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Risk-Deformed Regulation: What Went Wrong with NFPA 805

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Abstract

National Fire Protection Association (NFPA) Standard 805 was incorporated into Title 10 of the U.S. Code of Federal Regulations to allow commercial nuclear plants to transition their existing, deterministic fire protection licensing bases to ones that are "performance-based and risk-informed." Both the US Nuclear Regulatory Commission (NRC) and the commercial reactor industry championed this major leap forward in "risk-informed regulation." However, hidden behind all the "success" are compromises and manipulations that were necessary to make this "work," as revealed in this article. It is written by a former employee of the NRC (views do not nor ever did represent an official position), the first to receive a PhD on a thesis specifically related to fire probabilistic risk assessment (PRA) in nuclear plants, and later hired in 2003 as the expert in fire PRA for the Office of Nuclear Reactor Regulation (NRR). He participated in the NFPA-805 program from the start in 2005 until mid-2014. The perspectives here cover that time period, with some extended time specific to issues that the interested reader can find detailed in "Risk-Deformed Regulation: What Went Wrong with NFPA 805" http://vixra.org/pdf/ (access latest version of entry 1805.0403).

NFPA 805 will have been "successful" in that adopting plants are as safe as or safer than before, at a minimum having at least become more knowledgeable of potential safety weaknesses. Plants that made effective changes will be safer than before, although "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, then perhaps actual risk-reduction changes that could have been made were not. At worst, the plant merely missed an opportunity to become "safer," a consequence of the problems with "risk-deformed regulation."

Keywords: Fire Protection; Probabilistic Risk; Nuclear Power; Regulation.

1. Introduction

National Fire Protection Association (NFPA) Standard 805 [1] was incorporated into Title 10 of the U.S. Code of Federal Regulations to allow commercial nuclear power plants to transition their existing, deterministic fire protection licensing bases to ones that are "performance-based and risk-informed." Both the US Nuclear Regulatory Commission (NRC) and the commercial reactor industry championed this major leap forward in "risk-informed regulation." However, hidden behind all the "success" are compromises and manipulations that were necessary to make this "work," as revealed in this article. It is written by a former employee of the NRC (views do not nor ever did represent an official position), the first to receive a PhD on a thesis specifically related to fire probabilistic risk assessment (PRA) in nuclear plants, and later hired in 2003 as the expert in fire PRA for the Office of Nuclear Reactor Regulation (NRR). [2, 3] He participated in the NFPA-805 program from the start in 2005 until mid-2014. The perspectives here cover that time period, with some extended time specific to issues that the interested reader can find detailed in reference [4].

NFPA 805 was written as a risk-informed, performance-based standard intended for use after a risk-informed, performance-based fire protection program had been established. There was more than just semantics to the commonly

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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. NFPA 805 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 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. [5] As evidenced by the following sample of selected statements from NFPA 805, "change evaluations" were intended to apply to a plant after the risk-informed, performance based fire protection program had been established (see underlines):

> ***§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 …*

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, as exemplified by the following sample of selected statements:

> ***§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.*

> ***§2.2.4.3 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...*

2. 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 [6] 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 [7], 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. The author does acknowledge that total risk did play at least a minor role in applying the quantitative guidance in RG 1.174 in that, if the total core damage frequency (CDF) (large early release frequency [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."

2.1. 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. Very early during the pilot program, Figure 1 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 FAQ as part of an NFPA-805 FAQ program, but the NRC chose not to pursue. [8] 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." The author subsequently expressed the delta-risk calculational approach in a hopefully simpler way, as shown in the Attachment.

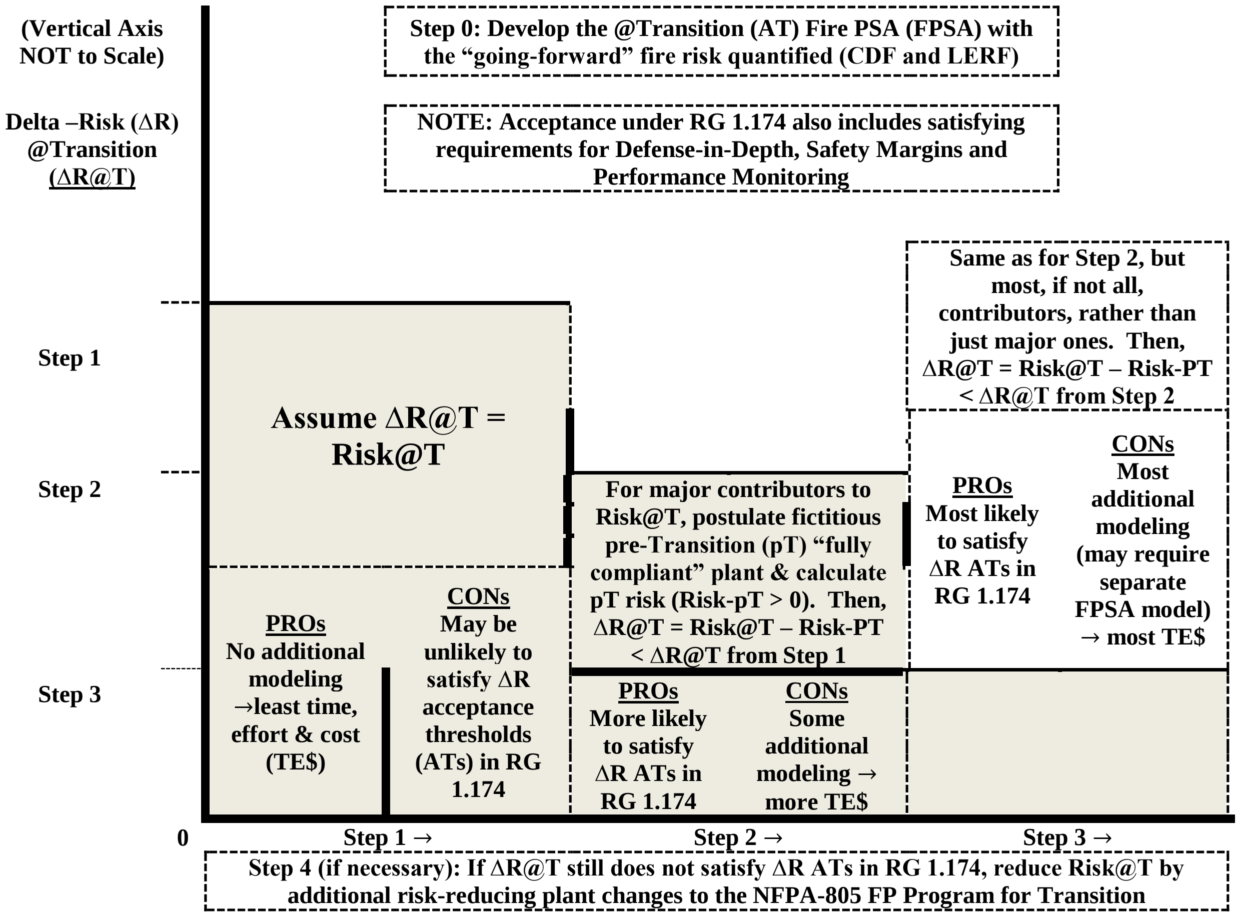

Figure 1. Measuring @Transition ΔRisk for Plant Change Evaluations (as presented at March 2006 Observation Visit)

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").* Both individual and cumulative delta-risks, with

* Note that, where multiple forms of compliance are available (e.g., 10CFR50.48, 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

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.

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 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 1 were the reported fire CDFs, 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.

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.

Table 1. Pre- and Post-Transition Fire CDFs and LERFs from Non-Pilot Plant Submittals

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

With regard to Table 1, except for the first plant with pre-transition fire CDF = 1.54E-3/yr, 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.

Furthermore, 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/yr, 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 higher than any of the ten, that being 7.58E-5/yr. 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.

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.

3. "Fire PRA is Too Conservative!"

In 2005, the NRC and Electric Power Research Institute (EPRI) published NUREG/CR-6850 (EPRI 1011989) [9], 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.

3.1. "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 [10], 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 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 (the author's) 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 [11], 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 NRR (the author) 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 plants. 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.

The developers 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 at a factor of 50. [12] 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. [13]

The NRC Office of Nuclear Regulatory Research (RES) subsequently established a testing program to examine the potential benefits from very early warning fire detection (VEWFD), producing its results in NUREG-2180. [14] 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 developers had proposed in reference [12]. 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 and subsequent Differing Professional Opinion (DPO) by the author when NUREG-2180 was endorsed for use by 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! The reader interested in the details, including the author's reassessment of the appropriate risk reduction credit for VEWFD and the associated DPO filed against NUREG-2180, should consult reference [4].

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 developed 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.

As an example, the principal investigator, Steven Nowlen of Sandia National Laboratories, who led the development of NUREG/CR-6850, asked during a 2010 Advisory Committee on Reactor Safeguards (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." [15] 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 frequencies from EPRI 1016735. Not unlike his experience with FAQ 08-0046, the author was initially a prime reviewer of the industry proposal and intended author of the FAQ, but ultimately had to dissociate himself entirely (at least voluntarily this time). Recognizing its faulty basis, the author 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, the author's 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, the author recused himself from further involvement with the FAQ as this was much too inadequate.

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: [16]

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 developers 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 [17]), 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: [18]

> *… [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), to 1.1E-5/yr, according to the updated Attachment W tables.* [This is only the fire LERF. The total LERF is 1.82E-5/yr, excluding any estimate for seismic hazards.] *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. The reader interested in the calculational details, as well as the DPO filed with respect to FAQ 08-0048, should consult reference [4].

3.2. "We're not going to Play Anymore"

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." [19] Citing intermediate results from the early non-pilots, with only partial calculations from the "fire risk equation," they "proved" that the current state-of-the-art for fire PRA, as allegedly supported by the NRC via NUREG/CR-6850 (EPRI 1011989), i.e., using only the scoping/screening approach while ignoring the recommendation to perform fire phenomenological modeling to reduce any "conservatism," generated "results that do not comport with operating experience." What the industry conveniently overlooked was that fire CDF 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. [20] Limited efforts by the NRC to counter these claims were insufficient to deflect this mantra.

Examples of the author's attempts at countering include references [21] through [23]. 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.

The industry opposition finally progressed to the point where it "threatened" to discontinue its participation in risk-informed applications because of the "805 fiasco." [24] This industry "threat" was subtly veiled in an NEI letter to the NRC Chairman as "severely diminished industry confidence:" [25]

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 <u>severely diminished industry confidence</u> 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 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 toward providing phenomenological support for its "operational-experienced-based" proposals.

4. "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: [26]

… [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: [27]

> *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. 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: [28]

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.

4.1. “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 a number of specific areas toward their NFPA-805 submittals. [29] 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, tasked to review these “progress reports,” was able to develop a “quasi-quantitative” means by which to compare among the various licensees (see Table 2). [30]

Table 2. Assessment of “Progress” to Justify Extending Enforcement Discretion

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 & compensatory measures	**Available**		**Available**		**Available**		**Available**		**Available**		**Available**		**Available**		**Available**	
Operator manual actions as compensatory measures	**Feasible**		**Feasible**		**Feasible**		**Feasible**		**Feasible**		**Feasible**		**Feasible**		**Feasible**	
Physical modifications	**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 operations	**0**	**3Q09**	**58**	**122608**	**75**	**121508**	**12**	**3Q09**	**0**	**Dec08**	**65**	**Oct08**	**5**	**Sep09**	**2**	
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**	**Oct10**
Rad release	*75*	*3Q09*	*98*	*121508*	*100*		*0*	*2Q09*	*55*	*Oct08*	*95*	*Sep08*	*5*	*Sep09*	*100*	
Safe-Shutdown analysis	*100*		*82*	*021509*	*90*	*102208*	*NA*		*NA*		*95*	*Sep08*	*90*	*Feb09*	*NA*	
Plant change evaluations					*5*	*063009*										
Bold required; *italic optional*																
Colors represent:	**May be unacceptable**				**Probably acceptable**				**Seemingly appropriate**				**Clear = no judgement**			

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. (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.)

5. "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 [31] and NEI-07-12 [32], revealed use of "unreviewed analysis methods" (UAMs), either present (and discounted) during the pilots or new to the non-pilots. 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.

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. [33] For the fourth, and arguably most important method, the NRC panelist (the author) 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.

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. [34] This led to repeated complaints by the industry of the NRC deferring to "single staff opinions" (e.g., [35, 36]) 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. 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 the author had been "phased out" [37].

5.1. 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 [38], the EPRI proposed developing this approach to pre-empt the need for more fire tests. Since this approach appeared promising, the NRC deferred fire testing.

It should be noted that, 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. [39] Industry fire test support has been limited to providing equipment, reviewing test plans, etc., for the NRC-sponsored tests (e.g., from reference [40] in 2005 through reference [41] in 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."

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. [34]

6. 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. [42] This was prompted by the then 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. [43] 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: [44]

> *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 reference [42].

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 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."

7. 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 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 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. (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.") 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.

Another feature of this new paradigm is "re-auditing" following the initial audit, possibly more than one, 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. Additionally, 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 (if these are not delayed, or even eliminated, as recently recommended by the industry).

Since the author was "phased out" from NFPA-805 reviews in mid-2014, he did not participate in the issuance of the final safety evaluation reports for those plants on which he had been working. However, he knows that what he 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), was neither requested nor mentioned in these final reports approving these and any other plants' transitions to NFPA 805 (and all plants ultimately are approved since "Rejection is not an option").

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 RCP seal modifications designed to reduce the likelihood of loss-of-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 [45], received credit in advance of installation and operation under the misguided concept of "freeze point" (discussed below and, for the interested reader, in reference [4] with respect to the DPO filed against FAQ 08-0048). Another seal package, proven to fail despite successful test experience once installed and used in operation [46], 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 from practices intended solely for new reactors, not existing reactors [47], 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.

8. Conclusion

Despite his obvious opposition to the use of "delta-risks" during transition, the author 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 the author leaves this issue unanswered.

The author himself must confess to being guilty of false optimism in December 2006 when writing "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]'." [48] Now, in retrospect, he must conclude that, while NFPA 805 worked to make plants safer (or at least remain at their current level), nonetheless 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.

9. Conflicts of Interest

The authors declare no conflict of interest.

10. References

[1] National Fire Protection Association. "Standard NFPA-805: Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants" (2001 Edition).

[2] Gallucci, Raymond. "A Methodology for Evaluating the Probability for Fire Loss of Nuclear Power Plant Safety Functions" (Doctoral Thesis). Rensselaer Polytechnic Institute, Troy, NY (1980).

[3] Gallucci, R., and R. Hockenbury. "Fire-Induced Loss of Nuclear Power Plant Safety Functions." Nuclear Engineering and Design 64, no. 1 (March 1981): 135–147. doi:10.1016/0029-5493(81)90039-x.

[4] Gallucci, Raymond. "Risk-Deformed Regulation: What Went Wrong with NFPA 805." http://vixra.org/pdf/ (access latest version of entry 1805.0403), 2018.

[5] USNRC. "Regulatory Guide (RG) 1.205: Risk-Informed, Performance-Based Fire Protection for Existing Light-Water Nuclear Power Plants" (December 2009, Rev. 1).

[6] USNRC. "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).

[7] USNRC. "SECY-97-287: Final Regulatory Guidance on Risk-Informed Regulation Policy Issues" (December 12, 1997).

[8] Gallucci, Raymond. "Measuring at-Transition Delta-Risk for Plant Change Evaluations (as Presented at March 2006 Observation Visit)." ADAMS Accession No. ML14108A062 (2006).

[9] USNRC and EPRI. NUREG/CR-6850 (EPRI 1011989), "Fire PRA Methodology for Nuclear Power Facilities" (2005), with Supplements.

[10] EPRI. "Report 1016735: Fire PRA Methods Enhancements" (December 2008).

[11] USNRC. "Close-out of National Fire Protection Association 805 Frequently Asked Question 08-0046 on Incipient Fire Detection Systems." ADAMS Accession No. ML090300496 (March 2009).

[12] Gallucci, Raymond, 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.

[13] USNRC. "NG-13-0182: 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." ADAMS Accession No. ML1322A045 (May 1, 2013).

[14] USNRC. "NUREG-2180: Determining the Effectiveness, Limitations, and Operator Response for VEWFD Systems in Nuclear Facilities (DELORES-VEWFIRES)" (December 2016).

[15] USNRC. "Official Transcripts of Proceedings, NRC: ACRS Reliability and PRA Subcommittee Meeting." ADAMS Accession No. ML110050249 (December 13, 2010).

[16] Baranowsky, Patrick. "Fire Ignition Frequency Estimation Using Recent Fire Events Data." ANS PSA 2013 International Topical Meeting on Probabilistic Safety Assessment and Analysis, 2013, Columbia, South Carolina, September 22-27, 2013.

[17] USNRC and EPRI. "NUREG-2169 (EPRI 3002002936): Nuclear Power Plant Fire Ignition Frequency and Non-Suppression Probability Estimation Using the Updated Fire Events Database" (October 2014).

[18] USNRC. "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)." ADAMS Accession No. ML13210A449 (September 10, 2013).

[19] USNRC. "Transmittal of NEI Report 'Roadmap for Attaining Realism in Fire PRAs - December 2010'." ADAMS Accession No. ML103430372 (December 6, 2010).

[20] Chapman, James. "Seeking Realism in Fire PRA," Scientech. ANS PSA 2013 International Topical Meeting on Probabilistic Safety Assessment and Analysis, Columbia, South Carolina, September 22-27, 2013.

[21] Gallucci, Raymond. "Predicting Fire-Induced Core Damage Frequencies - A Simple 'Sanity Check'." Transactions of the American Nuclear Society, Vol. 94, Reno, Nevada, pp. 202-204 (2006).

[22] Gallucci, Raymond. "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 (2011).

[23] Gallucci, Raymond. "'What-Me Worry?'1'Why So Serious?':2 A Personal View on the Fukushima Nuclear Reactor Accidents." Risk Analysis 32, no. 9 (March 6, 2012): 1444–1450. doi:10.1111/j.1539-6924.2011.01780.x.

[24] True, Douglas, 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.

[25] Pietrangelo, Anthony (NEI). "Letter to A. MacFarlane (USNRC): Industry Support and Use of PRA and Risk-Informed Regulation" (December 19, 2013).

[26] USNRC. "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)." ADAMS Accession No. ML103000047 (November 9, 2010).

[27] USNRC. "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]." ADAMS Accession No. ML103630612 (December 29, 2010).

[28] USNRC. "Notice of Violation and Confirmatory Order Related to a Fire Protection Program License Condition (Oconee Nuclear Station, Units 1, 2, and 3)." ADAMS Accession No. ML13114A928 (July 1, 2013).

[29] Federal Register. "NRC Enforcement Policy: Extension of Discretion Period of Interim Enforcement Policy." FR 52705 (September 10, 2008).

[30] Gallucci, Raymond. "Enforcement Discretion Matrix (Scrubbed)." ADAMS Accession No. ML14108A072 (April 18, 2014).

[31] ASME and ANS. "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).

[32] NEI. "NEI-07-12: Fire PRA Peer Review Process Guidelines, Rev. 1" (June 2010).

[33] Giitter, Joseph (NRC). "Letter to B. Bradley (NEI): Recent Fire PRA Methods Review Panel Decisions: Clarification for Transient Fires and Alignment Factor for Pump Oil Fires." ADAMS Accession No. ML113130446 (September 27, 2011).

[34] Giitter, Joseph (NRC). "Letter to B. Bradley (NEI): Recent Fire PRA Methods Review Panel Decisions and EPRI1022993, 'Evaluation of Peak Heat Release Rates in Electrical Cabinet Fires'." ADAMS Accession No. ML12171A583 (June 21, 2012).

[35] Southern Company and Constellation Energy. "Reclaiming the Promise of Risk-Informed Decision-making: Obstacles and Opportunities." Presented to the NRC, September 16, 2013.

[36] NEI NSAIC. "Industry PRA Vision and Plan." Presented to the NRC, October 17, 2013.

[37] USNRC. "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).

[38] Hunt, Sean. "Maximum Fire Size in Closed Vent Electrical Panels," Kleinsorg Group. Presented at the NEI Fire Protection Information Forum, September 22, 2009.

[39] EPRI. "Report 1003326: Characterization of Fire-Induced Circuit Faults: Results of Cable Fire Testing" (December 2002).

[40] USNRC. "Information Notice 2005-07 – Results of HEMYC® Electrical Raceway Fire Barrier System Full Scale Testing." ADAMS Accession No. ML050890089 (March 30, 2005).

[41] USNRC. "NUREG/CR-7197: Heat Release Rates of Electrical Enclosure Fires (HELEN-FIRE), Final Report" (April 2016).

[42] Gallucci, Raymond. "How 'Fuzzy' Are the RG 1.174 CDF and LERF Regional Change Threshold Values?" ADAMS Accession No. ML14108A041 (April 18, 2014).

[43] USNRC. "Notification of the Potential Existence of Defects Pursuant to 10 CFR Part 21." ADAMS Accession No. ML13211A168 (July 26, 2013).

[44] USNRC. "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]." ADAMS Accession No. ML13140A398 (October 24, 2013).

[45] Combustion Engineering. "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.

[46] Westinghouse Electric Co. "LTR-NRC-13-52: Notification of the Potential Existence of Defects Pursuant to 10 CFR Part 21" (July 26, 2013).

[47] USNRC. "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).

[48] Gallucci, Raymond H. V. "Thirty-Three Years of Regulating Fire Protection at Commercial U.S. Nuclear Power Plants: Dousing the Flames of Controversy**." Fire Technology 45, no. 4 (May 1, 2008): 355–380. doi:10.1007/s10694-008-0052-x.

[49] Gallucci, Raymond. "Delta-Risk Calculations for NFPA-805 Transition (FAQ)." ADAMS Accession No. ML14108A051 (April 18, 2014).

Appendix I: Delta-Risk Calculations for NFPA-805 Transition (FAQ) [49]

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 2 and 3, 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.

AP I.1. 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 2 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 2, 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 2. 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 2 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:

(Delta-Risk with VFDRs) = (Risk for PT/PI plant) – (Risk for COMP plant) > 0

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

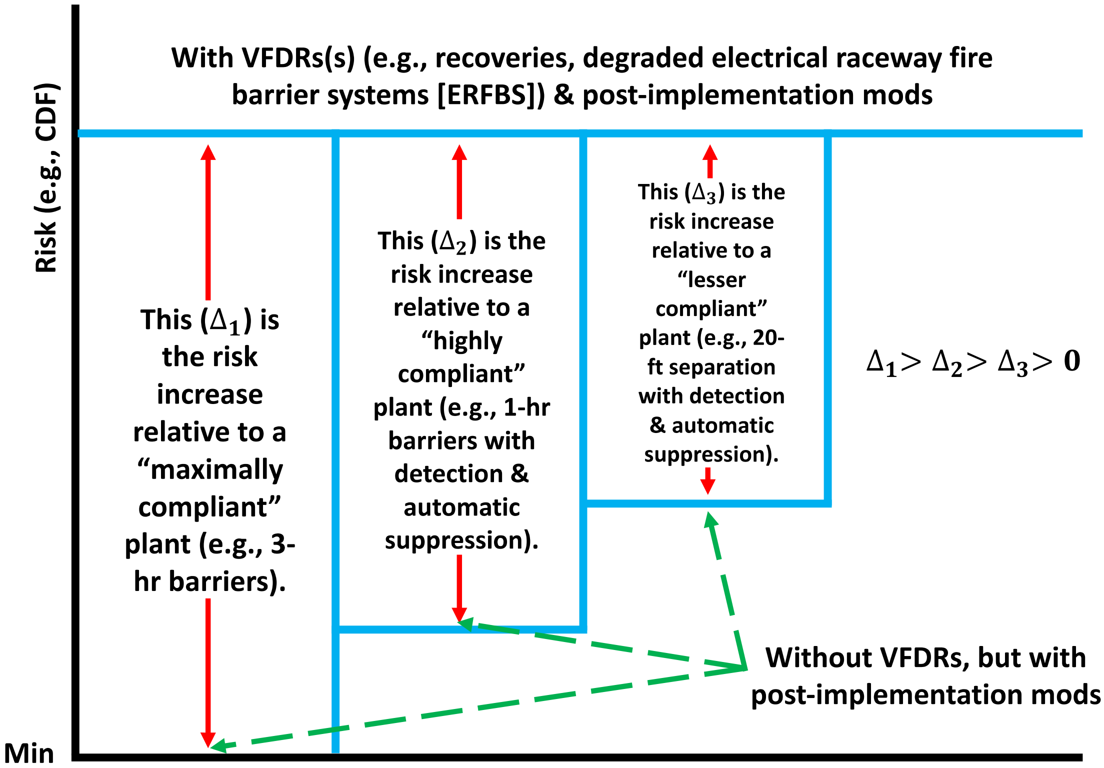

Figure 2. Calculating Risk Increases for VFDR(s) (e.g., recoveries, degraded ERFBS) or for sensitivity analyses (increases ALWAYS > 0)

AP I.1.1. 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.

AP I.2. 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 3 and parallels that from Figure 2 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 3, 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 3). 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.

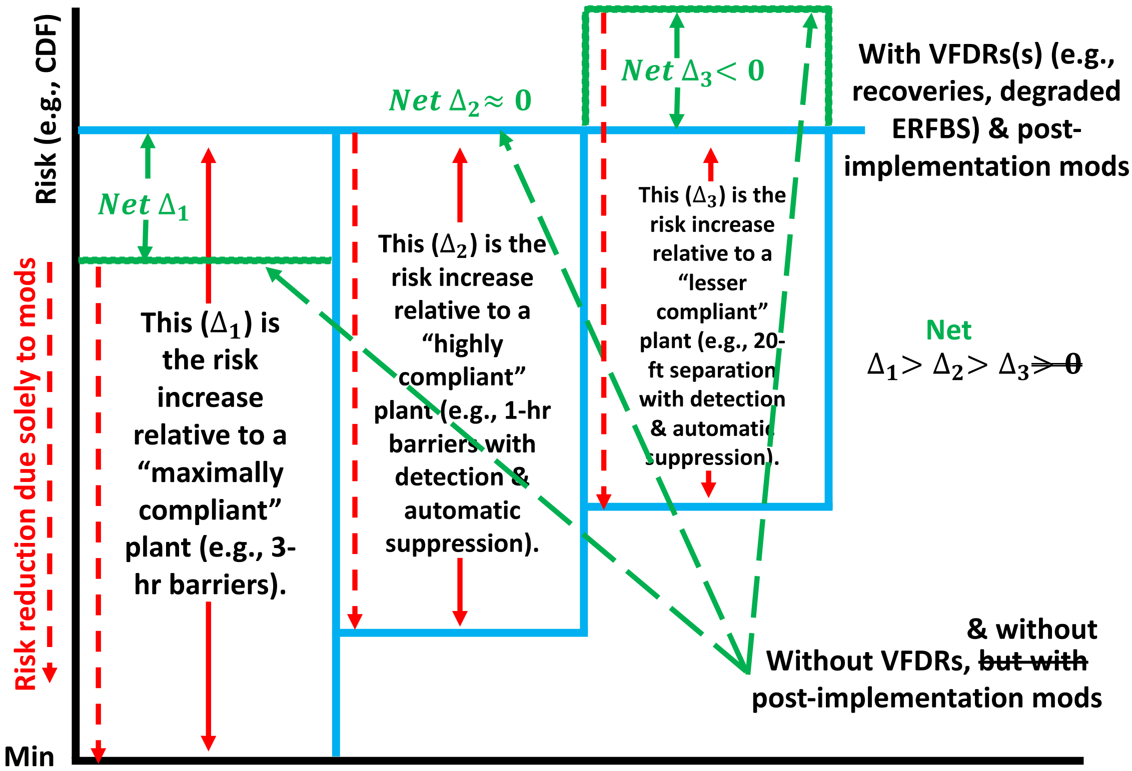

Figure 3. Calculating ~~Risk Increases for VFDR(s) (e.g., recoveries, degraded ERFBS) or for sensitivity analyses (increases ALWAYS > 0)~~ Overall NET Risk Increases after Transition & Implementation (+, 0, -) [Note that strike-throughs are intentional to show differences relative to Figure 2)

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 3 as the equivalent difference between the risks of the COMP plant with and without the modifications). In equational format, this is as follows:

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