Using An Integrated Risk-Informed Decision-Making Process to Address High Energy Arcing Fault (HEAF) Issues at United States Nuclear Power Plants

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ABSTRACT

In June 2013, the Organization for Economic Co-operation and Development (OECD) Nuclear Energy Agency (NEA) issued a report entitled "Analysis of High-Energy Arcing Fault Fire Events (HEAF)" [1], describing the international operating experience for 48 high energy arcing fault (HEAF) events occurred at nuclear power plants (NPPs). At that time, these HEAF events accounted for approximately ten percent of all fire events collected in the OECD/NEA FIRE (*F*ire *E*vents Records *E*xchange) Database. This effort highlighted concerns about the magnitude of HEAF risk to overall risk at nuclear power plants (NPPs). The United States Nuclear Regulatory Commission (U.S. NRC) has a special interest in fire events, and particularly HEAF risks, since (a) risks associated with fires constitute a large fraction of the total core damage frequency, and (b) approximately 50 % of the U.S. NPPs have adopted NFPA 05, "Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants" [2], which relies on Fire PRAs (Probabilistic *R*isk *A*ssessments). In addition, testing conducted under the OECD/NEA HEAF Project identified that PRA methods may not adequately address the zones of influence (ZOIs) associated with certain HEAF events.

Therefore, NRC's Office of Nuclear Regulatory Research (RES), in collaboration with the Electric Power Research Institute (EPRI) and the OECD/NEA embarked on an initiative to enhance the state-of-the art technology in using PRA in assessing the impacts due to HEAFs. Specifically, one objective of this initiative was to examine the validity of the PRA method documented in NUREG/CR-6850 [3] entitled "Fire Probabilistic Risk Assessment Methods", using additional operating experience, tests, and analyses performed since the publication of that document. In parallel with this research effort, in 2021, the NRC investigated the HEAF issue using NRC's Office of Nuclear Reactor Regulation (NRR) Office Instruction, LIC-504 entitled "Integrated Risk-Informed Decisionmaking Process for Emergent Issues" [4] to apply best available information and NRC risk assessment tools to determine whether the NRC should take prompt and/or longer-term regulatory actions to ensure that HEAF risks to the public remain at acceptable levels. This paper explains how the NRC used its Integrated Risk-Informed Decision-Making (RIDM) process via the LIC-504 process to address potential safety concerns associated with HEAF.

INTRODUCTION

The current HEAF PRA modelling methodology accepted by the NRC as documented in NUREG/CR-6850 was first published in 2005 and addresses HEAFs associated with electrical switchgears. That method was based primarily on the evaluation of a limited number of HEAF events. Supplement 1 to NUREG/CR-6850 [3] was published in 2010 and addresses HEAFs from bus ducts. Since the publication of these HEAF methods, the NRC, in collaboration with EPRI, has updated and issued the HEAF PRA methodology [5] for public comment using more recent operating experience, testing, and other enhancements to fire modelling. (NRC expects to issue the final report after dispositioning public comments during the fiscal year 2022). Some of the key advances to the new HEAF PRA methodology include the following:

- Changes to HEAF frequencies and non-suppression failure probabilities;
- Substantial changes to ZOIs for non-isophase bus ducts and for low and medium voltage switchgears;
- Crediting qualified electrical raceway fire barrier systems (ERFBS) in the HEAF ZOI as a means of preventing damage from HEAF effects;
- Changes to HEAF frequencies;
- More realistic HEAF damage potential that considers factors such as arc duration.

The above list constitutes significant changes to the PRA assessment methodologies of HEAF. The NRC used the updated HEAF PRA method above to examine changes to the estimated HEAF risks by comparing the current HEAF PRA methodology described in NUREG/CR-6850 [3] to the updated HEAF PRA methodology. In addition to comparing quantified risks, consistent with NRC risk-informed decision-making (RIDM) practices, the LIC-504 team's analysis also included a review of the HEAF related information to develop recommendations that could assist plant operators to maintain or reduce HEAF related risks at their facilities and to assist the NRC's inspection staff to further risk-inform HEAF related oversight activities.

This paper includes the following information:

The first section describes the motivation for and development of the NRC's LIC-504 process. The second section of this paper summarizes the approach, results, risk-informed insights, and observations obtained by comparing estimated risks for two reference U.S. NPPs) via the LIC-504 process. In the third section the NRC LIC-504 team's approach, results, risk-informed insights, and observation obtained by reviewing other HEAF related operating experience are summarized. A fourth section provides the regulatory processes that the LIC-504 team used to generate its risk-informed recommendations. The fifth section of the paper provides the recommendations developed by the LIC-504 team, and finally Conclusions are provided.

INCEPTION OF THE LIC-504 PROCESS

The LIC-504 process grew out of a lesson learned initiative from a risk significant event that occurred at the Davis Besse NPP. Specifically, during an inspection of the control rod drive mechanism (CRDM) nozzles in February 2002 at the Davis Besse NPP, the licensee discovered significant degradation of the reactor pressure boundary [6]. Subsequent investigation revealed that a circumferential crack in one of the CRDM nozzles had led to leakage and boric acid corrosion that formed a cavity around the nozzle in the low-alloy steel portion of the reactor pressure vessel (RPV) head. This left only the stainless steel-clad material to maintain the reactor coolant pressure boundary over an area of approximately 16.5 square-inches.

The risk significance of this event was analysed under NRC's Accident Sequence Precursor (ASP) study program. The ASP program is described in more detail in below. The NRC staff estimated that the degraded condition that existed imposed an additional core damage probability (ΔCDP) of 6×10^{-3} during a one-year period. Since this value exceeded the ASP program "significant precursor" threshold (i.e., greater than or equal to 1×10^{-3} ΔCDP), this event was reportable in the NRC's annual Abnormal Occurrence Report [7]. Subsequently, the U.S. General Accounting Office (GAO) (now known as the Government Accountability Office), in 2004, documented its findings pertaining to the Davis Bessie event in its report GAO-04-415, entitled "Nuclear Regulation – NRC Needs to More Aggressively and Comprehensively Resolve Issues Related to the Davis-Besse Nuclear Power Plant's Shutdown" [8]. In the areas of risk evaluation, communication, and the decision-making process for determining if plant shutdown is warranted, the GAO made two recommendations:

1. Develop specific guidance and a well-defined process for deciding when to shut down a nuclear power plant. The guidance should clearly set out the process to be used, the safety related factors to be considered, the weight that should be assigned to each factor, and the standards for judging the quality of the evidence considered.
2. Improve the NRC's use of PRA estimates in decision-making by ensuring that the risk estimates, uncertainties, and assumptions made in developing the estimates are fully defined, documented, and communicated to NRC decisionmakers and provide guidance to decisionmakers on how to consider the relative importance, validity, and reliability of quantitative risk estimates in conjunction with other qualitative safety related factors.

In response to these recommendations, the NRC developed office instructions entitled "LIC-504, Integrated Risk-Informed Decision Making for Emergent Issues" [4] and "LIC-106: Issuance of Safety Orders" [9].

APPROACH, RESULTS, AND RISK-INFORMED INSIGHTS FROM THE ANALYSES OF TWO REFERENCE PLANTS

This section summarizes the approach, results, and risk insights obtained from the quantitative risk analyses performed by the LIC-504 team with the assistance from the PRA practitioners at two reference plants. Details of these analyses are provided in Enclosure 1 to the NRC's LIC-504 Team Memorandum [10].

The staff secured the support of two licensees and selected two reference plants, including a Boiling Water Reactor 4 with a Mark I containment and a three-loop Pressurized Water Reactor (PWR) with a large dry containment. The use of these reference plants enabled the NRC staff to compare the estimated risks between the current NUREG/CR-6850 HEAF PRA methodology [3] and the new HEAF PRA methodology.

The staff noted that there was some variation in how each reference plant addressed HEAF modelling. For example, one reference plant credited post-Fukushima Daiichi FLEX strategies (diverse and flexible coping strategies) added to their facility in response to a NRC post-Fukushima order with regards to beyond-design-basis (BDB) external events EA-12-049 [12] in their PRA. The other reference plant did not. The reference plants also used different PRA methods and levels of refinement to develop the HEAF risk. The staff attributes this latter difference primarily to the different reference plant philosophies for evaluating fire risk; one reference plant exercised its model extensively to refine its fire risk, while the other plant concluded that a simpler level of detail was adequate to meet their intended objectives.

The LIC-504 team leveraged insights derived from the reference plants' HEAF PRA analyses to support the quantitative analysis. For example, the dominant sequences of the fire PRA HEAF scenarios were a key input that the staff used to select the areas for the plant walkdowns. The plant walkdowns enabled the LIC-504 team to determine how HEAF scenarios and associated frequencies could be modified to capture the changes related to the updated HEAF Fire PRA methodology. The walkdowns were instrumental in identifying which additional targets would be impacted and which could be eliminated. The larger ZOIs for certain configurations associated with the updated HEAF PRA methodology expanded the number of targets in some areas. Whereas some ERFBS protected scenario targets in the HEAF ZOIs were eliminated, as they were previously assumed to fail according to the current NUREG/CR-6850 guidance.

Table 1 below summarizes the results for the two reference plants' base HEAF related risks using the current NUREG/CR-6850 guidance [3] versus the updated HEAF methodology.

Table 1 Comparison of core damage frequency (CDF) and large early release frequency (LERF) using current versus new HEAF PRA guidance (all numbers are events/year)

Description	CDF (Updated Method)	CDF (Current NUREG/CR-6850 Method)	∆CDF	LERF (Updated method)	LERF (Current NUREG/CR-6850 Method)	∆LERF
Reference Plant No. 1						
SWGR related	1.7 E-06	1.3E-05	-1.1 E-05	3.9E-08	3.5 E-07	-3.2 E-07
Bus Duct related	5.0 E-07	4.6 E-07	4.5 E-08	3.6 E-08	1.5 E-08	2.0 E -08
Total HEAF risk	**2.2 E-06**	**1.4 E-05**	**-1.1 E-05**	**7.5 E-0 8**	**3.7 E-08**	**-3.0 E 07**
Reference Plant No. 2						
SWGR related	8.7 E-07	3.7 E-07	5.0 E-07	2.2 E-08	1.2 E-08	9.2 E-09
Bus duct related	3.3 E-05	1.4 E-07	3.3 E-05	3.7 E-06	7.4 E-09	3.7 E-06
Total HEAF risk	**3.4 E-05**	**5.1 E-07**	**3.4 E-05**	**3.7 E-06**	**1.9 E-08**	**3.7 E-06**

For Reference Plant No. 1, the reduction in HEAF risk associated with the new method is largely driven by the reduction in switchgear related HEAF risks. The ability of the new method to credit protection from the ERFBS and the relatively small arc duration time for the reference plant (i.e., short electrical fault clearing time), which reduces the energy released from the HEAFs and, consequently reduces the ZOIs. For Reference Plant No. 2, the increase in HEAF risk is dominated by the estimated risk increases associated with the bus ducts due to increased ZOIs, and the potential for damaging additional targets.

To further refine the staff's perspective on the risk significance, several sensitivity studies were also performed. Details on these sensitivity studies are provided in [10], which led to risk-informed insights.

The risk-informed insights given below are based on the information obtained from the two reference plants. It is important to emphasize that since the HEAF related risks are highly plant specific, they may not be applicable to other plants. Also, as conveyed below, staff noted some increases as well as some decreases in risk when the new HEAF methodology was applied. However, it is important to note that based on the results of the overall staff's assessments, the staff concluded that there was no significant increase in total HEAF risk, warranting the need for any additional regulatory requirements.

- Application of the new methodology for bus duct HEAFs provided a significant increase in estimated risk in many, but not all, cases. The instances that showed significant increases in risk were attributed to larger ZOIs resulting from the new HEAF PRA methodology. The major difference between the new HEAF PRA methodology and the existing NUREG/CR-6850 Supplement 1 methodology is the assignment of larger ZOIs for long fault duration times. Thus, the staff concludes that those plants with relatively long fault clearing times, and consequently larger ZOIs for bus ducts, could experience a significant increase in risk due to HEAFs.

- Application of the updated HEAF methodology for switchgear HEAFs showed an increase in estimated risk for certain configurations. The change in risk from Reference Plant No. 2 is larger than that for Reference Plant No. 1. However, the staff performed a more simplified analysis for Reference Plant No. 2 relative to Reference Plant No. 1. Furthermore, the vertical ZOI above the switchgear for the new HEAF PRA methodology is always smaller than the value from NUREG/CR-6850 [3]. Additionally, the new methodology predicts fire damage from HEAF in a region near the cabinet (just above and in front of) not covered by NUREG/CR-6850. For plant configurations with additional targets in this region, the switchgear could see a significant increase in risk with the new PRA HEAF methodology. Additionally, in a few cases the ZOI other than the vertical ZOI increased in the new methodology. Finally, longer fault clearing times lead to multiple, simultaneous switchgear HEAF fires, which may expose additional cables to fire damage.
- The updated HEAF PRA methodology credits ERFBS for preventing damage to cables within the new ZOI of the bus ducts and switchgear, unlike NUREG/CR-6850 and its Supplement 1. The staff noted that the risk decrease for the switchgear in Reference Plant No. 1 was primarily attributed to the credit given for ERFBS in the new methodology. Depending on the plant-specific configurations, fault clearing times, and risk profiles, application of the new methodology, including credit for preventing damage by ERFBS, may result in an estimated risk reduction.
- The changes in risk from the application of the updated HEAF method in Reference Plant No. 2, including the sensitivities, were generally larger than those for Reference Plant No. 1. Reference Plant No. 2 had rooms with larger amounts of cabling that were more sensitive to effects from HEAFs. Because HEAF risk, as in general for fire risk, is configuration dependent, this resulted in larger risk impacts for Reference Plant No. 2. As demonstrated by the sensitivities from Reference Plant No. 2 for the switchgear, protecting important cabling from fire damage is important to mitigate fire risk.
- A review of HEAF scenarios from the two reference plants provided additional risk-informed insights that could assist licensees in reducing their HEAF risks. Specifically, the team noted that a significant fraction of HEAF related risks were associated with only a handful of HEAF scenarios while reviewing HEAF scenarios included in their PRAs both plants. Since significant fractions of the HEAF related risk is distributed among a very small number of HEAF scenarios, it may be possible to use these scenarios to identify the subset of components that dominate the HEAF risks and focus maintenance or other related resources on that subset.

APPROACH, RESULTS, AND INSIGHTS FROM OTHER SOURCES OF OPERATING EXPERIENCE

The NRC staff reviewed information from several other operating experience sources to obtain qualitative observations related to HEAF events. Each of the events reviewed provided one or more observations relating to measures that a licensee may adopt to minimize the likelihood of HEAFs or to mitigate the consequences if a HEAF were to occur. Since the staff reviewed many events, there was the potential to generate and list a large number of observations. However, a lengthy list of observations might be too unwieldy and inhibit the readers' ability to bring focus on a handful of risk-informed insights. Therefore, the staff focused on the more risk significant issues.

Risk-Informed Insights and Observations from the ASP Event and the Maanshan NPP Station Blackout Event

The NRC's ASP program evaluates potentially risk significant events and degraded conditions that occur at NPPs. To assess the risk significance of events, the ASP uses conditional core damage probability (CCDP). To assess the risk significance of degraded conditions that exist for a specific exposure time, the ASP program uses the change in core damage probability (ΔCDP). Events or degraded conditions for which CCDP or ΔCDP exceed a set threshold are identified as precursors and saved in the ASP database. Irrespective of the metric used, events documented in the ASP Program provide a basis to identify the subset of risk significant HEAF events, and consequently, to generate risk-informed insights. Therefore, HEAF events or degraded conditions associated with HEAFs in the ASP database can be characterized as the subset of HEAF events that had the highest impact on safety.

Enclosure 2 of the LIC-504 memorandum [10] provides details of nine HEAF events in the ASP database as well as the 2001 Maanshan NPP HEAF event that were risk significant enough to be characterized as accident sequence precursors [11]. The staff added the 2001 Maanshan NPP event to the mix of the ASP database events because (1) the Maanshan NPP design (a power plant with two Westinghouse three loop PWRs is similar to a number of U.S. plant designs, (2) the event constitutes the most risk significant HEAF event (highest estimated CCDP) and as such has the potential to be a rich source of risk-insights, and (3) an ASP-like analysis had been performed on the Maanshan NPP event.

Details on the HEAF event that occurred at Maanshan, Unit 1 in 2001 are provided in [11] which describes several significant HEAF events that occurred between 1986 and 2001. In summary, a fire started as the result of a fault in the safety related 4 kV switchgear supply circuit breaker. The initial fault caused explosions, arcing, smoke, and ionized gases, which propagated to adjacent safety related 4 kV switchgear and damaged six switchgear compartments. The damage resulted in the complete loss of the faulted safety bus and its emergency diesel generator (EDG) and a loss of offsite power (LOOP) to the undamaged safety bus because of faulting of its offsite electrical feeder circuit. An independent failure of the redundant EDG resulted in a loss of all alternating current (AC) power. Smoke hindered access to equipment, delaying the investigation and repair of the failures. The station blackout (SBO) was terminated after about two hours when an alternate AC EDG was started and connected to the undamaged safety bus. This event prompted the following risk-informed insight:

- HEAFs that can lead to SBOs are likely to initiate at buses or switchgear that are essential to supply AC power from both offsite power and emergency diesels (or another emergency supply). Resources focused to minimize the likelihood of HEAF occurrence at those switchgear and buses (e.g., improved preventive and predictive electrical maintenance) can reduce HEAF related risks. Measures taken to minimize the possibility of a HEAF at one emergency bus, causing failure of the redundant electrical train due to consequential failures (e.g., due to smoke, or design deficiencies), will also minimize the SBO related HEAF risks.

The plant impacts associated with the ten events identified in the Enclosure 2 of the HEAF LIC-504 memorandum [10] which documents nine ASP events and the Maanshan event included full or partial LOOP events, and the loss of a single 4 kV emergency bus. These events, in conjunction with other consequential failures have the potential to lead to SBO events such as that at Maanshan. Therefore, plant features that could mitigate SBOs can be used to further mitigate SBO related HEAF risks. In light of that, the LIC-504 team offered the following risk-informed insight:

- In general, HEAFs leading to SBOs constitute the highest HEAF related risks. Plant design and operational changes that have been adopted to enhance the mitigation of BDB accidents order [12] are likely to reduce HEAF related risks.

In addition to the risk-informed insights, based on review of the ASP events, the LIC-504 team offered the following additional observations:

- Of the nine events screened into the ASP database, eight events occurred in high- or medium-voltage equipment. The other event occurred at a 480 V load center.
- The staff investigated whether there were predominant root causes of the HEAFs that appeared in the ASP database. The root causes varied: four of the events occurred because of inadequate maintenance {two due to presence of foreign material (carbon fiber, aluminum debris), two events occurred due to other unspecified inadequate maintenance practices}; and other causes included deficient design controls, water intrusion, random failures, and faulty protective relay coordination.
- Low voltage (480 V or less) components cannot be screened out as negligibly risk significant. Particularly, HEAFs at low voltage load centers can lead to moderately risk significant events unless the systems are designed to prevent long duration arcing.
- Ingestion of dust or any other material to bus ducts creates the potential for multiple concurrent HEAFs.

To assess the risk of HEAF events in a more generic manner, the staff used a subset of the nine ASP events, and outputs of the NRC's suite of Standard Plant Analysis Risk (SPAR) models to develop a HEAF related average core damage frequency (CDF) for U.S. NPPs. The estimate is based on the frequency of risk significant ASP events multiplied by a suitably bounding CCDP. That estimate, however, is simply an approximation, and is not representative of HEAF related risks at any U.S. NPP since HEAF risks are highly plant specific. Further, as illustrated by the HEAF operating experience, the plant and operator response to the HEAF event can lead to other failures and conditions that are unrelated to the initial HEAF and are difficult to capture in a risk assessment. However, this approximation approach provides some insights regarding the relative magnitude of HEAF related risks in a general sense.

Of the nine ASP events, six occurred between 2010 and 2021. One occurred between 2000 and 2009 and two occurred before 2000. There could be a variety of possible explanations for this, including under-reporting of HEAF events before 2010 or changes in the ASP risk assessment process over time. Although the staff did not investigate the reason for this trend, the staff is confident that risk significant HEAF events occurring since 2010 have been appropriately captured in the ASP database. Therefore, to prevent inappropriate biasing of the risk significant HEAF event frequency, the staff assumed operating experience of the last twelve years is most representative of the current risk. That assumption yields 6 events over approximately 1200 reactor years (or $\sim 5 \times 10^{-3}$ events/year).

The staff noted that the ASP HEAF events led to a variety of initiating events, including transients (reactor or turbine generator trips), LOOPs, or loss of a vital emergency AC power bus. Based on a review of SPAR model results, the most limiting CCDP for these initiating events is associated with a loss of a vital AC bus with a CCDP value of $\sim 1 \times 10^{-3}$ (representing a 95 % upper bound value for all SPAR model results). The SPAR model CCDP results for transients and LOOPs were all below a CCDP value of 1×10^{-3}. Based on these estimates, the staff concluded that a reasonably bounding average HEAF NPP CDF value, based on ASP events, is approximately 5×10^{-6} per reactor year. This value is generally considered to be a small risk impact, compared to the NRC's safety goals [13], but constitutes a non-negligible fraction of the risk. Furthermore, on a plant-specific basis, HEAFs may contribute to a substantial fraction of the fire risk. As mentioned earlier, the HEAF related risk is highly plant specific. For instance, for Reference Plant No. 1, the HEAF related CDF was about 2×10^{-6} per reactor year.

For Reference Plant No. 2, the HEAF related CDF was about 3×10^{-5} per reactor year. However, the Fire PRA associated with Reference Plant No. 2 included several more challenging fire scenarios and used a more simplified and bounding modelling approach compared to Plant No. 1.

Summary of Risk-Informed Insights from EPRI 3002015459

In March 2019, EPRI published a report entitled “Critical Maintenance Insights on Preventing HEAFs” [14]. The Executive Summary of that report noted that HEAFs can occur, and when combined with latent protective device or switchgear issues, could escalate, and cause significant equipment damage and impact to the licensee’s capability to generate electrical power at the NPP. The Executive Summary also noted that (1) an analysis of industry data demonstrated that an effective preventive maintenance program is important in minimizing the likelihood and severity of HEAF events, (2) 64%of HEAF events were considered preventable, and (3) the most prevalent cause of failure due to HEAFs was inadequate maintenance.

The report examined four types of electrical equipment: circuit breakers/switchgear, bus ducts, protective relays, and cables. In addition to discussing the general importance of maintenance, the report provided insights on circuit breakers/switchgear. The staff characterizes two key findings of the EPRI report as “risk- informed insights” because these insights are focused on a subset of components that are likely to be of relatively high-risk significance. These two risk-informed insights from the EPRI report are provided below:

- With respect to circuit breakers, the report noted that maintenance of the Unit Auxiliary Transformer (UAT) breaker is particularly important because its failure can lead to an extended duration generator-fed fault at the first switchgear bus. Operating experience has shown this breaker to fail during automatic bus transfers. The report acknowledged the challenges that licensees confront in performing preventive maintenance due to constraints associated with outage schedules and offered risk-informed guidance so that licensees may focus their maintenance on the risk critical subset of maintenance activities.
- With respect to switchgear, the report noted that for critical switchgear, such as feeder circuit breakers that carry higher currents and switchgear that is part of a bus transfer scheme, proper maintenance of connections on both the bus duct side and the circuit breaker side is especially important.

Observations from the OECD/NEA HEAF Fire Events Report

The staff reviewed the OECD/NEA report on HEAF fire events from 2013 [1] detailing 48 HEAF events, eleven of which occurred in the U.S. The definition of HEAF events used by the NRC is narrower than that used in the OECD/NEA report. For example, the OECD/NEA report includes several HEAF events that took place within large transformers installed outdoors, which are not included in the NRC HEAF definition. The large number of events included in the OECD/NEA report generated several potential observations. Based on the review of the events from this report, the LIC-504 team identified the following observations relating to HEAF event prevention and mitigation:

<u>Equipment Side</u>

- Proper maintenance practices: several HEAF events were attributed to poor, or lack of maintenance.
- Aging management for electrical components: some HEAF events were caused by age related degradation of protective components, for example of bus insulation.
- Post-maintenance testing and inspection to ensure as-left conditions: the root cause of some HEAF events was identified as components not being left in the correct condition post-maintenance.

Operations Side

- Housekeeping to prevent dust and other foreign matter accumulation: the root cause of many events was identified as the build-up and presence of dust, debris, and other foreign material inside bus ducts or breaker enclosures.
- Identification and correction of existing design issues: the severity of many of the reported events was exacerbated by long-standing design errors or problems.
- Understanding of the electrical system and event conditions to prevent incorrect operator actions: the severity of some of the reported events was increased by operators taking incorrect actions or not understanding what the correct actions were.

APPROACH USED TO LIC-504 TEAM RECOMMENDATIONS

Enclosure 3 of the HEAF LIC-504 memorandum [10] provides recommendations for NRC's senior management's consideration. Some of the guidance that the LIC-504 team used to generate their recommendations are included in the LIC-504 Office Instruction itself. For instance, Section 4.2.1 of the LIC-504 Office Instruction described when the NRC should consider issuing prompt regulatory requirements such as Orders to shutdown units based on risk insights. LIC-504 also provides guidance on the nature of generic communications to licensees that NRC should consider based on risk significance. The LIC-504 team considers other NRC guidance documents also to generate its recommendations such as:

- NRC's Management Directive (MD) 8.18 entitled "Generic Communications Program" [15] to further inform on whether NRC should consider issuing a Bulletin, a Generic Letter, a Regulatory Issue Summary, or an Information Notice to address the emerging issue;
- MD 6.3 entitled "Rulemaking Process" [16] and the associated guidance document NUREG/BR-0058 entitled, "Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission" [17] to determine whether the issue warrants the LIC-504 team to recommend new rulemaking (or modifying an existing rule).

In addition to the above, the LIC-504 team leveraged the "Teaching Element" of the NRC's "Be RiskSMART" framework [18]. In doing so, the LIC-504 team considered various types of communication venues that the NRC will leverage to convey the actions a licensee may consider to mitigative risks associated with the HEAFs.

LIC 504 TEAM RECOMMENDATIONS TO NRC MANAGEMENT

The NRC's LIC-504 team considered and investigated a full range of potential options to recommend under the NRC's licensing, rulemaking, and oversight responsibilities. As conveyed above, the team noted some increases as well as some decreases in risk when the new HEAF methodology was applied; however, team concluded that there is no significant increase in risk warranting additional regulatory requirements. In addition, the team evaluated various communication options to share its insights with licensees so they can implement effective steps to further reduce and/or mitigate HEAF risks. The final management-endorsed recommendations are provided below:

- Issue an Information Notice (IN) to share information on (1) the operating experience and risk insights from the LIC-504 assessment, (2) regulatory framework/license conditions, and (3) the availability of the new HEAF risk assessment methodology for licensee consideration.

- Incorporate risk insights obtained from the LIC-504 assessment to inform NRR's ongoing PRA configuration control initiative.
- Consider incorporating risk insights obtained from the LIC-504 assessment to inform NRR's Reactor Oversight Process.
- Communicate risk insights gleaned from the HEAF related risks / LIC-504 process with regional inspectors and senior reactor analysts.
- Share risk insights gained from the HEAF LIC-504 analysis with external stakeholders via public meetings (e.g., workshops), participation at owners group meetings, and communications at national and international forums.

CONCLUSIONS

The NRC has successfully developed a process to address safety issues that emerge as a result of world-wide nuclear power plant operating experiences in an efficient and effective manner. NRR developed an Office Instruction entitled, "LIC-504, Integrated Risk-Informed Decisionmaking for Emergent Issues" that describes this process, which enables NRC staff to use best available information to assess risk (quantitative or qualitative), defence-in-depth, and safety margins. This process allows for the NRC to disposition issues in a timely manner, consistent with risk-informed decision-making principles.

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