An Approach for Using Probabilistic Risk Assessment [PRA] in Risk-Informed Decisions on Plant Specific Changes to the Licensing Basis,* [May 2011, Rev. 2; January 2018, Rev. 3]) was deemed as the appropriate guidance by which to determine acceptability during transition. However, since NFPA 805 cited this in connection with a "plant change," a post-established fire protection program activity, it was intended to be applied after

transition, not during. Nonetheless, the NRC arbitrarily chose this to apply during transition, not recognizing, or else choosing to overlook, the complications that would ensue.

First, consider that the guidance in RG 1.174 was intended for "use of PRA findings and risk insights in support of licensee requests for changes to a plant's licensing basis." Also, in SECY-97-287 (*Final Regulatory Guidance on Risk-Informed Regulation Policy Issues* [December 12, 1997]), the NRC Executive Director for Operations stated that the "set of regulatory guides [including RG 1.174] … describe how probabilistic risk assessment should be used in a risk-informed process to change those portions of the current licensing basis …" Though the terms "change" and "portions" were somewhat subjective, one reasonable interpretation of these was that they implied that RG 1.174 was to be used not to replace in full an entire licensing basis, such as a fire protection program, but only to make relatively small perturbations to an existing licensing basis. Under this interpretation, this translated into NFPA-805's citing of RG 1.174 as an example approach for use with a post-established fire protection program, not for the transition itself.

However, because entrenched elements within the NRC rejected institution of a "total risk" safety goal in favor of the RG-1.174 "delta-risk" philosophy, the agency forced RG 1.174 to be used as the sole determiner for risk-informed acceptance during the transition period, even though there was no existing baseline risk against which to measure the change (use of the plant's current configuration was deemed inappropriate, a logical determination given that the configuration would be changing as a result of the transition). However, instead of rejecting the whole "delta-risk" philosophy for the transition, which would have made sense since only the final, post-established fire protection program configuration would be relevant, the NRC borrowed the dictum from NFPA 805 to "compare the risk associated with implementation of the deterministic requirements with the proposed alternative" to define the "deterministically compliant" plant in RG 1.205:

> *The "deterministically compliant plant" has been referred to as "an ideal plant" that may not exist or be feasible in practice. Based on experience with the two NFPA 805 pilot plants, the risk of most variances from the deterministic requirements can readily be evaluated by postulating modifications, such as moving or protecting cables, which would meet the deterministic requirements. This provides the base case against which the added risk of the proposed alternative is evaluated ...*

This extrapolation was even farther afield than would have been by using the current plant configuration as the base case, since "deterministic compliance" could be defined in multiple ways for fire protection. The logical approach was rejected, namely establishing a total risk (or at least total fire risk) criterion (in conjunction with other considerations, such as defense-in-depth and safety margin, which could be qualitative) against which to measure the risk of the plant configuration after establishing a fire protection program to which NFPA 805 would apply. For, if one rejected the use of RG 1.174 for the transition process, retaining it as intended for the post-established fire protection program, of what relevance was the change in risk vs. some subjective configuration? Did not only the "final" risk matter? The requirement of a "delta-risk" evaluation during transition constituted the most fundamental flaw upon which all subsequent complications associated with the NFPA-805 program derived. The voices of a not-so-silent minority within the NRC against this delta-risk philosophy went unheard then and continued unheeded throughout the endeavor.[4]

The "Delta-Risk" Problem

From the start of the NFPA-805 pilot program, involving the Shearon Harris and Oconee 1-3 nuclear plants, there was confusion on both the regulator and licensee sides of just how to implement this "delta-risk" approach. Licensees were concerned that they would have to develop two fire PRAs, one for the "deterministically compliant" plant and one for the post-established fire protection program configuration.

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[4] The author acknowledges that total risk did play at least a minor role in applying the quantitative guidance in RG 1.174 in that, if the total CDF (LERF) exceeded 1E-4/yr (1E-5/yr), risk increases >1E-5/yr in CDF (1E-6/yr in LERF) were generally prohibited, although some "wiggle room" might have been granted if these exceedances were "slight." (See discussions later in this paper as well as Appendix I for the author's thoughts on this "wiggle room" and what was allowed.)

Very early during the pilot program, Figure I was developed by the author to indicate a staged process for estimating the delta-risk without the need for two full fire PRAs; later it was offered as a Frequently Asked Question (FAQ) as part of an NFPA-805 FAQ program, but the NRC chose not to pursue (ADAMS Accession No. ML14108A062, "Measuring at-Transition Delta-Risk for Plant Change Evaluations [as Presented at March 2006 Observation Visit]," April 18, 2014). While it may appear much more complicated than it really is, the process indicated the additional effort to force the transition phase to satisfy the RG-1.174 guidance, whereas a simple total (fire) risk approach would have been much simpler and required essentially no such "clarification."[5]

A prime source of confusion that arose from the NFPA-805 dictum (again, intended for use after transition) was the delta-risk requirement for "recovery actions," defined as actions "to achieve the nuclear safety performance criteria that take place outside of the main control room or outside of the primary control station(s) for the equipment being operated, including the replacement or modification of components." Unfortunately, "primary control station" was not defined in NFPA 805, but left to RG 1.205, which chose to "define" this in a rather extensive manner, making use of illustrations in an attempt to "simplify." Nonetheless, just what constituted a recovery action, along with a primary control station, continued to be a source of confusion that, while requiring a delta-risk evaluation after transition, did not need to be ratcheted as part of what should have been a "total (fire) risk" approach during transition.

A spin-off from the "recovery action" delta-risk was the concept of the "Variance from Deterministic Requirements" (VFDR), defining a licensee's intention to retain a fire protection feature that would have been "non-compliant" (presumably requiring an exemption) under a deterministic licensing basis in its post-established fire protection program. As with the delta-risk evaluation for the recovery action, a similar calculation had to be performed for any VFDR during transition, measuring the risk increase from retaining this previously "non-compliant" feature (or instituting a "new" one). Again, a "deterministically compliant" version of the plant that compensated for the presence of the VFDR needed to be postulated for the forced delta-risk calculation during transition. This established yet another set of, in this author's opinion, unnecessary and irrelevant risk-type calculations, again subjected to the RG-1.174 guidance during transition, when only the final configuration after transition mattered.

Past the halfway point with the non-pilot transitions, it was evident that use of the delta-risk approach likely led to misrepresentation of at least the current fire risk spectrum for a number of plants. Shown in Table I were the reported fire core damage frequencies (CDFs), large early release frequencies (LERFs), delta-CDFs and delta-LERFs from ten of the submittals. While both the negative delta values, indicating risk reductions, and final CDFs and LERFs posed no undue concern, the "back calculation" using these indicated all ten plants implied high current ("pre-transition") fire CDFs (>3.0E-4/yr), four of which also indicated high fire LERFs (>1.6E-5/yr). While these implied high values were likely the result of over-conservative fire PRA modeling on the part of the licensees, probably from using screening/scoping approaches extensively rather than plant-specific fire phenomenological modeling (since generating negative delta-risks was desirable, prompting no need to refine the evaluations for NFPA-805 purposes), when challenged, these licensees did not opt for a recalculation. This prompted the NRC, through its Regional inspectors, to require each licensee to establish "extraordinary" compensatory measures until the plant completed its transition to NFPA 805 and implemented the commitments cited as producing the risk reductions.[6,7]

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[5] The author subsequently expressed the delta-risk calculational approach in a hopefully simpler way, as shown in the Attachment to Figure I (ADAMS Accession No. ML14108A051, "Delta-Risk Calculations for NFPA-805 Transition [FAQ]," April 18, 2014).

[6] Except for the first plant in the Table, with pre-transition fire CDF = 1.54E-3/y, the remaining pre-transition fire CDFs reflected the assumed "deterministically compliant" plant configuration, meaning that the true pre-transition fire CDFs were higher. How much higher was unknown, but, at least for the first plant, the reported pre-transition fire CDF reflected a value approximately four times higher than what it would have been if the "deterministically compliant" configuration had been assumed. Therefore, if this factor was somewhat representative for the remaining nine, it was possible, and perhaps likely, that all ten had pre-transition fire CDFs > 1E-3/yr.

[7] Subsequent to my "phasing out" from the NFPA-805 program, at least one more plant reported a pre-transition fire CDF higher than any of the ten, that being 2.38E-3/y, at least cited as being for the current plant as-built (i.e., not a non-conservative estimate based on the "idealized" plant used for delta-risk calculations). The corresponding pre-transition LERF was also

While, for the NFPA-805 program, risk decreases were always desirable, the optics associated with implying very high current fire CDFs and/or LERFs were not. And, recognize that these delta-risks were measured against a "deterministically compliant" ("ideal") fire protection program configuration, implying that the current risks vs. the actual configurations would be higher. Furthermore, non-fire risks were not included in these back-calculated totals. A more concerned public, or nuclear power opponents, should they happen to have reviewed any of these publicly available license amendment documents, could easily have reached these same conclusions.

"Fire PRA is Too Conservative!"

In 2005, the NRC and Electric Power Research Institute (EPRI) published NUREG/CR-6850 (EPRI 1011989), *Fire PRA Methodology for Nuclear Power Facilities*, which was cited in RG 1.205, but with the following caveat: "… [since] using the methods explicitly documented in NUREG/CR-6850/EPRI 1011989 may result in a conservative assessment of fire risk, licensees may choose to perform more detailed plant-specific analyses to provide greater realism in the fire PRA model." Early results from the pilot plants, based primarily on the admittedly conservative "scoping/screening" guidance from this document, not surprisingly yielded relatively high estimates for both risk and delta-risk. Over-reacting to these early estimates, the Nuclear Energy Institute (NEI) and supporting nuclear industry entities questioned the utility of the document, even though it had received full consensus from the EPRI and its industry participants. In an attempt to "reduce" alleged over-conservatism, the NRC and nuclear industry agreed to expand the NFPA-805 FAQ program to include "modeling improvements" specifically related to NUREG/CR-6850 (EPRI 1011989) in early 2008. Several FAQs were proposed, most of which were ultimately completed (see Supplement 1 to NUREG/CR-6850 [EPRI 1011989]), although not necessarily to the extent the nuclear industry might have preferred (although each received joint consensus upon completion) and, in some cases, with a change of cognizant NRC staff when the FAQ was not proceeding as both the NRC and nuclear industry preferred in order to "expedite" the NFPA-805 process.

"A Tale of Two FAQs"

While this "extended" NFPA-805 FAQ process was proceeding, the EPRI sprang a "Christmas surprise" on the NRC in the form of EPRI 1016735, *Fire PRA Methods Enhancements* (December 2008), which attempted to pre-empt the joint NRC-industry effort on three of the FAQs currently in process. Dissatisfied with the "progress" (or lack thereof, in the industry's opinion) on these three particular FAQs, the EPRI published its own solutions, which prompted the NRC, in this author's opinion, to prematurely accept questionable resolutions to two of what subsequently proved to be key "methods enhancements" utilized extensively by licensees transitioning via NFPA 805.

In one case, the NRC pulled a "Baltimore Colts middle-of-the-night escape maneuver" during the lead analyst's (my) temporary absence by switching nearly all of the cognizant staff working on one FAQ, already in draft final form as part of the concurrence process (ADAMS Accession No. ML090300496, "Close-out of National Fire Protection Association 805 Frequently Asked Question 08-0046 on Incipient Fire Detection Systems," March 2009), to other staff, believed (and ultimately proven) to be amenable to a more "industry-friendly" version of the final FAQ, based in part on no more than manufacturer claims and limited operating experience. The original set of NRC cognizant staff, consisting of the fire PRA expert in the Office of Nuclear Reactor Regulation (NRR) [me] and several fire protection engineering experts, had proceeded along a pathway based on well-documented test results that, alas, was not going to grant the industry anywhere near the amount of risk reduction credit it was seeking, especially at one of the pilot

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higher than any of the ten, that being 7.58E-5/y. Given what should have been "lessons learned" from the earlier ten plants, to receive an application from one of the last transitioning plants under NFPA 805 at such a late stage is troubling, perhaps indicative of NRC having "gone easy" on the first ten by only requiring compensatory measures instead of recalculation of the pre-transition risk. For this latest plant, the NRC reconsidered its previous philosophy and decided to require a recalculation of the pre-transition risk since the fire CDF exceeded 1.0E-3/yr. This was met with resistance from the licensee because its previous NFPA-805 site, that with the fire CDF >1.0E-3/yr, had not been so required, but had been allowed to exercise the "extraordinary" compensatory measures option.

plants.[8] The authors of the final FAQ, quite different from what had been drafted, did not include experts in fire PRA or fire protection engineering. While it ultimately lowered the risk reduction credit first claimed in EPRI 1016735 by a factor of three, this credit still remained excessively over-generous, in this author's opinion, at a factor of 50 (see FAQ 08-0046, "Incipient Fire Detection Systems," in Supplement 1 to NUREG/CR-6850 [EPRI 1019259] and 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). The NRC's issuance of this FAQ led to rather exorbitant claims by at least one manufacturer regarding the value of these systems in nuclear power plants (see, e.g., *http://www.safefiredetection.com/nuclear* ["Proven Results - Reduced PRA by 170 Times … Reduced CDF 3 Orders of Magnitude"]).

Some NFPA-805 applicants even tried to extend the risk reduction credit from the FAQ to the constantly occupied Control Room, a generosity not even the FAQ itself allowed. Upon being told this credit would not be given, one of these licensees demonstrated the degree to which it believed in the fire protection benefit of this system by removing its commitment to install the system entirely from its application (ADAMS Accession No. ML1322A045, "Response to Request for Additional Information, License Amendment Request to Adopt National Fire Protection Association Standard 805, Performance-Based Standard For Fire Protection for Light Water Reactor Generating Plants," NG-13-0182, May 1, 2013).[9]

For the second FAQ, suspected of being flawed from the beginning, the NRC nonetheless adopted the EPRI recommendations from EPRI 1016735, with limited modifications (and even these rankled the nuclear industry) over objections from some of the cognizant experts. Observing an alleged "industry improvement" occurring around 1990 in the fire events database from NUREG/CR-6850 (EPRI 1011989), which spanned the years from 1968 through 1999, the EPRI proposed a new set of fire ignition frequencies which much more heavily weighted the 1990-1999 experience, effectively reducing the overall fire frequency from collective ignition sources by a factor of two. Cognizant NRC staff, including contractor experts who had authored NUREG/CR-6850 (EPRI 1011989), strongly suggested that this alleged reduction was due more to changes in reporting and or recording processes that occurred around 1990, rather than some "sea change" in industry fire protection practices at that arbitrary date.[10] Nonetheless, even with a new effort underway to collect fire events data from 1999 onward in a more comprehensive manner, as well as update some of the 1990-1999 data, the NRC issued FAQ 08-0048, "Fire Ignition Frequency," in Supplement 1 to NUREG/CR-6850 (EPRI 1019259), essentially adopting the revised

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[8] It was likely more than coincidence that this FAQ was championed by this NFPA-805 pilot plant, for which excessive credit for the proposed installation of enhanced fire detection reduced risk in a critical location of the plant. With this reduction, other modifications or enhanced fire phenomenological modeling became unnecessary. To what extent the NRC's amenability to expediting this FAQ was based on promoting acceptance of the pilot plant's transition to NFPA 805 may be questioned.

[9] The NRC Office of Nuclear Regulatory Research (RES) subsequently established a testing program to examine the potential benefits from VEWFD, producing its results in NUREG-2180, *Determining the Effectiveness, Limitations, and Operator Response for VEWFD Systems in Nuclear Facilities (DELORES-VEWFIRES)*, December 2016. Results indicated that the FAQ 08-0046 risk reduction credit factor of 50 was roughly an order of magnitude too high, in line with what the FAQ's original authors had proposed in 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. Unfortunately, the testing program failed to address a key aspect of the phenomenology, namely whether what would be counted as a "challenging" fire that is part of the fire ignition frequency for electrical enclosure fires, even if detected in the pre-combustion stage by a VEWFD, would actually evolve into such a fire. The necessary long-term testing period to determine this was not pursued. Additionally, there were several non-conservatisms embedded in the analytical method developed from the test results, prompting a Non-Concurrence by the author when NUREG-2180 was endorsed for use by the Office of Nuclear Reactor Regulation (NRR). Finally, RES uncovered an error in the original FAQ 08-0046 indicating a potential under-estimate of risk for scenarios crediting VEWFDS by the full factor of 50! All this is discussed in detail in Appendix III.

[10] As an example, the principal investigator, Steven Nowlen of Sandia National Laboratories, who led the development of NUREG/CR-6850, asked during a 2010 ACRS Subcommittee meeting regarding this FAQ "… What's the basis for 1990 being a watershed year? We don't know and so that give us a little trepidation as to … how much reliance we should put in the trend … I'd offer up the mixed bag of reporting. I mean, there was a comprehensive search for events through `89 and after that it is a little ad hoc." (ADAMS Accession No. ML110050249, "Official Transcripts of Proceedings, NRC: ACRS Reliability and PRA Subcommittee Meeting," December 13, 2010)

frequencies from EPRI 1016735.[11] As the new data collection program was underway, early reviews by the NRC seemed to confirm that the 1990-1999 "reduction" was artificial, as data from 1999 onward were suggesting fire ignition frequencies similar to the originals from 1968-1999 in NUREG/CR-6850 (EPRI 1011989). This artificiality was finally confirmed by the industry itself after completing its data collection (Baranowsky, "Fire Ignition Frequency Estimation Using Recent Fire Events Data," ANS PSA 2013 International Topical Meeting on Probabilistic Safety Assessment and Analysis, 2013):

> *There is an obvious discontinuity in the 1990s data …[T]he difference in the data collected in the 1990's may not have had the same level of completeness as the data from the 1968-1989 and 2000-2009 time periods …[T]he data from the 1990's was considered to be missing fire reports that would be comparable to the 2000's.*

However, despite the overwhelming evidence that had been mounting for several years regarding the error in this FAQ, and now even with the documented admission by the FAQ's industry authors of the original error, the NRC still declined to "sunset" this FAQ despite the constant urging by some if its expert technical staff.

While Requests for Additional Information (RAIs) to NFPA-805 licensees during transition often prompted a sensitivity analysis which used the original NUREG/CR-6850 (EPRI 1011989) fire ignition frequencies (which were more consistent with the results from the completed database update [NUREG-2169 {EPRI 3002002936}, *Nuclear Power Plant Fire Ignition Frequency and Non-Suppression Probability Estimation Using the Updated Fire Events Database*, October 2014]), there was at least one documented case where a licensee achieved transition to NFPA 805 based at least in part on the continued existence of this FAQ (ADAMS Accession No. ML13210A449, "Duane Arnold Energy Center - Issuance of Amendment Regarding Transition to A Risk-Informed, Performance-Based Fire Protection Program in Accordance with 10 CFR 50.48(c)," September 10, 2013):

> *… [T]he total LERF is close to 1E-5/yr but not significantly above it. The sensitivity analysis discussed in Section 3.4.7 below shows that this LERF is conservative since use of the EPRI 1016735 fire bin ignition frequencies, as allowed in FAQ 08-0048, decreases the LERF. The decrease provided from this frequency consideration is from 1.6E-5/yr (which uses the Bayesian updated NUREG/CR-6850 generic fire frequencies),[12] to 1.1E-5/yr, according to the updated Attachment W tables. Therefore, the quantified LERF would be approximately 1.2E-5/yr by summing this LERF with the internal events PRA LERF. However, based on sensitivity studies …, the NRC staff cannot definitively conclude the LERF is less than 1E-5/yr... The NRC staff concludes that the RG 1.174 risk acceptance guidelines of 1E-7/yr ΔLERF apply since the total LERF is slightly greater than 1E-5/yr.*

In other words, using the original NUREG/CR-6850 (EPRI 1011989) fire ignition frequencies, which were more consistent with the most recent database update, the total (fire) LERF was 1.6E-5/yr, and not even reduced below 1.0E-5/yr via the erroneous FAQ 08-0048 values. Whether this would still qualify as "slightly greater than 1E-5/yr, vs. the conclusion of 1.2E-5/yr allowing use of FAQ 08-0048, could be debated (see Appendix I).[13]

"We're not Going to Play Anymore"

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[11] Not unlike my experience with FAQ 08-0046, I was initially a prime reviewer of the industry proposal and intended author of the FAQ, but ultimately had to dissociate myself entirely (at least voluntarily this time). Recognizing its faulty basis, I pushed for a requirement that sensitivity analysis for all the fire ignition frequencies using the original NUREG/CR-6850 (EPRI 1011989) values be included with the FAQ. Initially accepted, my staff colleagues backed down after pushback from the industry, such that only a few select frequency "bins" would be subjected to this sensitivity requirement. At that point, I recused myself from further involvement with the FAQ as this was much too inadequate.

[12] This is only the fire LERF. The total LERF is 1.82E-5/yr, excluding any estimate for seismic hazards.

[13] See Appendix II for discussion of a Differing Professional Opinion filed with respect to FAQ 08-0048.

Since the industry, led by the NEI and its supporters, first complained about NUREG/CR-6850 (EPRI 1011989) specifically, and fire PRA generally, in 2008, its opposition to how NFPA-805 transitions "progressed" was vehement and quite vocal. Claims of "gross over-conservatism" reached a peak at an ACRS meeting in November 2010, where the NEI, et al., unveiled its "Roadmap for Attaining Realism in Fire PRAs" (ADAMS Accession No. ML103430372, "Transmittal of NEI Report 'Roadmap for Attaining Realism in Fire PRAs - December 2010,'" December 6, 2010). Citing intermediate results from the early non-pilots, with only partial calculations from the "fire risk equation,"[14] they "proved" that the current state-of-the-art for fire PRA, as supported by the NRC via NUREG/CR-6850 (EPRI 1011989), generated "results that do not comport with operating experience." Limited efforts by the NRC to counter these claims were insufficient to deflect this mantra.[15] It progressed to the point where the industry "threatened" to discontinue its participation in risk-informed applications because of the "805 fiasco" (True, et al., "Risk Informed Decision-making: Addressing Very Large PRA Uncertainties," plenary speech at International Topical Meeting on Probabilistic Safety Assessment and Analysis, PSA 2013," Columbia, South Carolina, September 22-27, 2013).

This industry "threat" was subtly veiled in an NEI letter to the NRC Chairman as "severely diminished industry confidence" (Pietrangelo to MacFarlane, "Industry Support and Use of PRA and Risk-Informed Regulation," December 19, 2013):

> *While there are some pockets of progress, … the overall level of industry support for risk-informed initiatives is at a relative low point … The following summarize the major impediments to advancing risk-informed decision-making: NFPA-805's Chilling Effect – An example of a failed risk-informed process is NFPA-805. The long and problematic history surrounding fire protection has been carried forward in the use of risk methods in this area. Political pressure drove the use of untested PRA fire methods laced with conservatisms in the required fire-risk analyses. As a result, fire PRAs are not consistent with operating experience and obscure the insights that could be gleaned from these PRA studies. The consequence is that the expected benefits of NFPA-805 programs have been elusive. The process is protracted, costly and unstable. These fire PRA problems have severely diminished industry confidence in risk-informed approaches and programs … Currently, enthusiasm for risk informed approaches has been seriously diminished, as very large resource impacts, extended review cycles and unpredictable (and potentially incorrect) outcomes*

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[14] Fire core damage frequency is the product of fire ignition frequency and a series of conditional failures: failures to detect/suppress the fire, given fire severity and propagation; failures of the plant equipment or personnel to successfully mitigate the accident using non-fire affected measures. The industry calculation was "partial" in the sense that aspects of detection, suppression propagation and mitigation were not considered. (For a summary, see "Seeking Realism in Fire PRA," Chapman, Scientech, ANS PSA 2013 International Topical Meeting on Probabilistic Safety Assessment and Analysis.)

[15] See, e.g., Gallucci, 2006, "Predicting Fire-Induced Core Damage Frequencies - A Simple 'Sanity Check'," Transactions of the American Nuclear Society, Vol. 94, Reno, Nevada, pp. 202-204; Gallucci 2011, "How Immature and Overly Conservative is Fire PRA? - A Comparison of Early vs. Contemporary Fire PRAs and Methods," American Nuclear Society International Topical Meeting on Probabilistic Safety Assessment, PSA 2011, Wilmington, North Carolina; Gallucci, 2012, "'What – Me Worry?' 'Why so Serious?' A Personal View on the Fukushima Nuclear Reactor Accidents," Risk Analysis: An International Journal, Volume 32, Number 9, Society for Risk Analysis, McLean, Virginia, pp. 1444-1450. Unlike the industry calculations, two of these papers utilized the full risk equation to enable comparison of fire CDF results to fire CDFs based on historical experience, both domestic and worldwide. The third qualitatively reviewed the history of conservatism in PRA in general, and fire PRA in particular, concluding as follows:

> *It is certainly desirable that the techniques of PRA enable more realistic modeling of the complex interactions associated with plant operation, including the human element, and the resulting ability to optimize resources and focus strategies to a more practical level than traditionally afforded by the more deterministic "all-or-none" approaches. However, we must not lose sight of the legacy of PRA, namely that it is first and foremost a technique for assessing safety, which entails erring on the side of conservatism where necessary, and only then one for resource allocation, strategy optimization, etc. Regardless of the extent to which fire PRA methods can ultimately be refined, the inherent chaotic phenomenology of fire will always keep fire PRA on a lower pedestal than that to which its critics place internal events PRA in terms of maximum realism and minimal uncertainty. External events such as fire, earthquakes and tornadoes have an aleatory uncertainty because of the nature of the phenomena that will always exceed that associated with the phenomena governing internal event failures. In conclusion, is fire PRA immature? No. Is it conservative? Yes. Is it too conservative? No.*

have been experienced ... NFPA 805 is a significant existing application that illustrates the issues at hand ... Attempts by industry to develop a coherent framework that would allow the integration of fire frequency, fire severity, and suppression response to better reflect with actual industry fire experience are rejected in favor of analytical approaches based solely [on] bounding input parameters.

Of course, omitted throughout the NEI diatribe was industry's abdication of its responsibility to provide the phenomenological basis needed as technical justification for the "coherent framework that would allow the integration of fire frequency, fire severity, and suppression response to better reflect with actual industry fire experience." Evidence for this is provided in the subsequent section on "Unreviewed Analysis Methods," including industry failure to perform fire tests since 2001 and its obstinacy in providing phenomenological support for its "operational-experienced-based" proposals.

"Rejection is not an Option"

When the two NFPA-805 pilot applications were formally submitted in 2008, there was much ballyhoo and photo opportunities among executives from the NRC and licensees. While not "officially" true, in effect acceptance of these transitions was essentially "guaranteed," even if significant hurdles would remain to be overcome. The reviews for both pilots were intensive, including a "peer review" type of audit of both fire PRAs by the NRC. Neither fire PRA was close enough to being final for these reviews to be conclusive, so they served more as just a "mid-stream" check. One pilot chose to have an industry follow-on peer review at a later stage.

Ultimately, as "guaranteed," both pilots were transitioned in 2010 to NFPA 805, primarily because each committed to implement a significant modification to install additional equipment that would be of benefit to mitigate both fire- and non-fire-induced accident sequences. One pilot's fire PRA was essentially "clean" (other than the questionable over-credit granted via FAQ 08-0046). The other pilot's fire PRA was initially deemed to lack "sufficient technical adequacy," as follows (ADAMS Accession No. ML103000047, "Draft Safety Evaluation for Oconee Nuclear Station Units 1, 2 and 3, Transition to a Risk-Informed, Performance-Based Fire Protection Program in Accordance with Title 10, 'Energy,' of the Code of Federal Regulations, Part 50, Subpart 48(c)," November 9, 2010):

... [G]iven the number of resolutions that are not fully completed or have not been implemented and will involve PRA method and model changes, the NRC staff cannot conclude that the current Fire PRA has sufficient technical adequacy to determine that future identified VFDRs or FPP plant changes that are identified as less than very small increases in CDF and LERF are indeed less than very small increases. Therefore, implementation items are identified ... for the specific conditions related to the internal events PRA that must be addressed and the license condition does not allow the licensee to self-approve risk-informed changes to the FPP, pending a license amendment application (per 10 CFR 50.90) requesting such approval capability following a full-scope peer review of the Fire PRA and resolution of peer review findings.

After the licensee "chose" to remove its request for "self-approval," this was subsequently "softened" in the final safety evaluation to read as follows (ADAMS Accession No. ML103630612,"Oconee Nuclear Station, Units 1, 2, and 3, Issuance of Amendments Regarding Transition to a Risk-Informed, Performance-Based Fire Protection Program in Accordance with 10 CFR 50.48[c]," December 29, 2010):

The proposed license condition also requested self-approval of quantitative risk-informed fire protection program changes. By letter dated December 22, 2010, ... the licensee replaced the original proposed license condition with a new license condition. The new proposed license condition did not request self-approval of quantitative risk-informed fire protection program changes. The new proposed license condition requires the licensee to request NRC review and approval in accordance with 10 CFR 50.90 prior to being allowed to self-approve quantitative risk-informed fire protection program changes except for those associated with the

implementation items listed … needing a plant change evaluation provided the overall transition risk remains a decrease.

This essentially sanctioned it as an "805 plant(s)" in name only. Without the right of "self-approval" (ability to approve plant changes which increase risk by no more than 1E-7/yr in CDF and 1E-8/yr in LERF without pre-approval by the NRC), the "805" moniker was more of a false façade, necessary since "victory" had essentially been declared during the initial submittal ballyhoo.[16]

"At Your Discretion"

As the pilot process was proceeding in 2008, it became evident that the two safety evaluations would not be issued as quickly as first anticipated. Enforcement discretion regarding potential non-conforming conditions related to fire protection was in effect for those licensees who had already committed to transitioning to NFPA 805, but this delay could cause the reviews to be started after this discretion terminated. The NRC decided to extend the discretion period provided the licensees could demonstrate progress in the following specific areas toward their NFPA-805 submittals ("NRC Enforcement Policy: Extension of Discretion Period of Interim Enforcement Policy," Federal Register [73 FR 52705], September 10, 2008):

- Compile a list of all fire protection related non-compliances and the related compensatory measures for those non-compliances.
- Document that each Operator Manual Action put in place as compensatory measures is feasible and reliable, in accordance with guidance in Regulatory Issue Summary 2005–07 (USNRC, *Compensatory Measures to Satisfy the Fire Protection Program Requirements*, April 2005).
- Submit a description of the physical modifications performed to address existing risk-significant fire protection issues (Table B-1, cited in Figure II).
- Submit a status report of the transition, including a schedule of milestones for completing the fire PRA. The status report should be broken down into the following major areas:
  - Classical fire protection transition (in accordance with NFPA 805 Chapter 3) (Table B-2, cited in Figure II).
  - Nuclear Safety Performance Criteria transition (in accordance with NFPA 805 Chapters 1, 2 and 4) (Table B-3, cited in Figure II).
  - Non-power operational transitions.
  - NFPA 805 monitoring program.
  - Fire PRA.
- In addition, reporting progress in the following was optional:
  - Radioactive Release
  - Safe Shutdown Analysis
  - Plant Change Evaluations

All non-pilots currently committed to transition submitted their "progress reports." Evaluating whether or not the progress was adequate to receive the extended discretion was somewhat subjective, but the author,

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[16] Note that this licensee failed to implement the modification to which it committed, and by which the NRC approved its transition "despite" the state of its fire PRA, in the promised time. Nonetheless, the NRC allowed it to retain its "805" status provided it met a series of "progress" deadlines to install and activate the new system (ADAMS Accession No. ML13114A928, "Notice of Violation and Confirmatory Order Related to a Fire Protection Program License Condition [Oconee Nuclear Station, Units 1, 2, and 3]," July 1, 2013):

Due to your particularly poor performance associated with the planning and execution of this modification, the NRC staff … concluded that the issuance of a Confirmatory Order (CO) containing specific milestones and dates for achieving compliance is a more appropriate means of enforcement to assure timely completion of the PSW [Protected Service Water] project. There are six milestones, with final completion due by November 15, 2016. Each of the intermediate milestones provides risk reduction … The NRC staff is hereby issuing a CO which specifies the milestones which must be met as you work to complete the terms of the license condition … Failure to comply with the terms of the CO will result in additional enforcement action up to, and including, daily civil penalties.

tasked to review these "progress reports," was able to develop a "quasi-quantitative" means by which to compare among the various licensees (see Figure II [ADAMS Accession No. ML14108A072, "Enforcement Discretion Matrix (Scrubbed)," April 18, 2014]). Although only a representative sample of the submittals is shown here, it does indicate a wide spectrum in the degrees of "progress" among the licensees. Some, such as Plants B, C and F, showed significant progress, such that the author recommended they readily receive the extension. Some, such as Plants A, E and H, were not as far along, but seemed to have made at least sufficient progress to likely also warrant extension. However, two, Plants D and G, were substantially behind the others, and the author recommended neither receive the extension. However, the NRC opted to give all plants the extension, making this evaluation exercise essentially a false façade. At least one of the plants (D) was extended under a "gentleman's agreement" by which they periodically communicated their "progress" to the NRC as a condition of retaining their extension. The other plant (G) is owned by one of the pilot licensees, so was extended without even this condition.[17]

"Unreviewed Analysis Methods"

The extent to which the industry was aware that the one pilot's "victory" was "conditional" is unknown. However, it did seem curious that the contractor which had performed the fire PRA for this pilot managed to procure the lion's share of fire PRA support for the non-pilot applicants. The fallout from this was that the early industry peer reviews of various "805" fire PRAs (typically in, at best, an intermediate state), using ASME/ANS RA-Sa-2009, *Addenda to ASME/ANS RA-S-2008, Standard for Level 1/Large Early Release Frequency PRA for Nuclear Power Plant Applications* (2009), and NEI-07-12, *Fire PRA Peer Review Process Guidelines, Rev. 1*, June 2010, revealed use of "unreviewed analysis methods" (UAMs), either present (and discounted) during the pilots or new to the non-pilots.[18]

The UAMs posed a problem for both the licensees and NRC, as they were left "open-ended." Rather than defer their adjudication to the NRC during its review of the application (not necessarily something the NRC desired anyway), the industry recommended a "UAM Review Panel," with NRC participation, to say "yea" or "nay" to the method. A "nay" would prompt the method advocate to revise or take a different tack. Chaired by the EPRI, it became evident fairly early on that the first set of UAMs, all stemming from the "lion's share" contractor, would not produce quick "yea's" and without, in some cases, major revision, would be "nayed." The EPRI unofficially decided to "expand" the UAM Panel's charter from one of quick adjudication to one of developmental assistance to the method advocate until a "yea" was obtained.

Right or wrong, this strategy essentially worked for three of the methods, although one was quite different from its original proposal. (See ADAMS Accession No. ML113130446, "Recent Fire PRA Methods Review Panel Decisions: Clarification for Transient Fires and Alignment Factor for Pump Oil Fires," Giitter, NRC, to Bradley, NEI, September 27, 2011.) For the fourth, and arguably most important method, the NRC panelist (me) indicated at the very first meeting that this method would require a phenomenological basis in addition to its proposed development solely from subjective interpretation of the fire events database (the same database containing the questioned 1990-1999 event reports). Without phenomenological backing, the NRC panelist would not approve the method.

As the deliberation progressed on this method, the Panel continued to focus solely on the database, managing in many cases to uncover additional detail valuable in its own right. While the NRC panelist reminded the rest of his caution for the need of some phenomenological backing during the teleconferences, this path remained untrodden. About halfway through the process, the NRC panelist drafted a written dissent, including a recommended "path forward" via a phenomenological approach. He provided this to the EPRI Panel chair, but it remains unknown whether this written document was shared with the rest of the Panel.

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[17] This reminds the author of the story of the Soviet weight-lifting champion whose salary was based on breaking his own world record. Therefore, each week he would add one gram to his training regimen, thereby earning a steady income.

[18] The degree to which these UAMs were "flagged" by the early peer reviews varied, depending on which Owners Group had performed the review. Eventually, consistency was established by specifically identifying "UAM" as a unique peer review category in NEI 07-12.

Eventually, the Panel approved a method based solely on database interpretation, to which the NRC panelist formally dissented. Lo and behold, the industry treated this as a "last-minute surprise," especially when the NRC upheld the dissent and did not endorse the Panel method. (See ADAMS Accession No. ML12171A583, "Recent Fire PRA Methods Review Panel Decisions and EPRI 1022993, 'Evaluation of Peak Heat Release Rates in Electrical Cabinet Fires,'" Giitter, NRC, to Bradley, NEI, June 21, 2012) This led to repeated complaints by the industry of the NRC deferring to "single staff opinions" (e.g., "Reclaiming the Promise of Risk-Informed Decision-making: Obstacles and Opportunities," Southern Company and Constellation Energy, presented to the NRC, September 16, 2013; "Industry PRA Vision and Plan," NEI NSAIC, presented to the NRC, October 17, 2013), as if, under the hierarchic approval process inherent to the NRC, one single opinion, no matter how expert, could carry the day unless there was widespread agreement.[19]

Unfulfilled Promise

While this fourth method was under "review" (really development), the EPRI published a draft method to achieve similar results that included a phenomenological basis. Stemming from a promising presentation at the 2009 NEI Fire Protection Information Forum (Hunt, "Maximum Fire Size in Closed Vent Electrical Panels," Kleinsorg Group, September 22, 2009), the EPRI proposed developing this approach to pre-empt the need for more fire tests.[20] Since this approach appeared promising, the NRC deferred fire testing.

The industry approach, originally expected to be completed in about a year, eventually required three. Intermediate reviews of parts of the report by the NRC indicated the need for a different tack. A draft of the final report was offered to the UAM Panel for review. However, being both statistical and phenomenological, the NRC panelist felt that a more comprehensive review was needed than the Panel could provide. The EPRI agreed to submit the final to the NRC prior to publication, having received preliminary comments from the NRC from a limited review. Alas, the final report was published without affording the NRC the promised review. Lacking proper revision of the phenomenological approach as recommended by the NRC, this method, too, was not endorsed (ADAMS Accession No. ML12171A583, "Recent Fire PRA Methods Review Panel Decisions and EPRI 1022993, 'Evaluation of Peak Heat Release Rates in Electrical Cabinet Fires,'" Giitter, NRC, to Bradley, NEI, June 21, 2012).

Warm and "Fuzzy"

Previous reference was made to "wiggle room" inferred from the numerical guidance in RG 1.174. As stated there, "… [T]he somewhat 'fuzzy' boundaries between regions ('fuzzier' for the total CDF and LERF than for the delta-CDF and LERF) should not be interpreted as being definitive; the numerical values associated with defining the regions in the figure are to be interpreted as indicative values only." In an attempt to quantify this "fuzziness," this author performed a rather simple, admittedly subjective, analysis, presented in Appendix I (ADAMS Accession No. ML14108A041, "How 'Fuzzy' Are the RG 1.174 CDF and LERF Regional Change Threshold Values?" April 18, 2014). This was prompted by the then

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[19] The NRC, under renewed pressure from the nuclear industry, especially the "lion's share" contractor, later relented by approving a method similar to this rejected one, albeit still based solely on database interpretation and devoid of any phenomenological basis, through the FAQ process, from which I had been "phased out" (See "Close-out of Fire PRA FAQ 14-0009 on Treatment of Well-Sealed MCC Electrical Panels Greater than 440V," ADAMS Accession No. ML15114A441, April 29, 2015).

[20] Except for isolated utility tests, the nuclear industry has sponsored no fire test since 2001, when it was "burned" by results much contrary to what it had intended to prove, namely that fire-induced electrical cable "hot shorts"/spurious actuations were exceedingly rare occurrences (EPRI 1003326, *Characterization of Fire-Induced Circuit Faults: Results of Cable Fire Testing*, December 2002). Industry fire test support has been limited to providing equipment, reviewing test plans, etc., for the NRC-sponsored tests (e.g., from 2005*, USNRC Information Notice 2005-07 – Results of HEMYC® Electrical Raceway Fire Barrier System Full Scale Testing* [ADAMS Accession No. ML050890089, March 30, 2005], through 2016, USNRC NUREG/CR-7197, *Heat Release Rates of Electrical Enclosure Fires (HELEN-FIRE), Final Report*, April 2016) that continue today. Unfortunately, this has promoted an attitude that the NRC must accept proposed methodological "enhancements" from the nuclear industry (e.g., via FAQs or UAMs) unless NRC testing can prove otherwise. The NRC tests should be confirmatory, not developmental, which should be the role of industry tests that should serve as the bases for these "enhancements."

impending issuance of transition approval for one of the non-pilots. Just before issuance, Westinghouse revealed a problem with a major modification being adopted by some of its PWRs, to the extent that "credit" (risk reduction) taken in PRAs, including fire, was no longer justified (ADAMS Accession No. ML13211A168, "Notification of the Potential Existence of Defects Pursuant to 10 CFR Part 21" [July 26, 2013]). As this non-pilot had taken this credit, and was close to the RG-1.174 numerical threshold for permissible risk increases, it was asked to re-evaluate. Results showed new risk increases of 1.7E-5/yr and 1.9E-5/yr in CDF and 1.7E-6/yr and 1.9E-6/yr in LERF at the two units. In approving the transition, the NRC stated the following (ADAMS Accession No. ML13140A398, "Donald C. Cook Nuclear Plant, Units 1 and 2 - Issuance of Amendments Issuance Regarding Transition to a Risk-Informed, Performance-Based Fire Protection Program in Accordance with 10CFR50.48[c]," October 24, 2013):

> *These estimated risk increases slightly exceed the RG-1.174 guidelines of 1E-5/yr for ΔCDF and 1E-6/yr for ΔLERF … The NRC staff concludes that further improvements to the fire PRA would reduce the change in risk estimates but that further reduction of the quantitative estimates from additional analytical efforts is not necessary. Based on the quantitative and qualitative evaluation performed by the licensee …, the NRC staff concludes that the risk increase associated with the transition to NFPA 805 is acceptable and meets the guidelines described in RG 1.174.*

Although the NRC cited these as "slightly" exceeding the RG-1.174 delta-risk thresholds, all exceed even the relaxed "fuzzy" limits from Appendix I.

Since the licensee claimed to have significant conservatism embedded in its risk estimates, it believed re-analysis that removed this conservatism would satisfy the thresholds even without the credit for the discounted modification. However, this re-evaluation would have required more time. The NRC, already over-sensitized to missed deadlines for issuing non-pilot approvals, opted to accept the licensee's belief and approve the transition with the, in this author's opinion, too large risk increases. Preferable would have been delaying approval a few more months to let the licensee "prove its belief" and recalculate these delta-risks so they could meet the RG-1.174 guidance. Then the approval could have been "clean."

Trust, but Verify?

Since the first non-pilot application was submitted, there was debate over the extent to which "docketed" vs. "non-docketed" material should be reviewed. The license amendment request and its supplement, if any, were always docketed and subject to review. It could be referenced in its entirety by the reviewers. However, since its PRA-related material was often "higher level," much of the more informative PRA-related information existed only in "supporting material," consisting of plant-specific engineering calculations, etc. Typically these were not docketed and therefore not *a priori* able to be referenced. However, early on, a compromise was reached whereby this "supporting" material would be provided via a licensee-controlled "share-point" or "portal" site. While nothing could be reproduced or directly referenced from this portal, reviewers could examine the material in an effort to answer questions arising from the review of the docketed material.

It quickly became apparent that much, often the majority, of the critical information needed for the review of the PRA, both internal events and fire, could not be found exclusively from the docketed submittal. Review of the portal material often uncovered UAMs not identified in the submittal, as well as other plant-specific idiosyncrasies employed by the licensee that potentially affected the quality of the PRAs and/or the accuracy of the evaluations. Debate raged between different factions within the NRC as to how much of the portal material was "fair game." More traditional reviewers preferred to limit their search mainly to the docketed material, with limited review of the portal solely to verify questions arising from the submittal. Other reviewers, this author included, considered everything on the portal as "fair game" and reviewed all the PRA-related material on the portal in detail, usually uncovering much more information to be questioned. Naturally, this latter approach resulted in more questions, and eventually RAIs, but, in this author's opinion, led to a much more thorough review and confidence in the licensee analysis.

One complaint raised by the traditionalists was that a detailed portal review stretched out the review process. However, it was this author's experience that a highly experienced and knowledgeable reviewer (me) could complete a detailed portal review in approximately two person-weeks. Typically there were around 10 PRA-related documents on the portal, so this translated roughly into one document per work day. The experienced reviewer knew what to focus on, certainly not every little detail within each document, and so could accomplish a quite thorough review in a relatively short time. Less experienced reviewers (and it was debatable whether ones without the requisite experience should have been lead reviewers in the first place) might take twice or three times as long. Of course, this more detailed review generated more questions and eventually RAIs, leading to complaints from both licensees as well as the NRC that the process was being "dragged out." And, given the licensees were usually afforded up to 120 days to respond to some RAIs (and some licensees could not accomplish this even in this extended period), second and third rounds of RAIs that inevitably resulted when licensee first-round responses were inadequate could lead to missing deadlines (which already had been artificially shortened to meet "political expediency").

Licensee and industry complaints leveled at the NRC Commissioners prompted the NRC to revise its review process. Yielding to the traditional approach, more time was allowed prior to the "site audit," at which the NRC received answers to its preliminary review questions at the site, from which the first round of RAIs were generated. Previously, these audits were "rushed" in that they were scheduled within four to six weeks of the opening of the "portal." However, despite this compressed time, the reviewers managed to generate a comprehensive set of questions based on both submittal and portal review, certainly sufficient to issue the first round of RAIs shortly after the audit.

Now, the paradigm became to delay the audit by several months and restrict the level of review allowed for the "portal," in the misguided assumption that more review time would lead to fewer questions and subsequent RAIs since detailed review of the portal would be "*verboten*," thereby streamlining the process.[21] What was not recognized was that the existing process already produced about as much detail as was possible in the audit questions, such that more time would not "improve" these questions or shorten the number of initial RAIs. The delays occurred because of the overly-generous amount of time given to the licensees to respond to RAIs and their sometimes not even meeting these extended deadlines. Now, with the audits delayed, additional time would be lost, since the licensee responses would still take the same amount of time as before.[22] And the limited portal review would lead to lower quality reviews, consistent with the traditionalists' philosophy of asking only questions with a "regulatory basis," as if technical reviewers should be adopting more of a legalistic approach than an engineering one. The repercussions from this "dumbing down" may not manifest themselves until several years after the NFPA-805 transitions, when the plants are subjected to their recurring triannual fire protection inspections.[23] Claims of improvement in the review process attributed to this new paradigm were somewhat disingenuous, e.g., see Slide 6 in *http://www.nrc.gov/reading-rm/doc-collections/commission/slides/2014/20140619/nrc-staff-20140619. pdf*), as much of the so-called streamlining was the result of less detailed review and the banning of the more probing questions on how the fire PRA was performed that were previously allowed. Naturally, the less that was asked, the fewer the responses that needed review. However, quality was being compromised for the sake of expediency.

A prime example of the reduction in quality was the acceptance of credit for future installation and operation of PWR reactor coolant pump (RCP) seal modifications designed to reduce the likelihood of loss-of-

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[21] The author is reminded of Sergeant Schultz from the comedy series *Hogan's Heroes* (*http://en.wikipedia.org/wiki/Hogan%27s_Heroes*) who "saw nothing" and "heard nothing."

[22] Another feature of this new paradigm is "re-auditing" following the initial, possibly more than once, to "facilitate" the interchange between RAIs and responses and the drafting of the safety evaluation. Ironically, this trend now toward multiple audits is completely contrary to the original plan that advocated eventual elimination of audits altogether as the NRC gained experience with these LAR reviews.

[23] Since I was "phased out" from NFPA-805 reviews in mid-2014, I did not participate in the issuance of the final safety evaluation reports for those plants on which I had been working. However, I know that what I considered critically needed information from the licensees, such as sensitivity studies on the effect of using the artificially lowered fire ignition frequencies from FAQ 08-0048 or the potential questionable crediting of risk reduction for future installation of yet to be proven reactor coolant pump (RCP) seals (discussed in the next paragraph), were not requested nor mentioned in these final reports approving these and any other plants' transitions to NFPA 805 (and all plants ultimately are approved).

coolant-accidents (LOCAs) via leaks through these RCP seals. One seal package, proven to merit risk reduction credit only after sufficient operational experience had been gained at a specific plant ("Final Safety Evaluation for PWR owners Group Topical Report WCAP-16175-P, Revision 0 [CE NPSD-1199, Revision 1], 'Model for Failure of RCP Seals Given Loss of Seal Cooling in CE NSSS Plants'," February 12, 2007), received credit in advance of installation and operation under the misguided concept of "freeze point" (discussed below). Another seal package, proven to fail despite successful test experience once installed and used in operation ("Notification of the Potential Existence of Defects Pursuant to 10 CFR Part 21," LTR-NRC-13-52, July 26, 2013, Westinghouse Electric Co.), also received this advance credit on the premise that new testing had assured that subsequent operation would this time prove successful. However, this was the premise previously used that proved false, so allowing such advanced credit for this second package seemed even less prudent. Again, the "freeze point" concept was cited.

Introduced by industry as an extrapolation (unjustified in my opinion) from practices intended solely for new reactors, not existing reactors ("Summary of October 25, 2013, Category 2 Public Meeting Workshop with the Nuclear Energy Institute and Stakeholders to Discuss the National Fire Protection Association Standard 805," ADAMS Accession No. ML13297A467, October 24, 2013), the "freeze point" concept compelled the NRC to "freeze" its review at some pre-determined date before completion of the review on the premise that the licensee would implement and demonstrate the claimed credit for future performance of the planned modification. The "assurance" of the licensee that it would take appropriate measures should this future performance not prove to merit the pre-determined credit was considered sufficient justification for approval. In reality, the NRC was essentially "tying its own hands" in its own review process for the expediency of approving NFPA-805 applications, despite questions as to PRA quality and future performance. If acceptability of the transition was conditional upon future action, the licensee was not yet ready to complete the transition.

In Closing[24]

Despite my obvious opposition to the use of "delta-risks" during transition, I cannot ignore the following. Without the imposition, however misguided, of the RG-1.174 criteria during transition, would total (fire) risk criteria have prompted modifications that would make plants "safer?" For example, if a plant's "final" total CDF were 8E-5/yr, including fire, but its "delta-risk" been an increase of 3E-5/yr (exceeding the RG-1.174 limit), would any modification need have been made based only on the total CDF? Without the delta-CDF, regardless of how artificial, would there be a safety improvement? Did the "end" justify the "means?"

To counter this, would a plant with a total CDF of 8E-5/yr even have needed to make a modification? Safety improvements are desirable, but at what cost? This would be more of a concern to the industry than the NRC, although money spent in one area might have precluded a better safety improvement in another. Perhaps a cost-benefit approach would have been a better paradigm. But I leave this issue unanswered.

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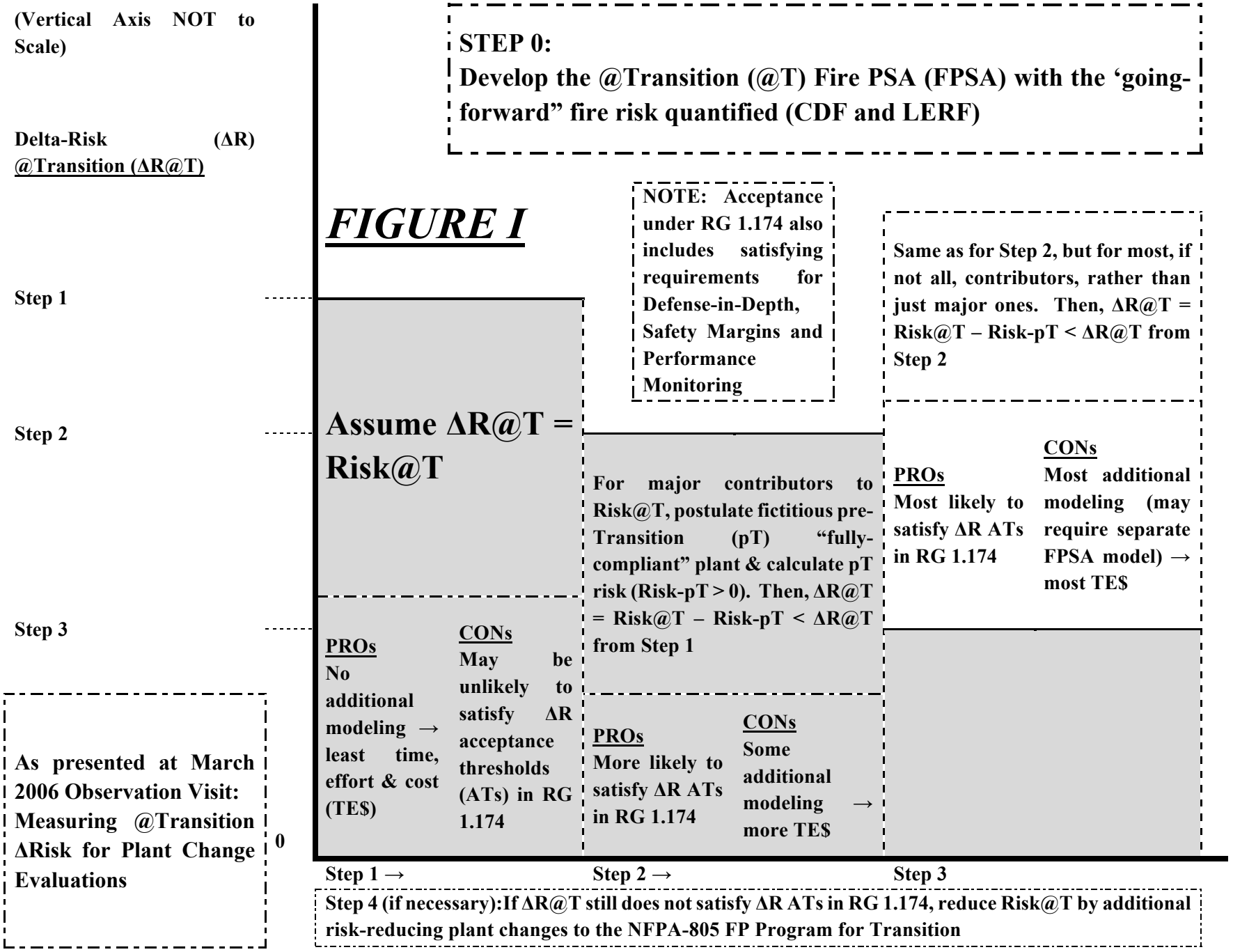
[24] I cannot be sure that the following unequal/unfair treatment by the NRC was merely a monumental mess-up. As I previously had filed a Differing Professional Opinion (DPO) against NRR on a technical/policy issue (Appendix II), and was in the process of filing a Non-Concurrence and possible second DPO on a similar issue (Appendix III), at least part of the following debacle may have been retaliatory. I and two fellow employees requested travel approval for a professional conference to be held in October 2016 in Seoul, Korea, the required three months in advance for international trips. The NRC "Executive Team" (ET) that approves these sat on this request, which had been combined into one, until only three weeks before the conference, finally approving all three travelers. After making arrangements, forced to do so after deadlines for cancellation were past, I was informed nine days later that the trip was disapproved because I did not have an official passport or visa, nor was there enough time (given how the ET had delayed so long) to procure these. When I had inquired regarding this in August, I had been told a personal passport (no visa) was sufficient. At least one of the other travelers was informed of the need for the official passport and visa when he inquired in August and was able to procure these just in time. As a final blow, it turned out the other traveler, who did not have the official passport or visa either, was allowed to travel on his personal passport, completely contradictory to how I was treated. Not only did I incur monetary losses due to last minute need to cancel, but also I did not receive an explanation for the discrepancies among how the three of us were treated, other than that there was "miscommunication" that will be "corrected in the future." Merely gross incompetence or retaliation? Neither the Inspector General nor the Government Accountability Office, supposedly government institutions dedicated to investigate unfair practices, took any interest in this matter.

In summary, NFPA 805 worked to make plants safer (or at least remain at their current level), but it was like removing tonsils through the rectum rather than the mouth. The end was the same (tonsils removed), but the means could be unnecessarily painful with a lot of collateral damage:

THIS END UP

Removing tonsils through the mouth
Imposes little complication.
But when the path starts from the south,
There can be much constipation.

In the end effect's the same –
Tonsils have vacated building.
But in terms of causing pain,
Southern route's like deep core drilling.


(Vertical Axis NOT to Scale)
Delta-Risk (ΔR) @Transition (ΔR@T)
STEP 0:
Develop the @Transition (@T) Fire PSA (FPSA) with the 'going-forward" fire risk quantified (CDF and LERF)
FIGURE I
NOTE: Acceptance under RG 1.174 also includes satisfying requirements for Defense-in-Depth, Safety Margins and Performance Monitoring
Same as for Step 2, but for most, if not all, contributors, rather than just major ones. Then, ΔR@T = Risk@T – Risk-pT < ΔR@T from Step 2
Step 1
Step 2
Step 3
Assume ΔR@T = Risk@T
For major contributors to Risk@T, postulate fictitious pre-Transition (pT) "fully-compliant" plant & calculate pT risk (Risk-pT > 0). Then, ΔR@T = Risk@T – Risk-pT < ΔR@T from Step 1
PROs
Most likely to satisfy ΔR ATs in RG 1.174
CONs
Most additional modeling (may require separate FPSA model) → most TE$
PROs
No additional modeling → least time, effort & cost (TE$)
CONs
May be unlikely to satisfy ΔR acceptance thresholds (ATs) in RG 1.174
PROs
More likely to satisfy ΔR ATs in RG 1.174
CONs
Some additional modeling → more TE$
As presented at March 2006 Observation Visit: Measuring @Transition ΔRisk for Plant Change Evaluations
0
Step 1 →
Step 2 →
Step 3
Step 4 (if necessary):If ΔR@T still does not satisfy ΔR ATs in RG 1.174, reduce Risk@T by additional risk-reducing plant changes to the NFPA-805 FP Program for Transition

The figure outlines a "staged approach" that, while in the end may result in performing a second full Fire PRA for the fictitious "fully compliant" plant pre-transition, may enable reduced effort to calculate the individual, and cumulative, delta-risks resulting from transitioning with previous non-compliances proposed for inclusion in the post-transition licensing basis (for which the delta-risk is estimated through a plant change evaluation). Note that the aggregation of the delta-risk from multiple plant change evaluations must ensure that any synergistic effects among them be properly captured, i.e., the simple summation of the delta-risks may not adequately represent the cumulative effect.

Step 0: Calculate the risk (CDF and LERF) "going forward," i.e., the risk of the plant after transition is complete, including implementation of all committed modifications, both to systems, structures, and components, and to procedures. This risk likely will be estimated for a future time after submission of the LAR and receipt of the SER, contingent upon fulfilling all commitments within a reasonable time frame, as outlined in the LAR and approved in the SER. This "going-forward" risk is labeled as "Risk@T" in the figure.

Step 1: This simplistic stage would suffice in the estimate of the individual and cumulative delta-risks from plant change evaluations if the "going-forward" risk were used as the maximum possible cumulative delta-risk and completely satisfied the acceptance thresholds ("ATs" in the figure) of RG 1.174. This simplistic case just assumes that the fictitious "fully-compliant" plant pre-transition had a total risk of zero, clearly an idealistic case (the "fully-compliant" pre-transition risk is labeled as "Risk-pT" in the figure). Here the cumulative delta-risk ("ΔR@T" in the figure) is equal to Risk@T. This stage represents the minimum expenditure of analysis resources (time, effort and cost ["TE$" in the figure]).

Step 2: This stage employs a realistic approach to defining the fictitious "fully-compliant" pre-transition plant, i.e., one where pre-transition forms of regulatory compliance are assumed to be in place, such as the requirements of Appendix R, Section III.G (these may include features approved specifically by SERs or exemptions in the licensee's pre-transition FP licensing basis, such as approved, feasible and reliable operator manual actions for "III.G.2 fire areas").[25] Both individual and cumulative delta-risks, with synergistic effects for the cumulative, are estimated for the plant change evaluations, now using this "realistic, but still fictitious, fully-compliant" pre-transition plant to estimate Risk-pT. The delta-risk is reduced from the bounding estimate in Step 1 since Risk-pT is no longer assumed to be zero, i.e., now ΔR@T = Risk@T – Risk-pT. This stage represents an increased, but hopefully still moderate, expenditure of analysis resources relative to Step 1. The expectation is that most plants could terminate their delta-risk calculations for plant change evaluations at this stage.

Step 3: This stage essentially requires the development of the second full Fire PRA, now for the fictional "fully-compliant" pre-transition plant, likely due to the inability to accurately account for the synergistic effects of the cumulative delta-risks from a simple summation of the delta-risks for the multiple individual plant change evaluations. Obviously, this requires the maximum expenditure of resources and effectively renders the staged approach ineffective, other than having performed some previous analyses that may streamline the final development of the full pre-transition Fire PRA. Hopefully, the individual and cumulative delta-risks resulting from this stage meet the acceptance threshold of RG 1.174, so no further analysis is needed. However, if they do not, Step 4 exists.

Step 4: Now with a pair of full Fire PRAs available, one for the "going-forward" plant and the other for the fictitious "fully-compliant" pre-transition plant, "what if" analyses are readily performed to ascertain which plant modifications, including procedural, will lower the going-forward risk to a level where the delta-risk becomes acceptable under the RG 1.174 thresholds. Note that a licensee may choose to perform aspects of Step 4 following Step 2 in lieu of the likely major expenditure of resources associated with Step 3, i.e., investigate "what if" modifications using the limited model of the fictitious "fully-compliant" pre-transition plant developed in Step 2. However, the licensee must ensure that the potential synergistic effects from cumulative plant changes comprising the "what ifs" are accurately incorporated, something that would be essentially assured by performing Step 3.

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[25] Note that, where multiple forms of compliance are available (e.g., Appendix R, paragraph III.G.2), the licensee may choose any of them to estimate Risk-pT. Obviously, choice of the "least non-risky" form of compliance will give the largest Risk-pT and smallest ΔR@T, an option that was intentionally left to the licensee's discretion in the development of RG 1.205. For example, it is likely that, for a fire area where a hot gas layer is possible, assuming full compliance consists of 20-ft separation with no intervening combustibles, and installed detection and suppression, may lead to a higher Risk-pT, and therefore lower ΔR@T, than assuming full compliance via a three-hour fire barrier.

ATTACHMENT

There are two major "delta-risk" calculations for NFPA-805 transition. The first must always be performed, including its subset. The second may need to be performed depending upon the results of the first.

For all delta-risk calculations, the starting point is the Fire PRA for the plant post-transition AND after implementation of all committed modifications, hardware and procedural. For simplicity, we will refer to this as the "post-transition/post-implementation" (PT/PI) plant. In both Figures 1 and 2, the risk associated with the PT/PI plant is shown as a straight line across the top. It is invariant in all delta-risk calculations.

Delta-Risk for Variances from Deterministic Compliance (VFDRs)

All transitions must evaluate the delta-risk (increase) associated with the retention of Variances from Deterministic Requirements (VFDRs), which includes all credited NFPA-805 "recovery actions" as a subset. To calculated the delta-risk (increase) associated with the VFDRs, a fictitious "pre-transition, deterministically compliant" plant, subsequently referred to as the COMP Plant, is postulated such that, for each VFDR, a deterministically-compliant (e.g., via 10CFR50.48, Appendix R), less "risky" configuration exists. For VFDRs related to cables or recovery actions, for example, a COMP plant might postulate removal of one of two redundant cable trains completely from a fire area, or enclosing the cables of one train in a three-hour-rated fire barrier. The change (increase) in risk of the PT/PI plant relative to the COMP plant is then calculated as the delta-risk associated with the VFDR(s).

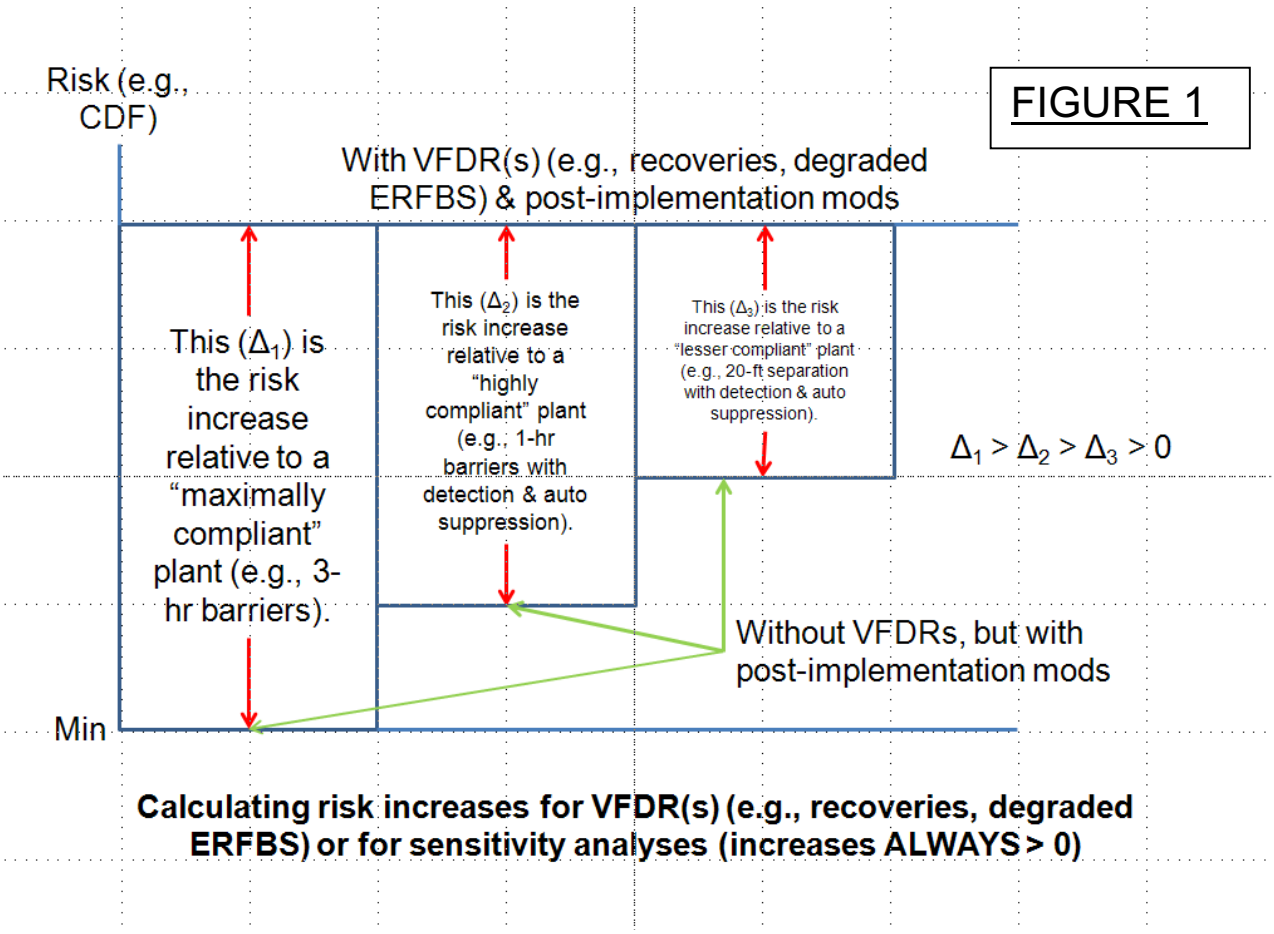
Figure 1 illustrates this calculation. In the first case, a "maximally" COMP plant is postulated, e.g., enclosure of the redundant cables in a three-hour-rated fire wrap (or, Electrical Raceway Fire Barrier System, ERFBS), or even complete relocation of the cables to another fire area. Since this represents the "minimally-risky" COMP plant configuration, the difference between the risks of the PT/PI and COMP plants will be maximum (Δ_1). One could stop the analysis here if the resulting delta-risk (increase) were deemed low enough to satisfy the RG-1.174 quantitative criteria applicable to the transition (also note there are qualitative criteria to be satisfied under RG 1.174, but these are not discussed here).

If the delta-risk (increase) does not satisfy these criteria, or the analyst desires to claim a lower delta-risk for the transition, a less, but still "highly," COMP plant configuration can next be postulated. Such would have a higher COMP plant risk than the previous, resulting in a lower, but still positive, delta-risk (increase). In Figure 1, this is illustrated by showing the COMP plant configuration as postulating a one-hour-rated fire barrier with detection and automatic suppression in the fire area (Δ_2). This can be taken further as well, as illustrated by the third part of Figure 1. Here, the COMP plant is postulated to have the "riskiest" configuration in terms of Appendix R protection, namely 20-foot separation without intervening combustibles, but with detection and automatic suppression. The resulting delta-risk (increase) is even smaller, but still positive (Δ_3).

What Figure 1 shows is that, no matter how deterministically compliant one postulates the COMP plant, the delta-risk (increase) will always be positive. These delta-risks can be reduced by postulating lesser degrees of compliance, but they will still remain positive. In equational format, this calculation is as follows:

$$\text{(Delta-Risk with VFDRs)} = \text{(Risk for PT/PI plant)} - \text{(Risk for COMP plant)} > 0$$

where BOTH the PT/PI and COMP plants include all modifications



Delta-Risk for Recovery Actions

As a subset of this calculation, the delta-risk (increase) associated with NFPA-805 recovery actions must also be evaluated. This parallels the previous calculation, except that now deterministic compliance is postulated ONLY for the VFDRs associated with recovery actions. Other VFDRs are not varied between the PT/PI and COMP plants. As a result, the delta-risk (increase) associated with recovery actions cannot exceed the corresponding value for all VFDRs with any level ("maximally," "highly," or "lesser" compliant). The delta-risk (increase) for recovery actions must be calculated at the same level as its counterpart for all VFDRs. Equationally, this is a slight modification of the above:

$$(\text{Delta-Risk with VFDRs})_{\text{recoveries only}} = (\text{Risk for PT/PI plant}) - (\text{Risk for COMP plant})_{\text{crediting only recovery compliance}} > 0$$

where BOTH the PT/PI and COMP plants include all modifications, but the COMP plant credit deterministic compliance only for the VFDRs involving recovery actions.

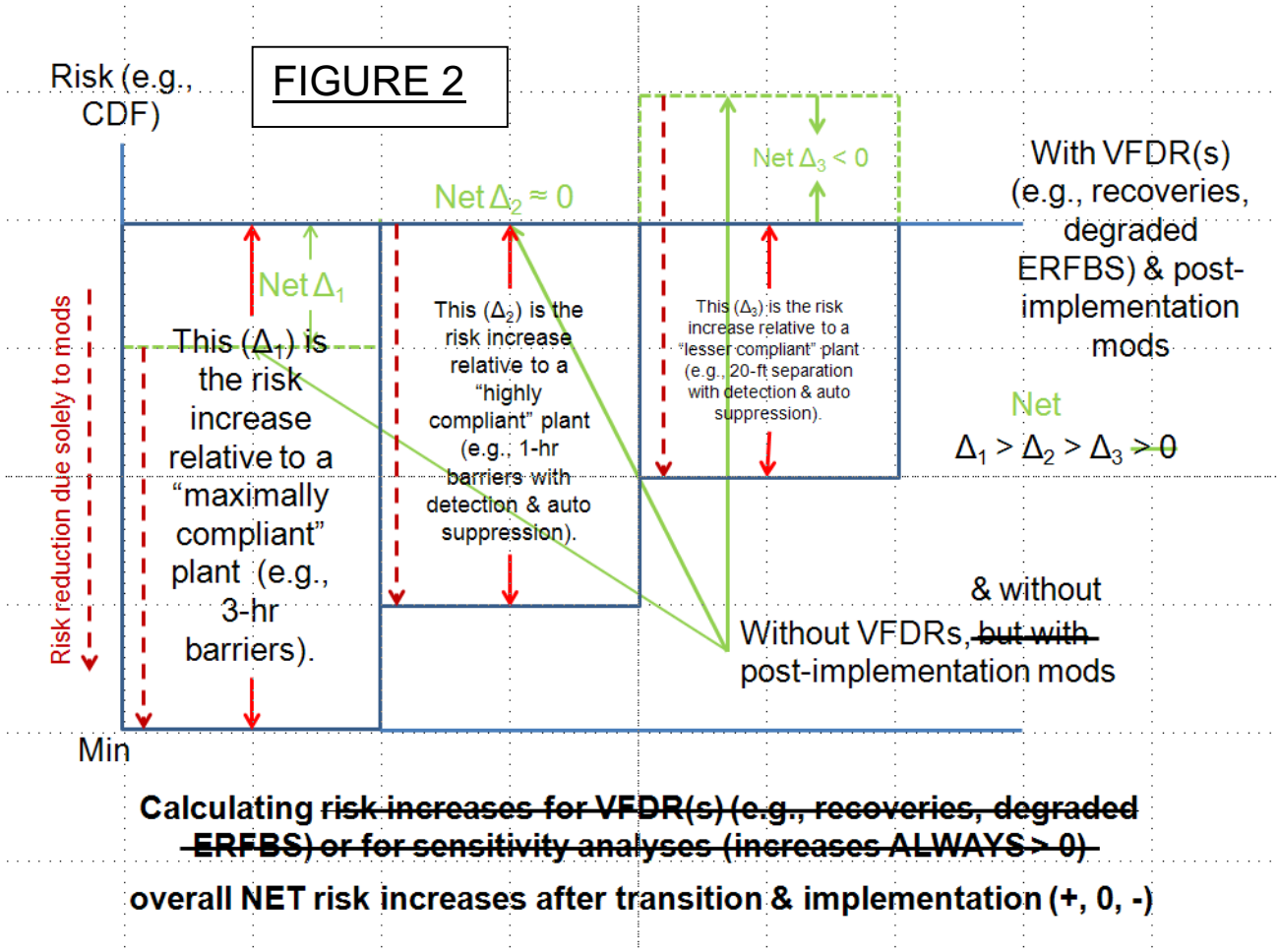
Overall Net Delta-Risk

If the results from these delta-risk (increase) calculations are deemed to satisfy the quantitative criteria from RG 1.174 for transition, the analysis can terminate (the qualitative criteria must also be satisfied). However, if they do not, or the analyst wishes to show even lower delta-risks (increase) or even a risk reduction (negative delta-risk), the "overall net delta-risk" can be evaluated. This process is shown in Figure 2 and

parallels that from Figure 1 with one key difference. When postulating the COMP plant, now the modifications are excluded from the COMP risk. This results in higher estimates of the COMP risk at each step, such that the net delta-risk (increase) could now actually become negative (decrease) as a result of the modifications. In Figure 2, this is shown by raising the COMP risk via the hatched green lines, thereby reducing each of the delta-risks, now termed the "overall net delta-risks," even to the point of becoming negative (shown as the third case in Figure 2). In equation format, the net delta-risk (increase) is as follows:

$$(\text{Overall Net Delta-Risk}) = (\text{Risk for PT/PI plant}) - (\text{Risk for COMP plant})_{\text{without modifications}}$$

where the COMP plant now excludes all modifications.



Also shown is the "risk reduction due solely to modifications," which is the difference between the risks of the PT/PI plant with and without the modifications (shown In Figure 2 as the equivalent difference between the risks of the COMP plant with and without the modifications). In equational format, this is as follows:

$$(\text{Risk Reduction due Solely to Modifications}) = (\text{Risk for PT/PI plant}) - (\text{Risk for PT/PI plant})_{\text{without modifications}} > 0$$

FIGURE II

PLANT →	Plant A		Plant B		Plant C		Plant D		Plant E		Plant F		Plant G		Plant H	
TASK ↓	%	Sched	%	Sched	%	Sched	%	Sched	%	Sched	%	Sched	%	Sched	%	Sched
Non-compliances & comp measures	Available		Available		Available		Available		Available		Available		Available		Available	
Operator manual actions as comp measures	Feasible		Feasible		Feasible		Feasible		Feasible		Feasible		Feasible		Feasible	
Physical mods	Non-805		Non-FP ID'd		None		None		None		None		None		None	
Table B-1	60	3Q09	91	121208	90	102008	27	3Q09	100		100		33	Aug09	84	Feb09
Table B-2	80	3Q09	80	013109	75	102808	67	1Q09	100		100		80	Aug09	50	May09
Table B-3	60	1Q10	60	021509	60	120508	10	4Q09	40	Dec08	94	Sep08	25	Mar09	24	May09
Non-Power Ops	0	3Q09	58	122608	75	121508	12	3Q09	0	Dec08	65	Oct08	5	Sep09	2	Jul09
Monitoring	Implied		Implied		Implied		Implied		Implied		Implied		Implied		Implied	
Fire PRA	40	1Q10	72	030209	30	063009	26	3Q10	39	Jun09	61	Nov08	10	Sep09	55	Oct09
Rad release	*75*	*3Q09*	*98*	*121508*	*100*		*0*	*2Q09*	*55*	*Oct08*	*95*	*Sep08*	*5*	*Sep09*	*100*	
SSD analysis	*100*		*82*	*021509*	*90*	*102208*	*N/A*		*N/A*		*95*	*Sep08*	*90*	*Feb09*	*N/A*	
Plant change evals					*5*	*063009*										

Bold required; italic optional

Colors represent:	**May be unacceptable**	**Probably acceptable**	**Seemingly appropriate**	**Clear = no judgment**

TABLE I

Plant	Fire CDF			Fire LERF		
	Post-Transition	Delta	Pre-Transition	Post-Transition	Delta	Pre-Transition
1	6.00E-05	-1.48E-03	1.54E-03	3.23E-07	-8.03E-06	8.35E-06
2	5.08E-05	-6.38E-04	6.89E-04	6.75E-07	-4.89E-06	5.57E-06
3	6.28E-05	-5.37E-04	6.00E-04	2.14E-06	1.93E-07	1.95E-06
4	5.30E-05	-5.45E-04	5.98E-04	1.83E-06	1.18E-07	1.71E-06
5	6.95E-05	-4.67E-04	5.37E-04	1.90E-06	3.19E-08	1.87E-06
6	6.47E-05	-4.40E-04	5.05E-04	1.39E-06	-1.52E-05	1.66E-05
7	4.70E-05	-4.50E-04	4.97E-04	5.20E-06	-5.70E-05	6.22E-05
8	4.59E-05	-3.33E-04	3.79E-04	1.03E-06	-5.51E-07	1.58E-06
9	6.51E-05	-2.41E-04	3.06E-04	6.05E-06	-3.10E-05	3.71E-05
10	5.17E-05	-2.50E-04	3.02E-04	3.09E-06	-2.35E-05	2.66E-05

APPENDIX I

How "Fuzzy" Are the RG 1.174 CDF and LERF Regional Change Threshold Values?

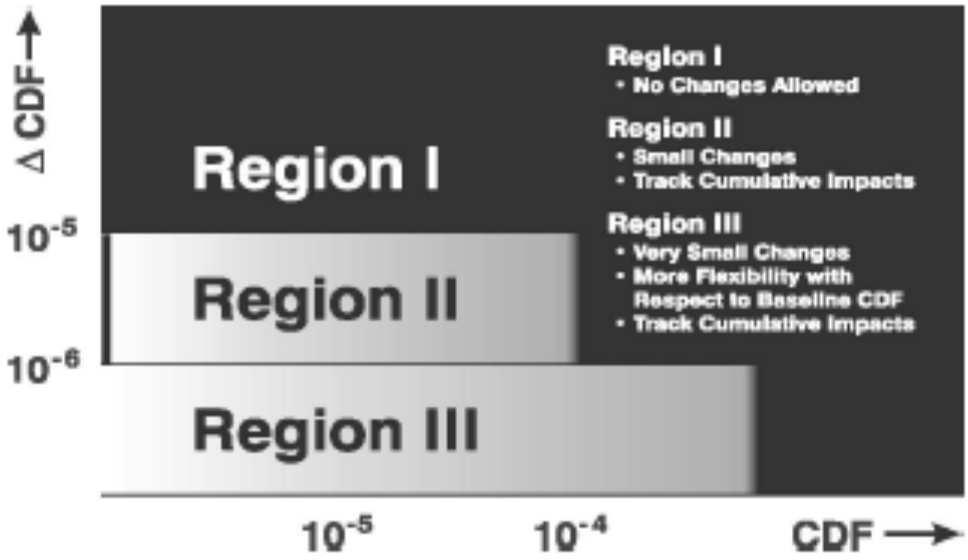


Figure 4 Acceptance guidelines* for core damage frequency

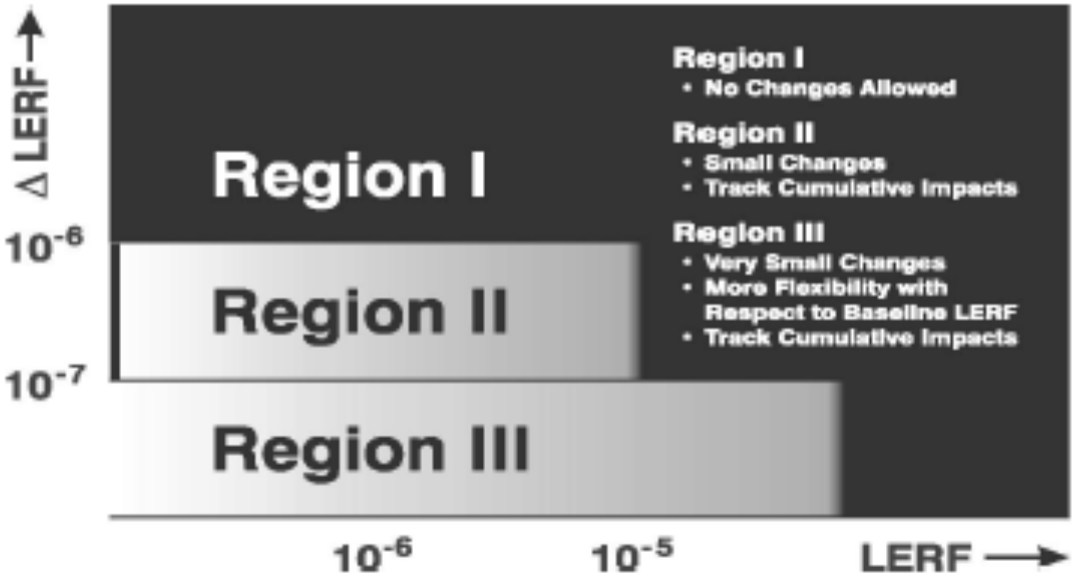


Figure 5 Acceptance guidelines* for large early release frequency

From these figures taken from RG 1.174, it appears that any "fuzziness" at the Regional thresholds occurs more so along the x (total CDF or LERF) than y (delta-CDF or LERF) axis. The transition lines for the delta values are quite distinct. That being said, we can still allow for some "fuzziness" along the vertical axes by adhering to the RG 1.174 philosophy (implied) of basing quantification on "order of magnitude" (factor of 10). If the vertical axis were linear, it would seem defensible to assume a maximum "fuzziness" at the transition lines of 10% (sticking to the "order of magnitude" philosophy). Thus, if the vertical range

is from 1 to 10 on a LINEAR scale, a 10% "maximum" would occur at 1 + 0.1 x (10 – 1) = 1.9, almost double the "distinct" limit. However, these figures are logarithmic. A 10% "fuzziness" on a LOGARITHMIC scale implies a maximum of $10^{0.1}$ = 1.26. Thus, an "absolute" upper limit before transitioning from one Region to the next vertically would be 1.26 times the "distinct" limit.

Note that allowance of this additional "wiggle room" is clearly more defensible for transitioning from Region III to II, since, even in Region II, increases are allowed with restrictions. Whether this additional "wiggle room" should be allowed for a transition from Region II into I is debatable, as Region I is strictly forbidden to increases. Proposing an equal upward shift (relative) for this threshold, which is "absolutely" 10 times greater than the Region III to II threshold, requires greater justification, if it is to be allowed at all.

APPENDIX II

The Plot Sickens

As stated, I opposed the issuance of FAQ 08-0048 from its inception, without a "backstop" requiring that all fire ignition frequencies be subjected to a sensitivity analysis using the original values from NUREG/CR-6850. Despite my repeated calls for its "sunsetting" as evidence mounted through audits by NRC's Office of Nuclear Regulatory Research (RES) of the more recent fire events data being collected indicating the "updated" frequencies would be similar to the originals, and not the artificially lowered values from the FAQ, and the "final straw" of the Baranowsky paper at ANS PSA 2013, NRC management finally officially refused to consider any further discussion of "sunsetting" FAQ 08-0048 (eight months after being informed of the Baranowsky paper). With no recourse left, I formally filed a Differing Professional Opinion (DPO) describing my objections to the continued use of this FAQ and called for its immediate rescinding (ADAMS Accession No. ML14058A360, "Differing Profession Opinion Involving Existing Frequently Asked Question for Fire Protection [08-0048, 'Fire Ignition Frequency'], DPO-2014-001," February 10, 2014). The full package of material supporting this DPO is available via the ADAMS Accession No. ML15273A079.

In addition to discussing the flaws with the FAQ and its tainted history, including my repeated attempts to have it "sunset," I emphasized that its continued use would be detrimental in two ways. First underestimation of risks (and delta-risks) used as the basis for transition created a false sense of "less riskiness" at the time of transition, discouraging potentially beneficial modifications/changes that would have been made to lower risk (and delta-risk). Second, with "approved" underestimates in risk, licensees could exercise their right of "self-approval" post-transition/implementation for plant changes where they should be reporting to the NRC or possibly requesting our approval. To address this generic issue, potentially affecting all plants transitioning to NFPA 805, including those already granted license approval, I roughly estimated the risks and delta-risks reported for the NFPA-805 plants and doubled them, as a surrogate for the potential effect of using the more representative original NUREG/CR-6850 fire frequencies instead of those from FAQ 08-0048. It appeared that most plants were potentially affected.

Two months transpired before this DPO began the review process. As reported by the DPO Project Manager (DPOPM), this was an unusually long time to start the review process. Apparently, there had been considerable "pushback" from cognizant NRC management not to accept this DPO into the process as it posed a considerable threat to disrupting the expeditious approvals being sought for the NFPA-805 non-pilot plants. The final acceptance memo further clouded the issue in an attempt to dilute the DPO by expanding the scope of the DPO to issues beyond the subject and better deliberated via a different forum. This expansion included the "freeze point" concept, previously discussed, as well as a mini-referendum on the role of risk-informed regulation itself.

I could only perceive this "expansion" of the DPO to be an attempt not only to dilute it but also to delay its processing in hopes that developments would transpire to perhaps render it moot. The DPOPM confirmed that this "expansion" of the DPO was unprecedented and, despite her efforts to have the language removed from the issuance of the memo, NRC management had remained obstinately opposed. I, naturally, immediately objected to its inclusion when the memo was issued, seeing this as intended to "pre-prejudice" the panel against my DPO as it represented the introduction of arguments by my immediate NRC management against my DPO formally to the Panel before they had even begun their review. After meeting with NRC management at their request, the DPOPM and I were able to obtain some "relaxation" in that the DPO panel would be directed to leave the "broader issue" and "freeze point" aspects out of the specific DPO evaluation. Nonetheless, these had been introduced and brought to the panel's attention, such that the

extent to which the panel could completely eliminate them from any consideration with respect to the DPO would be unknown.[26]

The panel completed its report in December 2014, not surprisingly rejecting my recommendation for "sunsetting" the FAQ (given how the DPO process transpired from the start). As justification, it argued that a limited sensitivity analysis required by FAQ 08-0048 adequately addressed any risk (and delta-risk) underestimate in the interim until the new fire event frequencies were completed. I had dismissed this early on in my DPO, as discussed previously, as woefully inadequate and had conveyed this to the panel. In my appeal of the DPO decision to the Executive Director for Operations (EDO), submitted in the same month, I re-emphasized this, particularly noting that

> *A representative sample of eight* [NFPA-805] *LARs* [licensee amendment requests indicated that] *... the contribution to total fire risk from Bin 15 fires* [from electrical cabinets, often cited as the dominant contributor to fire risk and the main "bin" subject to the limited sensitivity evaluation of the FAQ] *ranged from 6% to 60%, clearly not dominant at the lower end ... Even if those eight LARs used the limited sensitivity evaluation as their best estimate for total risk (which would NOT be an appropriate use of a sensitivity evaluation), with the fire frequencies on average being a factor of two underestimated, the correct total risk would still be 25% (for the 60% Bin 15 contribution) to 90% higher (for the 6% Bin 15 contribution) than the limited sensitivity estimate. Despite the Panel's accordance of significance to this limited sensitivity evaluation, it remains clear that it was woefully inadequate from the start.*

I further noted that a sensitivity evaluation, used in lieu of an uncertainty analysis, on one of the early non-pilot plants and employing the original NUREG/CR-6850 fire frequencies, increased total fire CDF from 2.0E-5/y (via FAQ 08-0048) to 5.0E-5/y, further illustrating the inadequacy of the limited sensitivity evaluation required by the FAQ. Also arguing against the panel's acceptance of the limited sensitivity evaluation as adequate is that sensitivity analyses presume that the base analysis uses the best available data and information, such that the sensitivity portion is merely to address uncertainty on what is considered a valid data set (it is often used in lieu of a more complicated full uncertainty analysis or to ascertain individual parameter effects). My appeal also cited the potential delaying/diluting effect of the unprecedented expansion of the scope of my DPO as discussed above.[27]

Upon issuance of the appeal decision by the EDO on September 22, 2015 (which extended the entire duration of this DPO to over a year and seven months, possibly the second longest DPO in the available

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[26] In response to this latest disappointment with the handling of the DPO by NRC management, I reviewed the previous eight DPO tasking memos available on the NRC DPO website (http://www.internal.nrc.gov/OE/DPO/) to determine if such "extraneous" language had ever been included before. Based on my review of these eight previous DPOs (DPOs 2008-001, 2008-002, 2009-001, 2010-001, 2011-001, 2011-002, 2012-001 and 2012-003), no such insertion had ever been made. Furthermore, a review of the guidance in Management Directive (MD) 10.159, "The NRC DPO Program," indicated that the Office Director (OD) or Regional Administrator (RA) in charge of creating and tasking the DPO Panel shall issue a **standard** tasking memorandum, not expanding the scope as was done. Coupled with the inordinate delay in assigning this DPO to the Panel (two months); the further delay (another month) when the Panel stopped all activity, after an initial meeting with me, in order to get clarification on the scope of their task, due to the extraneous insertion in the memo; and the final failure to divorce the DPO from the extraneous issues (confirming that my DPO should be treated as a "first step" in conjunction with subsequent examination of the extraneous issues), I informed the DPOPM that I considered the DPO Process to have been manipulated beyond the MD 10.159 guidance and all precedence considering the previous eight tasking memos such that bias against my DPO may have been intentionally introduced into the process.

[27] Subsequent to my filing the appeal, I learned of a possible bias by one of the panel members against me, as I overheard him during a meeting refer to me as "considering [myself] as 'God's gift to Fire PRA.'" Furthermore, another colleague who had been interviewed as part of the DPO process, informed me that the panel was misinformed by management interviewees when they were told that the NRC planned to rescind/update the FAQ as soon as the new fire frequencies were available, likely an influence on the panel's decision. This was misleading, at best (intentionally deceptive, at worst?), as the FAQ remained unchanged even after final issuance of the new report.

archives), I received mixed results. The EDO acknowledged the improper expansion of the scope of the DPO and, along with the DPOPM, instituted changes to the process to prevent this from happening in the future.

> *... [T]he tasking of the ad-hoc review panel was inconsistent with the standard process used for previous DPO reviews under MD 10.159. The additional charter to look at a licensing "freeze point" concept was beyond the scope of your DPO, and likely resulted in delay of the initial review by the ad-hoc review panel. This additional tasking also could be reasonably perceived as steering the independent ad-hoc panel to advocate management's established view in response to your DPO. I expect all staff and management to follow the current guidance in MD 10.159, which limits the scope of the review to that defined in the written DPO. On August 11, 2015, I approved an update to MD 10.159 to improve and incorporate lessons learned from a comprehensive assessment of the DPO Program, including concerns raised by you in your appeal. In part, the revised guidance now requires the DPO Program Manager to establish an independent panel to review a DPO in cooperation with the assigned office manager and the DPO submitter.*

However, he disagreed that this "expansion/dilution" would have affected the panel's interview process, deliberations and decision, thereby upholding their decision.

> *This additional tasking also could be reasonably perceived as steering the independent ad hoc panel to advocate management's established view in response to your DPO. However, I do not believe the panel findings were influenced or substantively biased. The panel independently and systematically reviewed the merits of your DPO and provided reasonable findings within the scope of your DPO.*[28]

Most troubling was the apparent disregard of the primary driver for this DPO, namely the questionable technical basis for the FAQ in the first place and the continued refusal by NRC management to rescind it, or at least permit a "full" sensitivity analysis for all fire ignition frequency bins that I had recommended from the beginning as an integral part of this FAQ. Over the nearly six years when this FAQ was in effect, during which the majority of NFPA-805 transitions were processed, the evidence mounted that the FAQ had been developed and approved on a knowingly flimsy, if not entirely false, basis. Even after this was confirmed by the primary author of the FAQ in his conference paper, the FAQ was allowed to promote artificial reduction of the fire risk and delta-risk estimates for NFPA-805 transitioning plants, a period of nearly two years. Meanwhile, NRC reviewers were prohibited by their management from requesting the full sensitivity analysis I had originally championed.

> *I agree with you that the FAQ was based on anomalous data. Subsequent to your appeal, this was further supported by the newest fire frequencies issued in January 2015 in NUREG-2169 "Nuclear Power Plant Fire Ignition Frequency and Non-Suppression Probability Estimation Using the Updated Fire Events Database." I support the decision by management not to immediately rescind or modify the FAQ at the time when a key industry consultant had published preliminary results because more time was needed to complete the analysis and for NRC staff to audit the results. However, I agree with you that NRC staff took too long to analyze and publish new data, rescind the FAQ, and update regulatory guidance for applying the new data ... With respect to the sensitivity analyses of a limited number of bins, I conclude the staff used its best judgment to attempt to identify the bins that could be most adversely affected by the yet-to-be-seen results of the 2000–*

[28] Note the failure to even comment on a possible bias by one of the panel members or the misinformation by management interviewees when they were told that the NRC planned to rescind/update the FAQ as soon as the new fire frequencies were available.

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2009 data review … In consideration of all the information provided in my appeal review, I do not believe this is a safety issue that is significant enough to require immediate licensing or inspection actions, given the defense-in-depth at operating plants. There are also safety margins, conservatisms, and defense-in-depth built into the overall NFPA-805 approach. The staff is currently developing the guidance for applying these new frequencies, along with new fire PRA methods and data in general, for all stages of NFPA-805 implementation. I am monitoring staff development of guidance to ensure it proceeds at a reasonable pace.

As is often the case, NRC management falls back on "conservatisms, defense-in-depth and safety margins" as a panacea for overlooking/overriding the quantitative risk results under the guise of "risk-informed ('not risk-based') regulation." In supporting the panel's conclusion that the limited sensitivity analysis was adequate because of these other considerations, overlooked was the fact that one of the dominant contributors to fire risk, if not the dominant itself, fires in the main control board of the main control room is now six times higher (NUREG-2169) than advocated in the FAQ, double even the original fire frequency from NUREG/CR-6850 which would have been subject to the limited sensitivity analysis. So far as the alleged "conservatisms" (an industry mantra since 2008, not actively fought by NRC management so that it has become an accepted "fact" and excuse for exceeding risk thresholds), these have been contradicted several times by NRC staff, to no avail so far as influencing NRC management to require licensees to remove the so-called conservatism when submitting NFPA-805 fire risk assessments (again, refer to the discussion in the main text regarding the approval of the NFPA-805 transition for the Duane Arnold Energy Center).[29]

I cannot help but be disillusioned with how this DPO transpired. Firm technical bases for rescinding the FAQ that should never have been approved in the first place were ignored throughout. Even the much needed requirement for a full sensitivity analysis that would have at least minimized the potential damage due to systematic underestimation of fire risk and delta-risk for NFPA-805 transitioning plants was prohibited by NRC management. One cannot help but conclude that an "*805 über alles*" policy took precedence over sound technical practice so as not to derail the NFPA-805 approval train. When given the opportunity to make a positive statement for technical integrity by rescinding this FAQ, NRC management refused, starting from the Branch Chief who not only refused to rescind the FAQ but also forbade requesting full sensitivity analyses on all fire frequency bins as part of the NFPA-805 review process; to the Division director who not only supported this policy (lest existing NFPA-805 transitioners be subject to reconsideration and future ones inconvenienced), but also strove to have this DPO dismissed (again, I wish to thank the DPOPM for persevering in allowing this DPO to go forward); to the original Office Director who attempted to dilute/derail the main thrust of the DPO, namely the false technical foundation of the FAQ, by improperly expanding the scope to include the "freeze point," no doubt at the Division Director's suggestion, and directed the panel to address both concerns, further confounding the process; to the subsequent Office Director who, despite recognizing the technical merits of the DPO, still chose to side with the panel and uphold the refusal to rescind the FAQ; and finally to the Executive Director for Operations who, despite receiving additional technical justification as to why the panel's basis for refusing

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[29] 1. Gallucci, R. 2006. "Predicting Fire-Induced Core Damage Frequencies - A Simple 'Sanity Check'," Transactions of the American Nuclear Society, Vol. 94, June 4-8, 2006, Reno, Nevada, pp. 202-204.
2. Gallucci, R. 2011. "How Immature and Overly Conservative is Fire PRA? (A Comparison of Early vs. Contemporary Fire PRAs and Methods)," American Nuclear Society International Topical Meeting on Probabilistic Safety Assessment, PSA 2011, March 13-17, 2011, Wilmington, North Carolina.
3. Gallucci, R. 2012. "'What – Me Worry?' 'Why so Serious?' A Personal View on the Fukushima Nuclear Reactor Accidents," Risk Analysis: An International Journal, Volume 32, Number 9, Society for Risk Analysis, McLean, Virginia, September 2012, pp. 1444-1450 (also available online as*http://onlinelibrary.wiley.com/doi/10.1111/j.1539-6924.2011.01780.x/full)*.
4. Siu, N., et al. 2015. "Fire PRA Maturity and Realism: A Discussion and Suggestions for Improvement,")," American Nuclear Society International Topical Meeting on Probabilistic Safety Assessment, PSA 2015, April 26-30, 2015, Sun Valley, Idaho.

to support the FAQ's rescinding was flawed, ultimately sided with NRC management and refused to acknowledge that the FAQ should have been rescinded.[30] Clearly, "*805 über alles*" prevailed and the decision-makers in the DPO process "circled the wagons" to uphold that policy. And, even if one does "not believe this is a safety issue that is significant enough to require immediate licensing or inspection actions," one cannot deny that for nearly six years the NRC's allowance of inappropriately reduced fire risks for NFPA-805 transition likely discouraged safety improvements that should have been made, even if the plants were "already safe."

[30] See "Author's Final Comments on Disposition of DPO-2014-001, 'Existing Frequently Asked Question for Fire Protection,'" for my reaction to the appeal, filed separately in ADAMS (Accession No. ML14063A088) from the DPO itself.

APPENDIX III

Completing the Circle

Appendix II described the fiasco that ensued from issuance of FAQ 08-0048 on fire ignition frequencies, complete through the DPO and eventual issuance of the new frequencies via NUREG-2169. Unfortunately, the other FAQ (08-0046 on VEWFD systems) cited for its lack of technical justification prompted a similar long-term misadventure, ultimately resulting in yet another unsatisfying conclusion, highlighted by a Non-Concurrence against the endorsement by NRC of the resultant NUREG (-2180).[31] As mentioned, this FAQ was issued based in part on no more than manufacturer claims and limited operating experience. As became standard practice with the nuclear industry during the NFPA-805 era, experiments were not performed to justify alleged risk reductions, leaving it to the NRC to perform "confirmatory experiments" (really first-principle experiments) as it felt unable to reject industry claims unless it could prove them lacking (contrary to requiring industry to prove its claims before NRC accepting, clearly a backward process). The DELORES-VEWFIRE program (NUREG-2180) was the "confirmatory research" conducted by the Office of Nuclear Regulatory Research (RES) to examine the risk reductions approved in FAQ 08-0046.

Before DELORES-VEWFIRE started, I recommended "wiping the slate clean" from the original FAQ which, in my opinion, had little, if any, technical basis, was politically motivated (to enable one of the pilot plants to achieve exorbitant risk reductions without having to make meaningful modifications), and clearly exaggerated any risk reduction attainable from installation of in-cabinet VEWFD systems. Specifically, I counseled against retaining the event tree approach used in the FAQ and appending unnecessary human reliability analysis (HRA) as was done in the FAQ. Also, it was critical to accurately assess just what fraction of fires that would evolve to be "challenging" and, therefore, counted as part of the fire ignition frequencies could be detected in the pre-combustion phase. This could only be done experimentally by performing fairly long-term tests whereby some initial overheat of a conductor was allowed to progress without interference to determine whether or not a "challenging" fire would evolve. If so, and it was detected by a VEWFD system during the pre-combustion phase, it could be assumed that the fire would be pre-empted and qualify as a reduction in the fire frequency. Otherwise, the only benefit from the VEWFD system might be some "bonus" time in suppression response once the "challenging" fire manifested itself and was detected. To my disappointment, but not my surprise, none of these recommendations was adopted,

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[31] Prior to issuing the Non-Concurrence ("Response to July 28, 2016, Letter Regarding Retirement of National Fire Protection Association 805 Frequently Asked Question 08-0046 'Incipient Fire Detection Systems,'" NCP-2016-017 [ADAMS Accession No. ML16253A111), I found it necessary to "threaten" (from some NRR management's perspective) yet another DPO, this one against failure to rescind FAQ 08-0046 on a timely basis. Several allegedly draft "final" versions of NUREG-2180 had been issued for review and comment since early 2015 with the intention that, after any modifications, the NUREG would be issued and endorsed by NRR as a replacement for the then sunset FAQ 08-0046. Unfortunately, each iteration resulted in substantial changes to the NUREG such that, after another year, it had still not be issued and FAQ 08-0046 still not sunset. Following what was supposed to be the final exhibition of the NUREG via a public meeting on April 26, 2016, followed by its issuance and endorsement by NRR as the replacement for the FAQ, the NEI requested yet another delay to "pilot" the NUREG. Once this delay was granted by RES (after yet a further delay of six weeks), I announced my intention to NRR to DPO the failure to have sunset FAQ 08-0046 on a timely basis (the evidence for its invalidity had long been overwhelming, including the results from the DELORES-VEWFIRE tests) in an effort to divorce the FAQ's rescinding from the NUREG (effectively the FAQ was being kept "hostage" so long as the NUREG remained unendorsed, thereby allowing the ridiculous credit from the FAQ to still be taken by licensees). Fearing yet another DPO in the NFPA-805 arena, NRR acceded to rescind the FAQ effective on July 29, 2016, independent from the status of NUREG-2180 (see "Retirement of NFPA-805 FAQ 08-0046 'Incipient Detection Systems'," July 1, 2016, ADAMS Accession No. ML16167A444). To no surprise, the industry officially objected to the elimination of the FAQ ("Industry Response to July 1, 2016, Letter on Retirement of NFPA Standard 805 FAQ 08-0046, Incipient Fire Detection Systems," July 28, 2016, ADAMS Accession No. ML16211A327), prompting a second letter re-emphasizing the rescindment and its technical basis and endorsing NUREG-2180 as is as "an accepted method that supersedes the interim guidance provided in the FAQ 08-0046 closure memorandum" ("Response to July 28, 2016, Letter Regarding Retirement of NFPA-805 FAQ 08-0046, 'Incipient Fire Detection Systems'," November 17, 2016, ADAMS Accession No. ML16327A460). This eliminated my need to issue a DPO, but not the need to still non-concur on NUREG-2180 whenever it would finally be endorsed.

and the DELORES-VEWFIRE program attached itself to the framework of the original FAQ and defaulted to interpretation of the fire events database to estimate the fraction of "challenging" fires that might be pre-empted. To me, this was akin to the refusal to establish a phenomenological basis for any quantification as with the Unreviewed Analysis Methods previously discussed, which prompted a dissent and ultimately refusal of the NRC to approve an industry-championed approach (although a version was later approved as FAQ 14-0009).[32]

Upon completion of DELORES-VEWFIRE, an updated, and much expanded (over-modeled in my opinion) event tree approach was developed to quantify the risk reduction attainable via VEWFD vs. "conventional spot" detection systems, both in-cabinet and area-wide. The "alpha" factor representing the fraction of "challenging" fires detectable by a VEWFD system remains based on interpretations from the fire events database and, in conjunction with, in my opinion, an optimistic HRA approach for responding to a VEWFD alert and pre-empting a fire, constitutes much of the reduction deemed attainable. While clearly an improvement over the original factor of 50 from FAQ 08-0046, as much as a factor around ten still can be obtained for the most optimistic case, based on several non-conservatisms with which I take issue. Ultimately, an alpha value ranging from 0.50 to 0.72 on average is advocated. This alone leads to a risk reduction via pre-empting fires, given successful human response, from a factor of two to nearly four (1/[1 – 0.50] = 2 to 1/[1 – 0.72] = 3.6). Even if this result is reasonable, it lacks any experimental confirmation.

Elaborating on the non-conservatisms embedded in the HRA is beyond the level of detail appropriate for inclusion here. Specific comments on the various phases were provided to the authors for their consideration. Suffice it to say that my belief on non-conservatism for the HRA stems from apparent overly optimistic assumptions of the response by plant operators to a pre-combustion phase VEWFD alert signal, namely that operators would essentially "drop everything" to flush out the potential fire. Alleged to be based on adherence to representative plant procedures, the reality of the situation is that any response, especially to a pre-combustion alert when no fire is manifest or likely to manifest in the near-term, would be "relaxed," perhaps alerting an auxiliary operator to check on the alert while making his rounds. Nonetheless, given sufficient time between the alert and the fire manifesting itself, it seems reasonable to assume that the potential fire location could reliably be identified. Therefore, even with the over-optimism, it appears unnecessary to perform such detailed HRA for identifying the fire source, hence my claim of "over-modeling." Of course, much of this depends on the "addressability" of the VEWFD system, i.e., its ability to isolate the location of the pre-combustion phenomenon to an individual electrical cabinet. This would vary with the type of VEWFD system and how it is configured. Note that it could be matched even using conventional spot detection if the detectors were placed inside every electrical cabinet, so any advantage from addressability depends highly upon the assumptions for the comparison.

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[32] "[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 without proper phenomenological fire modeling. The only defensible way to calculate a fraction of candidate fires for VEWFDS is to run the long-term tests I have continued to advocate from the start, where an initial molecule is emitted and allowed to progress to determine if an actual fire ever ensues and if the VEWFDS (vs. other detector) detects in the non-fire stage and, if so, when. Absent such testing, everything will remain speculative. No expert elicitation should be attempted to try to conjure up a factor so dependent upon chaotic phenomena such as the first molecule and subsequent fire growth. This requires controlled experimentation. 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 than 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)

The most egregious non-conservatisms stem from assumptions regarding suppression, in particular the choice of non-suppression probabilities for fires detected by VEWFD systems once the flaming stage has occurred. 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 Main Control Room (MCR) fires, as per NUREG-2169, "Nuclear Power Plant Fire Ignition Frequency and Non-Suppression Probability Estimation," October 2014. This itself is based 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 a self-contained breathing apparatus 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.[33]

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.

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[33] When actually confronted by such a VEWFDS "early warning" scenario, the Harris plant actually twice terminated the alarm after an hour since no "pre-fire" could be located, with the responder leaving the area. Only after the third alarm, 90 hours later, was the "pre-fire" located. Thus, if the "representative" plant did not even follow the idealized response procedure, what expectation would there be for another to do so? Clearly, it is unrealistic, and non-conservative, to assume the responder will remain at the site indefinitely after a "pre-fire" alarm. The VEWFDS will be reset and the scenario reinitiatied, as demonstrated at Harris itself.

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:[34]

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 (my concerns that the quantitative aspects are too optimistic preclude recommending their preservation).

[34] ASD = aspirating smoke detector; CC = cloud chamber; ION = ionization detector; LS = light-scattering detector.

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), 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.

This leaves quite a dilemma regarding the usefulness of NUREG-2180. As indicated in the paper cited above, only the cloud chamber VEWFD system exhibited on average a time "bonus" relative to conventional spot detection; neither the sensitive spot nor the laser-scattering VEWFD system did. Therefore, results from NUREG-2180 of a risk reduction factor depend on how much the one VEWFD system showing some benefit was not miscalibrated. This is a very flimsy framework on which to base an endorsement. Nonetheless, there are limited alternatives because, without endorsing something, the egregiously over-generous FAQ 08-0046 remains in effect. Clearly this needs to be rescinded.

In lieu of endorsing NUREG-2180 and all its flaws, I see three options. First would be to return to the original credit for in-cabinet high-sensitivity smoke detection from NUREG/CR-6850 (Appendix P):

> *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.* ***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).*** **[my emphasis]**

This would result in a risk reduction via the non-suppression probability for electrical fires of exp([0.098/min][5 min]) = 1.6. The second option would be to refer back to the paper produced by the original set of reviewers for FAQ 08-0046, i.e., 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. There a reduction factor spanning the range from three to ten was recommended. The failure of two of the three tested VEWFD technologies in NUREG-2180 to show any time "bonus" on average and the complications

associated with the miscalibration of the "cloud chamber" technology argues for the lower end of this range, perhaps no higher than the geometric mean of $\sqrt{(3 \times 10)} \approx 5$.[35]

The third option makes use of some of the results from NUREG-2180, but not the methodological approach. The details of the calculations are included with the Non-Concurrence and not repeated here. The results indicated the following. For conventional ceiling-mounted detection, 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 5.8 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. 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). This aligns well with the quantitative results from the second option.[36]

Potential Risk Increase for Proper Crediting of In-Cabinet VEWFDS

As shown below, 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:

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[35] 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. A copy of this paper is available with the Non-Concurrence.

[36] Subsequent to my filing of the Non-Concurrence and DPO, I developed a very simple bounding analysis to help the DPO panel evaluate the maximum possible reduction factor that might arise with VEWFDS – I provided it to them. Assume as a base case either no detection at all or just ceiling mounted something or other, such that NO fires can be caught during the pre-flaming ("incipient") phase. Therefore, any suppression must occur only after the fire is detected and then only after flaming (or significant smoke, whatever). For simplicity, assume the response time after being subtracted from the time available for successful suppression had the fire been detected at time zero (when it started) is T. Therefore, the probability of NON-suppression is just exp(-0.098T), where the 0.098/min term is the inverse of the mean time to **suppress an electrical enclosure fire** (~10 min).

(1) Now, install the most effectively possible VEWFDS (in-cabinet, per-cabinet addressability, etc.). Assume half of all electrical enclosure fires are such that they are detectable during the pre-flaming phase. With perfect human response and complete pre-emption, half of all electrical enclosure "potential" fires will never occur, leaving only 50% to be detected after the pre-flaming stage, as in the case above. However, now credit the VEWFDS as providing much earlier detection for these remaining fires (remember none of these could be detected during pre-flaming [maybe grew too fast, not the "right" type of fire, whatever]) than the above case, say 10 min, such that the probability of NON-suppression (for the remaining 50% of the fires) is reduced by providing an extra 10 min, i.e., 0.5 x exp(-0.098[T+ 10]). Compared to the above case, this is a reduction by a factor of exp(-0.098T)/{0.5 x exp(-0.098[T+10])} = 2 x exp(0.98) = 5.3

Thus, for totally effective pre-emption of half of all such fires AND quicker detection/suppression (for the remaining half), the maximum reduction factor from VEWFDS is ~5.

(2) If you want to stretch and assume 75% of all these fires are detectable in the pre-flaming stage, you double the reduction factor to exp(-0.098T)/{0.25 x exp(-0.098[T+10])} = 4 x exp(0.98) = 10.7, roughly the original maximum factor of 10 from the original version of the FAQ prior to its being "absconded."

If you limit the "bonus" time for VEWFDS detection to 5 instead of 10 min (in line with NUREG/CR-6850's original intent and the original data from the Xtralis tests), the reduction factors are decreased to the following values:

exp(-0.098T)/{0.5 x exp(-0.098[T+5])} = 2 x exp(0.49) = 3.3 (vs. 5.3 previously)
exp(-0.098T)/{0.25 x exp(-0.098[T+5])} = 4 x exp(0.49) = 6.5 (vs. 10.7 previously).

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.[37] 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.

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.

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.[38]

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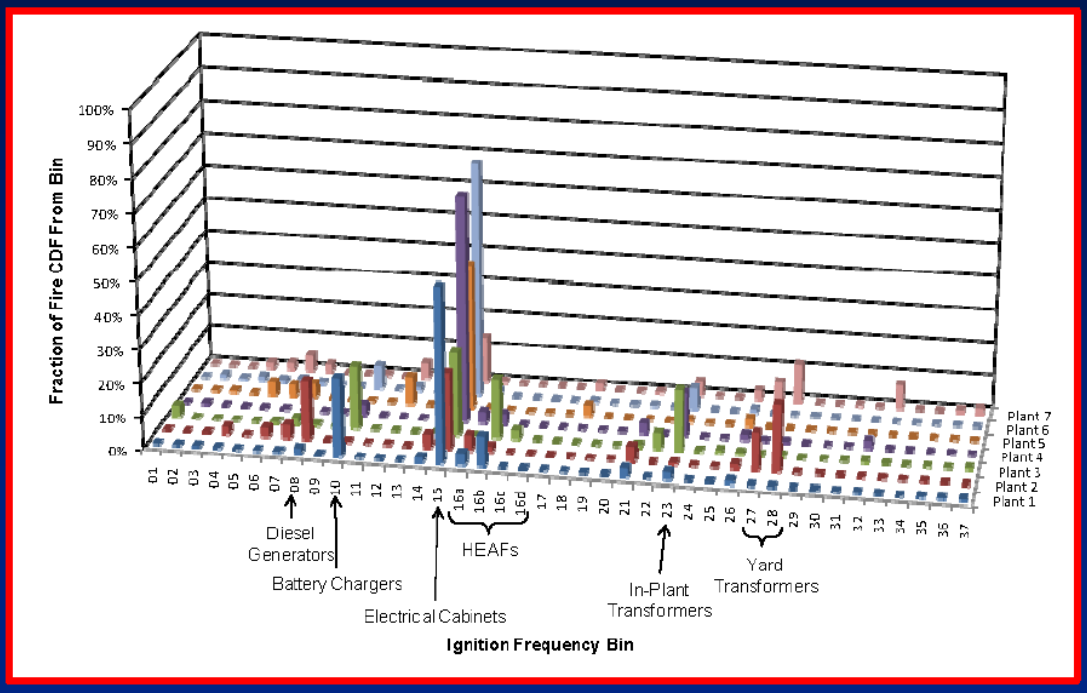
[37] For example, if a plant transitioned with a small risk (CDF) increase ("delta-risk"), say 1E-6/y, but a medium total risk (CDF), say 7E-5/y, both of which were acceptable under RG 1.174 as lying in Region II/III in its Figure 4, the change under the full 60% case would result in a delta-risk now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

[38] 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.

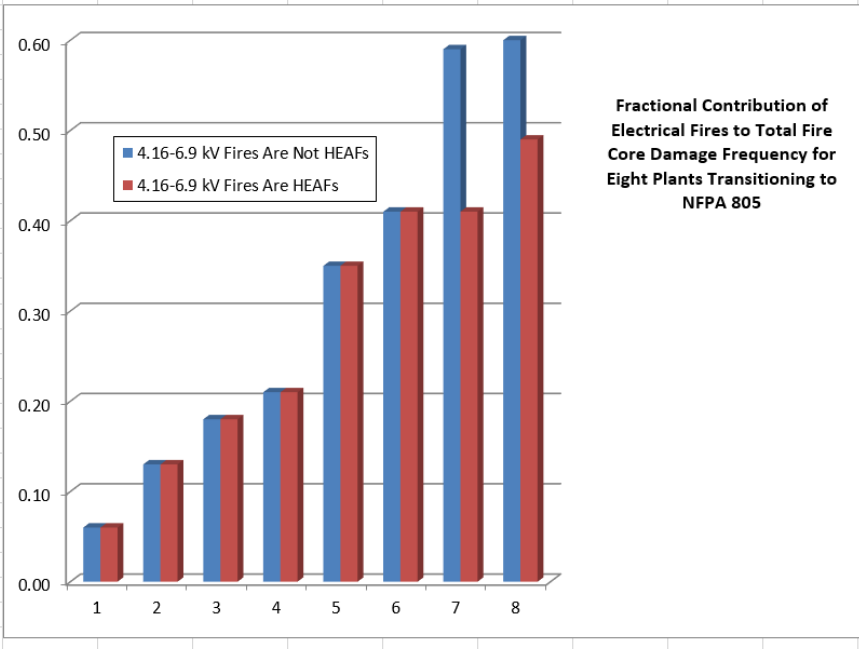
Fire PRAs – Risk Contributors



From Canavan, K., R. et al., "Roadmap for Attaining Realism in Fire PRAs," Nuclear Energy Institute, 2010.

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.

4.16-6.9 kV Fires Are Not 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.)

Potential Effect from Error in FAQ 08-0046

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 $1/0.021 \approx 50$ that fire damage at least within the cabinet occurred if the simplified event tree was used. Likewise, there would be a similar under-estimate by a factor of $0.001/2.0\text{E-}5 \approx 50$ 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 conditional core damage probability [CCDP] by factor of 50 from 1 to 0.02).

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. Previously 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.[39]

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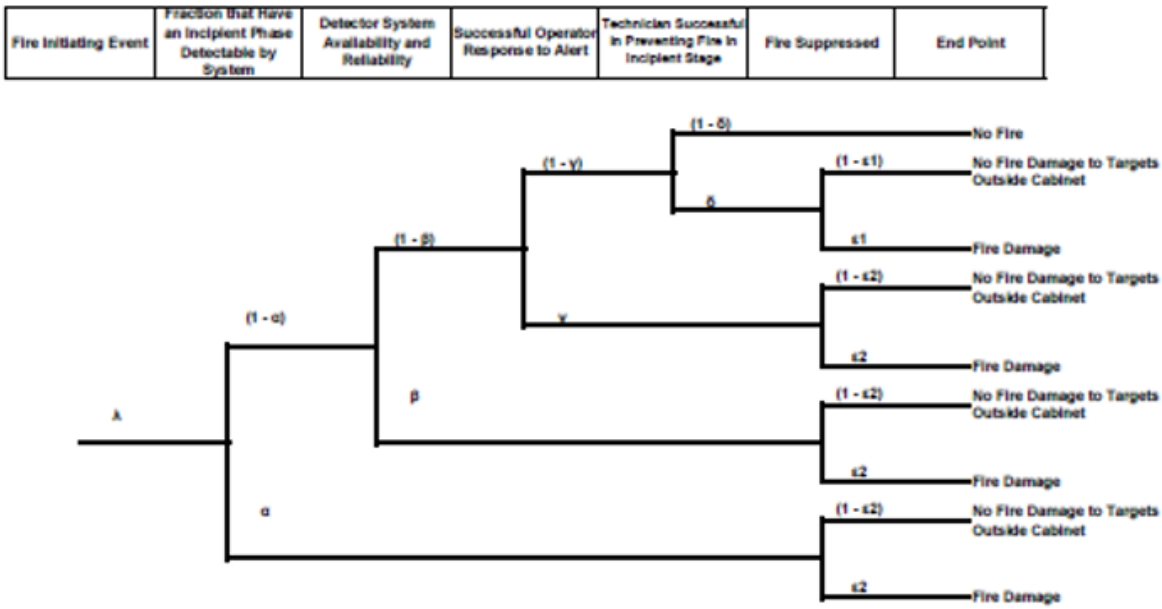
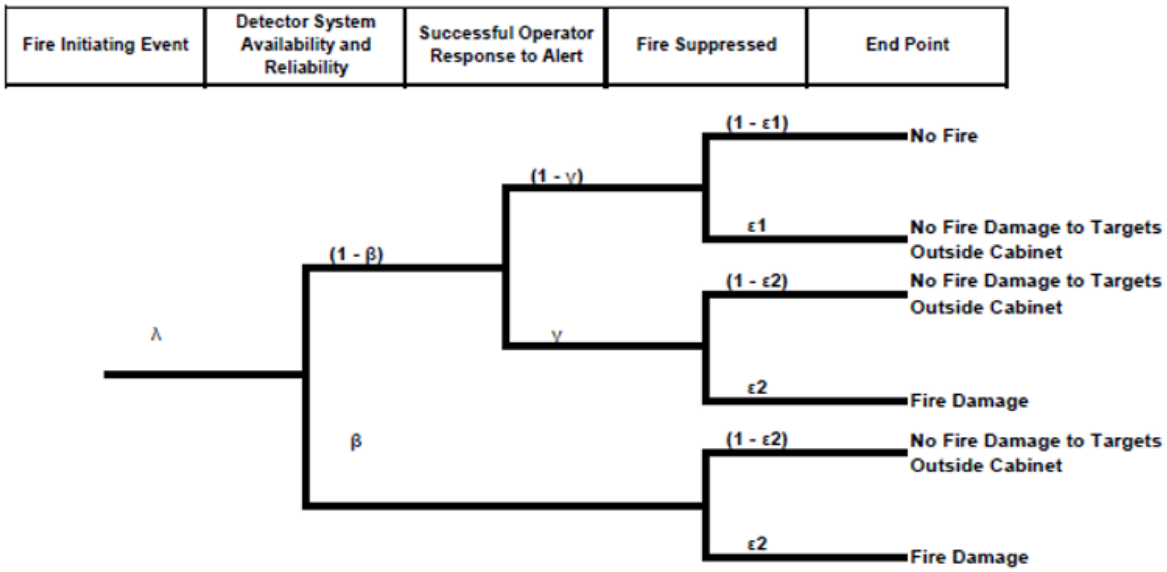
[39] For example, if a plant transitioned with a small risk (CDF) increase ("delta-risk"), say 1E-6/y, but a medium total risk (CDF), say 7E-5/y, both of which were acceptable under RG 1.174 as lying in Region II/III in its Figure 4, the change under the full 60% case would result in a delta-risk now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



Detailed Event Tree (from page 4 of FAQ 08-0046)

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.



Simplified Event Tree (from page 8 of FAQ 08-0046)

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.

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
				2.09E-02
			SUMS	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 (2E-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
				9.99E-01
			SUMS	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

Nicholas Melly

Fire Protection Engineer
Office of Nuclear Regulatory Research
Division of Risk Analysis

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

Fire Risk Quantification

- Fire Scenario Risk Equation

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

  - 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 $\mathbf{P_{ns}}$ (i.e., reduced risk)

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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 **P_{ns}** x CCDP= CDF

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

CDF= 1.77E-05

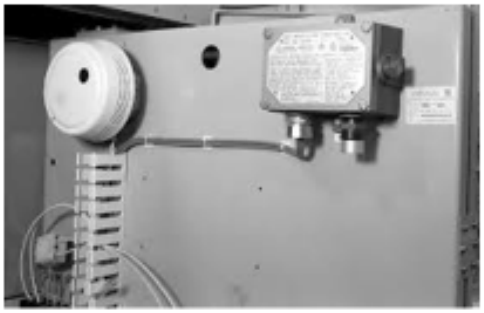
NUREG/CR-6850

In-Cabinet Detection

5 Minutes of additional time for detection prior to ignition

λ_{SF} x 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 P_{ns} x CCDP= CDF

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

CDF= 3.54E-07

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

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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

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Epilog: "You think … the race [is] over. It isn't over"[40]

Unfortunately, there is an epilog to the tale of this non-concurrence. As I had requested no response on the non-concurrence, being content to publicize my objections to the endorsement of NUREG-2180 because of its significant flaws and offering my alternative analyses, I hoped to close this FAQ 08-0046/NUREG-2180 affair with the non-concurrence. NRR management thought otherwise and responded to the non-concurrence, not surprisingly essentially dismissing it using the same tired arguments already included within NUREG-2180 itself with no new technical insights. The endorsement letter for NUREG-2180 was issued unchanged (ADAMS Accession No. ML16327A460). The inadequacy of management's response to my non-concurrence, which offered no new technical basis for endorsing the flaws in NUREG-2180 or fully address my issues in the non-concurrence, compelled me to file a DPO, essentially repeating the non-concurrence with some enhancements to address the responses (ADAMS Accession No. ML18065A931). It was my hope that the DPO would offer a chance for a much more independent review of my non-concurrence, i.e., one separate from any vested interests within NRR or RES to support the NUREG as is. As such, I requested that no panelist, and especially the Chair, be an NRR or RES staff member to maximize the potential for an independent review of the technical (and other) issues originally raised in the non-concurrence that carried over into the DPO. The key additional elements of the DPO are summarized below.

With each iteration of NUREG-2180 en route to its final publication, the credit for VEWFDS increased, until it reached what is now in the final version that, as currently quantified, only allows credit for "enhanced suppression." Additional credit can be taken for "pre-empting the fire," although the actual quantification of this is not performed but left to the licensees. When the industry takes that additional credit, most, if not all, of the erroneous "factor of 50" from FAQ 08-0046 will be recoverable, making the rescinding of the FAQ essentially moot. The approaches I offer in the non-concurrence already incorporate credit for fire pre-emption, so they are "complete" without the need for further manipulation by the industry. Of course, they do not approach the potential credit from the NUREG (or FAQ), which makes them unpalatable to the nuclear industry as well as to the NRC which wants NFPA 805 to finish up without further obstacles. The fact that incorporating my recommendations could place already-approved licensees for NFPA 805 into "backfit space" (see discussion in non-concurrence), not to mention stifle any remaining approvals, is untenable to the NRC. Thus, rejection of my recommendations in the non-concurrence has political motivation behind it, much more so than any technical basis for dismissal. This parallels what transpired with the original FAQ back in 2009 when technical defensibility was sacrificed for political expediency to expedite approval of the Harris pilot under NFPA 805.

The decision to retain the MCR non-suppression curve in NUREG-2180 was an unfortunate left-over from flawed and erroneous FAQ 08-0046. As the most aggressive suppression curve available at the time of the FAQ (i.e., leading to the lowest non-suppression probabilities for all fire types), it was ill-advisedly chosen to maximize the potential risk reduction from installation of VEWFDS so as to expedite Harris' transition to NFPA 805. The curve itself was developed for the entire MCR, i.e., both the front (horseshoe area) and back panel areas, where only the front is continuously occupied and in constant visual range of the operating staff. This was a likely non-conservative choice for the back panel area due to the inability to distinguish between MCR fires in the front vs. back panel areas from the original database literature, a limitation that remains today even with the updated database used in NUREG-2169. Therefore, it likely under-estimates the non-suppression probability for MCR fires in the back panel area, where there is not continuous occupation or vigilance, but rather a status similar to that for typical electrical fires in unoccupied areas of the plant, i.e., those governed by the electrical fire non-suppression curve. Even optimistically crediting the nearby presence of the operators in the front panel area, at best a non-suppression curve intermediate

[40] Messala to Ben-Hur, *https://en.wikiquote.org/wiki/Ben-Hur_(1959_film)*

between that for the MCR and electrical fires would have been the most optimistic that should have been chosen in FAQ 08-0046. At that time, this curve was the welding/cutting curve.

NUREG-2169 significantly reduced the credit for suppression now available for welding/cutting to the point where it is only comparable to that for electrical fires, leaving no similarly suitable curve available that is intermediate between the MCR and electrical fire curves. This prompted the NUREG-2180 analysts to develop the "new" electrical fire curve where a respondent is present, essentially yielding the same credit as the original welding/cutting curve. Again, this curve was the most optimistic that might have been allowed in NUREG-2180, not a repeat of the error from FAQ 08-0046 to allow the MCR curve again to be used. My analysis takes this approach. On the contrary, NUREG-2180 further compounds its non-conservatism by assigning different non-suppression curves for in-cabinet vs. area-wide VEWFDS, using the egregiously incorrect MCR curve for in-cabinet vs. the "new" electrical" enclosure curve for area-wide. In addition it also varies the response time (shorter for in-cabinet than for area-wide VEWFDS), a "double-counting" of credit that exacerbates its non-conservative over-optimism. If NUREG-2180 insisted on using different non-suppression curves, the appropriate choice would have been the "new" electrical fire curve for in-cabinet and the updated NUREG-2169 electrical fire curve for area-wide.

Both the FAQ and NUREG-2180 violate principles of PRA by assuming overly optimistic non-suppression for VEWFDS via the MCR curve rather than defaulting to a more conservative, and likely realistic, use of no better than the new electrical curve (or, in the FAQ, the comparable welding/cutting curve).[41] As with the FAQ, this appears to be a politically-expedient, not technically-defensible, "bone" being given to the industry to again maximize the possible risk reduction credit from VEWFDS so as to not require re-evaluation of already-approved NFPA-805 licensees or hinder those currently under review from transitioning. Arguments that have been espoused since the FAQ itself, namely that "NRC needs to encourage the installation of these systems, and risk reduction credit is the best way to accomplish this," remain as flawed as ever. One does not compromise the technical validity of PRA, the basis for NFPA-805 transitions and future risk-informed applications dependent upon fire PRA, to justify encouraging a particular plant modification. That modification must stand on its own merit.

A year after I filed this DPO, the Panel finally issued its Report, which included a dissenting opinion, with mixed results (ADAMS Accession No. ML17317A849). The Report was quite long (76 pages) and, while I addressed specifics directly in the Report via comments embedded there, I will only present an overview here of what were my overarching concerns. These can be viewed in more detail as an attachment to the Office Director's Decision Memo, which he graciously agreed to include as a means to publicly document my concerns with the Panel Report without having to file an Appeal (ADAMS Accession No. ML18039A784).

On the positive side, the Report acknowledged that my approaches had as much, if not more, technical merit as that developed by NUREG-2180, given the current limitations of sparse data for VEWFDS performance. Even after the DELORES-VEWFIRE program, there remains no information on the duration for the "pre-fire" phenomenon (from release of "first molecule" to onset of actual fire, for which my recommendation of an experimental investigation fell on deaf ears[42]) and, therefore, the probability that such a "pre-fire" actually evolves into a fire meriting concern for a nuclear power plant, which precludes any defensible estimation of the likelihood of successful pre-emption. However, the Panel missed an important difference when it concluded that my approaches, which yielded a maximum possible reduction by a factor of about five, and that of the NUREG, which yielded a maximum of nine (missed by the Panel

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41 Additional violation includes the overly optimistic HRA where the responder remains in place indefinitely, also discussed in the non-concurrence.

42 The Panel did not even address the failure of the NUREG authors to consider my recommended experimental process to determine "pre-fire" behavior, which would have yielded a statistically defensible estimate for the probability of "pre-fire" evolution into an actual fire and, therefore, the likelihood of pre-emption for VEWFDS.

when they concluded a factor of only seven), yielded similar results. Unlike the NUREG method, which did not quantify the effect of pre-emption, thereby already yielding more reduction credit than mine due solely to "enhanced suppression," my approaches included a numerical estimate for the pre-emption effect (to the extent possible given the preceding constraint). Thus, already the NUREG, without quantifying pre-emption, yielded more generous, non-conservative reductions than my complete method, which included both pre-emption and suppression effects. Naturally, this did not suffice for the nuclear industry, which immediately issued a FAQ attempting to increase the reduction credit just from the "enhanced suppression" aspect without even yet touching the pre-emption possibilities. Additionally, the industry indicated it would be embarking on a "VEWFDS reduction credit recovery" program. I fully expect that, with the generosity already provided via NUREG-2180, the erroneous factor of 50 reduction credit will inevitably be recovered in the not too distant future, since NRC management remains reluctant to discourage any de-emphasis of the value of VEWFDS given it was complicit in the use of inappropriate "risk reduction" means to encourage it in the first place.[43]

The Panel conclusion regarding the use of the MCR fire non-suppression curve was disappointing. Although acknowledging that there are circumstances where use of this curve could not be justified, it failed to align with my contention that such use could never be justified. Further, the Panel failed to recognize that, by selecting and embedding this curve into the NUREG methodology as the baseline, the NUREG already established the most optimistic, non-conservative level as the norm for VEWFDS analysis. The NUREG users are not given the option to select the non-suppression curve in the Excel spreadsheet provided with the NUREG for quantification, so any suggestion by the Panel that, in some circumstances, the less optimistic welding/cutting fire or "new" electrical" fire non-suppression curve (not to mention the most appropriate unchanged electrical fire curve) would be substituted instead is moot – it will never happen.[44] The Panel also failed to recognize that, while the HRA methodology similarly embedded within NUREG-2180 was admittedly based on idealized response procedures from just one licensee (which happened to be the one that initially proposed FAQ 0008-46 for its own purposes during the NFPA-805 pilot phase), these procedures were actually not followed by that licensee during an actual event. In fact, rather than station the responder "indefinitely" at the potential site of the "pre-fire," the licensee chose to abandon the site, not once but twice, when the fire did not materialize (nor its potential location be ascertainable), and reset the VEWFDS. Only after the third alert did the fire finally materialize and be suppressed, some 90 hours after the very first signal. Nonetheless, as with the MCR fire non-suppression curve, the Panel found no fault with the NUREG in once again embedding the most optimistic, non-conservative, idealized human response as the norm for the methodology. As much as the nuclear industry has whined over a decade now about fire PRA being overly conservative, particularly due to the alleged "compounding of conservatisms' by those who blindly follow NUREG/CR-6850, now the NUREG-2180 authors, and the NRC itself, is doing the complete opposite – compounding of non-conservatisms by embedding both the idealized MCR fire non-suppression curve and idealized HRA as the baseline. This is so contrary to PRA practice, even those who advocate "realism" over "conservatism," to be completely unpalatable to a lifelong practitioner such as myself.

A fundamental principle of PRA is ignored throughout the Report. "When in doubt, opt for conservatism." My approaches provide bounding estimates of the maximum possible credit for use of a VEWFDS, including both pre-emption (to the extent possible given the current limitations) and suppression. It uses actual results from NUREG-2180 where appropriate. Therefore, it is a conservative approach that bounds the credit available for these systems under the current state of knowledge. NUREG-2180 incorporates several non-conservative, optimistic assumptions, in particular use of the main control room suppression

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[43] As previously mentioned, the attitude of NRC management from the beginning has been that "NRC needs to encourage the installation of these systems, and risk reduction credit is the best way to accomplish this."

[44] When I performed the sensitivity evaluations for the examples in Chapter 12 of NUREG-2180, I had to hard-wire the other non-suppression curves into the Excel spreadsheet provided with the NUREG.

curve and an idealized procedural response for the HRA, in a limited capacity, i.e., quantifying only the suppression aspect while leaving open-ended the pre-emption aspect to the user's discretion. Yet this already yields potentially more credit than my complete approach, and this credit could very well be restored to the erroneous factor of 50 allowed by the rescinded FAQ via a licensee's manipulation. This is totally inconsistent with how PRA should be applied in a regulatory framework.

I did offer one possible solution that would have negated the need for my Appeal and brought this DPO to a somewhat palatable closure. Given that any recall or even modification of the endorsement of NUREG-2180 will not occur, at least the additional unveiling and endorsement of my alternative approaches should be made so as to place them on an equal footing as acceptable options along with NUREG-2180, the latter's faults as enumerated above notwithstanding. This would have been consistent with the Panel's conclusion that other alternatives to NUREG-2180 are reasonable. While the Office Director did not go so far as to task NRR with formally endorsing my alternatives, he did acknowledge their "technical defensibility" and validity as concluded by the Panel Report. Since he also included my detailed elaboration of my concerns with the Panel Report as an attachment to the Decision Memo, rendering them publicly available, I forewent the need to Appeal since my experience has shown this phase to be futile and serving only to allow public airing of my concerns with a DPO Panel Report and Office Director's Decision.[45] Additionally, he acknowledged my "strong denial of the propriety of using [the non-suppression curve] for the Main Control Room," tasking NRR to reconsider this as a result of this DPO. In light of the "political incorrectness" of actually casting serious aspersions on NUREG-2180 and formally endorsing my approaches as an alternative, this was the best I could expect.[46]

[45] My mark-up of the "Ad Hoc Review Panel Report for Differing Professional Opinion 2016–004" (November 13, 2017) is included separately from the documentation directly associated with the DPO itself, as "DPO Submitter's Mark-Up with Comments on Ad Hoc Review Panel Report for Differing Professional Opinion 2016-004 (November 13, 2017)" - ADAMS Accession No. ML18039A935.

[46] Despite my appreciation of the Office Director reinforcing the validity of my approach, accommodating my concerns and tasking NRR to reconsider the methods and assumptions in NUREG-2180 in his Decision, I am pessimistic about any substantive change to NUREG-2180 occurring as a result. Ultimately, I expect the Main Control Room non-suppression curve to be retained along with the overly-optimistic human response baseline, enabling the nuclear industry to once again achieve the factor of 50 reduction in risk after manipulating the factor for pre-emption of the fire to its benefit. I have no illusion that my valid approach will ever be used or even circulated beyond the DPO's archival material.