UNITED STATES
NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REACTOR REGULATION
WASHINGTON, DC 20555-0001

March 10, 2023

NRC INFORMATION NOTICE 2023-01: RISK INSIGHTS FROM HIGH ENERGY ARCING FAULT OPERATING EXPERIENCE AND ANALYSES

ADDRESSEES

All holders of and applicants for an operating license or construction permit for a nuclear power reactor issued under Title 10 of the Code of Federal Regulations (10 CFR) Part 50, "Domestic licensing of production and utilization facilities."

All holders of and applicants for a power reactor combined license, standard design approval, or manufacturing license under 10 CFR Part 52, "Licenses, certifications, and approvals for nuclear power plants." All applicants for a standard design certification, including such applicants after initial issuance of a design certification rule.

PURPOSE

The U.S. Nuclear Regulatory Commission (NRC) is issuing this information notice (IN) to share international and domestic operating experience relating to high energy arcing faults (HEAFs). This IN discusses qualitative and quantitative risk insights derived from operating experience using the NRC's Office of Nuclear Reactor Regulation's (NRR's) Office Instruction LIC-504, "Integrated Risk-Informed Decisionmaking Process for Emergent Issues," Revision 5 (Reference 1). This IN also provides information about the availability of the new HEAF probabilistic risk assessment (PRA) methodology developed by the NRC's Office of Nuclear Regulatory Research (RES) in collaboration with the Electric Power Research Institute (EPRI). This new PRA methodology was derived from recent operating experience, HEAF-related testing, enhanced analytical modeling using state-of-the-art methods, and lessons learned from the implementation of previous fire PRA guidance.

The NRC is issuing this IN to inform addressees of issues associated with HEAF operating experience beyond those included in IN 2017-04, "High-Energy Arcing Faults in Electrical Equipment Containing Aluminum Components" (Reference 2) and other INs included in the reference section of this IN. The NRC expects that recipients will review the information for applicability to their facilities and consider actions, as appropriate. INs may not impose new requirements, and nothing in this IN should be interpreted to require specific action.

DESCRIPTION OF CIRCUMSTANCES

In June 2013, the Organization for Economic Co-operation and Development (OECD) issued the report NEA/CSNI/R (2013)6, "OECD Topical Report No. 1, Analysis of High Energy Arcing Fault Fire Events" (Reference 3), on international operating experience that documented 48 HEAF events. The document stated that these events accounted for approximately 10 percent of all fire events collected in OECD's fire events database. These HEAF events were sometimes accompanied by a loss of essential power and complicated shutdowns. NEA/CSNI/R(2013)6 recommended performance of carefully designed experiments to better characterize HEAF events to obtain comprehensive scientific fire data that would support the development of more realistic models to account for failure modes and consequences of HEAF and provide better characterization of HEAF in fire PRA. Between 2014 and 2016, the NRC led the first phase of an international experimental campaign to examine whether the PRA methodology for HEAF analysis in NUREG/CR-6850, "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities," and its Supplement 1 (References 4 through 6) could be enhanced to include more recent information. The preliminary results of these experiments indicated a potential for an increase in the Zones of Influence (ZOIs) for aluminum components in or near electrical equipment, as well as the potential for new equipment failure mechanisms. These issues are described in detail in IN 2017-04.

BACKGROUND

In March 2016, the NRC evaluated the additional risk associated with aluminum using the NRC's Generic Issues Program (GIP) (Reference 7). Upon further review, the NRC staff determined that the HEAF issue no longer met the criteria for timely resolution prescribed by the GIP, as documented in an August 2021 memorandum (Reference 8). The staff exited the GIP and leveraged a two-pronged approach by (1) initiating the LIC-504 process to develop and document risk-informed options to disposition the HEAF issues using the best available information and (2) in parallel, completing a suite of improved HEAF data, tools, and methods in collaboration with EPRI.

DISCUSSION

In accordance with LIC-504, the NRC staff examined the potential change in the estimated fire risk associated with HEAF events based on recent operating experience, testing, and enhanced analytical tools. The results of the NRC staff's evaluation can be found in the memorandum "High Energy Arcing Fault LIC-504 Team Recommendations" (Reference 9).

The initial focus of the NRC staff's analysis was to develop and document risk-informed options to disposition the potential increases in estimated risk due to the differences in HEAF ZOIs between copper and aluminum conductors. This concern arose because the differences in physical properties between copper and aluminum. For example, differences in oxidation rates and heats of combustion can result in a more energetic plasma development during a HEAF event involving aluminum and result in transport of high energy particles and plasma further than previously assumed. However, concurrent with the LIC-504 evaluation, the NRC/EPRI HEAF working group determined that the difference in ZOIs for aluminum conductors and copper conductors is not significant based on the limited experimental data, state-of-knowledge, and results from analytical methods. The NRC/EPRI working group concluded that aluminum bus duct enclosures can result in a larger ZOI than a comparable steel enclosure. As a result, the focus of the LIC-504 evaluation was modified to estimate the change in risk based on the current state of knowledge, and to develop and document risk-informed insights, including options to disposition any safety or regulatory implications associated with the changes in the estimated risk between the new HEAF PRA methodology (draft issued for public comment) (Reference 10) and the current HEAF PRA methodology in NUREG/CR-6850 and Supplement 1.

The NRC staff used the best available information from various sources to conduct the LIC-504 analysis. To gain additional insights related to the application of the analysis methods to U.S.

operating light water reactors, the NRC staff secured the support of two reference nuclear power plants (NPPs) to obtain plant-specific information and insights to improve the realism of the analysis and the usefulness of the insights. Furthermore, to ensure that risk insights from operating U.S. plants were considered, the LIC-504 team evaluated the Accident Sequence Precursors (ASPs) related to HEAF events documented in the ASP database.

Review of Operating Experience

During the LIC-504 analysis, the staff identified four sources of HEAF-related information that may enable licensees to obtain risk-informed insights and identify plant components that contributed the most to HEAF risks. The LIC-504 team performed a comprehensive review of recent as well as past HEAF events to obtain and document risk-informed insights related to preventive or mitigative measures.

The first source, the ASP Program Dashboard (maintained by the NRC on the public webpage at https://www.nrc.gov/about-nrc/regulatory/research/asp.html), provides an interactive database of all accident precursors since 1969. The ASP program systematically evaluates U.S. nuclear power plant operating experience to identify, document, and rank operational events by calculating a conditional core damage probability or an increase in core damage probability. Therefore, the ASP database provides the subset of domestic HEAF events that are of relatively high risk significance. The staff conducted a thorough review of the HEAF events in the ASP database in addition to reviewing the HEAF events documented in the OECD report discussed above to obtain risk-informed insights.

The second source was a report prepared by EPRI entitled, “Critical Maintenance Insights on Preventing High Energy Arcing Faults” issued in March 2019 (EPRI Report No. 3002015559) (Reference 11). This report identified a subset of plant components that could significantly influence plant risk and emphasized the importance of maintenance on the components to preventing HEAF events.

The third source of risk-informed insights was the NRC’s report, “Operating Experience Assessment: Energetic Faults in 4.16 kV to 13.8 kV Switchgear and Bus Ducts That Caused Fires in Nuclear Power Plants 1986–2001,” February 2002 (Reference 12), which provides information about selected HEAF events.

Finally, the team examined the HEAF scenarios identified in the two reference plants’ Fire PRAs. The team found that these scenarios were a valuable source that provided plant-specific risk-informed insights as discussed below.

Risk-Informed Insights

The following risk-informed insights are based on a review of HEAF events performed during the staff’s LIC-504 evaluation,

- A focus on preventing HEAF events remains an important aspect of HEAF risk management. Frequently, HEAF events, even those that are not initially risk significant, can cause subsequent failures due to explosion effects, smoke, and ionized gases. These subsequent failures can create a chain of events that can pose special challenges to operators. Furthermore, some HEAF events involve operator errors that further contribute to the risk significance of the event. These subsequent failures, that can involve complex interactions among the operators, fire phenomenology, and mitigation capability, can be challenging. Due to these factors, it is important to prepare for and mitigate the consequences of a HEAF.

The following risk-informed insights were based on reviews of the HEAF scenarios of the reference plants, the EPRI maintenance report, and the HEAF event that occurred at the Maanshan site in 2001. These risk insights focus on design and maintenance resources in a subset of potential HEAF locations, which could contribute to a large fraction of the plant's HEAF risks:

- HEAFs that could lead to station blackouts (SBOs), like the one that occurred at Maanshan in 2001, are likely to initiate at buses or switchgear that are essential in supplying alternating current power from both preferred and standby power sources. Minimizing the likelihood of HEAF occurrence at those essential switchgear and buses (e.g., improved preventive and predictive electrical maintenance) could reduce HEAF-related risks. Minimizing the possibility of a HEAF at essential emergency buses, would also reduce the potential for a failure of redundant electrical buses (e.g., due to smoke, or design deficiencies) and could minimize the SBO-related HEAF risks.

- Maintenance of breakers that are used to isolate the main generator power supply from essential electrical safety buses is important. Failure of these breakers during a HEAF event could lead to an extended duration HEAF event due to the generator continuing to provide power to the electrical fault. Operating experience has shown that these breakers are more likely to fail during automatic transfers.

- The supply circuit breakers to a switchgear lineup carry higher currents and are susceptible to higher energy faults with larger damage footprints. In addition, proper operation of supply breakers is needed to isolate faults. Accordingly, proper maintenance of supply breakers is especially important.

The NRC staff observed the following based on information obtained by reviewing the HEAF scenarios at the two reference plants:

- Comprehensively modeling a full scope of HEAF scenarios within the fire PRA facilitates identification of a subset of components that can significantly impact plant risk. This information may allow licensees to minimize HEAF risks by focusing their resources (e.g., preventive maintenance) on that subset of components.

With respect to mitigating the effect of HEAF events, NRC staff observed the following based on information obtained by reviewing the HEAF scenarios at the two reference plants and the design objective used to develop FLEX strategies:

- In general, HEAFs leading to SBOs constitute the highest HEAF-related risks. Therefore, effective use of plant design and operational changes that have been adopted to enhance the mitigation of beyond design basis accidents rule (10 CFR 50.155 "Mitigation of beyond-design-basis events") are likely to reduce HEAF-related risks.

<u>New HEAF PRA Methodology</u>

A new HEAF PRA methodology was developed as a result of a multistep research plan implemented in collaboration with EPRI. Specific activities included (1) development of a

Computational Fluid Dynamics HEAF model capable of calculating the incident energy for a variety of equipment configurations and materials; (2) survey of U.S. NPP electrical applications and configurations; (3) conduct of physical testing needed to inform and validate the HEAF hazard model and assess component fragility; and (4) updates to PRA data and methods to improve the realism and fidelity of the HEAF hazard model. The LIC-504 team used the new HEAF PRA methodology published for public comment (Reference 10) in collaboration with the PRA staff of the refence plants to support the LIC-504 project activities.

Some of the key advances of the new HEAF PRA methodology include: 1) changes to HEAF frequencies and non-suppression failure probabilities using recent operating experience; 2) substantial changes to the ZOIs for non-segregated bus ducts and for low- and medium-voltage switchgear; 3) crediting Electrical Raceway Fire Barriers Systems (ERFBS) in the HEAF ZOI as a means of preventing damage from HEAF effects on systems and components; and 4) the ability to evaluate variation in HEAF-related damage due to fault clearing times. Some of these changes may increase or decrease the estimated HEAF risk. For example, refined analysis methods that reflect potential ZOI changes of non-segregated bus ducts could increase the estimated HEAF risk. Conversely, the allowable ERFBS credit in the new methodology may decrease the estimated HEAF-related risk. Whether the resulting overall estimated HEAF-related risk would increase, or decrease will be highly dependent on the plant-specific configurations.

The change in risk due to HEAF events at the two reference plants was estimated by applying the new HEAF PRA methodology and comparing it to the estimated risk using the 2005 and 2010 guidance documented in Appendix M of NUREG/CR-6850 and Sections 4 and 7 of NUREG/CR-6850, Supplement 1. The following insights were identified:

- A major enhancement in the new methodology is the consideration of fault clearing times. This enhancement more realistically models HEAF-related damage based on plant-specific characteristics related to the duration of the clearing times, which can increase or decrease the ZOIs and associated risk compared to the NUREG/CR-6850 method. Plants with relatively long fault clearing times, resulting in larger ZOIs, may have an increase in estimated HEAF risk compared to the risk previously estimated using the NUREG/CR-6850 methods.

- The new methodology moves the point of origin for the zone of influence in non-segregated bus ducts. Moving the ZOI point of origin to the exterior surface of the bus duct may, for some plant configurations with targets in this area, result in including additional equipment within the HEAF damage zone.

- Application of the new methodology for switchgear HEAFs showed increases and decreases in estimated risk based on specific circumstances. The vertical ZOIs above the switchgear consistently result in smaller values in comparison to those values that result from the application of the methodology in NUREG/CR-6850. Additionally, the new methodology predicts fire damage from HEAF in a region near (just above and in front of) the cabinet that was not covered previously by the NUREG/CR-6850 methodology. For plant configurations with additional targets in this region, the switchgear HEAFs could potentially see a significant increase in risk with the new methodology depending on the importance of those targets.

- The new HEAF PRA methodology credits ERFBS for preventing damage to protected cables within the ZOI of bus ducts and switchgear HEAFs, unlike the current guidance in NUREG/CR-6850 and its Supplement 1 which does not allow credit for ERFBS in preventing damage. Including credit for ERFBS may result in a substantial estimated risk reduction due to HEAF.

- Due to the cumulative impact of the items described above, the estimated risk could be higher or lower than calculated under the previous methodology and could vary significantly based on plant configuration.

GENERIC IMPLICATIONS

The risk insights documented in this IN derived from operating experience, such as those from the EPRI maintenance report and the ASP database review, are broadly applicable, independent of the existence of a Fire PRA used to meet the licensing basis of the facility.

U.S. NPPs licensed under 10 CFR 50 are not required to develop Fire PRAs. However, licensees who choose to adopt certain voluntary risk-informed programs, such as Risk-Informed Completion Times (RITS-4b) and the risk-informed, performance-based fire protection licensing basis under 10 CFR 50.48(c) (NFPA 805), developed Fire PRAs in order to receive NRC staff approval to establish and implement these programs. Furthermore, licensees may have used their fire PRA models to receive staff approval to adopt other risk-informed programs, such as 10 CFR 50.69, “Risk-Informed Categorization of Structures, Systems, and Components at Nuclear Plants,” and to risk-inform their surveillance frequencies (RITS-5b).

Licensees who have approved risk-informed initiatives such as RITS-4b, RITS-5b, 10 CFR 50.69 and NFPA 805 are required to maintain their PRAs to reflect the as-built, as-operated, and as-maintained plant.

Licensees are expected to review the information provided in this IN as it relates to the operating experience for applicability to their facilities and consider any actions, as appropriate. However, as discussed above nothing in this IN should be interpreted to require specific action.

REFERENCES

1. U.S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation Office Instruction LIC-504, “Integrated Risk-Informed Decisionmaking Process for Emergent Issues,” Revision 5, March 2020 (Agencywide Document Access and Management System (ADAMS) Accession No. ML19253D401).

2. U.S. Nuclear Regulatory Commission, Information Notice 2017-04, “High Energy Arcing Faults in Electrical Equipment Containing Aluminum Components,” August 2017 (ADAMS Accession No. ML17058A343).

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13. IN 2002-01, "Metalclad Switchgear Failures and Consequent Losses of Offsite Power," dated January 8, 2002 (ADAMS Accession No. ML013540193).

14. IN 2002-27, "Recent Fires at Commercial Nuclear Power Plants in the United States," dated September 20, 2002 (ADAMS Accession No. ML022630147).

15. IN 2005-21, "Plant Trip and Loss of Preferred AC Power from Inadequate Switchyard Maintenance," dated July 21, 2005 (ADAMS Accession No. ML051740051).

16. IN 2005-15, "Three-Unit Trip and Loss of Offsite Power at Palo Verde Nuclear Generating Station," dated June 1, 2005 (ADAMS Accession No. ML050490364).

17. IN 2006-18, Supplement 1, “Significant Loss of Safety-Related Electrical Power at Forsmark Unit 1 in Sweden,” August 10, 2007 (ADAMS Accession No. ML071900368).

18. IN 2006-31, “Inadequate Fault Interrupting Rating of Breakers,” dated December 26, 2006 (ADAMS Accession No. ML063000104).

19. IN 2007-14, “Loss of Offsite Power and Dual-Unit Trip at Catawba Nuclear Generating Station,” dated March 30, 2007(ADAMS Accession No. ML070610424).

20. IN 2008-18, “Loss of Safety-Related Motor Control Center Caused by a Bus Fault,” dated December 1, 2008 (ADAMS Accession No. ML082540130).

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